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Practical Experience with ex situ Conservation Stands of Tropical Pines

Assessment and analysis of ex situ conservation stands of tropicalpines established within the framework of FAO/UNEP project onconservation of forest genetic resources (1975-85)

Hansen, Christian Pilegaard; Theilade, Ida; Hald, S.; Ukendt, DFSC; Ukendt, FAO

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Practical Experience with *ex situ* Conservation Stands of Tropical Pines

Assessment and analysis of *ex situ* conservation stands of tropical pines established within the framework of 'FAO/UNEP' project on conservation of forest genetic resources (1975-85).

Danida Forest Seed Centre, Denmark and
Food and Agriculture Organization of the United Nations

in collaboration with

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Assessment of *ex situ* conservation stand in Zambia. All assessments were carried out jointly by DFSC, FAO and national institutions in charge of the stands.

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Technical editing: Melita Jørgensen, Danida Forest Seed Centre

The publication can be requested from:
Danida Forest Seed Centre
Krogerupvej 21
DK-3050 Humlebaek, Denmark
Phone: +45-49190500
Fax: +45-49190258
Email: dfsc@sns.dk
Web Site: www.dfsc.dk

Danida Forest Seed Centre (DFSC) is a Danish non-profit institute which has been working with development and transfer of knowhow 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. DFSC's programme is financed by Danish International Development Assistance (Danida).

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Preface

This report presents results of a field evaluation of 135 *ex situ* conservation stands of three Central American pine species - *Pinus caribaea* var. *hondurensis, P. oocarpa* and *P. tecunumanii* established in Australia, Brazil, Côte d'Ivoire, India, Kenya, Tanzania, Thailand and Zambia in the late 70's and early 80's. The evaluation was undertaken as a joint effort among institutions in the 8 countries in which the trials had been established, under the overall co-ordination of the Food and Agriculture Organization of the United Nations (FAO) and with financial and technical support from Danida Forest Seed Centre (DFSC), Denmark.

The field assessments took place in March-April 1996 (Thailand), September 1996 (India), October-November 1996 (Australia), September 1997 (Kenya, Tanzania and Zambia), February 1998 (Brazil) and February 1999 (Côte d'Ivoire). The assessment comprised a description of the planting site, the establishment and management of the stands, protection status and use of the stands. It further included assessment of growth, quality, health, flowering and cone production, registration of distance to contaminating pollen sources, and information on costs and revenues from the stands. The results of the field assessments were documented in 8 national assessment reports. The present report was prepared based on the individual reports.

Four annexes provide additional documentation on stands and seed lots in the study. A list of all stands, planting sites, species, provenances and seed lot is found in annex 1. Calculation of mean-stand values based on data for individual trees in each sample plot is presented in annex 2. Datasheets on all assessed conservation stands including maps are found in annex 3. Datasheets on seed sources used in the program are found in annex 4.

Annex 3 and 4 are very voluminous and are not included in this publication. Data sheets on specific stands or seed sources can be obained from DFSC.

Executive Summary

The objective of this study was to document and analyse practical experiences with *ex situ* conservation stands of three tropical pine species: *Pinus caribaea* var. *hondurensis, P. oocarpa* and *P. tecunumanii*. The study included 135 *ex situ* conservation stands with a total area of 950 hectares. The stands represent 40 seedlots of 28 different provenances of the three species. Thirty-six stands were established as part of the FAO/UNEP project on conservation of forest genetic resources, and 99 through national efforts. The stands were established in the late 70's and early 80's in 8 countries: Australia, Brazil, Côte d'Ivoire, India, Kenya, Tanzania, Thailand and Zambia. Field trips to all stands were made from 1996 to 1999.

The 135 stands were established at 39 different planting sites. Some planting sites varied considerably from conditions found in the natural range of the species/provenances. In general, the three pine species showed a remarkable adaptation to many different conditions and overall a satisfactory growth. However, the poor environmental match seriously reduced the reproductive potential of many stands. Coastal provenances of *P. caribaea* var. *hondurensis* overall were most affected, whereas inland *P. caribaea, P. oocarpa* and *P. tecunumanii* provenances seemed to be established at sites more similar to their origin.

Stands were in general well established and managed in the initial stages where external funding was available. However, active management in later stages was generally neglected which substantially reduced the conservation value of the stands. In particular, the majority of stands were never thinned. Stands were too dense - a condition which usually reduces flowering in pines. The lack of thinning is believed to be the main reason for the poor flowering and cone production observed. The poor environmental match most likely further reduced the reproductive potential of many stands.

Appropriate isolation of stands from possible, contaminating pollen sources is an important requirement for gene conservation and for an appropriate seed source for future conservation use. The survey revealed that about half of the stands fulfilled basic isolation requirements. In most cases more stands were found at one site, typically close to research or gene conservation and seed production stations. Many stands at one site provided advantages in terms of protection and management of the stands, but made it difficult to secure appropriate isolation. Moreover, as stands were typically established with a range of objectives, *ex situ* conservation not always being the prime one (e.g., initial testing of performance of a seedlot/provenance in a given environmental condition, and seed production) it is not surprising that not all stands could meet all criteria perfectly.

Stand size varied considerably from less than 1 ha to 37 ha. The majority of stands were smaller than the recommended 10 ha. Nonetheless, most stands were considered to have a sufficient number of individuals to secure genetic variation and decrease genetic drift to an acceptable level.

The assessment confirmed that most stands were still present and of satisfactory survival, growth and health. Of the 36 stands established within the framework of the FAO/UNEP project 8 were lost as were 15 of the 99 national stands. Fire originating from shifting cultivation and other human activity in nearby areas was the main reason for the loss of stands and fire affected 1/3 of the remaining stands as well. Encroachment and illegal cutting damaged a number of stands, but caused less damage than fire. Domestic animals, hail-storm, and termites caused damage locally.

The stands were in general perceived as a potential asset in the countries but demand for seed has so far been much smaller than envisaged at the time of establishment. In addition, cone production was not in any of the stands sufficient to undertake large-scale seed collection. Poor isolation from contaminating pollen sources and limited cone setting generally restricted the use of the stands as seed sources and has made regeneration more difficult. Hence the extent to which countries will be able to realise benefits from the conservation stands is uncertain.

At present, regeneration of the stands seems doubtful. The costs involved and the poor prospects for recovering part of the expenses by seed sales may hamper the interest of countries to regenerate the stands at the end of their rotation. As a basis for deciding how to manage the stands in the future, it is recommended that institutions in charge carefully evaluate the potential use of the species/provenances and define national conservation priorities. If a stand has only limited conservation value from a national perspective it may still be valuable from an international perspective. Therefore, an assessment of the international conservation value, identifying how stands may fit into an overall conservation network and thereby contribute to the conservation of genetic resources of the species, could be a useful decision tool. This activity would include an evaluation of the present conservation status of the species *in situ* complemented with information on any other *ex situ* initiatives.

In summary, the study illustrates some of the major difficulties in the establishment and management of *ex situ* conservation stands. The analysis stresses several key points for future consideration:

1) The need for informed and timely management and follow-up in all stages of development from establishment to generation turn-over. 2) Combining objectives of seed production and conservation may be difficult. This may contribute to stands not being able to meet any one of the objectives. 3) The study shows that viable *ex situ* conservation to a large extent depends on - or should be driven by - interest in utilising the species and provenances in question. A fundamental problem in forestry that may continue to hamper *ex situ* conservation efforts of this sort, is the uncertainty of local species priorities over time in concert with long conservation time frames. There may or may not be a demand for seed and other reproductive materials that will pay - fully or in part - for the costs of management, protection and regeneration of the *ex situ* stands. If not, the stands are likely to be seen as conservation with little local value, and the management costs as an expense without corresponding benefits to local forestry authorities. In the absence of appropriate external funding, it is likely that most of these conservation stands will be lost.

Picture 1. Low crown cover due to frequent fires. *P. oocarpa* stand at Siamambo, Zambia. Fire was the overriding threat to the conservation stands accounting for many lost and damaged stands.

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Acronyms

CAMCORE	Central America and Mexico Coniferous Resources Cooperative, North Carolina, USA
CBD	Convention on Biological Diversity
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
DFSC	Danida Forest Seed Centre, Denmark
FAO	Food and Agriculture Organization of the United Nations
ICFRE	Indian Council of Forestry Research and Education, India
KEFRI	Kenya Forest Research Institute, Kenya
OFI	Oxford Forestry Institute, United Kingdom
RFD	Royal Forest Department, Thailand
SODEFOR	Societé de Développement des Fôrets, Côte d'Ivoire
TAFORI	Tanzania Forest Research Institute, Tanzania
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environmental Programme

* Not included. Data sheets on specific stands or seed sources can be obtained from DFSC.

1. The Study and This Report

This chapter presents the background of the study on practical experiences with ex situ conservation of tropical pines and explains how it is part of a larger programme to develop practical guidelines for establishment and management of such stands. The 'study population' is described, as is the assessment and analysis methodology.

1.1 Study on practical experiences with *ex situ* conservation

1.1.1 Why a study on practical experiences with *ex situ* conservation

The need for conservation of biological diversity and genetic resources has received increased attention over past decades. At international level, this has for example lead to the adaptation of the Convention on Biological Diversity at the UNCED Conference in Rio de Janeiro in 1992 which has later been ratified by 175 countries (CBD 1999). In line with the increased attention towards conservation and sustainable use of biological diversity in general, there has been a steadily increasing awareness of the importance of conserving forests and forest tree species.

As of today, thanks to a large number of basic research programmes, more is known on the general concepts of conservation at ecosystem, species and within species levels, and the interactions and linkages between the different levels of conservation. A theoretical framework for conservation of forests genetic resources is in place supported by a wide range of methodologies, involving both *in situ* and *ex situ* techniques.

Moreover, research, field assessments and testing have been undertaken for some species, and information, although incomplete, is available to facilitate informed conservation planning. However, research is still needed for many species to facilitate sound conservation planning. This is especially true for tropical tree species.

With a theoretical framework at hand, field activities to conserve forest genetic resources have been initiated. Most such efforts have been 'pilot' activities while large-scale conservation plans have been implemented in the field only for a few forest tree species.

Practical guidelines on how to implement such programmes are lacking. Past experience has in many cases been insufficiently documented and 'lessons learnt' have been little analysed. As a result, planners are left with practical problems and questions on how to actually implement activities in a sound and efficient way.

1.1.2 Aim of study

The aim of the present study is to document and analyse practical experiences in establishment and management of *ex situ* conservation stands. The study is based on a larger programme on *ex situ* conservation of forest tree species with participation of national institutions in a number of countries, FAO and UNEP.

The study was initiated in line with recommendations of the FAO Panel of Experts on Forest Gene Resources, which at its sessions up through the 80's and early 90's recommended that a survey be carried out on experiences with *ex situ* conservation of forest tree species. This would enable the experience gained to be used in the planning of future programs (FAO 1984).

1.1.3 Why pines?

The study population of pines was chosen as numerous *ex situ* stands of pines had been established widely at an early stage. The pine stands offered a unique possibility to analyse stand establishment and management over a wide range of site conditions and socio-economic environments. Pines provided the opportunity to study management of *ex situ* stands over a long perspective (more than 20 years). No other forest tree species offered the same possibilities for a large-scale study of practical experiences.

Pines are pioneer species and fairly easy to establish in plantations compared to many other species and are fast growing. Moreover, they are wind-pollinated and start to flower and set cones relatively early in their life. The pines have been grown in plantation systems for decades and establishment and silvicultural management techniques are well established. For this reasons, it can be argued that pines represent a fairly 'easy' case of *ex situ* conservation, and that other species or groups of species may present more 'challenging' cases because of their reproductive biology or difficulties with establishment and management. Few forest tree species have been included in comprehensive *ex situ* activities, covering more countries and over a long period. Throughout the study focus is on general experiences and problems that may also be applicable to other species.

1.2 FAO/UNEP project on the conservation of forest genetic resources

In 1976, FAO and UNEP in collaboration with national institutions in a number of countries initiated a project on conservation of forest genetic resources. The FAO/UNEP project included both *in situ* and *ex situ* conservation activities, and had activities in various countries targeting a number of species (FAO 1985). In the context of this report, only the *ex situ* activities will be described.

At the time the project was conceived and started, there was a very big interest in the establishment of fast-growing plantations of forest trees in many tropical, developing countries. As interested coun-

tries started to identify species and the provenances, which performed well in their conditions, it was becoming increasingly difficult to procure seed of those provenances that had, fairly consistently, showed good performance over a range of sites. At the same time, it was realised that many of the native stands of these species and provenances, not being of high priority in their countries of origin, were not the object of specific conservation or management efforts and were, in some cases, vulnerable.

Establishment of *ex situ* stands under the framework of this project would therefore serve several purposes. First of all, the stands would serve the purpose of gene conservation. As mentioned above many natural populations were threatened and in need of conservation. *Ex situ* conservation was seen as a suitable conservation alternative. Secondly, the stands were envisaged to produce seed that could be used for plantation establishment in the countries. At the time of establishment, seed supply from the natural stands was difficult, and the stands should be able to provide the countries with a stable and own seed production. Stands would also function as reservoirs from where genetic material could be identified for further breeding and tree improvement. The stands would in other words 'bring the genetic resources closer to the user'. Stands were also seen as 'pilot' activities with a specific purpose to gain more practical experience on establishment and management (FAO 1985).

1.2.1 *Ex situ* conservation activities of the FAO/UNEP project

The FAO/UNEP project involved seed collection and establishment of *ex situ* conservation stands of two Central American pine species; *Pinus caribaea* var. *hondurensis* and *P. oocarpa*. It has later become evident from field testing that what was considered as *P. oocarpa* is in fact two distinct species: *P. oocarpa* and *P. tecunumanii* (see Chapter 2).

The FAO/UNEP project identified 6 provenances (three of *P. caribaea*, one of *P. oocarpa*, two of *P. tecunumanii*) for seed collection. These provenances were identified on basis of their potential for plantation establishment in the recipient countries and based on threats to the natural populations.

Seed collection for the purpose of *ex situ* conservation amounted to 20 kg of *P. oocarpa* (*P. oocarpa* and *P. tecunumanii*), 2.5 kg of *P. caribaea* var. *hondurensis*, 41.2 kg of *E. camaldulensis* and 2.7 kg of *E. tereticornis* (FAO, 1985). The planning and execution of the seed collections is described in more detail in Doran and Boland (1978), FAO (1978a) and FAO (1978b).

The availability of seed for the purpose of *ex situ* conservation was announced to all countries where the species had a potential. Based on the response, countries and institutions were selected to receive seed and support in establishment. Countries were: Congo, Côte d'Ivoire, India, Kenya, Nigeria, Thailand and Zambia.

Project funds were used to provide seed free of charge and to cover a substantial part of the establishment costs of the stands (FAO, 1985). The financial contribution towards stand establishment amounted to 250 US$/ha given as a standard rate. Protection and care of the stands in subsequent years were the responsibility of the host countries.

It was laid down in agreements at the time of establishment that the stands were the sole property of the host countries. They assumed full responsibility for establishment and management (FAO 1985). It was further agreed that countries should make available - at cost recovery basis - up to 50% of seed production to other countries. In this way, benefits of the stands could be extended to a wider range of countries.

Enough seeds were dispatched to establish 10 ha stands, which was the recommended stand size. In most countries the stands were planted during the years 1977-79. In India project operations started later and most plots there were planted in 1981-82. All FAO/UNEP stands were assessed after establishment and proposals were made on the future management of the stands. The project concluded activities in 1985 (FAO 1985).

1.2.2 Additional seed collection, seed exchange and stand establishment

Parallel to the implementation of the FAO/UNEP project, a number of other activities took place with tropical pines. Seed was distributed from the range-wide collections of Oxford Forestry Institute to a large number of countries. Danida Forest Seed Centre and CAMCORE undertook additional seed collections. These collections sampled the same provenances as used in the FAO/UNEP project and a number of other provenances. Seeds were distributed from these collections. As a result, a large number of stands were established in the late 1970's and early 80's in various countries. Stand establishment was in some cases supported with donor funding. Among these efforts, Danida supported establishment of stands in Tanzania and Thailand.

No global summary exists of the *ex situ* conservation stands of pines. The number, however, is believed to be significant. The FAO/UNEP project played a role in the distribution of the genetic resources of the species, but distribution also followed other pathways. The FAO/UNEP project probably also stimulated interest and triggered activities.

1.3 The 'Study population'

The study includes 36 *ex situ* conservation stands of the FAO/UNEP project, complemented by 99 national stands as explained in more details below. In total, the stands cover an area of 950 ha and the study population represents 40 different seedlots and 28 provenances.

1.3.1 Stands of the FAO/UNEP project constitute the core set

The *ex situ* conservation stands established within the framework of the FAO/UNEP programme constitute the core stands. Table 1 gives a summary of these stands by species, provenance and country. The intention was to include all FAO/UNEP stands in the study. Unfortunately, it was not possible to assess stands in Congo and Nigeria. Stands of the five other countries under the FAO/UNEP programme (Côte d'Ivoire, Kenya, Zambia, India and Thailand) are included in the present study. Thus, the core population consists of 36 stands covering 208.6 ha.

1.3.2 Additional stands

It was decided to complement the core set of stands with additional stands of countries participating in the FAO/UNEP project (India and Thailand) as well as stands in countries outside of the project (Australia, Brazil and Tanzania). The latter countries have been selected as they hold a large number of stands of the seed sources of the FAO/UNEP programme.

All in all, the core population of FAO/UNEP stands (36 stands) has been complemented by 99 additional stands (742 ha) in 5 countries. Table 2 provides a summary of these stands. Throughout the text they are denoted either 'additional stands' or 'national stands', whereas stands established within the framework of the FAO/UNEP project are denoted 'FAO/UNEP stands'.

The 'full' study population thus comprises the 'FAO/UNEP stands' (Table 1) and 'national stands' (Table 2). The full study population covers 135 *ex situ* conservation stands in 8 countries with an area of 950.6 ha. The population samples 40 seedlots of 28 different provenances of the three species.

In the analysis to follow, it is important to distinguish between the two types of stands. Stands of the FAO/UNEP project were established with the explicit objective of *ex situ* conservation and seed production. The 'additional' stands may have been established with a multitude of purposes, of which *ex situ* conservation might not have been the prime one. Many stands are believed to be 'pilot' plantings to observe the potential of a species/provenance. It is important to consider the origin and objectives of stands when analysing data. The 'additional' stands can not always be analysed/evaluated according to the same criteria as the FAO/UNEP stands.

Picture 2. *Ex situ* conservation stand of *P. caribaea* at Khong Chiam, Thailand. Stands of 3 species of pines were established in 8 countries.

Table 1. *Ex situ* conservation stands of pines established under the FAO/UNEP programme of conservation of forest genetic resources. Figures in brackets denote number of conservation stands. Stands in Congo and Nigeria were not assessed.

Species	Provenance	Total	Congo	Côte d'Ivoire	Kenya	Nigeria	Zambia	India	Thailand
		Ha (No.)	Ha (No.)	Ha (No.)	Ha (No.)	Ha (No.)	Ha (No.)	Ha (No.)	Ha (No.)
P. caribaea var. *hondurensis*	Alimicamba	40.0 (8)	16.4 (2)	7.0 (1)	-	1.4 (1)	-	5.0 (1)	10.2 (3)
	Los Limones	61.5 (13)	20.0 (2)	-	7.5 (3)	8.0 (2)	-	13.4 (3)	12.6 (3)
	Poptun	36.6 (6)	8.2 (1)	8.1 (1)	-	-	-	7.2 (2)	13.1 (2)
P. oocarpa	Bonete	44.0 (5)	20.0 (2)	-	-	-	20.0 (2)	4.0 (1)	-
P. tecunumanii	Mt. Pine Ridge	90.0 (12)	10.1 (1)	9.4 (1)	-	14.7 (3)	20.0 (3)	10.9 (1)	24.9 (3)
	Yucul	79.7 (11)	20. 1 (2)	9.0 (1)	-	24.3 (3)	10.0 (1)	4.0 (1)	12.3 (3)
Total		*351.8 (55)*	*94.8 (10)*	*33.5 (4)*	*7.5 (3)*	*48.4 (9)*	*50.0 (6)*	*44.5 (9)*	*73.1 (14)*

Table 2. *Ex situ* stands outside the FAO/UNEP project included in the present study.

Species	Provenance	Total Ha (No.)	Australia Ha (No.)	Brazil Ha (No.)	India Ha (No.)	Tanzania Ha (No.)	Thailand Ha (No.)
P. caribaea var. *hondurensis*	Alamicamba	114.1 (10)	78.0 (3)	9.6 (3)	-	9.8 (1)	16.7 (3)
	Culmi	36.5 (11)	-	9.7 (4)	5.4 (3)	-	21.4 (4)
	Guanaja	40.3 (2)	37.0 (1)	3.3 (1)	-	-	-
	Guatemala	21.0 (1)	-	-	-	-	21.0 (1)
	Karawala	14.9 (4)	-	7.4 (3)	-	7.5 (1)	-
	La Brea Colon	7.5 (2)	3.0 (1)	-	-	-	4.5 (1)
	La Mosquitia	31.8 (3)	18.0 (1)	-	-	-	13.8 (2)
	Lolobo Islands	5.3 (1)	-	-	-	-	5.3 (1)
	Los Limones	87.2 (11)	-	-	12.6 (5)	10.0 (1)	64.6 (5)
	Mixed 15 prov.	4.8 (1)	-	-	-	-	4.8 (1)
	Poptun	41.1 (7)	-	-	10.2 (3)	30.9 (4)	-
	San Carlos	3.5 (1)	-	-	-	-	3.5 (1)
	Santa Clara	14.2 (2)	-	8.2 (1)	-	-	6.0 (1)
	Unknown origin	14.0 (2)	-	-	10.0 (1)	-	4.0 (1)
	Subtotal	*436.2 (58)*	*136.0 (6)*	*38.2 (12)*	*38.2 (12)*	*58.2 (7)*	*165.6 (21)*
P. oocarpa	Bucaral (El Castaño)	5.0 (1)	-	-	-	-	5.0 (1)
	Dipilto	12.3 (1)	-	-	-	-	12.3 (1)
	Guatemala	8.8 (1)	-	-	-	-	8.8 (1)
	Jocatan	11.0 (1)	-	-	-	-	11.0 (1)
	Las Crusitas	9.0 (1)	-	-	9.0 (1)	-	-
	Mal Paso	33.3 (5)	-	-	-	-	33.3 (5)
	Mix of prov.	1.6 (1)	-	-	-	-	1.6 (1)
	Unknown origin	4.0 (1)					4.0 (1)
	Subtotal	*85.0 (12)*	-	-	*9.0 (1)*	-	*76.0 (11)*
P. tecunumanii	Chanel	0.8 (1)	-	0.8 (1)	-	-	-
	Mt. Pine Ridge	76.3 (6)	40.0 (2)	36.3 (4)	-	-	-
	Napite	1.0 (1)	-	1.0 (1)	-	-	-
	Pachoc	0.4 (1)	-	0.4 (1)	-	-	-
	Rancho Nuevo	0.8 (1)	-	0.8 (1)	-	-	-
	San Rafael	73.7 (11)	-	35.8 (5)	7.9 (3)	-	30.0 (3)
	Yucul	67.8 (8)	-	35.0 (4)	2.0 (1)	-	30.8 (3)
	Subtotal	*220.8 (29)*	*40.0 (2)*	*110.1 (17)*	*9.9 (4)*	-	*60.8 (6)*
Grand Total		*742.0 (99)*	*176.0 (8)*	*148.3 (29)*	*57.1 (17)*	*58.2 (7)*	*302.4 (38)*

1.4 Methodology

All stands in the study population have been assessed according to common guidelines (DFSC, 1996b). The assessments provided information on planting sites, establishment techniques, management, growth, quality, health, reproductive potential and cost-benefits.

The field assessment comprised for each stand:

- Description and mapping of the location (site) of the conservation stand;
- Collection of information on climate, soil and vegetation history of the site;
- Registration of original seed source used to establish the stand;
- Collection of information on owner(s) and user(s);
- Collection of detailed information on the various steps in stand establishment and management;
- Registration of the protection status;
- Registration of the use(s) of the stand to date;
- Assessment of growth parameters (height and diameter) of individual trees in sample plots;
- Assessment of quality parameters (stemform, foxtailing and forking) of individual trees in sample plots;
- Assessment of health and social status of individual trees in sample plots;
- Assessment of flowering and cone production-ing (5 stages) on individual trees in sample plots;
- Assessment of distance to contamination pollen sources;
- Collection of information on costs and used man-power in establishment, management and protection of the stand.

All data measured on individual trees in sample plots were stored in spreadsheet format and documented in national assessment reports. All data and information was transformed to SAS-datasets for calculation of stand-mean values. Calculations of stand mean values (from assessments on individual trees in sample plots) are explained in annex 2.

Picture 3. Assessment team at work in stand of *P. caribaea.*

2. Species and Provenances

This chapter gives a short description of the three pine species, their natural distribution and sampling in the *ex situ* conservation programme. Furthermore, basic knowledge on the provenance variation within the species is summarised.

2.1 The species

Three pine species are included in the evaluation: *P. caribaea* var. *hondurensis Barr*. & Golf., *P. oocarpa* Schiede and *P. tecunumanii* (Schw.) Eguiluz & Perry [*P. patula* subsp. *P. tecunumanii* (Eguiluz & Perry) Styles].

During the 1980s there was evidence from provenance trials that there were two taxa represented in the seed that had been distributed as *P. oocarpa* and some of the provenances of this species were re-identified as *P. patula* subsp. *P. tecunumanii* (Styles 1985). This report follows Eguiluz and Perry (1983) ranking *P. tecunumanii* as a species on its own. The following short species descriptions are based on Perry (1991).

P. caribaea var. *hondurensis* is a slender tree up to 30 meters in height. The crown is very open due to the sparse branches and separated bundles of needles on the twigs. The trunk is usually straight and the bark is deeply fissured. The needles are 15-25 cm long and usually in bundles of 3 located in whorls at the end of shoots with persistent 1.2 cm long basal sheaths. The male strobili are located in dense clusters around the twigs. The cones are variable in size (5-14 cm) and fall from the branches easily.

P. oocarpa is up to 20 meters high, rarely higher with a wide, open crown of long twisting branches. The bark on old trees becomes rough and scaly. The needles are long (20-25 cm), delicate and grouped in bundles of 3-4 with persistent 1.5-2 cm long basal sheaths. The cones are 6-10 cm long and usually ovoid. There is a relatively great variability within this species, which is not surprising in view of its very broad north-south geographical distribution.

P. tecunumanii grows up to 50 meters in height with a diameter of 50-120 cm. The trunk is straight and generally free of branches for 20-30 meters. The crown is narrowly pyramidal and dense. The bark is thin, scaly and brown to brownish red. The needles are 14-21 cm long in bundles of 4-5, borne thickly along the branchlet with persistent 1.5-2 cm long basal sheaths. The cones are 4-7 cm long, long-ovoid to conical, borne on slender slightly curved peduncles that remain attached to the cone when it falls.

In the field, the identification of these taxa is often difficult and there has been some disagreement regarding their classification. It has been found that *P. caribaea* var. *hondurensis* crosses naturally with *P. oocarpa* (Perry 1991) and probably also *P. tecunumanii* (Hodge & Dvorak 1997). Natural crosses could help to explain the introgression that appears to take place among these taxa (Furman *et al*. 1996).

Picture 4. Height measured using clinometer, Luiz Antonio, Brazil.

2.2 Natural distribution of the species

2.2.1 Distribution of *P. caribaea* var. *hondurensis*

P. caribaea occurs naturally in the Bahamas, Cuba and the Central American lowlands (Figure 1). *P. caribaea* var. *hondurensis* is confined to Central America where it forms discontinuous stands extending from north-eastern Nicaragua, through north and central Honduras, through to northern Belize with small and isolated stands in eastern Guatemala and Quintana Roo, Mexico. There is a single insular occurrence on the islands of Guanaja and Roatán off the north coast of Guatemala. Most of the pine forests of this variety occur as a band of variable width along the humid lowlands of the Atlantic coast but some stands are found along valleys 2-300 km inland. Its altitudinal distribution ranges from sea level to 800 m. The natural populations of *P. caribaea* were described in detail by Greaves (1978).

Throughout the range of *P. caribaea* summer rainfall and a winter dry season prevails. The rainfall decreases and the length of the dry season increases moving from south to north. *P. caribaea* grows best with annual rainfall of 2000 mm or more but there are scattered stands growing under very dry conditions east and south of Tegucigalpa near the village of Los Limones. The climate is frost-free and warm and humid for most of the year. Hurricanes occur throughout the coastal range of *P. caribaea* but are

Table 3. Selected morphological features and altitudinal range for *P. caribaea* var. *hondurensis, P. oocarpa* and *P. tecunumanii*.

Species	No. of needles	Needle length (cm)	Cone length (cm)	Height of tree (m)	Altitudinal range (m.a.s.l.)
P. caribaea var. *hondurensis*	3(4-6)	15-25	6-14	20-30	0-800
P. oocarpa	3-4(5)	20-25	6-10	15-20(30)	7-1500
P. tecunumanii	4-5	14-21	4-7	50	400-2800

most frequent along the coast of northern Honduras and Belize.

P. caribaea is typically found on soils of low fertility and with pH usually between 5.0 and 5.5. At Poptun in Guatemala, the pine forests are found on areas between limestone hills where the topsoil is slightly acidic. The soils are freely drained which allows the surface layers to dry out during the dry season and throughout its range *P. caribaea* is subject to frequent ground fires. Thus the pine savannahs in Nicaragua are thought to be a fire-caused disclimax, initiated by the first agricultural people settled in the region (Taylor 1963). As the rain forest on the seasonally dry soils were destroyed it allowed for the more fire-resistant pines to become established.

2.2.2 Distribution of *P. oocarpa*

At higher and drier altitudes in Central America *P. caribaea* is associated with and eventually replaced by *P. oocarpa*. *P. oocarpa* is typically found at altitudes ranging from 700-1500 m, but in Mexico it occurs in some areas up to 2000 m. The natural distribution of *P. oocarpa* forms a discontinuous band largely confined to the mountainous uplands running from north-west Nicaragua, through Honduras and northern El Salvador, the southern half of Guatemala, and the south west of Mexico (Figure 2). At high elevations *P. oocarpa* is replaced by mixed hardwoods or high elevation pine species like P. *tecunumanii*, *P. maximinoi* and *P. pseudostrobis*. A more detailed description of the natural populations of *P. oocarpa* was given by Greaves (1979).

Over its 3000 km wide northwest-southeast range *P. oocarpa* is found growing under conditions ranging from dry-temperate to humid subtropical. Rains occur during the summer with a dry season of four to five months in winter. The Central American populations grow in areas with annual rainfalls of 1000-3000 mm but Mexican populations are known where the mean annual rainfall is as low as 700 mm. The best growth is made on well-drained slopes under subtropical conditions with about 1500-2000 mm rainfall. Generally the climate of *P. oocarpa* is frost-free, temperatures below zero occur only very occasionally at some of the high altitude sites in Mexico.

CAMCORE (2000) used RAPD markers to assess the relatedness of various pine species. *P. oocarpa* from northern and western Mexico grouped in a different clade than Central American *P. oocarpa*. The finding that *P.oocarpa* from northern and western Mexico is notably different from its Central American counterpart raises important evolutionary questions and are also important in developing a comprehensive gene conservation strategy.

Throughout its range most *P. oocarpa* stands grow on infertile sandy soils and are frequently exposed to ground fires. Mature trees are fire-resistant but young seedlings are often killed, although saplings 2-4 years old, have a remarkable ability to sprout from the root following fires that have killed the original stem (Perry 1991).

2.2.3 Distribution of *P. tecunumanii*

P. tecunumanii is described from central Nicaragua, through north western Honduras, El Salvador, central and western Guatemala and Mountain Pine Ridge in Belize, to Chiapas, Mexico (Dvorak and Raymond 1991). *P. tecunumanii*, being confined mainly to higher altitudes, has a discontinuous distribution associated with mountain ridges and tops forming a number of more or less isolated

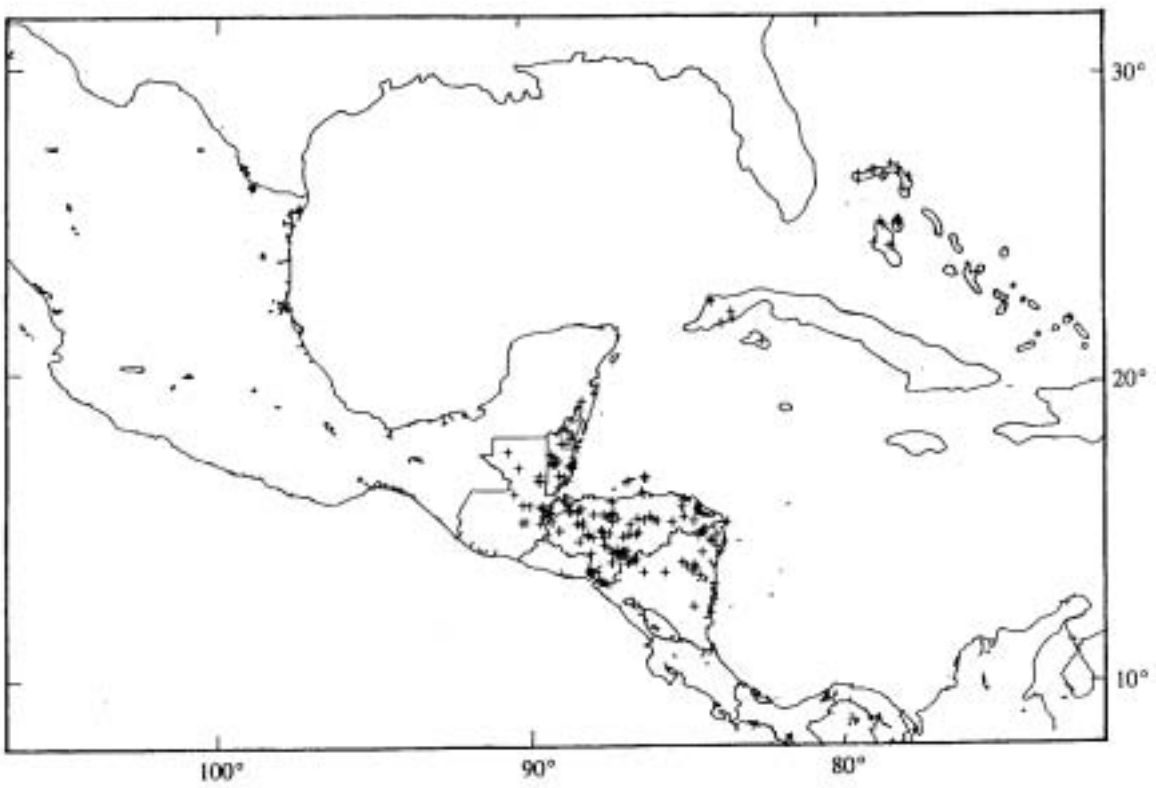


Figure 1. Natural distribution area of *Pinus caribaea*. Reproduced after Birks & Barnes (1990).

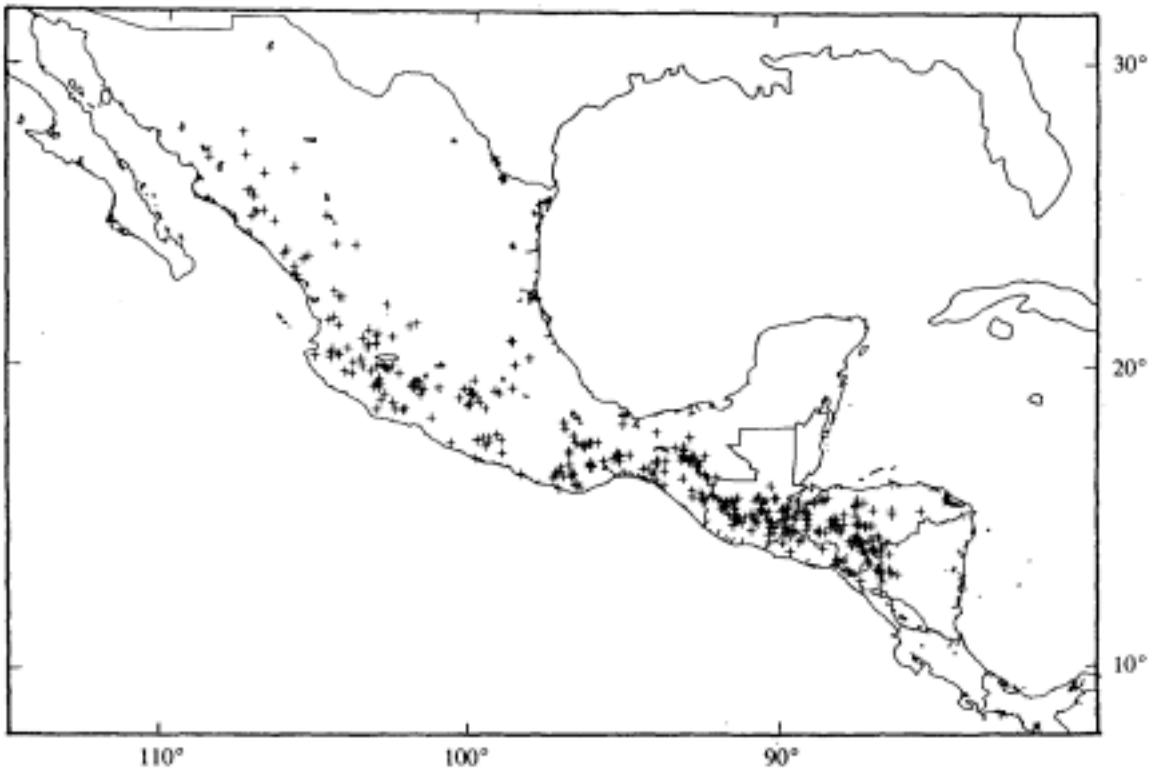


Figure 2. Natural distribution area of *Pinus oocarpa*. Reproduced after Birks & Barnes (1990).

populations. It is found at elevations of 1000-2800 m although it grows at lower altitudes in the far south of its range and in Belize where it is found down to 400 m altitude. The species grows at altitudes slightly above those normal for *P. oocarpa*, usually associated with more fertile upland valley sites with higher rainfall and deeper soils. Frost may occur at higher elevations (2200-2600 m) during the winter months. Several populations that occur at elevations below 1500 m appear to have introgressed with *P. oocarpa* and *P. caribaea* while populations that occur at elevations of approximately 1500 m to 2800 m have evolutionary links to *P. patula* (Dvorak and Donahue 1992). Based on differences in morphology and growth performance in field trials, *P. tecunumanii* have been divided into high elevation (>1500m) and low elevation (<1500 m) populations (Dvorak & Donahue 1992, Hodge & Dvorak 1999). The natural distribution of *P. tecunumanii* is shown in Figure 3.

2.3 Threats to the natural stands

The habitats of the Central American pine species are rapidly disappearing due to human interference. Guatemala, Honduras and Nicaragua have the highest deforestation rates in Central America coming to 2.0 - 2.5 % annually (FAO 1997). Although the deforestation figures are for the total forest area, and not exclusively for pine forest, they illustrate the strong pressure on natural forests, a pressure that has been steadily increasing over the past decades.

All three species are under pressure, but it is unclear if they are affected to the same degree. Styles (1985) mentions that *P. tecunumanii* is probably under more threat of genetic erosion and in greater need of conservation than any other Central American pine because it grows on deeper more fertile valley soils which are being heavily encroached upon for agricultural purposes. But also *P. caribaea*, growing in valleys and on plains, is often clearcut for agriculture (Robbins 1983a). The remaining stands have been heavily exploited for timber. Overfrequent fires also prevent proper regeneration of the stands. *P. oocarpa* generally has a more continuous distribution than the two other species, being broken up, particularly on better soils, by clear cutting for agriculture. The best stands have been heavily exploited for timber and frequent fires result in low stocking (Robbins 1983b).

For all three species the degradation of the forests has been accelerated by a widespread practice converting land to cattle grazing following exploitation of virgin stands. A dense grass cover decreases the survival of pine seeding and increases the fire hazard in the dry season. For all three pine species fire appears to be an important factor for the pines to compete successfully with the broadleaf vegetation. However, too frequent fires destroy the seedlings and prevent regeneration, which is a major threat to the remaining pine stands.

An overview of the conservation status of the genetic resources of *P. caribaea*, *P. oocarpa* and *P. tecunumanii* within the natural range is provided by CAMCORE (2000). Disturbance due to agriculture and the harvesting of trees for fuelwood and timber has resulted in a sharp reduction in many populations. There is a further need to evaluate the remaining stands, to prepare guidelines, and to initiate activities for conservation of valuable provenances and seed sources of all three species.

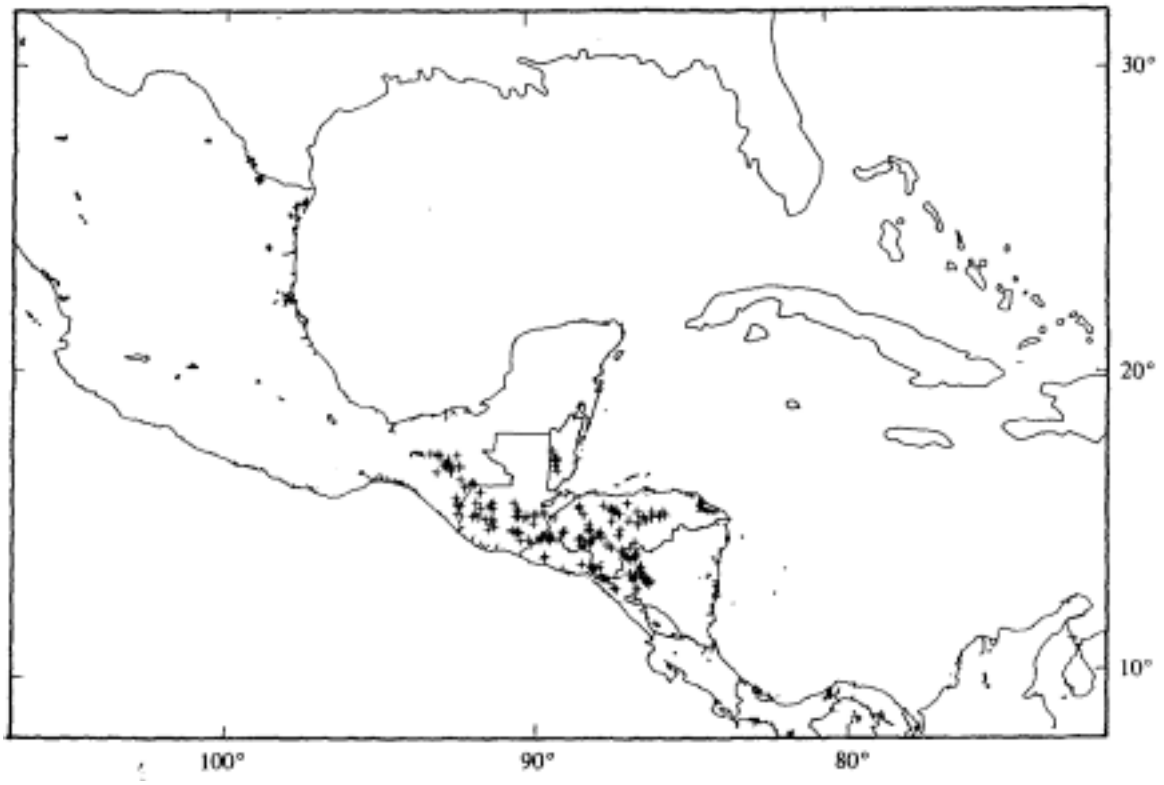


Figure 3. Natural distribution area of *Pinus tecunumanii*. Reproduced after Birks & Barnes (1990).

2.4 Knowledge of provenance variation from trials

P. caribaea, *P. oocarpa* and *P. tecunumanii* have been intensively tested in provenance and progeny trials, and they are probably among the forest tree species where most information is available on provenance variation. Several hundred field trials have been established of the three species in more than 50 tropical countries (Birks and Barnes 1990). This section gives a brief description of the provenance variation for each of the three species. For more detailed information on results of individual trials and results for specific provenances, the reader should consult the comprehensive literature.

2.4.1 OFI and CAMCORE activities

In particular the Oxford Forestry Institute (OFI), United Kingdom, and the Central America and Mexico Coniferous Resources Co-operative (CAMCORE), based at the North Carolina State University in USA, have undertaken intensive collection and testing of Central-American pines.

In 1969, OFI initiated the 'Central American Pine Provenance Research Project' where 36 provenances of *P. caribaea* were collected and distributed in the 1970's and 1980's to more than 40 countries for international provenance trials. The seed sources are described by Greaves (1978). The programme was soon after expanded to include *P. oocarpa*[1]. Seed collections were made throughout the species distribution from Mexico to southern Nicaragua and 74 provenances were distributed to 42 countries. Seed sources are described by Greaves (1979).

Some early results of these trials are summarised by Greaves (1980). Later it was decided to undertake an overall assessment and analysis of the most representative trials in order to produce a comprehensive and comparable set of data from the whole range of environments over which they had been planted. Birks & Barnes (1990) present the summary statistics and analysis.

CAMCORE has been actively involved in the exploration and testing of Central American pines since the early 80's. For *P. caribaea* var. *hondurensis*, CAMCORE used the early results of the OFI trials to define priorities in seed collection. 23 provenances have been sampled representing 1128 mother trees (Dvorak & Donahue, 1992). Seed collections of *P. oocarpa* sampled 15 provenances, and for *P. tecunumanii*, 45 provenances have been collected. Seeds were distributed to CAMCORE members in a number of countries for establishment of provenance trials. Results of 78 international trials of *P. tecunumanii* in Brazil, Colombia, South Africa and Venezuela have recently been summarised by Hodge & Dvorak (1999).

The research and breeding activities by other groups have probably made significant contributions to the *ex situ* conservation of these three pine species. The value of the *ex situ* project described in this report, in relation to the other initiatives mentioned above, requires a more detailed analysis. It should specifically examine the populations sampled, the number of genotypes represented and the number and relevance of sites they have been established on. It would be important to identify gaps that could be filled by stands described in this study. Otherwise, redundancy at a substantial cost could occur.

[1]Including seed sources later identified as *P. tecunumanii*.

2.4.2 Provenance variation

Results of the international trials revealed that *P. caribaea* var. *hondurensis* show a considerable provenance variation. The results below refer, where no other reference is mentioned, to Birks & Barnes (1990).

Three main provenance regions within the natural range can be delineated based on the trials: (i) the coastal plains; (ii) the higher and drier inland populations; and (iii) insular population (Guanaja).

The coastal origins and the insular occurrence of Guanaja included the most promising provenances notable for their good stem and crown form, high growth rates and wind firmness. A major disadvantage was their low wood density. Most promising for their productivity were Laguna del Pinar, Nicaragua and Guanaja, Honduras followed by Alamicamba and Karawala, both Nicaragua.

The provenances of inland origins were very variable in productivity with most provenances ranking low but a few very high (Birks & Barnes 1990). They had higher wood density, showed early flowering tendencies, produced more conelets, and generally gave rise to fewer foxtails than the coastal provenances. However, stem straightness, wind firmness and branching traits are not as good as the coastal sources and the inland provenances tend to dieback on lowland equatorial sites. Best among the inland provenances were Santa Clara, Nicaragua, which ranked third overall among the natural provenances, followed by Potosi, Honduras, Mountain Pine Ridge, Belize and Poptun, Guatemala.

Also *P. oocarpa* expresses considerable provenance variation. In general, the most promising provenances in the OFI trials were found to be the southern Nicaraguan provenances of Las Camelias, San Rafael and Yucul together with Mt. Pine Ridge in Belize. They combined good growth rates with favourable stem and crown form, but were susceptible to stem-break on exposed sites. However, these occurrences were later re-identified as *P. tecunumanii* (Barnes and Styles 1983, Styles 1985). The quality of the *P. oocarpa* provenances tends to decline with increasing latitude, being best in Honduras and poorest in Mexico (Robbins 1983b). The Mexican sources of *P. oocarpa* differ markedly from the Central American sources when grown as exotics; most conspicously, they have a very poor stem form. The best overall provenances of the OFI international trials were those from Pueblo Caido (Guatemala), Lima (Guatemala), Bonete (Nicaragua), Conacaste (Guatemala), Agua Fra (Honduras) and Canas (Guatemala). The four Guatemalan provenances were all from the NE part of the range in the country.

All the four provenances later identified as *P. tecunumanii* were outstandingly more productive than those of *P. oocarpa*. They also generally had thinner bark, straighter stems, fewer forks, fewer branches, longer internodes, fewer cones, lower seed yield per cone, and slightly lower wood density. In some traits the Mt. Pine Ridge provenance was found to be more associated with *P. caribaea* var. *hondurensis* and it is suspected that hybridisation and introgression is occurring between *P. caribaea* and *P. tecunumanii* in this region (Furman *et al.* 1996).

Based on subtle differences in morphology and growth performance in the field, CAMCORE has separated the *P. tecunumanii* populations into high (>1500 m altitude) and low (<1500 m altitude) elevation breeding groups (Dvorak 1985, 1986). Considerable provenance variation exists, with best provenances 10 to 15% better in volume growth than the mean (Hodge & Dvorak 1999). San Jeronimo and Chiul (Guatemala) together with Montebello and Napite (Mexico) were identified as the best overall performers amongst the highland provenances, whereas Villa Santa (Honduras), San Rafael del Norte and Yucul (Nicaragua) were the best lowland sources (Hodge & Dvorak 1999).

2.4.3 Genotype x environment interaction

Genotype x environment interaction has been studied for *P. caribaea* by Gibson (1982), and for *P. tecunumanii* by Hodge & Dvorak (1999). For *P. caribaea* statistically significant provenance x environment interactions was found for eight of the ten studied traits in field trials covering a wide range of sites. For *P. tecunumani* slight provenance x site interaction was found, but a larger interaction was seen between families (within provenance) and site. It thus appears that provenances are more stable across sites than families (Hodge & Dvorak 1999). No studies are available for *P. oocarpa*.

The trials described in this study deal primarily with genotype x environment interaction at 'macro-level', i.e. species/populations x trial sites x different countries. To facilitate gene conservation planning at national level, information on interaction be-tween trial sites representing the major planting zones within country is needed. Such information is, however, seldom available and planning has to be carried out based on general ecological information. The trial designs make it difficult to extract good information on genotype x environment interaction at the sampled and tested.

2.5 Provenances in the study

Background information from collecting teams, together with results from plantings and provenance trials, were used to indicate seed sources important to include in the programme. Provenances at the extremes of the range or those endangered were chosen, leaving intermediate sources, or those reasonably secure, for future consideration (FAO 1985).

The 135 *ex situ* conservation stands in this study represent 50 different seed lots of 29 provenances. The provenances and seed lots are listed in table 4, 5 and 6 and the seed collection locations are shown in fig. 4, 5 and 6.

P. caribaea var. *hondurensis* of 14 origins are included in the study, 10 provenances of known origin,

1 landrace from Fiji and 3 seedlots of unknown origin (Table 4).

The coastal plains are represented by 4 provenances, which together with the insular provenance of Guanaja constitute the low-laying, warm and humid provenances (Fig 4). The inland range is covered by 5 provenances growing at higher altitude and lower precipitation. The pine stands at Poptun are separated by broadleaf forest from the nearest stands of *P. caribaea* at Mt. Pine Ridge 70 km east and on the Sierra de las Minas 100 km to the south. The site at Culmi is located at the eastern extreme of the main expanse of inland pine forest. The locality at Los Limones is exceptional in being very dry. Generally, the coastal populations form more continuous stands, whereas stands in the highland are smaller and more disrupted.

The seed lots of *P. caribaea* provide a reasonably good sampling of the provenances within the natural range including the extremes. Birks and Barnes (1990) list some potentially valuable provenances, not included here. Among these is Laguna el Pinar from Nicaragua. It is the most southerly, tropical and wettest provenance and endangered within its natural range. Furthermore it has proved to be among the most promising provenances in trials.

P. oocarpa is represented by 6 provenances, two from Nicaragua, three from Guatemala and one from Honduras. In addition, an unidentified source from Guatemala and an unknown seed lot is included (Table 5). The Nicaraguan provenances are from the extreme southern limit of the species natural range, and are probably also among the most threatened populations. The provenance of Bonete was one of the most promising in the OFI trials. The Guatemalan sources are all from the north east part of the range in this country. Provenances from this area have been among the best overall performers in the provenance trials.

The *P. oocarpa* provenances in the study are all from higher and drier parts of its natural range, while the lower extreme of its altitudinal range (7-800 m) with generally higher precipitation has not been sampled. The best growth of *P. oocarpa* is found at these low-altitude slopes under subtropical conditions with about 1500-2000 mm rainfall. These areas are often more susceptible to human encroachment and pine forests at this altitude are often heavily depleted. This may explain the absence of provenances from lower altitudes but also stresses the need for additional provenance collections from this zone. CAMCORE has undertaken additional seed collections, but these mainly sample the higher elevations (Dvorak & Donahue 1992).

More than half of the natural distribution of *P. oocarpa* occurs outside Central America in Mexico and is not represented. The Mexican provenances are known to exhibit a very poor stem form when grown as exotics. The extensive pine forests of Honduras were relatively well sampled in the OFI seed collections, but none of the provenances proved to be among the best performers. None of the Honduran provenances are represented in the present study.

P. tecunumanii is represented by 7 provenances (Table 6). The Nicaraguan provenances of San Rafael and Yucul represent the southernmost range of the species, while Mt. Pine Ridge is the northernmost and isolated occurrence in Belize. These three provenances all represent populations growing at exceptionally low elevation of 7-1200 m, whereas the remaining altitudinal range up to 2800 m has not been sampled in the study, except for 4 CAMCORE seed lots, each of them planted at a single site. An extensive provenance collecting program representing the full geographical and altitudinal range of *P. tecunumanii* has since then been undertaken by CAMCORE (Dvorak & Donahue 1992). Results of the testing of these seed sources are presented by Hodge & Dvorak (1999).

Table 4. *P. caribaea var. hondurensis* provenances and selected data on collection sites arranged according to altitude. Provenances and seed lots of the FAO/UNEP project are shown in *italics*.

Provenance	Country	Latitude	Longitude	Altitude m	Rainfall mm/year	Temp °C	Seedlot
Guanaja	Honduras	16°28 N	85°50 W	0-300	2447	27.2	DFSC1143/83
Karawala	Nicaragua	12°58 N	83°34 W	10	3897	26.4	OFI 48/78, 29/77
Alamicamba	Nicaragua	13°34 N	84°17 W	10-30	2610	27.3	DFSC1033/82 *OFI 6/74*, 7/79
La Mosquitia	Honduras	14°43-15°20 N	83°16-84°24 W	10-170	2859	26.7	DFSC1060/82
La Brea Colon	Honduras	15°45 N	86°05 W	40-60			DFSC5517
Lololo Island	Fiji	17°34 S	177°35 W	110	2246		PIC2047
San Carlos	Honduras	15°18 N	86°50 W	350-450			PIC2044
Poptun	Guatamala	16°21 N	89°25 W	500	1689	24.3	OFI12/78, *OFI 29/70*; DFSC1134/83;
Culmi	Honduras	14°54-15°16 N	85°24-85°42 W	400-600	1440	23.5	DFSC5515, 5526, 1058/82; OFI15/76
Santa Clara	Nicaragua	13°48 N	86°12 W	700	1818	23.4	DFSC1049/82
Los Limones	Honduras	14°01 N	86°48 W	6-800	663	22.2	DFSC1056/82, 1137/83; *OFI24/75* PIC2277
Guatemala	Guatemala						PIC2028
Mixed 15 prov.	Unknown						PIC2030
Unknown	Únknown						004India

Figure 4. Seed collection sites of *P. caribaea* var. *hondurensis*. Poptun consist of seed lots DFSC1143/83, OFI12/78, OFI29/70 and XXX003INDIA. Guanaja: DFSC1134/83. La Brea Colon: DFSC 5517. Culmi: DFSC5526, DFSC5515; DFSC1058/82 and OFI15/76. La Mosquitia: DFSC1060/82. San Carlos: PIC2044. Los Limones: DSFC1056/82, DFSC1137/83, OFI24/75 and PIC2277. Santa Clara: DFSC1049/82. Alamicamba: DFSC1133/82, OFI6/74 and OFI7/79. Karawala: OFI29/77.

Table 5. *P. oocarpa* provenances and selected data on collection sites. Provenances of the FAO/UNEP project are shown in *italics*.

Provenance	Country	Latitude	Longitude	Altitude m	Rainfall mm/year	Temp °C	Seedlot
Bonete	Nicaragua	12°50 N	86°18 W	950	922	21.4	*OFI7/74*
Mal Paso	Guatamala	15°10 N	89°20 W	800-1000	1800	22.3	DFSC5519
Jocotan	Guatemala	14°50 N	89°50 W	850-1050	1400	22.0	PIC3130
Dipilto	Nicaragua	13°43 N	86°37 W	1200	1143	19.2	OFI10/73
Las Crusitas	Honduras	13°50-14°16 N	86°30-87°00 W	9-1300	1034	22.6	DFSC1059/82
Bucaral (El Castaño)	Guatemala	15°01 N	90°09 W	1300	900	21.6	OFI3/71
Guatemala	Guatemala						PIC3062
Mixed	Unknown						PIC3070

Figure 5. Seed collection sites of *P. oocarpa*. Bucaral (El Castaño) represents seed lot OFI3/71.Mal Paso: DFSC5519. Jocotan: PIC3130. Las Crusitas: OFI10/73. Dipilto: DFSC 1059/82. Bonete: OFI7/74.

Table 6. *P. tecunumanii* provenances and selected data on collection sites. Provenances and seed lots of the FAO/UNEP project are shown in *italics*.

Provenance	Country	Latitude	Longitude	Altitude m	Rainfall mm/year	Temp °C	Seed lots
Mt. Pine Ridge	Belize	17°00 N	88°55 W	700	1558	24.0	DFSC1118/83 *OFI11/74*, 30/70
Yucul	Nicaragua	12°55 N	85°47 W	900	1394	22.4	DFSC1021/82 OFI6/71, *OFI2/76* IRENA001
San Rafael	Nicaragua	13°14 N	86°08 W	1200	1366	20.8	DFSC1022/82 OFI7/77 IRENA002
Napite	Mexico	16°34 N	92°19 W	2210	1350		CAMCORE37
Pachoc	Guatemala	14°52 N	91°16 W	2200-2500	1350		CAMCORE15
Chanal	Mexico	16°42 N	92°19 W	2010-2350	1238		CAMCORE31
Rancho Nuevo	Mexico	16°41 N	92°35 W	2280-2340	1238		CAMCORE38

Figure 6. Seed collection sites of *P. tecunumanii*. Yucul include seed lots DFSC1021/82, OFI6/71 and IRENA001. San Rafael: DFSC1022/82, OFI7/77 and IRENA002. Mt. Pine Ridge: DFSC1021/82, OFI30/71 and OFI11/74. Pachoc: CAMCORE15. Chanal: CAMCORE31. Napite: CAMCORE37. Rancho Nuevo: CAMCORE38.

3. Genetic Quality of Seed Lots

The *ex situ* conservation stands were established to (i) safeguard genetic material under threat of extinction or genetic erosion; (ii) to make available the genetic material for future use (bring the genes close to the user); and (iii) to be used as seed production stands. In order to fulfil these purposes, seed lots should sample the genetic variation and be accompanied by full documentation.

This chapter examines whether requirements regarding sampling method and documentation are fulfilled for the seed lots in this study. We are not considering the physiological quality of the seed lot, e.g. germination percentage, fungi or insects, but such requirements are of course also important.

Data sheets on the individual seed lots are presented in annex 4.

3.1 Genetic variation in seed lots

The number of mother trees gives an indication of the genetic variation in the seed lot. The mother trees should be, as far as possible, unrelated to avoid inbreeding in the resulting stands and to secure a sufficient genetic variation. This is normally secured by requiring a certain minimum distance between mother trees in the collection. Number of mother trees and minimum distance between the mother trees varies with purpose of seed collection, species and structure of the stand. In general, seed should be collected from a minimum of 25 unrelated trees with a minimum distance between trees of 100 m (FAO 1969). When collecting seed for conservation purposes it may in some cases be difficult to fulfil these requirements because of small population sizes. Such special conditions may thus justify seed collections from fewer mother trees and/or at shorter minimum distances.

Table 7 show the number of mother trees and minimum distance for seed lots in this study. Most seed lots represent a number of mother trees well beyond the minimum requirements mentioned above. Only seed lot OFI2/76 of *P. tecunumanii* (Yucul), sampling 15 mother trees may have a restricted genetic base. The very large variation in number of mother trees is mainly because of different sampling methods. For about half of the seed lots there is no information regarding number of mother trees. However, the seed lots originate from bulk collections normally sampling a large number of mother trees.

Little information is available on the minimum distance between mother trees. Information is found for five of the seed lots and here the minimum distance varies between 50 and 100 m. For the OFI seed lots, they have been collected from cone-bearing trees at least 100 meters apart (Greaves 1978), i.e. in good accordance with the rule of thumb mentioned above.

Table 7. Seed lot information on number of mother trees, minimum distance and sampling method. The 6 FAO/UNEP seed lots in *italics*.

Seed lot	Species	Provenance	No. of trees	Min. distance (m)	Sampling method
CAMCORE15	Pinus tecunumanii	Pachoc	20	80	
CAMCORE31	Pinus tecunumanii	Chanal	29	50	
CAMCORE37	Pinus tecunumanii	Napite	36	60	
CAMCORE38	Pinus tecunumanii	Rancho Nuevo	25	50	
DFSC1021/82	Pinus tecunumanii	Yucul	50		Semi-bulk
DFSC1022/82	Pinus tecunumanii	San Rafael	>250		Bulk
DFSC1033/82	Pinus caribaea var. hondurensis	Alamicamba	>1000		Bulk
DFSC1049/82	Pinus caribaea var. hondurensis	Santa Clara	130		Semi-bulk
DFSC1056/82	Pinus caribaea var. hondurensis	Los Limones			
DFSC1058/82	Pinus caribaea var. hondurensis	Culmi	>200		Bulk
DFSC1059/82	Pinus oocarpa	Las Crusitas	>200		Bulk
DFSC1060/82	Pinus caribaea var. hondurensis	La Mosquitia	100		Semi-bulk
DFSC1118/83	Pinus tecunumanii	Mt. Pine Ridge	>100		Semi-bulk
DFSC1134/83	Pinus caribaea var. hondurensis	Poptun	250	100	Semi-bulk
DFSC1137/83	Pinus caribaea var. hondurensis	Los Limones	>300		Bulk
DFSC1143/83	Pinus caribaea var. hondurensis	Guanaja	>300		Bulk
DFSC5515	Pinus caribaea var. hondurensis	Culmi			
DFSC5517	Pinus caribaea var. hondurensis	La Brea Colon	20		Semi-bulk
DFSC5519	Pinus oocarpa	Mal Paso			
DFSC5526	Pinus caribaea var. hondurensis	Culmi			
IRENA001	Pinus tecunumanii	Yucul			
IRENA002	Pinus tecunumanii	San Rafael			
OFI10/73	Pinus oocarpa	Dipilto	150		Semi-bulk
OFI11/74	Pinus tecunumanii	Mt. Pine Ridge		(100)	Bulk
OFI12/78	Pinus caribaea var. hondurensis	Poptun		(100)	
OFI15/76	Pinus caribaea var. hondurensis	Culmi		(100)	
OFI2/76	Pinus tecunumanii	Yucul	15	(100)	Selected trees
OFI24/75	Pinus caribaea var. hondurensis	Los Limones	100	(100)	Selected trees
OFI29/70	Pinus caribaea var. hondurensis	Poptun		(100)	Bulk
OFI29/77	Pinus caribaea var. hondurensis	Karawala	180	(100)	Selected trees
OFI3/71	Pinus oocarpa	Bucaral(El Castaño)	111	(100)	Selected trees
OFI30/71	Pinus tecunumanii	Mt. Pine Ridge		(100)	Bulk
OFI48/78	Pinus caribaea var. hondurensis	Karawala	64	(100)	Selected trees
OFI6/71	Pinus tecunumanii	Yucul	46	(100)	Selected trees
OFI6/74	Pinus caribaea var. hondurensis	Alamicamba		(100)	Bulk
OFI7/74	Pinus oocarpa	Bonete	80	(100)	Selected trees
OFI7/77	Pinus tecunumanii	San Rafael	170	(100)	Selected trees
OFI7/79	Pinus caribaea var. hondurensis	Alamicamba		(100)	Bulk
PIC2028	Pinus caribaea var. hondurensis	Guatemala			
PIC2030	Pinus caribaea var. hondurensis	Mixed 15 prov.			
PIC2044	Pinus caribaea var. hondurensis	San Carlos			
PIC2047	Pinus caribaea var. hondurensis	Lololo Islands			
PIC2276	Pinus caribaea var.hondurensis	Unknown			
PIC2277	Pinus caribaea var. hondurensis	Los Limones			
PIC3062	Pinus oocarpa	Guatemala			
PIC3070	Pinus oocarpa	Mixed			

Picture 5. *P. tecunumanii* seed source, Yucul, Nicaragua.

3.2 Sampling method

The applied sampling method should be in accordance with the objectives of the collection. Collections may sample a restricted number of plus trees in a population, based on traits of economic importance. Bulk collections on the other hand sample a larger number and broader range of trees. Hence, bulk collections - at least from a theoretical point of view - capture more genetic variation though the differences should be relatively minor. Seed lots from selected trees may be valuable when establishing stands to be used for further selection and breeding. The efficiency of plus tree selection in natural populations will in many cases be low, and therefore the differences in genetic variation between selective and bulk collections in many cases are of little importance. This has been confirmed in a recent CAMCORE isozyme study on differences in genetic variation between bulk collections and collection from selected trees in populations of *P. tecunumanii* in Guatemala. The study showed little difference between the two sampling methods, and the selected trees captured the vast majority of the genetic variation present (Dvorak *et al.* 1999).

Unfortunately, little information is available on the sampling method for many of the seed lots (Table 7). Many seed lots can be characterised as 'semi-bulk' collections. They sample a relatively large number of trees, usually more than 100, over an extensive area. The mother trees were selected among the better half of the phenotypes but still sampling a broader range of trees than collections from plus trees.

For OFI collections, 8 of 16 seed lots are from selected trees. Selection criteria are in most cases stem straightness and persistence of axis while the number of mother trees varies from 15 in seed lot OFI2/76 to 180 mother trees in OFI29/77. Thus, in most cases seed lots from plus trees have a broad genetic base. The remaining 8 OFI seed lots are semi-bulk/bulk collections.

For approximately half of the seed lots no information is available on the sampling method applied in the seed collection. As mentioned above, these seed collections are likely to be semi-bulk or bulk collections.

Picture 6. Seed harvest *P. tecunumanii*, Yucul, Nicaragua.

3.3 Appropriate documentation

In all seed collection appropriate seed lot documentation is a prerequisite. Appropriate seed lot documentation is needed as background information for matching site and planting material and hence to avoid a poor adaptation of resulting stand(s). It is also a prerequisite for returning to the original seed collection site, if necessary. Seed lot documentation should include: 1) information on the seed collection location, i.e. name, exact position (longitude, latitude, altitude), map reference and/or sketch map(s), access information, ownership, 2) a description of the collection site, including information on climate, soil, vegetation and stand characteristics, and 3) information on the seed collection itself, i.e. number of mother trees, selection principles, the minimum distance between trees and method of seed harvesting.

An example of a seed source description format to document the 50 seed lots in this study is found in annex 4.

The amount of seed lot documentation varies greatly among the seed lots. In general, the seed collections undertaken by OFI and CAMCORE are well described and most hold information regarding collection site, altitude, climate, soil, vegetation type and stand characteristics. Most also have information on number of mother trees collected and sampling method. Only few of them have information on minimum distance between trees. Usually a brief description of the location and access to the collection site is provided. Maps of the collection sites accompany only a few of the descriptions.

For the DFSC collections basic information is available, but for some documentation is wanting. These seed lots were usually purchased through seed dealers and seed banks in the region and seed documentation is not as complete as for own collections.

For the remaining 14 seed lots, documentation is very restricted, and for some of the seed lots virtually no information is available. Most of these seed lots have been obtained by national institutions through purchase, usually from national seed banks or private seed dealers. For four of the 14 seed lots, no documentation is available at all. Future use and potential benefits of the resulting stands are seriously reduced because of insufficient documentation.

4. Planting Sites

4. Planting sites

The overall aim of this chapter is to investigate how well species and provenances have been matched to planting sites. A good match is important for the long-term adaptation, growth and reproductive potential of stands.

4.1 General overview of planting sites

The 135 stands were established at 39 sites in 8 countries. The trial sites are listed in Table 8 together with key site characteristics. Site locations are showed on country maps in annex 3.

The tables on the following pages give a break-down of species and provenances to planting sites.

Table 8. Planting sites of the *ex situ* conservation stands.

Site	Country	Latitude	Longitude	Altitude m.a.s.l.	Rainfall mm	Mean Temp C	No of stands
Imanawuti	Australia	12.45S	130.30S	120	1750	25	2
Yapilika	Australia	12.45S	130.30S	85	1750	25	6
Batatais	Brazil	20.54S	47.35W	800	1484	20.2	1
Bento Quirino	Brazil	21.29S	47.33W	640	1398	20.7	2
Luiz Antonio	Brazil	21.40S	47.13W	550	1280	21.2	10
Itirapina	Brazil	22.15S	47.49W	780	1501	22	6
Itapetininga	Brazil	23.42S	47.57W	645	1128	19.3	4
Angatuba	Brazil	25.15S	50.49W	?	1190	17.9	6
Silver Cascade	India	10.14N	77.28E	1800	1659	14	1
Korapur	India	10.14N	77.28E	1800	1659	14	1
Perumalmalai	India	10.14N	77.28E	1801	1659	14.0	1
Marappalam	India	11.40N	76.10E	2638	2989	?	1
Devala	India	11.40N	76.10E	2637	2989	?	1
B.K. Gudda	India	13.43N	75.20E	609	1510.6	?	7
Neratoor	India	13.46N	75.12E	626	2021.4	26.1	1
Gorgod2	India	13.53N	75.30E	569	2949	22.2	1
Behalli	India	13.53N	75.30E	567	2949	22.2	1
Mumbar	India	13.53N	75.30E	566	2949	21.3	1
Gorgod	India	13.53N	75.30E	566	2949	22.2	1
Talavata	India	14.13N	74.55E	593	3259.8	25.2	1
Sydoor	India	14.13N	74.55E	593	3259.8	25.2	1
Madenoor	India	14.13N	74.55E	592	3259.8	25.2	1
Maredumilli	India	17.36N	81.43E	500	1500	?	1
Mangra	India	18.52N	82.41E	820	1165	?	1
Janijuda	India	18.52N	82.41E	822	1165	?	1
Deoghati	India	18.52N	82.41E	821	1165	?	1
Kurandih	India	19.05N	82.20E	556	1549	25.5	2
Rapide Grah	Côte d'Ivoire	05.50N	06.45W	?	1633	25.7	4
Katende Hill	Kenya	01.31S	37.17E	1680	908	19.3	3
Kwamarukanga	Tanzania	05.14S	38.29E	305	1063.6	25.6	1
Ruvu	Tanzania	06.35S	38.28E	70	1037	26.1	3
Nongkhu	Thailand	14.43N	103.5E	170	1280	27.3	5
Khong Chiam	Thailand	15.50N	104.52E	123	1577	27.1	1
Nong Krating	Thailand	17.57N	98.23E	1080	1223	26.3	10
Mae Sanaam	Thailand	18.08N	98.10E	1100	1223	26.3	10
Huey Bong	Thailand	18.10N	98.25E	800	1223	26.3	22
Intakin	Thailand	19.08N	98.58E	400	1194	25.4	7
Chati	Zambia	13.00S	28.39E	1250	1226	20.3	3
Siamambo	Zambia	16.51S	27.04E	1210	825	18.2	3

Table 9. Location of *ex situ* conservation stands of *P. caribaea* var. *hondurensis* by provenance. Figures indicate number of stands.

Site	Country	Provenance													
		Alimicamba	Culmi	Guanaja	Guatemala	Karawala	La Brea Colon	La Mosquitia	Lololo Islands	Los Limones	Mixed 15 prov.	Poptun	San Carlos	Santa Clara	Unknown
Imanawuti	Australia														
Yapilika	Australia	3		1			1	1							
Batatais	Brazil			1											
Bento Quirino	Brazil		1												
Luiz Antonio	Brazil	1	1			1								1	
Itirapina	Brazil	1	1			1									
Itapetininga	Brazil														
Angatuba	Brazil	1	1			1									
Silver Cascade	India														
Korapur	India									1					
Perumalmalai	India														
Marappalam	India									1					
Devala	India									1					
B.K.Gudda	India		2							2		1			
Neratoor	India														1
Gorgod2	India									1					
Behalli	India									1					
Mumbar	India											1			
Gorgod	India														
Talavata	India		1												
Sydoor	India											1			
Madenoor	India														
Maredumilli	India	1													
Mangra	India									1					
Janijuda	India														
Deoghati	India														
Kurandih	India											2			
Rapide Grah	Côte d'Ivoire	1										1			
Katende Hill	Kenya									3					
Kwamarukanga	Tanzania					1									
Ruvu	Tanzania	1								1					
Nongkhu	Thailand	1								1		1			
Khong Chiam	Thailand	1													
Nong Krating	Thailand		2				1	1	1			2			
Mae Sanaam	Thailand				1					3	1				
Huey Bong	Thailand	3	1					1		4		2	1	1	
Intakin	Thailand	1	1									1			1
Chati	Zambia														
Siamambo	Zambia														

Table 10. Location of *ex situ* conservation stands of *P. oocarpa* by provenance. Figures indicate number of stands.

Site	Country	Provenance								
		Bonete	Bucaral (El Castaño)	Dipilto	Guatemala	Jocatan	Las Crusitas	Mal Paso	Mixed	Unknown
Imanawuti	Australia									
Yapilika	Australia									
Batatais	Brazil									
BentoQuirino	Brazil									
LuizAntonio	Brazil									
Itirapina	Brazil									
Itapetininga	Brazil									
Angatuba	Brazil									
SilverCascade	India	1								
Korapur	India									
Perumalmalai	India									
Marappalam	India									
Devala	India									
BK_Gudda	India									
Neratoor	India									
Gorgod2	India									
Behalli	India									
Mumbar	India									
Gorgod	India									
Talavata	India									
Sydoor	India									
Madenoor	India									
Maredumilli	India									
Mangra	India									
Janijuda	India						1			
Deoghati	India									
Kurandih	India									
RapideGrah	Côte d'Ivoire									
KatendeHill	Kenya									
Kwamarukanga	Tanzania									
Ruvu	Tanzania									
Nongkhu	Thailand									
KhongChiam	Thailand									
NongKrating	Thailand					1		2		
MaeSanaam	Thailand				1			1	1	
HueyBong	Thailand		1	1				1		
Intakin	Thailand							1		1
Chati	Zambia	1								
Siamambo	Zambia	1								

Picture 7. Stand of P. *tecunumanii* (Yucul) at Luiz Antonio in Brazil. Documentation of seed source is essential for the conservation value of *ex situ* stands.

Table 11. Location of *ex situ* conservation stands of *P. tecunumanii* by provenance. Figures indicate number of stands.

Site	Country	Provenance						
		Chanal	Mt. Pine Ridge	Napite	Pachoc	Rancho Nuevo	San Rafael	Yucul
Imanawuti	Australia		2					
Yapilika	Australia							
Batatais	Brazil							
Bento Quirino	Brazil						1	
Luiz Antonio	Brazil		2				2	2
Itirapina	Brazil		1				1	1
Itapetininga	Brazil	1		1	1	1		
Angatuba	Brazil		1				1	1
Silver Cascade	India							
Korapur	India							
Perumalmalai	India		1					
Marappalam	India							
Devala	India							
B.K. Gudda	India						1	1
Neratoor	India							
Gorgod2	India							
Behalli	India							
Mumbar	India							
Gorgod	India						1	
Talavata	India							
Sydoor	India							
Madenoor	India						1	
Maredumilli	India							
Mangra	India							
Janijuda	India							
Deoghati	India							1
Kurandih	India							
Rapide Grah	Côte d'Ivoire		1					1
Katende Hill	Kenya							
Kwamarukanga	Tanzania							
Ruvu	Tanzania							1
Nongkhu	Thailand		1					1
Khong Chiam	Thailand							
Nong Krating	Thailand							
Mae Sanaam	Thailand						1	1
Huey Bong	Thailand		2				1	3
Intakin	Thailand						1	
Chati	Zambia		1					1
Siamambo	Zambia		2					

4.2 Matching of species and provenances to planting sites

Regarding matching of species and provenances to planting sites three factors were analysed: altitude, annual rainfall and mean temperature. They are of course interrelated, as altitude influences rainfall and temperature.

Species have different plasticity to adapt and develop satisfactorily on planting sites different to the conditions within the natural range (e.g. radiata pine in New Zealand, Douglas-fir in France). However, a close match is an appropriate starting point for satisfactory stand development.

4.2.1 *P. caribaea* var. *hondurensis*

The species was represented by 76 stands at 29 planting sites, and represented 14 different provenances. The planting sites ranged from 19°08 N to 25°15 S. The altitude range was 85 m to 2638 m with most sites found between 500 and 1100 m altitude. The mean annual rainfall varied from around 1000 mm to more than 3000 mm at some sites in India. The mean annual temperature ranged from 14°C to 27.3°C.

Figure 7 shows altitudes of collection and planting sites. The figure illustrates the origin of *P. caribaea* is divided into a group of coastal, lowland provenances (Alamicamba, Guanaja, Karawala, La Mosquitia and La Brea Colon) and a group of inland provenances (Culmi, Los Limones, Poptun, San Carlos, Santa Clara) from higher altitudes.

The lowland provenances were generally established at planting sites at considerably higher altitude than in their natural range. Less than half of stands were found below 300 m alt., and in some cases stands were established above 1000 m. The poor match of the lowland provenances did not so much influenced survival and growth, but seriously reduced cone setting. This will be analysed further in Chapter 6.

The inland provenances sampled approximately the same range of planting sites as the coastal provenances, i.e. from sea level to about 1000 m. As the natural range is from 350 m to 800 m, stands have been established at both higher and lower altitudes. The figure show a general lack of match of coastal provenances to low altitudes sites andinland provenances to higher altitude sites. The inland provenances were in general better matched than the coastal provenances. The Los Limones provenance, collected at about 700 m above sea level provided an exception as it was established at sites from sea level and up to 2600 m.

Data on annual rainfall at collection and planting site illustrate that one group, mainly of inland origin had a relatively good match in regard to annual rainfall. Another group of stands were established on sites with much higher rainfall than found in the natural range. The most extreme case was the Los Limones provenance that was established at sites with annual rainfall around 3000 mm. This is four times the average rainfall at collection

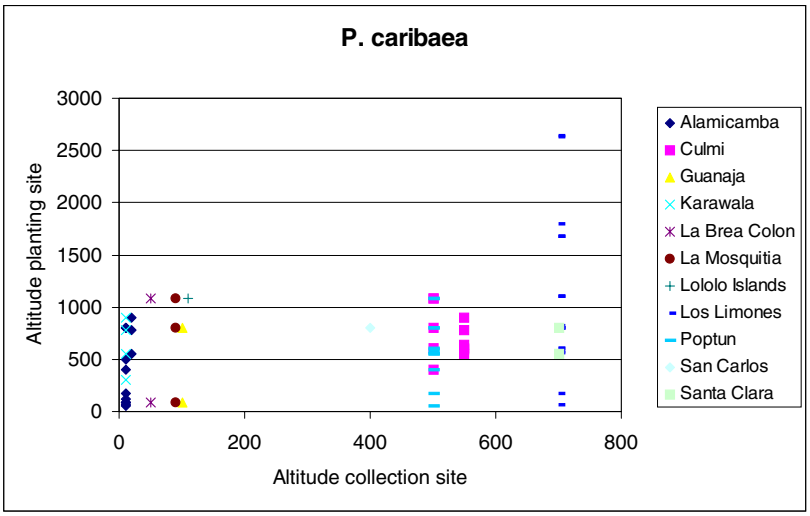


Figure 7. Altitude of planting sites and collection sites for stands of *P. caribaea* var. *hondurensis*. Please note the different scales on x- and y-axis.

site. The last group of stands of coastal, lowland origin was established at sites with much lower rainfall than in the natural range. Many of them are of Alamicamba provenance. Apart from the annual rainfall, also the distribution of rainfall over year and the number of dry and wet months may differ between collection and planting sites.

Mean annual temperature at planting sites varied between 14°C and 27.3°C. As for annual rainfall, many of the planting sites varied considerably from the collection sites (Figure 9). Stands of both highland and lowland origin, but especially lowland provenances, were established at sites with mean annual temperatures considerably below that of the collection sites. The trend is most evident for the lowland provenances Alamicamba, Guanaja and Karawala. On the other hand, stands of inland origin were established at warmer, more tropical sites than the natural range. This group included stands of Los Limones, Culmi, Poptun and Santa Clara.

With regard to temperature, not only the mean annual temperature is of importance, but also the variation in temperature throughout the year, as will be further discussed in section 6.6.

In conclusion, the conditions at the planting sites of *P. caribaea* varied considerably from the natural range. The poor match was more pronounced for the coastal provenances than for the inland sources, and may be an important factor in the explanation of poor cone setting especially for coastal sources (discussed in Chapter 6). At time of establishment of the stands, there probably was limited awareness on lack of cone setting for lowland provenances at high altitude sites which became known later (Sirikul *et al.* 1991).

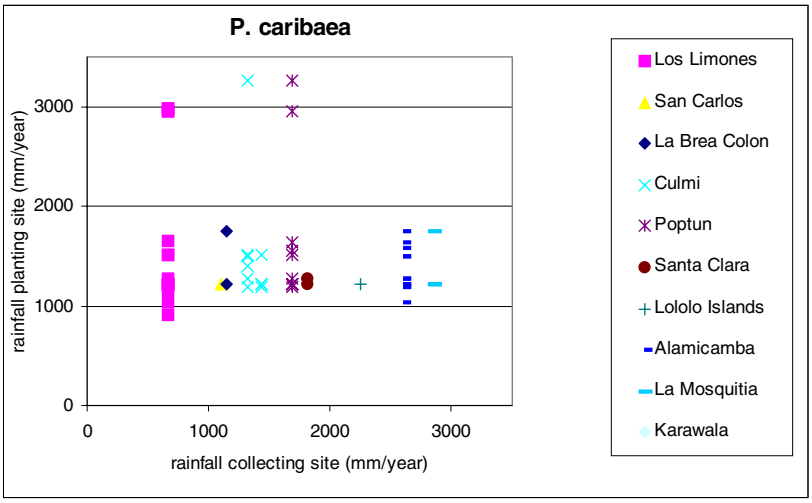


Figure 8. Precipitation at collection and planting sites of *P. caribaea* var. *hondurensis*.

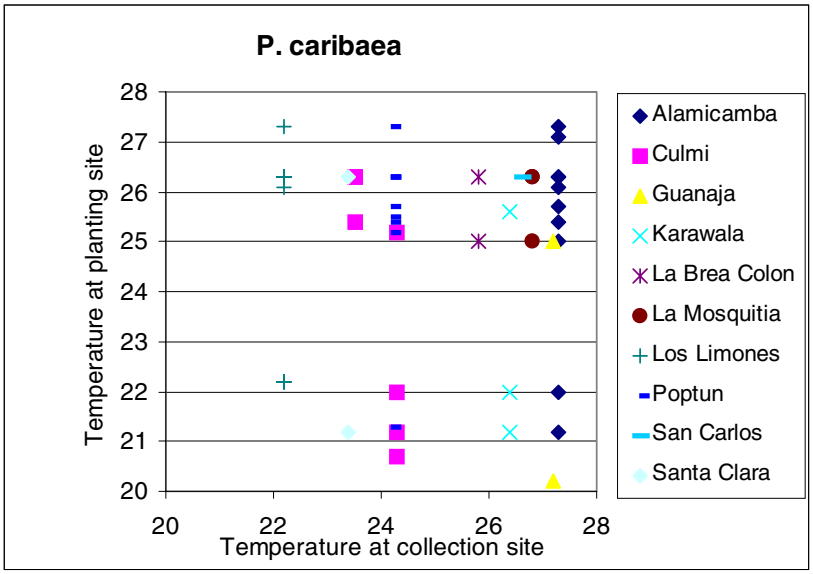


Figure 9. Mean annual temperature of collecting and planting sites of *P. caribaea* var. *hondurensis*.

4.2.2 *P. oocarpa*

15 stands, representing 9 sources of *P. oocarpa*, were planted at 7 sites. Sites ranged from 18°52 N to 16°51 S and from 800 to 1800 m above sea level. The mean annual rainfall varied from 825 to 1659 mm with average temperature between 14°C and 26.3°C.

The majority of *P. oocarpa* stands were established at sites between 800 and 1200 m above sea level, which is very similar to the altitude range within the natural distribution area (Figure 10). Only a few stands were established at extreme sites, one of the Bonete stands at high altitude, and a Mal Paso stand at low altitude. *P. oocarpa* was generally planted at higher altitudes than *P. caribaea*, reflecting the distribution of the species in the natural range.

P. oocarpa stands were in general established at sites where the annual rainfall was similar or a little higher than within its natural distribution area (Figure 11). Mal Paso provenance from Guatemala is an exception. Compared to the relatively high rainfall (1800 mm) in the natural range, it was established at sites with annual rainfall around 1200 mm.

The planting sites matched the collection sites fairly well in regard to mean annual temperature. A few planting sites were somewhat warmer than the collection sites. One cool site (in India) was matched with Bonete provenance originating from a much warmer climate.

In conclusion, the match of provenances of *P. oocarpa* to planting sites is better than for *P. caribaea*. The better matching is probably an effect of available planting sites being better suited for *P. oocarpa* than for *P. caribaea*. There is no indication that more efforts were made on seed source matching of *P. oocarpa* than for *P. caribaea*.

Picture 8. *P. caribaea*, Karawala, established at Luiz Antonio, Brazil. Lowland provenances of *P. caribaea* set few cones when planted at higher altitudes.

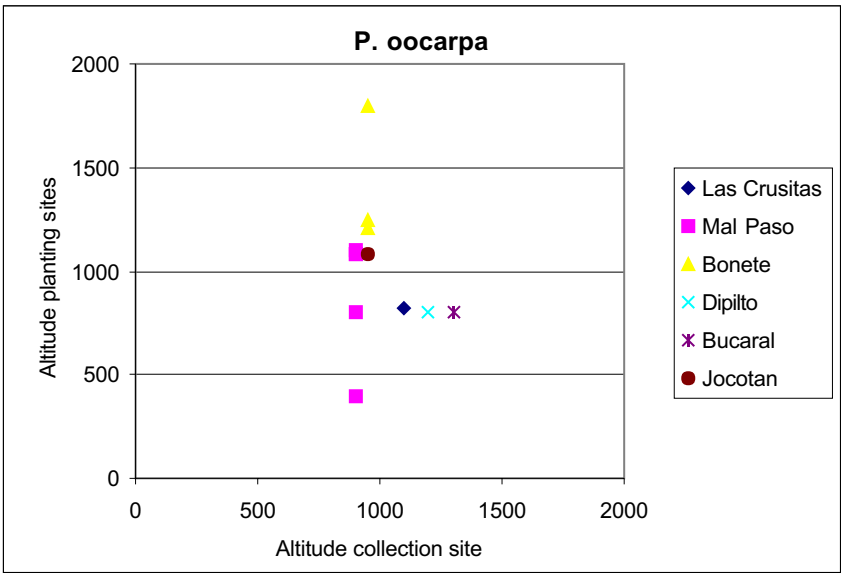


Figure 10. Altitude of collection and planting sites of *P. oocarpa*.

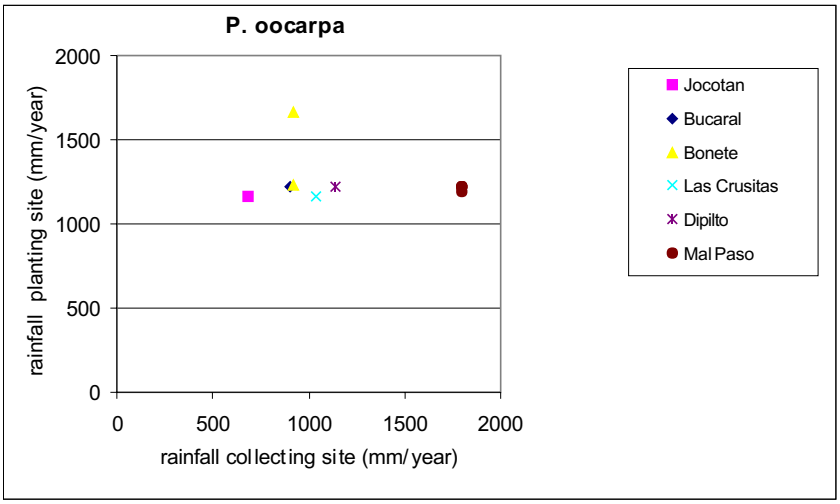


Figure 11. Precipitation for collection and planting sites shown of *P. oocarpa*.

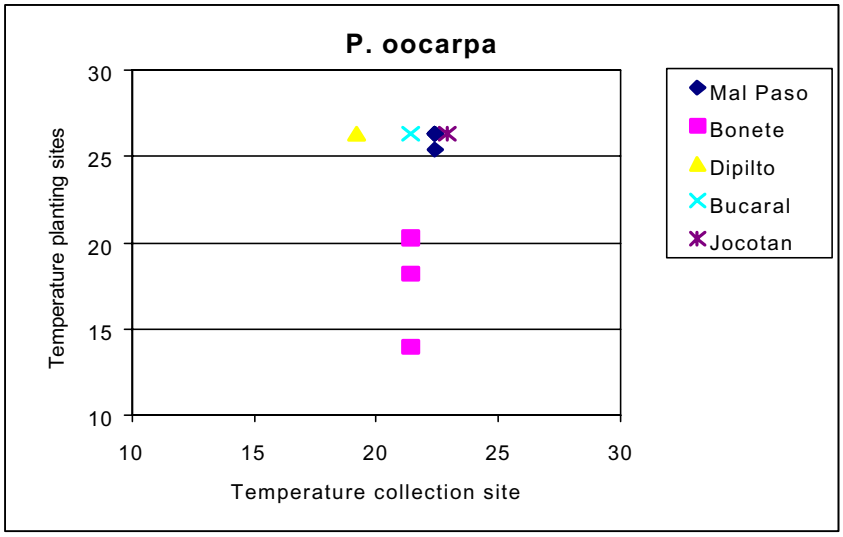


Figure 12. Mean annual temperature of collection sites and planting sites of *P. oocarpa*.

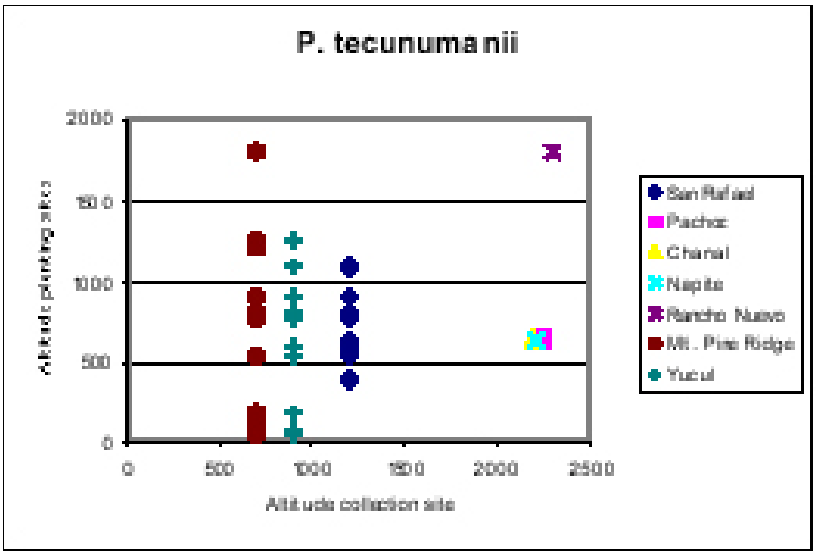


Figure 13. Altitude of collection and planting sites of *P. tecunumanii*.

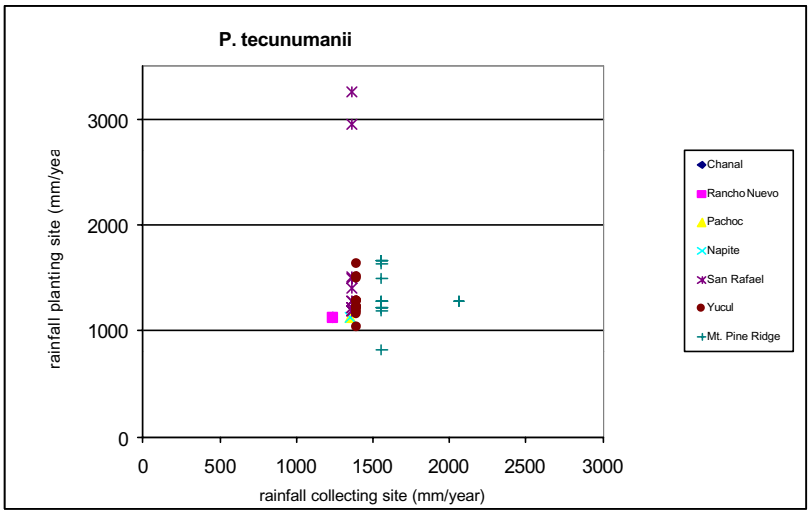


Figure 14. Precipitation for collection site and planting sites of *P. tecunumanii*.

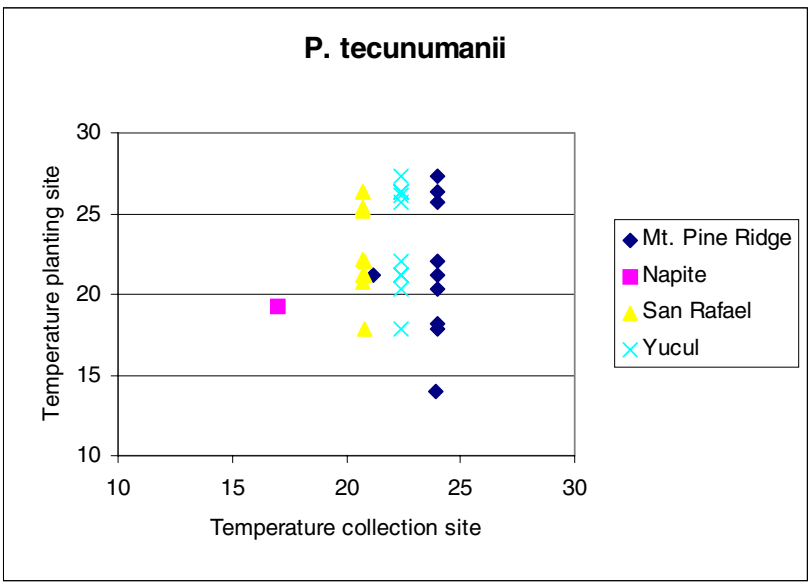


Figure 15. Mean annual temperature at collection and planting sites of *P. tecunumanii*.

4.2.3 *P. tecunumanii*

P. tecunumanii was established at 19 different sites ranging from 19°08 N to 25°15 S. A total of 43 stands were established from 7 different sources.

The total altitude range of the planting sites was 70 m to 1800 m with most sites found between 400 m and 1100 m altitude (Figure 13). The collection sites represented a variation in altitude from 700 to 2300 m. Some provenances (Mt. Pine Ridge and Yucul) were established alongside those of *P. caribaea* at lower altitudes which might be too tropical for *P. tecunumanii* to show its full potential. The high altitude provenances Pachoc, Chanal, Napite and Rancho Nuevo have been established at considerably lower altitudes than their origin. A large group of Mt. Pine Ridge, Yucul and San Rafael stands were well matched to planting sites.

The mean annual rainfall at planting sites varied from 825 mm in Zambia to more than 3000 mm at some sites in India. Most sites had annual rainfall between 1200 and 1500 mm similar to the situation within the natural distribution area. Two planting sites (in India) had much higher annual rainfall than the corresponding collection site (San Rafael).

The average temperature at planting sites ranged from 18.2°C to 27.3°C (Figure 15). A large number of stands were found at either warmer or cooler planting sites, whereas relatively few stands were well-matched. One Mt. Pine Ridge stand was established at a cool high altitude site in India.

In general, *P. tecunumanii* seed sources were better matched to planting sites than *P. caribaea*, but not as good as for *P. oocarpa*. Again, the availability of planting sites is believed to be the deciding factor.

5. Establishment and Management of Stands

The FAO/UNEP project made recommendations for stand establishment and management, and provided financial support for the initial phase of establishment (see Chapter 1). The present study analysed to what extent the recommendations have been followed.

For the national stands, no common guidelines were available. Establishment and management followed local practices. The establishment and management of the national stands were financed locally in some cases with support from external donors.

5.1 Layout

5.1.1 Deployment of stands

Deployment of stands refers to whether stands have been established at separate sites or grouped together at a few sites.

Clustering of stands was preferred in most countries, e.g. Australia, Brazil, Côte d'Ivoire, Kenya, Tanzania, Thailand and Zambia. India is the only country where most stands were established at separate sites (Table 8).

Clusters of stands were typically established at silvicultural research stations or seed production and gene conservation stations. Number of stands at any one site varied considerably. The largest number of stands were found at Huey Bong in Thailand where 22 stands were established. Most clusters consisted of 5-10 stands.

Clustering of stands offers advantages in terms of management and protection of the stands, as permanent staff in most cases will be available at the site. Clustering of stands may also be more cost-efficient as travelling distances will be shorter and because of 'economics of scale'. On the other hand, clustering of stands may hamper sufficient isolation between stands, which was identified as a serious problem at many sites.

5.1.2 Stand size

A minimum stand size of 10 ha was recommended at the project start in order to secure a viable conservation stand in the long run (FAO 1985). This was based on a number of biological/genetic considerations such as calculations on pollen flight and, above all, the ability of the overall pollen cloud to dilute pollen arriving from outside sources and, thus, reduced risk of pollen contamination (FAO 1992). Smaller plots than 5 ha may not produce enough pollen to reduce pollen contamination. Furthermore, genetic drift will increase with decreasing plot size (FAO 1992). Smaller stands may go some way towards securing genetic variation, their value depending on local circumstances.

Actual stand size after establishment ranged from 0.2 ha to 37 ha with an average of 7.0 ha. For the stands established under the FAO/UNEP programme the average size was 5.8 ha with a range from 1.2 ha to 10.9 ha. Average size for 'national' stands was 7.5 ha. Figure 16 illustrates the distribution of stands to size categories for all stands, FAO/UNEP stands, and national *ex situ* conservation stands, respectively.

Only 8 (23 %) FAO/UNEP stands and 30 (22%) of the stands fulfilled the size requirement of 10 ha. Most stands were between 3 and 6 hectares. It is not clear which factors determined the size of the stands in local decision-making, however, it is likely that land availability, and success in seedling propagation, may have played important roles, as may financial resources available.

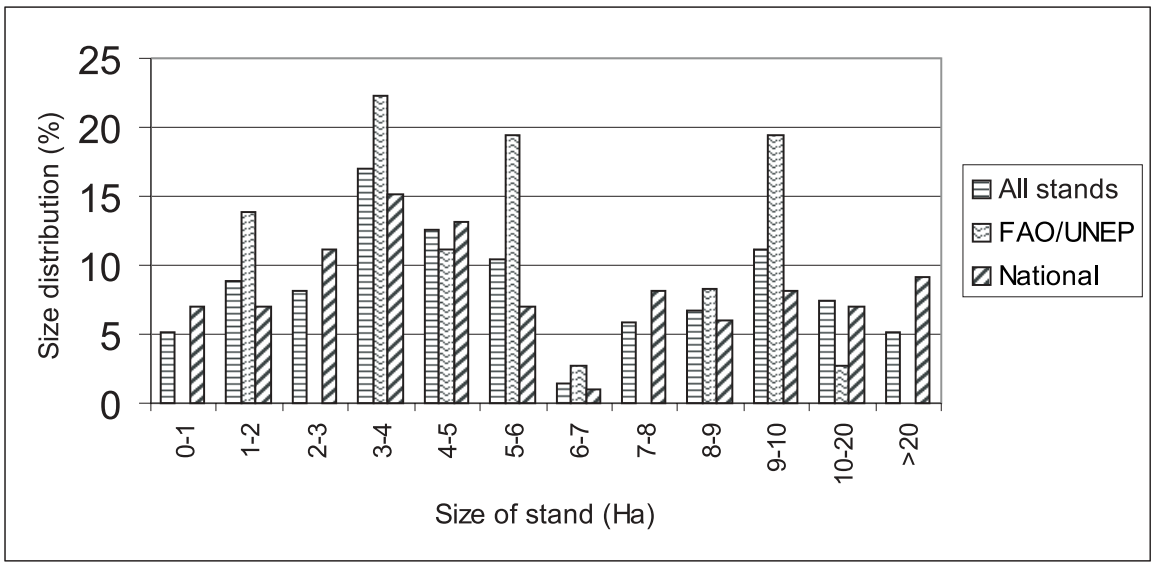


Figure 16. Distribution of stands to size categories in hectares. Size refers to area established. Distribution shown for all stands (135 stands); FAO/UNEP stands (36 stands) and national stands (99 stands), respectively.

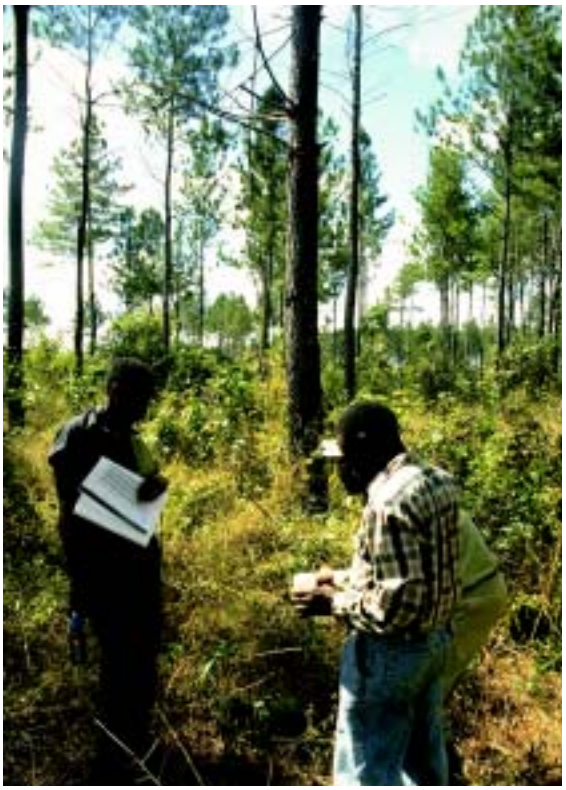
The above figures refer to size of stands at time of establishment. The present stand size is in many cases less, as part of the stand may have been lost. Annex 3 of this study provides details on individual stands. For each stand the established area, the present stand size and a crown cover percentage is given. A 'net' area of stand can be calculated by multiplying crown percentage and present stand size.

Figure 17 illustrates the cumulative distribution of stands to various 'net' size classes. The figure illustrates that 70 % of stands have a net area of 5 hectares or below and that only about 15 % of the stands have a 'net' area of 10 hectares or above. This compared to 22% at time of establishment.

What is an adequate stand size? The answer depends on the specific objectives of the stand. If the main purpose is conservation of the genetic resource, the population should be large enough to reduce risk of losing genetic variation and to avoid build-up of inbreeding depression in future generations. As a rule of thumb, a population size of 500-1500 adult individuals is recommended to maintain the genetic variation (DFSC 1997). If on the other hand, the stand is later to serve for selection of superior individuals for further breeding, this may require a larger stand. Demand for seed and seed production objectives may also influence stand size. Apart from population genetics and technical considerations, natural disturbances and human threats are of course also to be considered, and are often of immediate importance. All factors must be considered together to establish stand size/population size.

A stand of 10 ha (as recommended by the FAO/UNEP project) with an average spacing of 3x3 m, would consist of approximately 11,000 trees. This should be sufficient to conserve a broad genetic base, and to enable later selection. The population (number of trees) will decrease over time because of thinning and natural mortality. If the recommended FAO/UNEP thinning regime is applied as an example, the number of trees is reduced with 50% at each of two thinnings. This reduces the number of individuals to 2,800 trees, which should still be sufficient both for conservation and selection purposes, and with a 'buffer capacity' to allow natural and human disturbances. If we approach the question from the opposite end, a population of 500 individuals - would require a stand size of 1.8 ha, given a spacing of 3x3 m, two thinnings and no outside disturbances.

The 10 ha recommendation for the FAO/UNEP stands is thus probably a rather conservative recommendation, but a recommendation that provides the manager with a suitable buffer against natural and human disturbances and a high level of flexibility. If only conservation aspects are considered then smaller stands will still go some way towards securing acceptable levels of the genetic variation.



Picture 9. Assessment was done jointly by DFSC and national institutions in charge of the *ex situ* conservation stands.

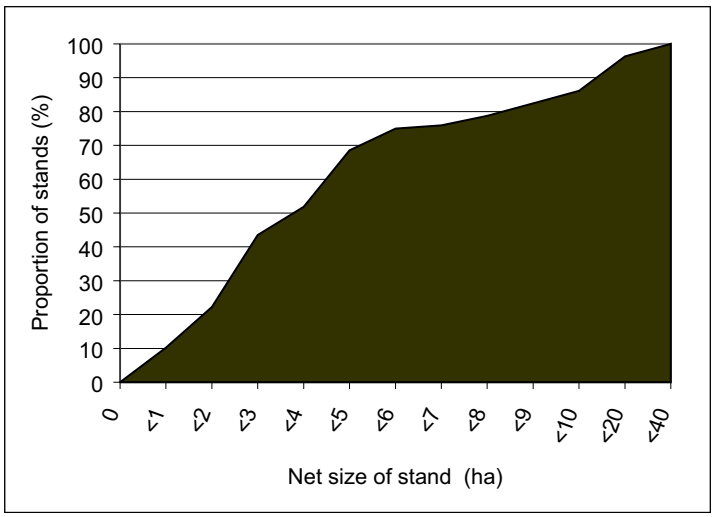


Figure 17. Proportion of stands (%) fulfilling various levels of net stand size (ha). Net stand size is actual stand size multiplied with the crown cover percentage.

5.1.3 Shape of stand

The FAO/UNEP project recommended square plot shape, but also indicated that rectangular or other modifications would be acceptable. Shape of stand is mainly of importance for the mating within stand. Very long and narrow stands restrict random mating and should be avoided.

Most stands were laid out with square shape, and no stands were unsuitable for *ex situ* gene conservation due to shape of the stand (see maps of stands in annex 3).

5.1.4 Isolation

Ex situ conservation stands should be well isolated from stands of the same and hybridising species to avoid influx of pollen that may change the genetic composition of the offspring. Contaminating pollen sources can not be totally avoided, but efforts should be made to minimise the influx through proper isolation of stands.

General recommendations on required isolation distance are difficult to formulate. First, it depends on the species as wind-pollinated species like pines will travel longer distances than pollen carried by insects. Therefore, a better isolation is in general required for wind-pollinated species. Second, it depends on the actual conditions on the site, e.g. background pollination from pine plantations in the vicinity. Pollen travels more freely over open areas than in dense forests, so the vegetation cover of the isolation zone also influences the required isolation distance.

The FAO/UNEP project recommended a minimum distance of 330 m between stands of same species/hybridising species of pines (FAO 1985) which is also the general recommendation for *ex situ* conservation stands of wind-pollinated species given by FAO (1992). Since the start of the FAO/UNEP project, the issue of proper isolation has received increased attention, and a number of studies have illustrated high levels of background pollination, see e.g. Harju & Muona (1989). Thus, many organisations at present operate with more strict isolation requirements than 330 m.

In this study, it has been decided to use the 330 m mentioned above as a general reference, while recognising that this is not a fixed reference, and that site specific considerations may justify shorter or longer isolation distances.

Looking at the actual isolation distances of stands and using the 330 m as reference, 20 (71%) of the FAO/UNEP stands were properly isolated while 8 stands (29%) were established within 330 m of one or more contaminating pollen source. For 8 stands information on isolation was lacking. For the 99 national stands, an isolation distance of 330 m categorized 48 (55%) stands properly isolated while 39 (45%) were not. For 12 national stands, no information was available.

It was found that insufficient isolation was mainly a problem where more stands were established at research stations or at gene conservation and seed production stations. This may indicate that limited land is a crucial factor and maybe of greater importance than lack of knowledge or attention to the need for appropriate isolation. India was the only country where most stands were established at separate sites with no pines in the vicinity.

Figure 18 illustrates the proportion of stands fulfilling various isolation requirements. If, for example, a more conservative minimum distance of 500 m is applied, only half of the FAO/UNEP stands and only one third of the national stands are sufficiently isolated.

The above results are all based on minimum distance to stands of the same species. Often the conservation stands are planted next to a stand of one of the other species. Hybridisation and introgression is suspected for many tropical pine species, though the extent of hybridisation is unknown

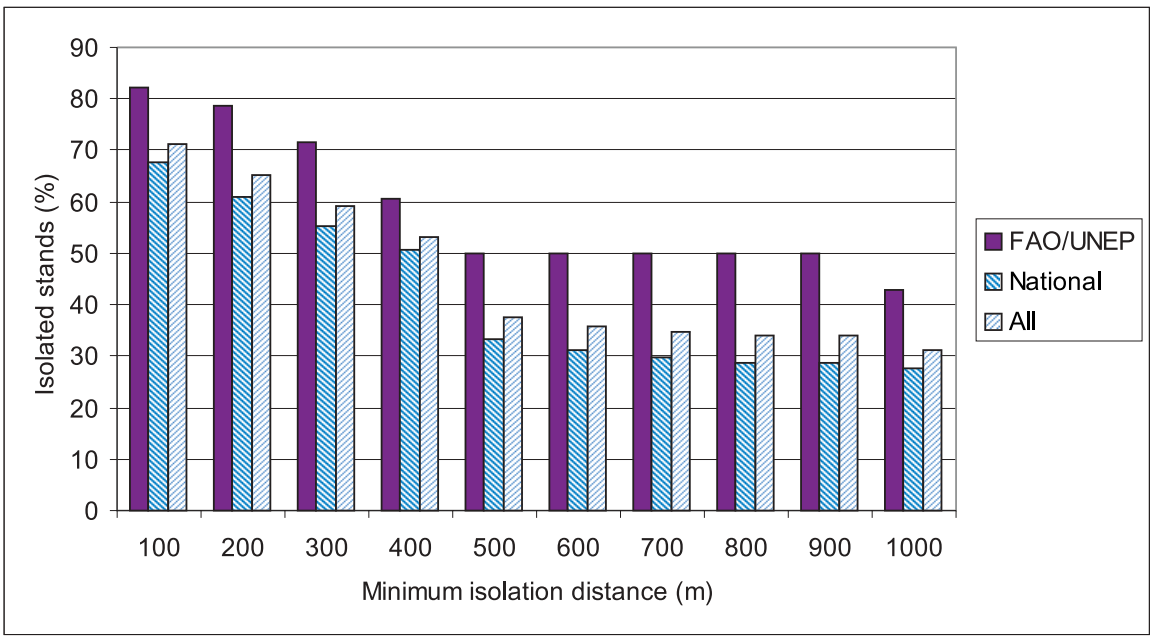


Figure 18. Proportion of stands properly isolated from stands of the same species at a given minimum isolation distance.

(Furman *et al.* 1996). Distance to other hybridising species has not been taken into account in the present study, but if doing so, actual isolation distances are shorter, as many stands were established next to hybridising species.

5.1.5 Demarcation

Of the assessed stands 97 (87%) had efficient demarcation. For 15 stands (13%), the borders were difficult or impossible to identify. The most serious demarcation problems were encountered in Australia, Côte d'Ivoire and Kenya. Of 15 stands without proper demarcation, 7 are FAO/UNEP stands, and 8 national stands. For 23 stands, of which most no longer exist, no information was available.

At sites where a sole *ex situ* conservation stand was established demarcation was not a problem. Problems arise where more conservation stands of the same species (and provenance) were been established next to each other. Various means of demarcation were used such as forest roads, fire lines, border rows of different species, paint or poles.

Picture 10. Demarcation between stands of *P. oocarpa* and *P. caribaea* at Ruvu, Tanzania.

5.2 Establishment

The sections below gives a brief description of the methods and techniques applied in the establishment of the stands. In many cases no record was available on establishment and management. The description is therefore based on information from a subset of stands, varying in size, according to the observed step in stand establishment.

5.2.1 Soil preparation

Soil preparation was carried out for 88 stands (86 %) whereas 14 stands (14 %) were established without prior soil preparation. For 33 stands no information was available on soil preparation. Stands with no soil preparation were located in Thailand (10 stands) and in Côte d'Ivoire (4 stands). These 14 stands still existed, showing that soil preparation was not essential. However, it is not known, whether the lack of soil preparation has influenced the survival rate or growth and development.

The soil preparation was in most cases a mechanical, complete cultivation of the site after removal of debris from prior stand or natural vegetation, in line with the recommendations of the FAO/UNEP project (FAO 1985). In some cases, the debris was burnt before soil preparation.

5.2.2 Planting and beating up

Seedlings grown in plastic tubes were applied in all cases. In most cases, planting was carried out in planting pits of variable sizes and to variable depths. Sticks were used to identify the precise planting positions. For the 6 stands in Zambia, seedlings were planted with the polythene bags on, which did not seem to affect the survival rate.

Replacement of dead seedlings (beating up) was carried out in 66 stands (65%) versus 35 stands (35%) without beating up. No information was available on beating up for 34 stands. Replacement of dead seedlings has mainly been done within one year of establishment, in some stands the following year. In some cases replacement of dead seedlings was done over more years, and in a few cases the entire stand was replaced. The intensity of replacement was not well documented. In most cases it was believed to be between 10 and 20 %.

5.2.3 Spacing

The FAO/UNEP project recommended an initial spacing of 3 x 3 m to allow for possible mechanical cultivation and later thinnings. Most stands were established at this spacing which is a typical spacing in establishment of tropical pines, and probably very familiar to the institutions in charge of stand establishment.

Some stands in Thailand were established at a spacing of 6 by 1 m (6 meters between the rows); a system applied to facilitate future seed production. The rationale behind this system is not fully understood, but the idea may have been to increase exposure of the individual trees to light and thereby maximise seed production. The system requires more seedlings than the standard spacing (1,667 against 1,111 seedlings per ha).

5.2.4 Fertiliser application

Of the 135 stands, 29 stands (29%) had fertilisers applied during establishment while 72 stands (71%) did not. For 34 stands no information was available. Fertilisers were in most cases applied in the planting pit at the time of establishment. For a number of stands, additional fertilisers were applied in the first and second year after establishment. Different types of fertilisers were applied, but in most cases commercial NPK fertilisers were chosen. Fertilisers were applied according to local knowledge of soils.

5.2.5 Weeding

Complete removal of weeds was strongly recommended for the FAO/UNEP stands as a precaution against fire damage during the early years. The importance of weeding in monsoon climates with a marked dry season was especially stressed (FAO 1985).

The large majority of stands 80 (88 %) were regularly weeded in the years following establishment while 11 stands were never weeded (12 %). For a relatively large number of stands (44), no information was available.

Weeding was carried out according to local procedures - in most cases manually, but mechanical weeding had also been applied in a few cases. The intensity and duration varied considerably. The most common system involved two weedings per year and at some sites, weeding was carried out for the first three years, in other places weeding continued for a period of 7 to 10 years. Either complete weeding of the area or a spot weeding around the trees was applied. The first method is more efficient in securing the trees from damage by fires,

but of course also more costly. The extent of full weeding compared to spot weeding is not known.

Eleven stands were not weeded, of which 5 FAO/UNEP stands and 6 national stands, all situated in Brazil and India. The reason for the lack of weeding is not known. As an illustration of the importance of weeding, 4 of the 11 stands were seriously damaged by fire. Several other stands were damaged by fire (see section 6.3.) and it seems likely that damages occurred because of poor weeding or lack of weeding in a particular year.

5.3 Long-term management

5.3.1 Fire protection

Fire constitutes the most serious threat to stands of tropical pines and it is essential that adequate measures be taken to protect the stands from fire. The FAO/UNEP project recommended that appropriate fire lines be cleared and maintained around the plots, giving special attention to grassland areas, and monsoon climates with a marked dry season (FAO 1985).

Fire lines were established and maintained for 94 stands (87%) while it was neglected for 14 stands (13%). For 27 stands, including 13 lost stands, no information was available. Of the 14 stands lacking fire lines, 6 are FAO/UNEP stands found in Côte d'Ivoire and in India on relatively humid sites with limited fire risk. The remaining 8 stands are located in Australia.

Many stands were guarded in the dry season and in addition, controlled burnings were carried out in some stands before the dry season to remove debris and grasses that could fuel more serious fires. This study shows that controlled burnings must be carried out with great care since control was lost in some cases, resulting in serious fire damage to the stands. More about fire damage in section 6.2.

5.3.2 Thinning

Thinning was recommended in order to secure optimal growth conditions and secure the long-term stability of the stands. Moreover, it is needed for proper crown development and to enhance flowering and cone setting. Thinning is thus required to secure the reproductive potential of the stands.

A systematic thinning regime removing 50% of the stems in each of two thinnings was recommended (FAO 1985). Thinnings were to be carried out at 8 and 12 m of height, respectively. Even if a systematic thinning regime was recommended, the recommendations included some flexibility to meet needs for local seed supply in the sense that a number of plus trees (e.g. 10 per ha) could be retained in the stands for production of superior seed and for inclusion in breeding programmes (FAO 1985). The proportion of thinned stands is shown in figure 19.

Of the 115 existing *ex situ* conservation stands, only 19 of the 93 stands (17 %) were thinned. For three stands (in Kenya) no information was available on thinning status. Only one of the 36 FAO/UNEP stands was thinned.

Thinning practises differ significantly from site to site. Almost 50% of the stands in Brazil were thinned, although many of them only in part since annual budgets did not allow thinning of the entire stands. Thinning intensity varied between 20 and 30%. In a few stands, more than one thinning was carried out. A few stands in Australia, Zambia, India and Thailand were thinned, whereas none of the stands in Tanzania and Côte d'Ivoire were thinned.

In the thinned stands no detailed information was available on the applied thinning regime. It is believed, however, that the thinning regime in most cases was selective, i.e. removal of inferior phenotypes.

As mentioned above a first thinning was recommended at 8 m of height. All stands in the study except two had reached this height (Figure 19) and most stands had stem numbers far exceeding what was recommended in the FAO/UNEP thinning regime (Figure 24).

It is an open question whether thinning should be recommended at this relatively late stage of development. Many stands were approaching 25 years of age and thinning at this stage may reduce the overall stability of a stand and expose it to wind damage. Even if the stability of a stand is not put at risk, it is questionable whether thinning would improve the crown characteristics of trees at this stage. For the younger stands, the situation is less critical, and thinning may still be able to trigger crown development and cone setting. In all cases, the decision on thinning should be based on local experience and on an assessment of the stand objectives, especially conservation objectives and future seed demand. The question of thinning is discussed further in section 6.6.

Picture 11. Prescribed burning to remove debris and prevent serious fires during the dry season. Huey Bong experimental and gene conservation station, Thailand.

Picture 12. Lack of thinning results in dense stands with thin crowns and reduced flowering and cone productioning. *P. tecunumanii*, Chati, Zambia.

Why has thinning been neglected? First of all, there has been no demand for seed of the species and provenances in question in many countries. Consequently stand management, especially thinning, has not been given priority. Secondly, and probably related to the issue of seed demand, there were few funds available for thinning. In Thailand, a national logging ban acted as a barrier for thinning. Finally, some organisations may have had doubts about what thinning regime to apply, i.e. selective or systematic, and have subsequently postponed thinning.

5.4 Man-power and costs in establishment and management of stands

The establishment and management of the *ex situ* conservation stands in this study did probably not differentiate much from conventional forest plantations of the same species. Stands were established with the same silvicultural techniques (site preparation, type of seedling, planting, spacing, and weeding) as normal plantations of the same species. Probably more attention was given to beating up, weeding and protection (including fire guarding and fire protection) than is the case for conventional plantings, but this is not known for certain.

Estimates of man-power input and costs were recorded as part of the field assessment. However, data was difficult to compare because of differences in applied techniques (manual contra mechanical methods) and because of the varying price and cost level in the countries. Also the time span during which stands were established made a direct comparison difficult. A rough estimate of total costs of stand establishment and initial care is 4,000 to 6,000 US $ per ha (1996 prices). This covers the direct costs for clearing and establishment of stands and management and protection for the first 10 years. Indirect costs such as administration, planning and thinning are not included. The *ex situ* conservation stands thus represented a considerable investment by the participating countries and institutions.

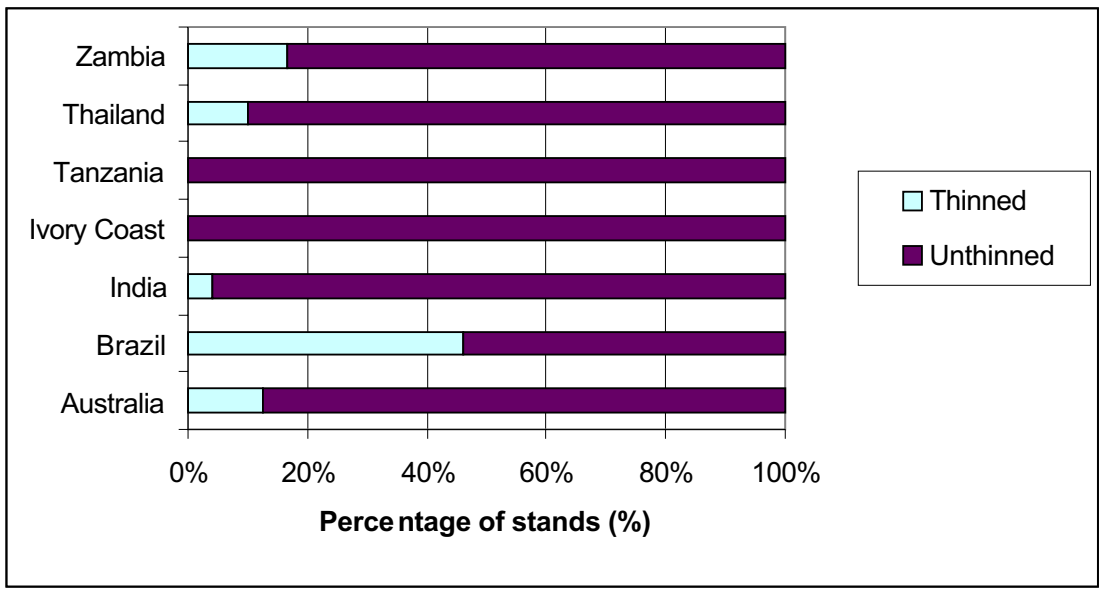


Figure 19. Proportion of thinned and not thinned stands at the time of assessment.

6. Status of Stands

6. Status of stands

This chapter reports on how stands were performming in terms of growth, quality and flowering. Moreover, the benefits derived from the stands are evaluated. Finally, the overall value of the stands is discussed and stands are divided into categories according to their overall conservation value.

6.1 Do stands still exist?

A natural starting point is to look at survival rate of individual stands.

In this aspect a clear distinction is made between FAO/UNEP stands and national stands since the initial population of national stands is not known. National stands lost on earlier occasions may not be included in the study population and consequently the 'success rate' of national stands would be overestimated.

Of 36 FAO/UNEP conservation stands, eight stands (22 %) no longer existed. The eight stands were four *P. caribaea* and four *P. tecunumanii* stands. Seven stands were located in Thailand and the eighth stand in India. The seven stands lost in Thailand were established at two sites; Nong Khu (four stands) and Huey Bong (three stands). For one of the stands at Huey Bong (THA53- *P. caribaea* var. *hondurensis,* provenance Poptun) it was uncertain whether the stand was ever established.

All eight stands were lost at an early stage. Damage by fire was the reason for stand failure for seven of the eight stands. Sambar deer destroyed the last stand. Although not known for certain, most fires were probably started by farmers practising slash and burn agriculture. Subsequently the fires spread into the conservation stands. Most fires were thus believed to have origin in human activities.

If we turn towards stands outside the FAO/UNEP project, 12 out of 99 included stands were lost: six *P. caribaea* stands, four *P. tecunumanii* and two *P. oocarpa*. In Thailand eight stands were lost, three in Brazil and one in India.

Fire destroyed seven of the 12 lost stands and was the main reason for loss as was the case for the FAO/UNEP stands. Encroachment for slash and burn was reported in five cases in Thailand. Encroachment in all cases resulted in serious fire damage to adjacent stands. In a number of cases, reason for stand failure is unknown. Fire may have played a major role in these cases as well.

With a total of 15 lost stands of 52 established stands (28%), Thailand had the lowest stand survival rate, followed by Brazil with 10 % lost stands. Stands in Thailand were situated in areas of high human pressure, and on dry sites susceptible to fires. These two factors may explain the relatively low survival rate.

6.2 Disturbance of stands

Of the remaining 28 FAO/UNEP stands, 15 were categorised as undisturbed, while 13 were damaged by one or more of the following factors: fire, illegal cutting or wildlife. Thus almost 50% of the assessed stands were disturbed to some extent. Fire and illegal cutting accounted for most disturbances, giving rise to 2/3 of the damages. Disturbances were in most cases slight to moderate, but three FAO/UNEP stands were so seriously damaged, that their overall survival was doubtful, and their value as *ex situ* gene conservation stands severely restricted.

Of 87 existing national stands, 47 were undisturbed while fire, illegal cutting, encroachment or domestic animals affected the remaining 40 stands in some manner. Fire was the dominant threat in Thailand, Tanzania and Australia damaging 24 stands. In India, domestic animals disturbed 13 out of 16 stands in early stages of development. This resulted in many dead seedlings in the establishment phase, whereas the present health status of surviving trees is generally excellent. In Brazil, wind and hail constituted a serious threat at a number of sites causing stem break and wind throw.

Most stands categorised as disturbed were only slightly to moderately damaged, whereas 10 stands were so severely damaged that their value as conservation stands were restricted.

In all, fire was the all-important threat to the conservation stands. Besides accounting for the loss of 14 of the 20 lost stands, fire was also the primary disturbance. Second to fire, illegal cutting accounted for most damages to stands.

Problems with resin tapping, encroachment, wind, drought and termites were encountered at particular sites. Damages from domestic animals and wildlife tended to be restricted to the establishment phase.

Picture 13. Stand lost due to shifting cultivation. Mae Sanaam, Thailand.

6.3 Survival

Survival rate was measured as the ratio between number of trees remaining over the number of trees originally planted. Interpretation of survival rate at this late stage of stand development was difficult in the unthinned, dense stands, as it was not always clear where all dead trees were located. Therefore, survival rate was measured in sample plots in each stand. For stands with large gaps, plots were only laid out in the denser parts of stand. In annex 3, the sampling method is described in more detail, and in the stand summary sheets the actual stand sampling method is denoted.

The average survival rate for FAO/UNEP stands was 57%, varying from 9% to 100%. The average survival rate for national stands was 68%, with a range from 13% to 100%, which was somewhat higher than for the FAO/UNEP. This is believed to be partly a result of the national stands in general being younger than FAO/UNEP stands.

Picture 14. Second to fire, illegal cutting accounted for most damages to stands. Illegal cutting was reported a problem in 10% of the conservation stands.

6.4 Growth

In the below sections height growth, diameter, basal area, standing volume, and stems per hectare of the stands is described. In addition, data on social status (Kraft score) and crown development is presented. Calculation of mean-stand values is explained in annex 2.

6.4.1 Height

The heights of stands are illustrated in Figure 20. The figure illustrates the large variation between stands, even between stands of same age. This reflects the variable site conditions (rainfall, temperature, soil), and differences in the growth potential between the species and provenances, as have been illustrated in provenance trials (Birks and Barnes 1990).

None of the stands exceed a height of 30 m. Figure 19 shows that stands seemed to reach the maximum height at 15-20 years of age. The height growth of the stands corresponded well to the growth within the natural distribution range, where *P. caribaea* seldom exceeds 30 m of height and *P. oocarpa* 20 m. Under optimal conditions in the natural range, *P. tecunumanii* grows up to 50 m in height, but it is questionable if such growth can be achieved in plantations.

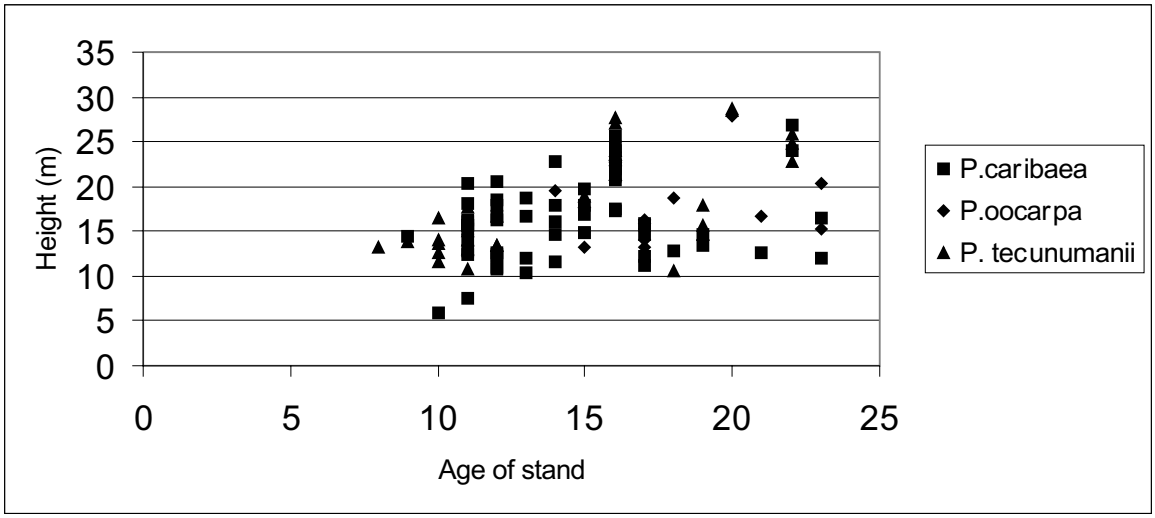


Figure 20. Height versus age of stand.

6.4.2 Diameter

Diameters of stands are illustrated in Figure 21a. As was the case for height growth, the large variation between stands is the most prominent feature of the figure. The large variation reflects - as was the case for height growth - differences in site conditions and differences in growth potential of the species.

6.4.3 Basal area

The basal area (m² per ha) of the *ex situ* conservation stands is plotted in Figure 21b versus age of stand.

There was large variation in the basal area among stands, even among stands of same age. Basal area varied from less than 10 m² per ha to more than 60 m² per ha. The latter occurred in dense, un-thinned stands at optimal sites. The highest basal areas were reported from Angatuba in Brazil and Marappalam in India.

Some stands had large gaps (open patches, rocky areas, erosion gullies etc.), that were excluded in the sample plots. In such cases, the basal area figures corresponds to the closed parts of the stands. Consequently care should be taken in the interpretation of the basal area figures. For each stand, the stand summary sheets in annex 3 indicate if gaps were left out of the sampling.

6.4.4 Standing volume

Figure 22 illustrates the variation in standing volume (m³ per ha). As was the case for the other growth characters, a large variation was found. The main reasons are the same as discussed above.

6.4.5 Number of stems per hectare

The number of stems per hectare has been plotted versus age of stand and height of stand in Figure 23 and 24, respectively.

The figure illustrates the large variation in number of stems per hectare between the stands, varying from 200 to 1800 stems per ha. It primarily reflects differences in survival rate including mortality due to competition. It is not considered an effect of thinning regime (few stands have been thinned) or initial spacing (most stands were established at same spacing).

The number of stems per ha has been plotted against height of stand in Fig. 24. The purpose was to compare the present number of stems with the stem reduction according to the recommended thinning regime, which suggested the removal of 50 % of stems at each of two thinnings (FAO/UNEP 1985). Thinnings were to take place at stand heights 8 and 12 meters, respectively. In Figure 24, the thinning regime is illustrated for a stand with an initial spacing of 3 x 3 m (1111 stems per ha).

Figure 24 illustrates that only in a handful of stands were stem numbers reduced in accordance with the recommended thinning regime. Most stands had considerably higher stem numbers. The figure thus illustrates that most stands are in strong need of thinning. As will be discussed later, lack of thinning is believed to be a key factor in the poor flowering and cone productioning of the stands.

6.4.6 Kraft index and crown competition

The assessment included registration of »social status« of individual trees (Kraft index) and crown competition. Both traits were assessed on a scale from 1 to 5, where 5 was a large dominating tree with free crown, and 1 was a suppressed tree with restricted crown development. Score 3 represented an average tree. A detailed description of the traits and their assessment is found in DFSC (1996b). The two traits are interrelated, as large dominating trees will have a large, free crown, and vice versa.

The mean value of all stands was 3.27 for Kraft score and 3.20 for crown development, i.e. close to the average score of 3. Figure 25 illustrates the distribution of Kraft and crown scores to the five classes. Most trees were grouped around class 3 and

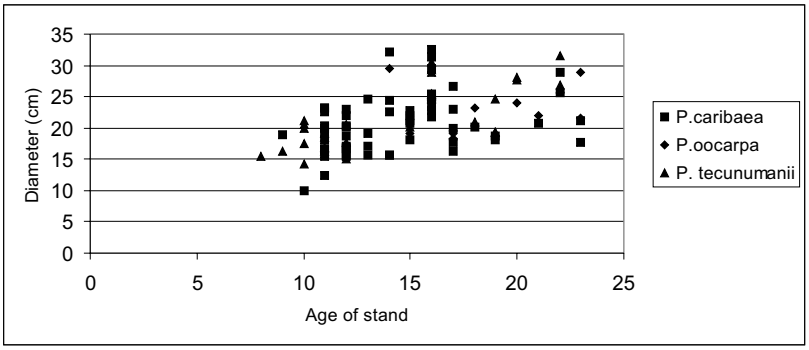


Figure 21a. Diameter of *ex situ* conservation stands versus age of stand.

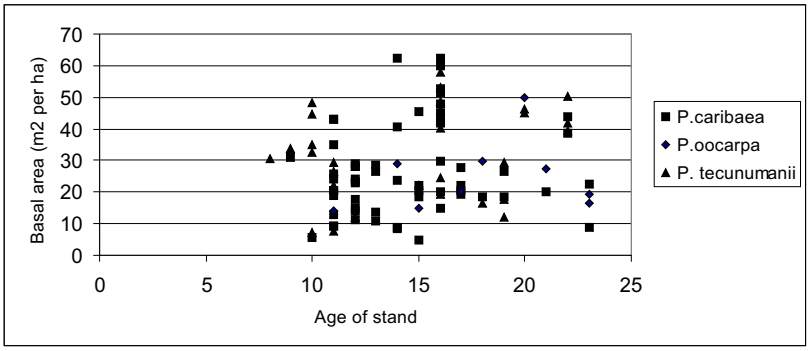


Figure 21b. Basal area in m² per ha of stand plotted against age of stand.

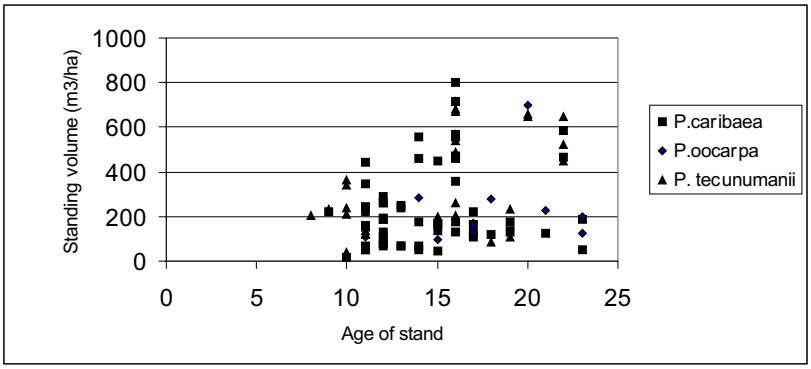


Figure 22. Standing volume over bark in m³/ha versus age of stand.

with few trees in the upper (dominating trees) and lower (suppressed trees) classes. Competition has not lead to a large segregation of trees in the stands to dominating/suppressed trees. Most stands, consequently, had average trees with rather small and somewhat restricted crown development. The figure illustrates that pines need thinning in order to develop trees with large crowns. The figure, like figure 24, also illustrates the urgent need for thinning of stands.

6.4.7 Conclusion on growth

Stands in general showed satisfactory growth. Large variations were found in all analysed growth traits. This was to be expected due to the variable site conditions and age differences.

As illustrated in Chapter 4, stands were in many cases established at sites which, in terms of ecological conditions, were quite different from the natural range. In regard to survival and growth, the pines were in general able to adapt well to the different planting sites. As will be illustrated later, adaptation was more problematic in terms of flowering and seed seting.

Stands were in general too dense for sound stand development and for maintaining a high flowering and cone productioning potential. Within-stand competition did not lead to a large segregation in size classes (dominating/suppressed trees). Most stands consisted of high number of trees with restricted crown development and these conditions were believed to reduce flowering and cone productioning.

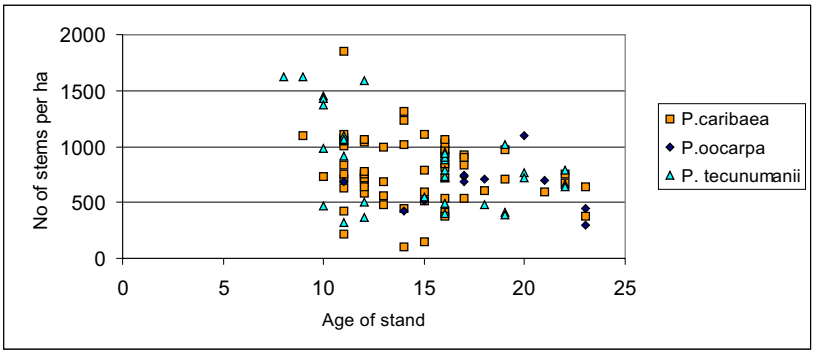


Figure 23. No of stems per ha versus age of stand.

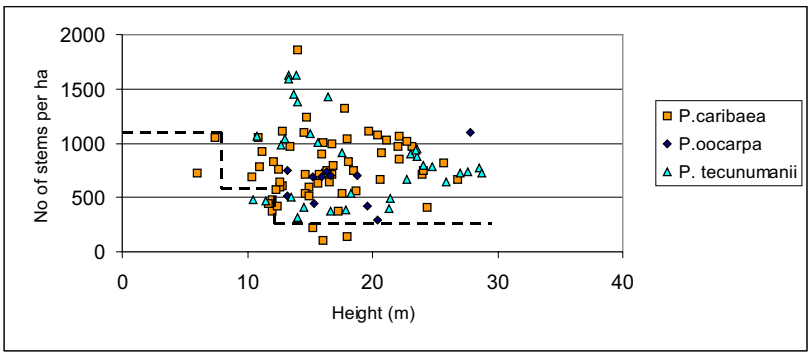


Figure 24. No of stems per ha versus height of stand. The recommended thinning regime for the FAO/UNEP stands is shown with the dotted line for reference.

6.5 Quality

6.5.1 Stemform

Stemform was assessed in all stands on individual trees using a scale from 1 to 9. The scoring was done in a two-step process where main class (straight, fair or unacceptable trees) was first determined followed by a sub-classification within each of these three main classes. A detailed description is given in DFSC (1996b). Score 9 is a perfectly straight tree with no faults, and 1 a completely crooked, bent or twisted tree.

Figure 26 shows the distribution of mean stand values to stemform classes (1-9). Most stands were around stemform classes 5 and 6, i.e. in the middle and upper end of 'fair trees'. The overall mean was 5.7. Note the very narrow distribution of *P. oocarpa* stands; all stands were located in the 5-6 interval, whereas stands of *P. caribaea* and *P. tecunumanii* had much wider variation. This may be a result of the poor representation of *P. oocarpa* in the study.

It is interesting to investigate the value of the stands for selection of superior phenotypes for further breeding. Stem form is an important trait to consider when selecting plus trees. Therefore the frequency of trees with good stem form, here defined as trees with stemform 7, 8 or 9, has been calculated and is shown in figure 27. Only a few stands, had the majority of trees in the upper classes. Of all stands, 70% had at least 20% trees of good stemform, which should be sufficient to enable plus tree selection for further breeding.

6.5.2 Forking

The number of trees with one or more forks varied between stands from 0 to 69 % with an overall mean of 18.7 %. Species and provenance influenced the forking percentage but furthermore, site conditions played an important role. This is illustrated in Figure 28 where the forking percentage of Alamicamba provenance (*P. caribaea*) at various sites is shown. Alamicamba, established at 11 sites had the best site representation in the study. The figure illustrates the large variation in forking percentage over site. Note also the large within-site variation at Yapilika (Australia) and at Huey Bong (Thailand).

6.5.3 Foxtailing

Field assessment of quality characters also included frequency of foxtails. A surprisingly large number of stands have none, or very few foxtails, recorded. On the other hand, especially the field assessment in Brazil recorded a very large number of foxtails. The data suggests that assessment has not been consistent in different countries, and that the assessment teams had a different perception of foxtails. Furthermore, foxtails may be difficult to assess on very tall trees, and foxtails in previous years may be difficult to identify or to distinguish from long internodes. The above reasons are believed to account for the presumed inconsistencies

in data recording. In conclusion, data on foxtails in the stand summary sheets (annex 3) has to be treated with great caution.

6.6 Flowering and cone productioning

Flowering and cone productioning is of crucial importance for *ex situ* conservation stands. It is a prerequisite for maintaining the genetic resource over time and to allow adaptation to the prevailing site conditions (dynamic conservation versus static conservation). A good seed setting is of course also important when seed production is among the stand objectives. Finally, flowering and seed setting is a valuable indicator of overall adaptation to site of the species/provenance. In conclusion, the flowering and cone productioning ability of the stands is of particular interest, and has consequently been given special attention in the study.

In the sections below the assessment methodology is briefly described and the overall results are presented. Subsequently, flowering and cone production is compared to environmental factors at the planting sites. Finally, the results are compared to results of other studies.

6.6.1 Assessment methodology

Flowering and cone production were quantified for all stands. Five developmental stages were registered: male and female strobili, conelets, closed cones and old open cones. The flower and cone setting was assessed on single trees using a log score scale developed by Wellendorf (1989). The score scale is shown in figure 29 and described in more details in the assessment manual (DFSC 1996b). Occurrence of flowers or cones on the ground was also noted.

Studies of flowering and cone production generally require re-occurring data collection throughout the year, and over several years. The present assessment is a 'snapshot' assessment and the results should be interpreted with care. Assessment of flowers is especially problematic since the flowering period in Pinus is in general short and flowers observed in the crown, at a certain time, may not be representative of total flowering. In addition, flowers may be difficult to observe. The same is true for conelets, but compared to flowers they will generally be present in the trees for a longer period of time. The development of mature cones takes up to two years and assessment of closed cones is therefore less influenced by the time of the assessment as assessment of flowers and conelets. Old open cones may persist on trees for several years, and the score for old cones may therefore reflect cone setting over more years. The five stages are believed to give a good representation of how flowering develops over whole the reproductive cycle, while the assessment of closed cones is probably the single best measurement of the ability of a stand to flower and produce cones.

The layout of the conservation stands was not designed to compare species performance and the data material is insufficient for a statistical analysis. It is, however, interesting to compare the present results with those of earlier provenance trials, as the conservation stands have been assessed at a later stage (20-25 years of age) than is the case in provenance trials.

Picture 15. *P. caribaea.* Female strobili borne in the upper part of the crown.

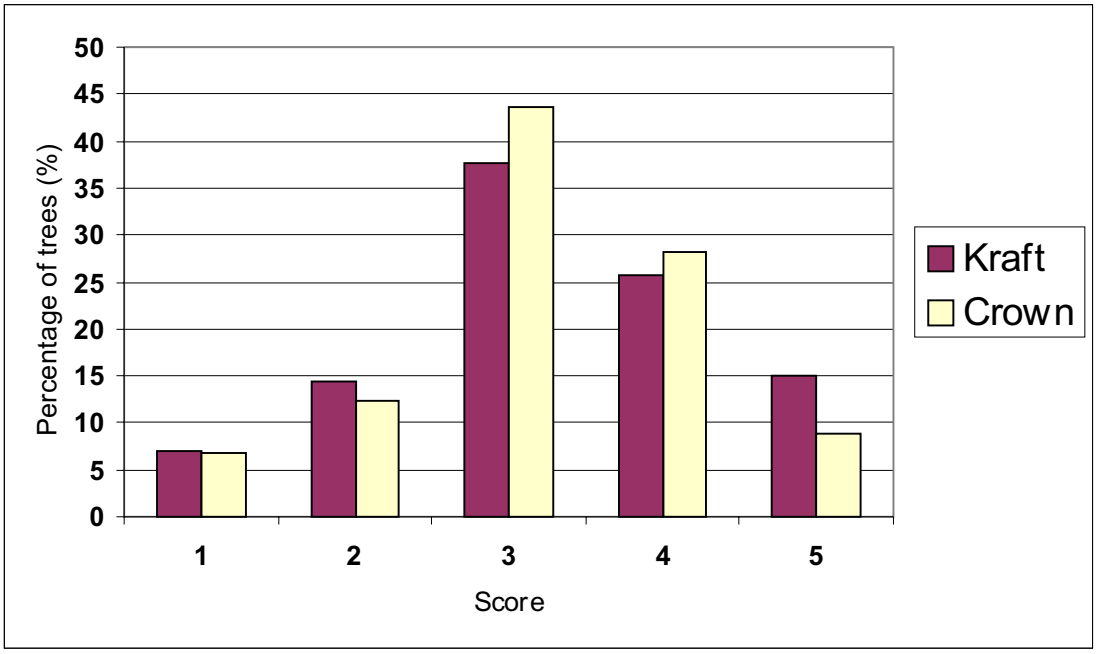


Figure 25. Distribution of Kraft and crown development scores.

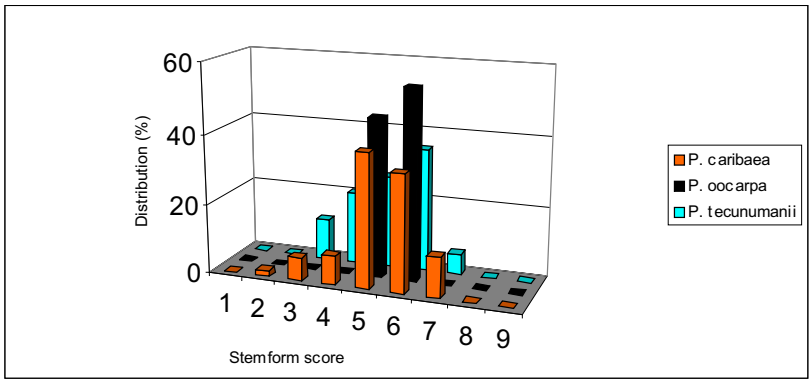


Figure 26. Distribution of stands (average stemform of stands).

6.6.2 Overall flowering and cone production

In Figure 29 the overall flower and cone crop at stand level is shown. For all five development stages the rating was poor. None or very light flowering and cone set were recorded for almost all stands. Light cone setting corresponds to an average crop rate of 2-8 cones per tree. None of the stands showed heavy flowering or cone production and all stands set far less cones than required for commercial seed collection.

For 75% of the stands no male flowers were recorded and in 96% of the stands no female flowers were observed. This may be partly explained by the timing of the assessment as explained above. More conelets and closed cones were observed though the majority of the stands had none. Old open cones were seen in 83% of the stands of which most showed a light seed set. Overall flowering and cone production were very poor for all stands.

6.6.3 Cone production at species and provenance level

The general low level of flowers and cones made it difficult to detect differences at species and provenance level. Moreover, the study population was not suitable for this kind of analysis as a good site representation and replications at planting sites were lacking. Provenance trials are required for a detailed analysis.

In Table 12 and figures 30-37 the flowering and cone production is presented. The tables and figures must be interpreted with care as there are differences in site representation and age of stands at the time of assessment.

Average cone production of species and provenances are displayed in Table 12. Stands of *P. oocarpa* produced slightly more cones than *P. caribaea* and *P. tecunumanii. P. oocarpa* had a mean score (open cones) of 2.71, followed by *P. caribaea* with 1.94 and *P. tecunumanii* with 1.76. For closed cones the scores were 1.17, 1.26 and 1.04, respectively.

Below, the effect of site representation and matching of seed sources to planting site is discussed in more detail - in particular the relationship between cone setting and altitude of seed source and planting sites.

6.6.3.1 Coastal provenances of *P. caribaea* var. *hondurensis*

Many of the coastal provenances of *P. caribaea* were established at planting sites at considerably higher altitudes than the natural range. This seemed to influence flowering and seed set since no closed cones were observed in stands at altitudes above 350 m. The scores were somewhat higher for old, open cones with a tendency towards lower scores at higher altitudes (Figures 30 and 31). Hence, it seemed that the coastal provenances require a good match to set cones.

There seemed to be little differences in cone setting among the different coastal provenances. Such differences have however been found in provenance trials (Birks & Barnes 1990).

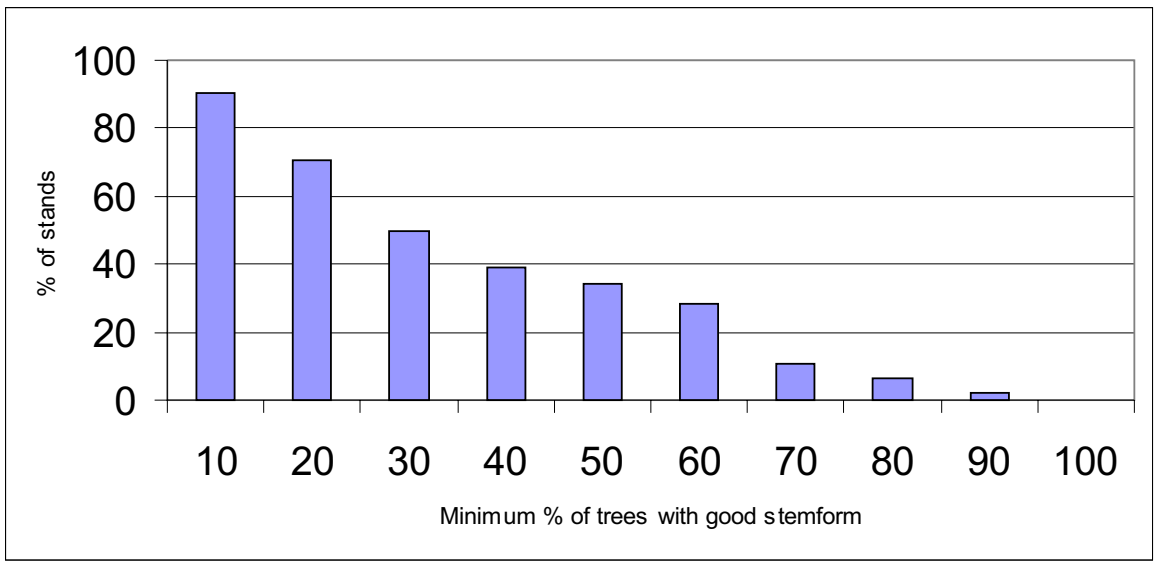


Figure 27. Percentage of stands meeting various levels of trees with good stemform (scoring classes 7,8,9).

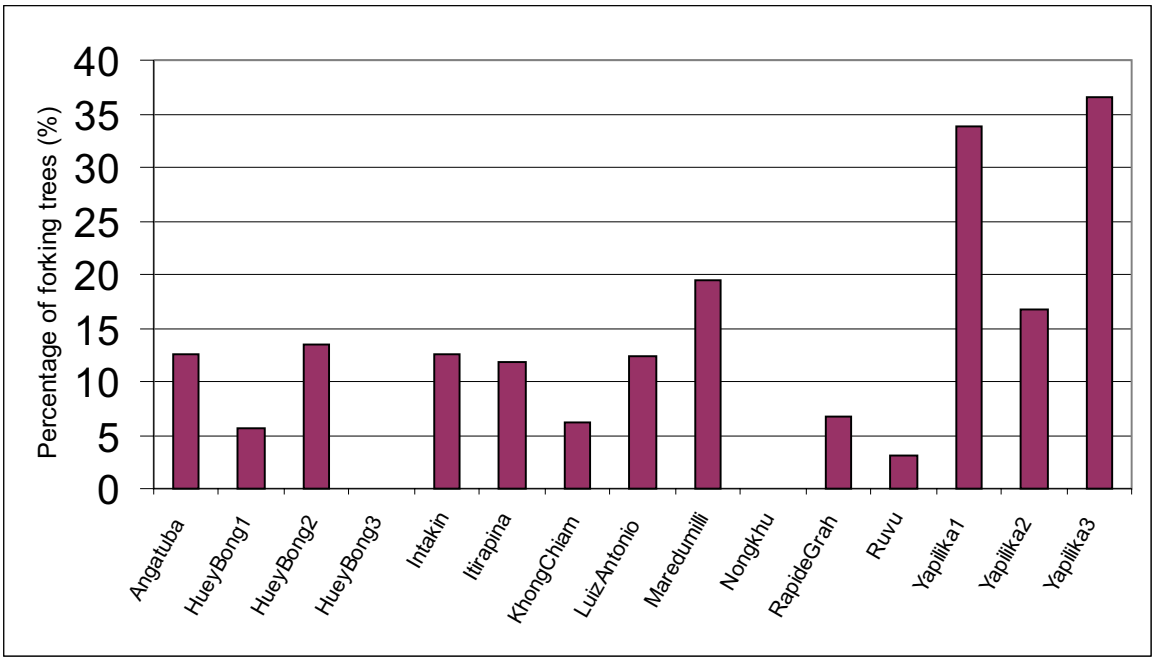
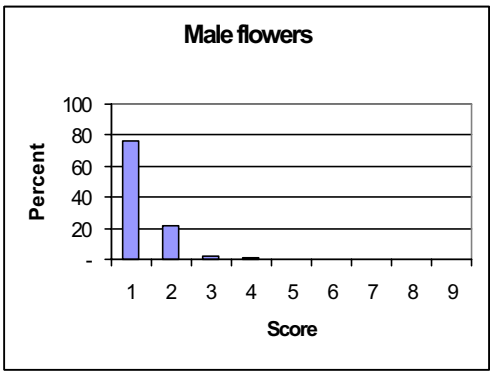
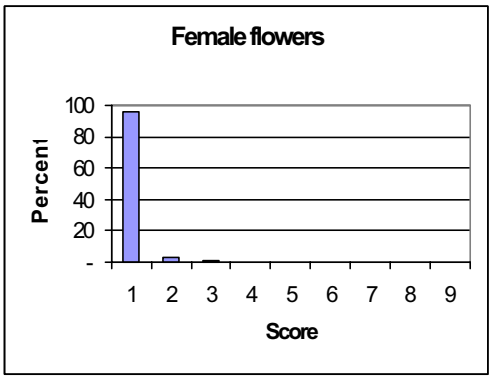
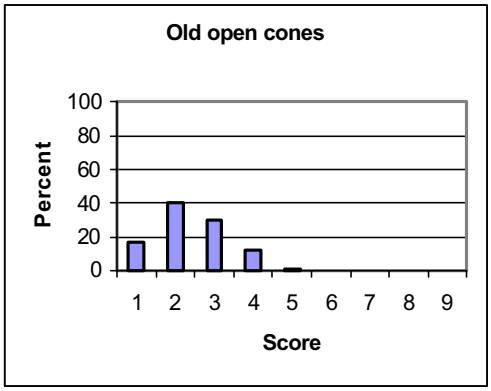
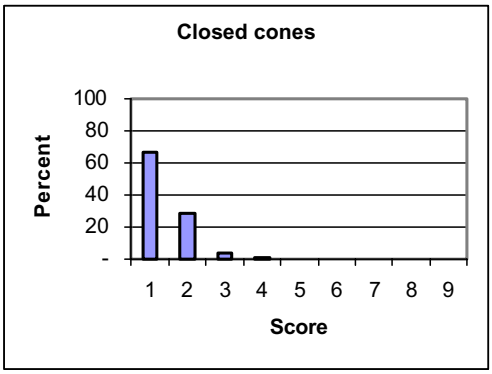


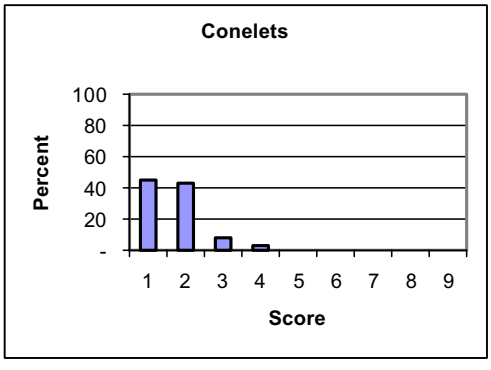
Figure 28. Variation in forking percentage over 11 different sites for Alamicamba provenance, *P. caribaea* var. *hondurensis*.











Avg. no. of flowers or cones	Score	No. of flowers or cones	Crop rating
0	1	0	None
2	2	1-3	Light
8	3	4-15	
30	4	16-60	Medium
125	5	61-250	
500	6	251-1000	Heavy
2000	7	1001-4000	
8000	8	4001-16000	
32000	9	> 16000	

Wellendorf log score for flowering and cone setting of single trees

Figure 29. Flowering and cone score for the *ex situ* conservation stands (percentage of stands with a given score). The score is according to Wellendorf's log score scale which is shown for reference.

Table 12. Provenance mean scores and range for closed cones and old open cones.

Provenance	No. of stands	Closed cones mean score	Closed cones range	Open cones score	Open cones range
P. caribaea – coastal					
Alamicamba	14	1.29	1.00-3.67	1.69	1.00-3.00
Guanaja	2	1.58	1.00-2.15	1.95	1.13-2.78
Karawala	4	1.17	1.00-1.67	1.00	1.00-1.00
La Brea Colon	2	1.30	1.00-1.60	2.48	2.20-2.75
La Mosquitia	3	1.42	1.00-2.25	1.74	1.00-2.92
Lololo Islands	1	1.00	-	1.98	-
P. caribaea – inland					
Culmi	9	1.28	1.00-2.67	1.96	1.54-2.38
Los Limones	12	1.29	1.00-2.15	2.45	1.00-4.00
Poptun	8	1.13	1.00-1.80	1.83	1.00-2.99
San Carlos	1	1.00	-	2.63	-
Santa Clara	2	1.00	1.00-1.00	2.32	1.09-3.54
P. oocarpa					
Bonete	3	1.56	1.33-1.69	3.09	2.71-3.33
Bucaral (El Castaño)	1	1.00	-	1.86	-
Dipilto	1	1.00	-	3.75	-
Jocotan	1	1.00	-	3.90	-
Las Crusitas	1	1.03	-	1.33	-
Mal Paso	3	1.00	1.00-1.00	2.34	1.00-3.18
P. tecunumanii					
Chanal	1	1.00	-	1.19	-
Mt. Pine Ridge	10	1.04	1.00-1.19	1.69	1.00-3.08
Napite	1	1.00	-	1.06	-
Pachoc	1	1.00	-	1.00	-
Rancho Nuevo	1	1.0	-	1.25	-
San Rafael	9	1.03	1.00-1.15	1.78	1.08-2.91
Yucul	12	1.04	1.00-1.38	2.02	1.00-3.34

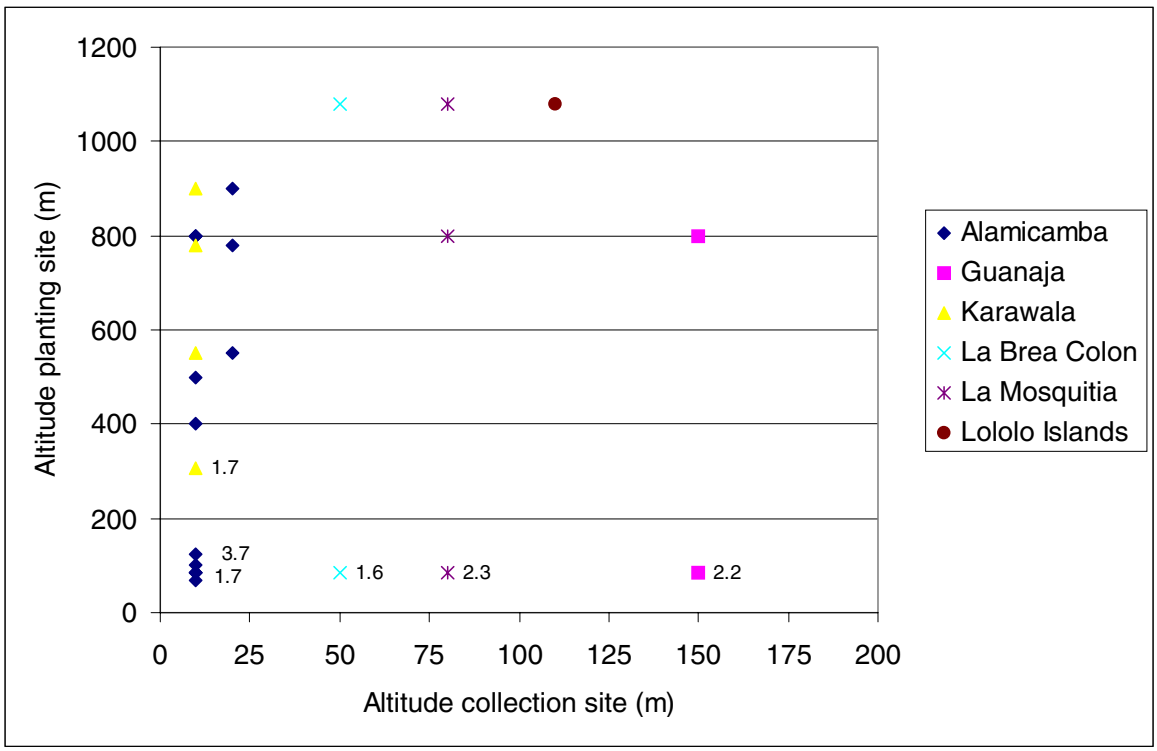


Figure 30. Scores of closed cones of coastal provenances of *P. caribaea* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

6.6.3.2 Inland provenances of *P. caribaea*

The inland provenances were generally better matched to planting sites than the coastal provenances. For most of the inland provenances closed cones were lacking while most stands had few open cones (Figures 32 and 33). Los Limones provenance is an interesting case as it is planted from sea level to above 2500 m and in this study actually shows best cone production at the extreme altitudes.

6.6.3.3 *P. oocarpa*

Provenances of *P. oocarpa* had a low representation in the study. Only three stands of provenances Bonete and Mal Paso, and one stand of each of the other provenances, were established. Stands of Bonete had few closed cones while old open cones were observed in all stands.

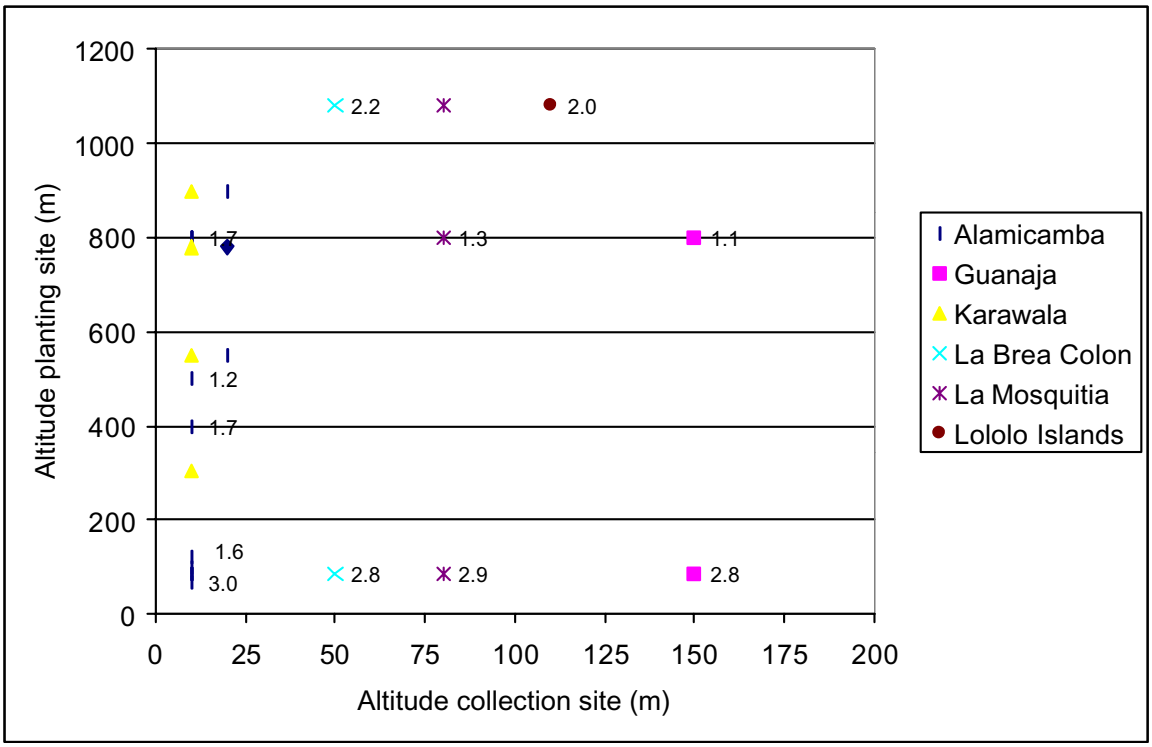


Figure 31. Scores of old, open cones of coastal provenances of *P. caribaea* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

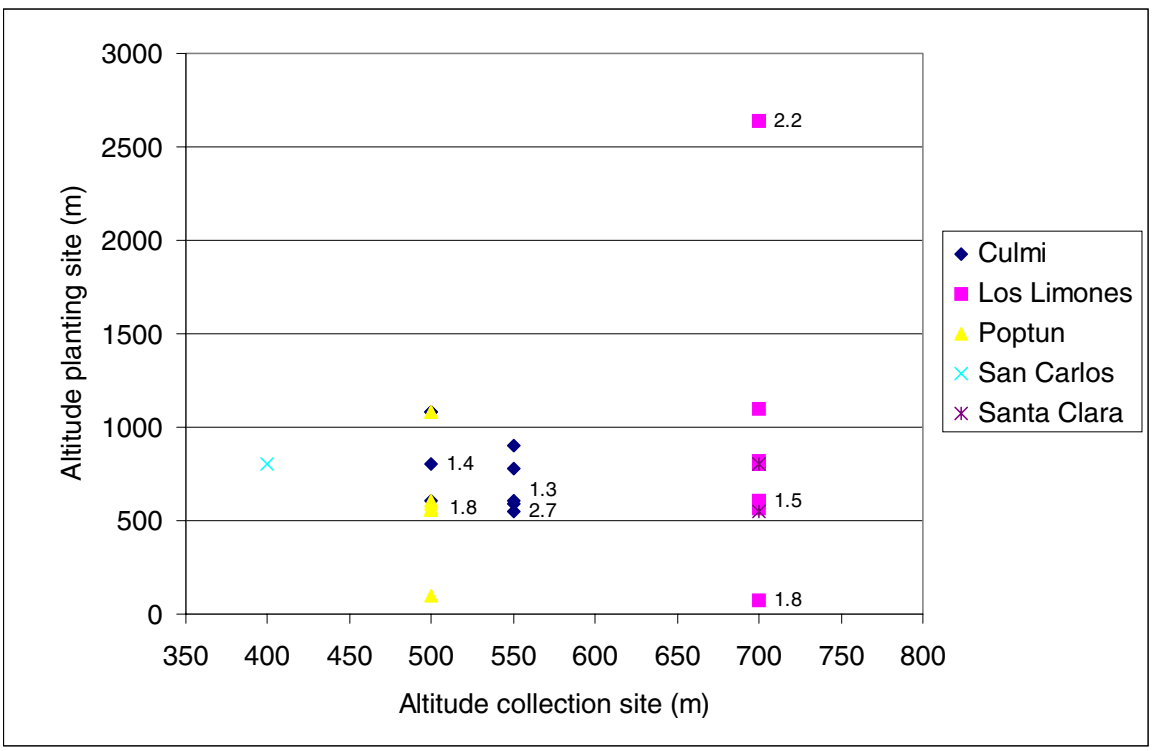


Figure 32. Scores of closed cones of inland provenances of *P. caribaea* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

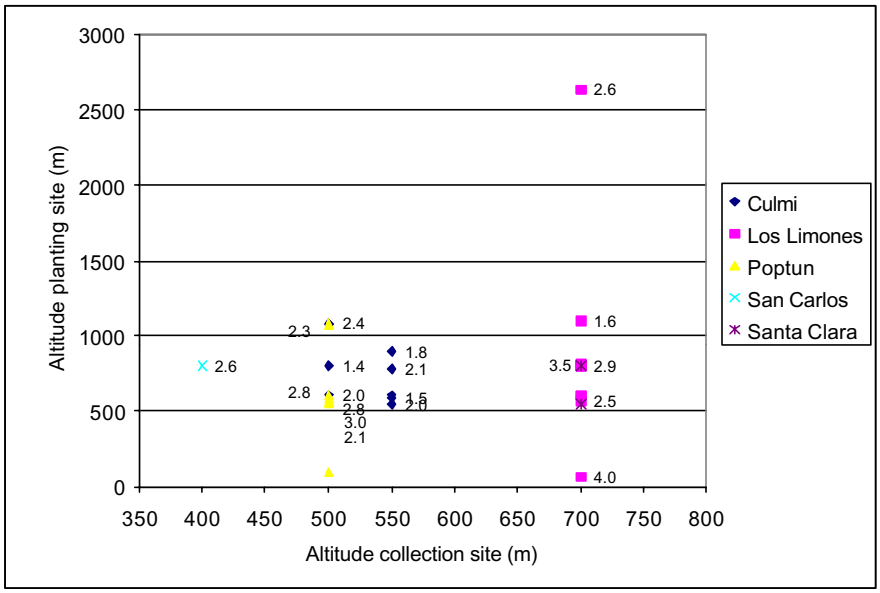


Figure 33. Scores of old, open cones of inland provenances of *P. caribaea* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

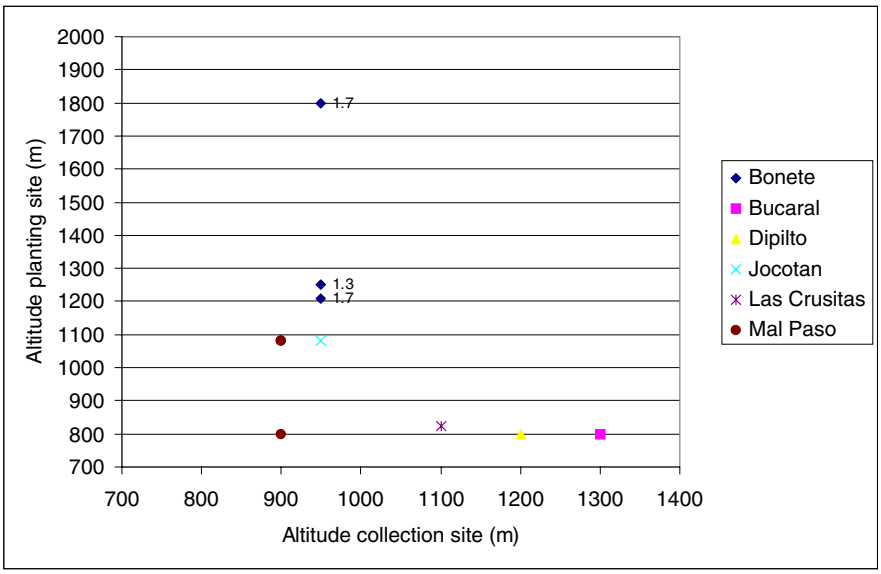


Figure 34. Scores of closed cones of provenances of *P. oocarpa* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

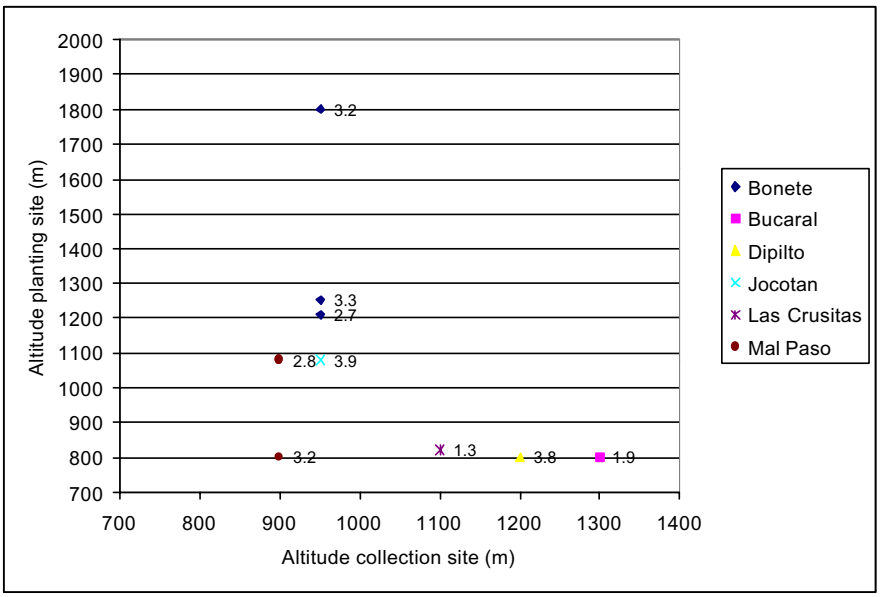


Figure 35. Scores of old, open cones of provenances of *P. oocarpa* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

6.6.3.4 *P. tecunumanii*

Very few of the *P. tecunumanii* stands had closed cones, and in general the cone setting was very poor (Figures 36 and 37). In some stands old, open cones were present. Many *P. tecunumanii* stands were established at lowland sites, or at sites at a lower altitude than the collection sites. These stands all had limited cone setting whereas cone setting was better for stands established at higher altitudes and stands established between 800 and 900 m had the highest scores, regardless of provenance.

Looking at the rating at provenance level none of them produced significantly more flowers or cones compared to others, although significant differences on earlier occasions been reported from provenance trials (Birks & Barnes 1990).

6.6.4 Why so few flowers and cones?

The level of flowers and cones were in general very low as shown in the previous sections. Although there were minor differences between species and provenance, e.g. the extremely low cone setting level of the coastal provenances of *P. caribaea*, the level for all species and provenances was lower than expected.

The low level is believed explained primarily by lack of thinning. As mentioned earlier, only 20 of the 135 stands were thinned, and most stands were dense restricting flowering and cone setting. Thinning is an established practise in the management of seed production areas and seed orchards to secure a good seed crop and the effect of thinning on cone production is well documented, see e.g. Granhof (1993); Lauridsen & Olesen (1994) and Faulkner (1975).

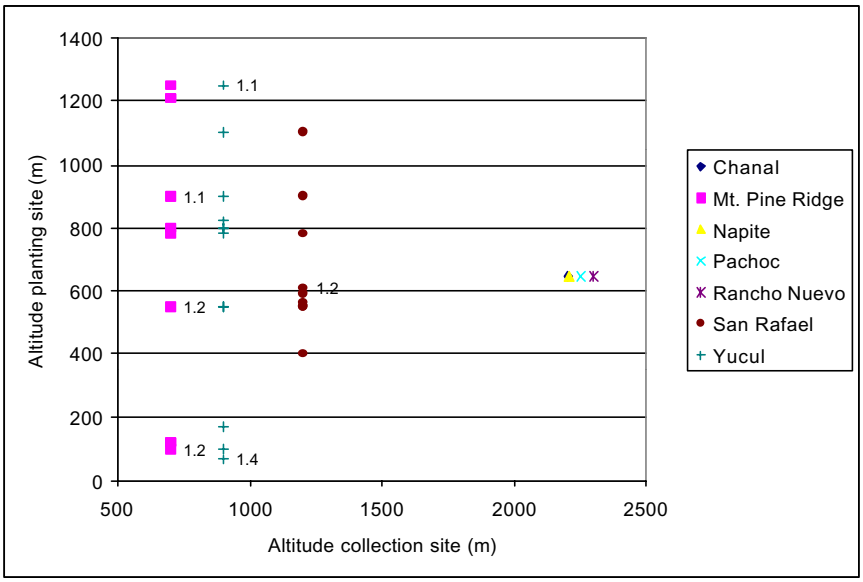


Figure 36. Scores of closed cones of provenances of *P. tecunumanii* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

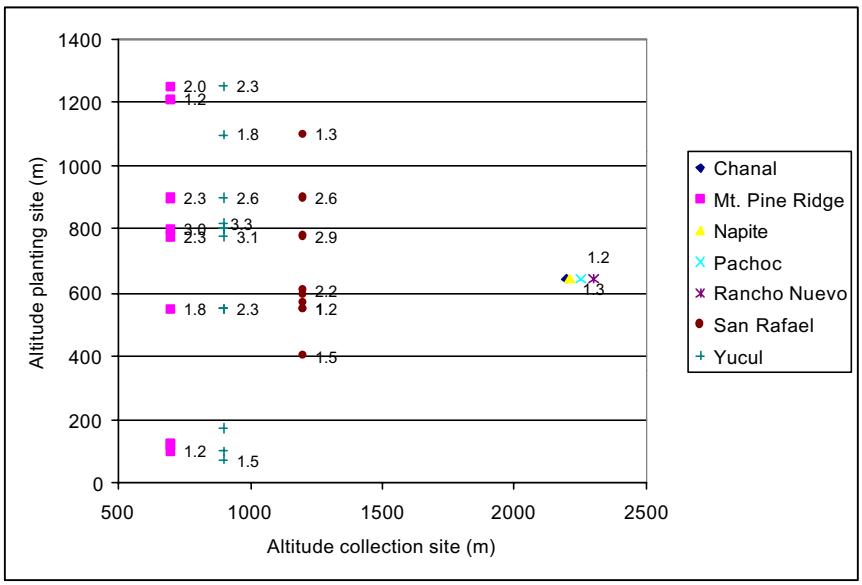


Figure 37. Scores of old, open cones of provenances of *P. tecunumanii* in relation to altitude of collection and planting site. Stands with no value have no cone setting, i.e. score 1.

The study population did unfortunately not provide data to illustrate the effect of thinning on flowering and cone production. First of all, few stands were actually thinned and differences in age, site representation and thinning intensity made a comparison between thinned and non-thinned stands difficult. In a number of stands in Brazil, thinning was partly carried out, and these stands offered an opportunity to measure the effect of thinning. These stands, however, did not reveal any significant differences in cones (old, open cones) between thinned and non-thinned stands. The data material is rather restricted, with 4 sample plots (two thinned and two non-thinned plots) in each of 5 stands. In addition, two of the stands are of coastal *P. caribaea* origin, sources that have showed very restricted cone setting, regardless of thinning.

A positive effect of thinning on cone setting was supported by observations of enhanced flowering and cone production on free-standing trees and on trees in border rows. This indicates a positive relation between light and flowering/cones.

Apart from lack of thinning, environmental factors may have played a role too. As we have seen above, the lack of site matching may influence flowering and cone production. In the next section flowering and cone production is correlated to climate at the planting site.

Picture 16. Scoring flowers and cones using binoculars, Ruvu, Tanzania.

6.6.5 The effect of ecological factors on flowering and cone production

6.6.5.1 Earlier studies on flowering and cone production in tropical pines

This section gives a brief review of other studies on the flowering of tropical pines. Studies have concentrated on *P. caribaea* var. hondurensis, probably because of the importance of this species in plantation forestry throughout the tropics, and because most problems have been experienced with this species. Few studies are available on *P. oocarpa* and *P. tecunumanii*.

A model relating strobilus production in *P. caribaea* to day-length and temperature is proposed by Slee (1977). He suggested a temperature x day-length control of flowering and cone setting. In a diagram with mean monthly temperature on the x-axis and mean monthly day-length on the y-axis, he defined a line from 24°C and 11 hours of daylight to 30°C and 14 hours of daylight. Various combinations of temperature and day-length to the right of this curve will initiate flower differentiation. In order to develop flowers and cones, the temperature x day-length regime has to change to the left, i.e. lower temperature or shorter day-length or a combination of the two. The model has been developed based on phenological observations at a few sites and subsequently supported by observations on sites throughout the tropics. The data material, however is limited, and does not give quantitative data on flowering and cone production. Moreover, there is no consideration of differences in the flowering and cone production between provenance groups (coastal, inland) or at provenance level.

Gallegos (1981) summarised results of a worldwide questionnaire survey on flowering and cone set of *P. caribaea* var. *hondurensis*. He concluded that the best areas for seed production are between 9° and 27° off the equator although seed may also be produced at higher altitudes at lower latitudes. Delwaulle (1982), however, suggested that Gallegos paid too little attention to the varying climatic zones lying within the latitudinal belt in question. He pointed out that *P. caribaea* produces little or no viable seed at low latitudes in permanent humid areas. In areas with a pronounced dry season, the species will flower and set seed normally.

The most extensive study on flowering and cone production of *P. caribaea* is that of Gibson *et al.* (1983) who have studied flowering and its interaction with environment in international provenance trials of *P. caribaea*. The study included 16 provenances planted at 17 localities. The traits assessed were male strobilus production, number of conelets and number of mature cones. Analysis of variance was used to estimate the significance of the provenance effect within localities and joint regression analysis to estimate the significance and nature of the genotype-environment interaction (Gibson *et al.* 1983). Conclusions of the study were:

- There are very significant provenance differences at all planting sites;
- Upland sources flower earlier and more prolific than lowland sources;
- Strobilus production was low or non-existent in sub-tropical locations where mean annual temperature (MAT) was 21°C, mean temperature of coldest month (MINT) < 17.5°C and the mean temperature for the hottest month (MAXT) < 26°C;
- Tropical locations (MAT=24.5°C, MINT=21°C and MAXT=27°C) were more productive;
- At the lowest tropical altitudes and latitudes (MAT=26.5°C, MINT=24°C and MAXT=28°C), abnormalities in flowering periodicity and synchronisation of male and female flower production, reduce flowering and cone setting;
- Lack of between block variation in trials suggested that climatic rather than edaphic conditions control cone setting. This observation is confirmed by investigations by Sirikul *et al.* (1991).

A multiple regression analysis using the following variables: latitude, altitude, rainfall, coefficient of variation of annual rainfall, mean annual temperature and mean maximum and minimum daily temperatures of the hottest and coldest months was carried out, but the regression did not explain much of the total variation in flowering.

Sirikul *et al.* (1991) investigated cone setting in four provenance trials of *P. caribaea* in Thailand. For coastal/lowland provenances the cone setting decreased with increasing latitude and altitude. For inland/highland provenances, the cone setting increased at higher altitude trial sites. Normal conelet production took place at low-altitude sites, but few mature cones were found. This may be due to the high temperature and equatorial day-length all year round, which inhibit the development of conelets into mature cones (Slee 1977).

Bridgen & Haines (1984) have investigated seed production of *P. caribaea* in Northern Territory, Australia. They found few, small cones per tree, small seed and low counts of viable seed. They were able to explain the low flowering and cone production based on the climatic conditions at the site using the theory of Slee (1977).

For *P. oocarpa* and *P. tecunumaii* much less information is available than for *P. caribaea*. Birks & Barnes (1990) summarise information from the international provenance trials and state that flowering and cone setting of *P. oocarpa* is generally better than for *P. tecunumanii* and that cone setting for the two species was more frequent at trial sites most distant from the equator.

6.6.5.2 Flowering and cone production related to climate at the planting sites

Below, the flowering and cone production of the three species are correlated with geographic and climatic parameters of the planting sites. The parameters include: altitude, latitude, annual rainfall, difference in rainfall between driest and wettest month, coefficient of variation in annual rainfall, mean annual temperature, mean of daily maximum temperatures, mean of daily minimum temperatures, difference in temperature between hottest and coldest month and coefficient of variation in temperature.

Data was analysed using simple linear regression via PROC REG in the SAS statistical analysis package (SAS, 1989). Response variables were closed cones, old, open cones and conelets, whereas the low scores of male and female flowers did not warrant an analysis. Results of the analysis are presented in Table 13.

The Alamicamba provenance (coastal *P. caribaea*) presented the clearest results. There seemed to be an effect of both altitude and latitude. The correlation was negative, i.e. lower cone setting with higher altitude and latitude. This is in accordance with other studies and what was displayed in Figure 30. The effect of altitude and latitude was further broken down and showed a strong effect of both temperature and rainfall. For rainfall, the difference between wettest and driest month explained most of the variation. The correlation was positive, i.e. large differences gave better cone setting. This indicated that the coastal provenances require a dry season in order to produce a good seed crop as also suggested by Delwaulle (1982). There were also significant effects of both maximum temperatures, variation in temperature and difference between hottest and coldest month. These characters were probably strongly correlated and may express the

Picture 17. Cones were examined more closely by collecting samples from the crown of selected trees. In some stands cones developed but no seeds. Ruvu, Tanzania.

same underlying effect of temperature. The correlation is negative, i.e. larger differences gave lower cone crop. It was believed to be an effect of higher altitude sites with extreme temperature differences, and not the temperature effect described by Slee (1977) on tropical, low altitude site, as this correlation would be expected to be positive.

For the inland provenances of *P. caribaea* (Culmi, Los Limones and Poptun), there was no clear picture. For Culmi and Poptun, the variation in flowering and cone setting was not clarified, whereas climatic factors seemed to explain a large part of the variation for Los Limones. There were significant effects of altitude, latitude, rainfall, minimum temperature, maximum temperature, temperature variation and also difference between hottest and coldest month. These characters seemed to explain a large proportion of the variation for closed cones but not for open cones and conelets. The Los Limones provenance originates from an extremely dry and hot climate, which is different from the other inland provenances. Moreover, some of the stands of Los Limones origin had been established at deviant planting sites, and results may therefore not be representative

For *P. tecunumanii* (Mt. Pine Ridge, Yucul and San Rafael) there was no clear tendency, and none of the climatic parameters alone seemed to explain the variation in flowering and cone set. For *P. oocarpa* (Bonete) there was not enough data available for an analysis.

6.6.6 Flowering and cone production - conclusion

In explaining the general absence of flowers and cones, lack of thinning was believed to play the most important role, although the study population did not allow a detailed testing of this hypothesis as it included only few thinned stands. Environmental factors at the planting sites are also expected to play a role. The low levels of flowers and cones were thus believed to be a combined effect of lack of thinning and climatic factors. Based on the available data it was not possible to clarify how specific climatic parameters influence flowering and cone setting. For example cone crops

Table 13. Results of linear regression analysis with various climatic parameters. -: no significance, *: significant effect at 0.05 level, **: significant effect at 0.01 level, ***: significant effect at 0.001 level, NA: too few data for analysis.

Provenance	**Altitude**	**Latitude**	**Annual rainfall**	**Coefficient of var. in rainfall**	**Difference between wettest and driest month**	**Mean annual temperature**	**Mean daily min. temperature**	**Mean daily max. temperature**	**Coefficient of var. in temperature**	**Difference between warmest and coldest month**
Closed cones										
Alamicamba	*	**	-	*	***	-	-	***	***	**
Culmi	-	-	-	-	-	-	-	-	-	-
Los Limones	***	**	**	-	-	-	***	***	***	***
Poptun	-	-	-	-	-	***	-	-	-	-
Mt. Pine Ridge	-	-	-	-	-	-	NA	NA	-	-
Yucul	*	-	**	-	-	-	-	-	-	-
San Rafael	-	-	-	-	-	-	-	-	-	-
Bonete	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Open cones										
Alamicamba	**	***	*	-	(*)	-	*	*	**	**
Culmi	-	-	-	-	-	-	-	-	-	-
Los Limones	-	-	*	-	-	-	-	-	-	-
Poptun	-	-	-	-	-	-	-	-	-	-
Mt. Pine Ridge	(*)	-	*	-	-	-	-	-	-	-
Yucul	-	-	-	-	-	-	**	-	*	-
San Rafael	-	-	-	-	-	-	-	-	-	-
Bonete	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Conelets										
Alamicamba	*	*	-	*	***	-	-	*	**	*
Culmi	-	-	-	-	-	-	-	-	-	-
Los Limones	-	-	-	-	-	-	-	-	-	-
Poptun	-	*	-	-	-	-	*	-	-	-
Mt. Pine Ridge	-	-	**	-	-	-	-	-	-	-
Yucul	-	**	**	-	**	-	-	-	**	***
San Rafael	**	-	-	-	-	-	-	-	-	-
Bonete	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

in *P. tecunumanii* are usually extremely light with fewer than 50 cones on trees as large as 45 m. An average of six filled seeds per cone was found for trees in high elevation populations, yielding a seed efficiency rate of 7% (Dvorak and Lambeth 1993).

More detailed investigations are required to describe and explain the flowering and cone setting of the three species under different environmental conditions.

The low levels of cones were a serious constraint to the use and regeneration of the *ex situ* stands. As mentioned in the section on thinning, it is a question whether thinning at this stage will facilitate cone setting, as many of the mature stands may not be able to respond to thinning.

In some cases, poor matching of planting site and seed source makes it doubtful whether stands will be able to produce (abundant) cones, even with proper thinning. For lowland provenances of *P. caribaea* planted at high altitude sites cone setting may not be possible at all. The data on flowering and cone setting stresses the importance of a close match of seed source to planting site. Furthermore, continued management and thinning of the stands is necessary. Only then the full potential of *ex situ* conservation stands can be achieved.

Picture 18. Border tree of *P. tecunumanii* showing good cone setting. Yucul provenance, Chati, Zambia.

7. Use and Benefits

7.1 Uses and benefits apart from gene conservation

Most stands were established with a multitude of objectives. For many stands seed production was probably among the key objectives. Seed was, however, only collected in four of the 135 stands; two FAO/UNEP stands and two national stands. In all cases seed was harvested in small quantities for research purposes. No seed collection on a commercial scale had taken place in any of the stands.

The low level of seed harvest was of course related to the low cone setting in the stands but most likely also to the actual demand for seed in the countries. Demand for seed was probably much lower than anticipated at the time of establishment. In Thailand and Côte d'Ivoire, pines did not play any significant role in the development of the plantation forestry sector. In other countries where the Central American pines were important, e.g. in Australia, Brazil, Tanzania and Zambia, most of seed demand was covered by other sources in the sense that seed demand was focused towards improved sources or was covered through new imports. The low demand for seed has created little incentive for thinning of stands, and can thus be seen as the overall underlying cause of the low seed production, as thinning - at the right time - in most cases would have brought about flowering and cone setting. The prospects for seed production probably varies considerably from stand to stand. In some younger stands it will still be possible to bring about flowering and cone production by proper management, in others (mature stands) it will be more difficult. Again, the future demand for seed will be an important factor when planning future stand management for seed production.

Picture 19. Resin tapping. Katende Hill, Kenya.

Plus trees were selected and grafting materials collected in two stands only. The stands had thus so far contributed only little to national tree improvement programmes, probably because such programmes had not been initiated in most of the countries. Valuable genetic material, however, could be provided from the stands if such programmes were to be considered in the future. The stands thus made the genetic resources readily available to the countries, which was considered an important benefit from the stands. The active use of the genetic resource via seed (e.g. collection of open-pollinated offspring from plus trees) would be problematic in many stands because of the low cone setting. Vegetative propagation may be the only feasible method to capture and utilise the genetic variation for breeding programmes.

Other uses of the stands included resin tapping in one of the Indian stands and three Kenyan stands. Wood harvesting was restricted to small quantities of poles plus of course the small amounts of wood extracted by illegal cutting.

In conclusion, direct benefits from stands had been very limited. That holds true in quantitative terms as well as in monetary terms. Many of the stands hold a potential for future use but it will to a large extent depend on seed demand.

7.2 Value of the stands for gene conservation

All stands in the study were established with *ex situ* conservation as one of the objectives. Stands fulfilled this role to a varying degree. In this section, we try to categorise stands according to their overall conservation value.

7.2.1 Assessing the conservation value of the stands

Many factors have to be considered in assessing the conservation value of a stand. First of all, the conservation value will be influenced by *direct factors* related to the stand itself such as:

- size of stand (number of individuals in the conservation population);
- health of the stand;
- threats (biotic and abiotic);
- reproductive potential (flowering and cone set);
- isolation from contaminating pollen sources;
- documentation of seed source;
  genetic variation within the stand (no. of mother trees);

These factors were all discussed in the previous chapters. Most of them are fairly easy to assess objectively, i.e. criteria can be set up for their assessment.

The conservation value is also influenced by *indirect factors* such as:

- How valuable is the genetic material for the country in question - i.e. is it a promising provenance?
- How many *ex situ* stands of the same origin are found in the country or within the same planting zone?
- Is there a tree improvement programme that will contribute to the conservation of the genetic resources?

The answers to these questions are not straightforward and will in many cases include an element of subjectivity. Overall conservation value is therefore a combination of objective assessments combined with more subjective ones.

The above refers to conservation value at a national level. The stands may also represent an *international* conservation value. This will depend on the conservation status and availability of reproductive material in the natural populations, and the extent of *ex situ* conservation world-wide. The original criteria used in selecting these populations for conservation were based on knowledge from existing trials (e.g., Greaves 1978), perceived physical threats to the stands and access to seed. If these stands are still highly threatened and *ex situ* conservation is not carried out elsewhere, then the existing stands have a high international conservation value. To establish the international conservation value, good knowledge is required on the status of the natural populations. Moreover, an overview of *ex situ* stands is needed, in relation to all other ongoing collections, programs and studies around the world with these species. Such complete information is seldom easily available, and international conservation value is often to be established based on incomplete data, both regarding status of natural populations and number and distribution of *ex situ* stands.

7.2.2 Conservation value of stands

An attempt was made to broadly categorise stands according to conservation value. Conservation value was only assessed from a national perspective since only very restricted information on the status of the natural populations was available and no overall analysis of *ex situ* activities of the three species world-wide existed. In consequence it was not possible to assess the international conservation status here. As the study did not examine in detail the indirect factors to be considered to establish the conservation value at national level, conservation value was assessed in regard to the above-mentioned 'direct' factors; in particular the size of stands, threats and health status, isolation and flowering and cone setting. Stands were given a value from one to five stars, where five stars were given to a stand which fully complies to the requirements for an *ex situ* conservation stand to fully meet conservation objectives. That is: a population not threatened by biotic and/or abiotic factors, with an appropriate genetic variation, sufficiently isolated from contaminating pollen sources, with a high reproductive potential, etc. On the other hand, one star was given to a stand where none or very few of the above requirements are fulfilled. Two, three and four stars represent intermediate values, where a higher number of stars indicate a better fulfilment of the basic requirements.

The actual designation of a value is of course subjective, and it depends on what relative value is given to the various factors under consideration. In the ranking below, we have given high priority to sufficient isolation and reproductive potential. Other considerations would lead to a different ranking. Only the managing institutions are in a position to make a full assessment of conservation value at national level, and to decide on the future management of stands.

The results of the assessment are shown in tables 14-21, separated by country. None of the stands in the study complied with all requirements. Few stands fulfilled most of the basic requirements (4 stars), and most stands fell in an intermediate group (2 and 3 stars) where one or more factors were not fulfilled, hence restricting the full use of the stand for conservation purposes. The FAO/UNEP stands were expected to have a higher value than the national stands as they were established and managed using common guidelines and because ex situ conservation was the most important stand objective but in general no difference was found.

The study population consisted of 135 *ex situ* conservation stands of three pine species, covering a total area of 950 ha, established in the late 70's and early 80's. The stands were established as part of the FAO/UNEP project on conservation of forest genetic resources (36 stands), as well as through national efforts (99 stands) of which some were established with support from Danida. Eight countries, including Australia, Brazil, Côte d'Ivoire, India, Kenya, Tanzania, Thailand and Zambia, took part in the programme. All stands were visited in the field from 1996 to 1999 as part of this evaluation.

Table 14. Australian *ex situ* conservation stands in the study (all national stands). ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size Ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Aus1	20	50	Fire	Severe	>1000	None	Poor demarcation	**
Aus2	20	50	Fire	Severe	>1000	None	Poor demarcation	**
Aus3	35	95	Fire	Moderate	0	None	Poor demarcation	**
Aus4	37	95	Fire	Moderate	0	Light	Plus trees selected in the stand. Poor demarcation	**
Aus5	18	95	Fire	Moderate	0	Light	Other seed sources mixed in the stand	*
Aus6	3	95	Fire	Moderate	0	Very light	Poor demarcation	**
Aus7	8	95	Fire	Moderate	100	Very light		**
Aus8	35	86	Fire	Moderate	0	Very light		**

Table 15. Brazilian *ex situ* conservation stands in the study (all national stands). ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size Ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Bra1	10	100	No problems		10	None	Many trees with good stem form.	***
Bra2	6.3	44	Wind damage	Severe	0	None		**
Bra3	8.2	100	No problems		100	None	Many plus tree candidates.	**
Bra4	5.6	100	No problems		>1000	Very restricted		***
Bra5	2.7	100	No problems		>1000	Very restricted		***
Bra6	2.7	>90	No problems		0	None	Some plus tree candidates	**
Bra7	5.9	70	Wind damage	Severe	>1000	Very light		**
Bra8	3.6	100	No problems		>1000	None	Many climbers overgrowing stand	***
Bra9	20.4	100	No problems		10	None	Many plus tree candidates	**
Bra10	4.9	100	No problems		10	Very light		**
Bra11	3.5	90	No problems		500	Very light		**
Bra12	5.4	>90	No problems		500	Very light		**
Bra13	2.7	90	No problems		500	None		**
Bra14	5	>90	No problems		500	Very light		**
Bra15	2.6	90	No problems		500	None		**
Bra16	3.3	90	No problems		500	None		**
Bra17	3.3	90	No problems		500	Light	Stand thinned	***
Bra18	3.3	>80	No problems		500	Very light	Stand thinned	***
Bra19	2.1	>80	No problems		500	None	Stand thinned	***
Bra20	3.3	90	No problems		500	Light	Stand thinned	***
Bra21	2.1	90	No problems		500	None	Part of stand thinned	**
Bra22	0.4	80	No problems		50	None		**
Bra23	1	90	No problems		50	None		**
Bra24	0.8	90	No problems		50	None		**
Bra25	0.8	95	No problems		50	None		**
Bra26	3.3	90	Potential danger of encroachment	Moderate	>1000	None		**

Table 16. *Ex situ* conservation stands in Côte d'Ivoire. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size Ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Ivo1	8.1	25	Stand overgrown	Severe	500	None	Many large gaps	**
Ivo2	9	15	Stand overgrown	Severe	1800	None	Many large gaps	**
Ivo3	7	25	Stand overgrown	Severe	400	Light	Many large gaps	**
Ivo4	9.4	15	Stand overgrown	Severe	1800	None	Many large gaps	**

Table 17. *Ex situ* conservation stands in India. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size Ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Ind1	1.1	95	No problems		10	Light		**
Ind2	1.5	80	No problems		10	None		**
Ind3	1.9	85	No problems		10	Very light		**
Ind4	2.8	85	No problems		10	Very light		**
Ind5	0.9	90	No problems		10	None		**
Ind6	0.2	90	No problems		10	None		**
Ind7	1.5	95	Fire, illegal cutting	Severe	>1000	None	Stand no longer managed	***
Ind8	5.7	50	No problems		>1000	Very light	Low survival, no longer managed	***
Ind9	4	100	No problems		>1000	Very light		****
Ind10	4	70	No problems		>1000	Light		****
Ind13	9	70	No problems		>1000	None		***
Ind14	5	50	No problems		>1000	Light	Stand converted to seed production area	****
Ind15	10	95	Fire	Moderate	>1000	None	Seed source unknown	*
Ind16	5	100	No problems		>1000	None		***
Ind17	4	95	No problems		>1000	Very light		***
Ind19	1	90	No problems		>1000	None	Regeneration of broadleaved species	***
Ind20	5	90	No problems		>1000	Very light	Seed source unknown, probably Poptun	*
Ind22	1.5	100	No problems		>1000	Very restricted	Many plus tree candidates	***
Ind23	4.2	20	Fire	Severe	>1000	Very light	Only remnants of stand left	*
Ind24	5.2	100	Fire, illegal cutting	Slight	>1000	Very light		***
Ind25	4	80	Fire, illegal cutting, wildlife	Severe	>1000	Light		**
Ind26	5	?	Fire, wildlife	Severe	>1000	Very restricted		**
Ind27	4	90	Fire, wildlife	Moderate	>1000	Very light	Stand on extremely steep slope	***
Ind30	2.2	?	No problems		>1000	?		-

Table 18. *Ex situ* conservation stands in Kenya. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Ken1	4.6	?	Encroachment	Moderate	100	?	No demarcation	*
Ken2	1.7	?	Encroachment	Moderate	100	?	No demarcation	*
Ken3	1.2	?	Encroachment	Moderate	100	?	No demarcation	*

Table 19. *Ex situ* conservation stands in Tanzania. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Tan1	7.45	15	Fire	Severe	1000	None	Poor initial survival	**
Tan5	9.8	85	Fire	Severe	500	Very light		**
Tan6	2	90	Fire	?	500	Medium		**
Tan7	3	100	Fire, illegal cutting	Severe	>1000	None	Poor initial survival.	**

Table 20. *Ex situ* conservation stands in Zambia. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand	Actual size ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
zam1	10	100	No problems		100	None		**
zam2	10	100	No problems		500	Very light		**
zam3	10	100	No problems		100	Light		**
zam4	10	70	Fire, illegal cutting	Slight	1000	Very light		***
zam5	6	20	Fire, illegal cutting	Severe	500	None		**
zam6	0.3	100	Fire, illegal cutting	Severe	1000	None		*

Picture 20. *Ex situ* conservation stand of *P. caribaea* at Melville Island, Australia.

Table 21. *Ex situ* conservation stands in Thailand. FAO/UNEP stands shown in bold. ***** refers to a stand fulfilling all requirements, * to a stand where requirements are not fulfilled.

Stand ID	Actual size ha	Crown cover %	Threat/health status	Threat assess-ment	Isolation (m)	Cone production	Remarks	Value
Tha1	11	85	No problems		150	Light		**
Tha2	4.5	80	No problems		400	Very light		**
Tha3	8	100	No problems		200	None		**
Tha4	4.4	95	No problems		800	Very light		**
Tha5	2.5	100	No problems		150	Very light		**
Tha6	5.3	90	No problems		450	None		**
Tha7	2.5	95	No problems		225	Very light		**
Tha8	8	50	No problems		225	None	Many large gaps.	**
Tha9	3.2	95	No problems		>1000	None		****
Tha12	10	90	Encroachment	Slight	300	Light		**
Tha13	12.3	90	No problems		10	Light		**
Tha14	5	85	No problems		600	None		**
Tha15	5.9	50	No problems		400	Very light	Stand very uneven	**
Tha16	5.9	100	No problems		400	Light		**
Tha17	3.3	80	No problems		300	Light		**
Tha18	18	60	No problems		100	None		**
Tha19	5.8	90	No problems		400	None		**
Tha20	1.1	80	Fire	Slight	>1000	Very light	Only part of the stand left	***
Tha21	5.5	70	No problems		>1000	None		**
Tha22	6	60	No problems		600	None		**
Tha23	5	85	Fire	Severe	400	Very light		**
Tha24	3.5	80	No problems		300	None	Stand on swallow soil	**
Tha25	5.3	100	No problems		150	Light-medium	Seed harvested	**(*)
Tha26	6	90	No problems		150	Light	Many plus tree candidates.	**
Tha27	5	80	Fire	Moderate	500	Very light		**
Tha28	9	90	Fire	Slight	200	None		**
Tha29	4.5	90	Fire, encroachment	Severe	>1000	None		***
Tha30	21	95	Illegal cutting	Medium	0	Very light	Origin of seedlot unknown	*
Tha31	4.8	50	No problems		0	None	Mix of 15 provenances	*
Tha32	0.8	90	Encroachment	Severe	250	Medium	Mix of several provenances	*
Tha33	8.8	27	Illegal cutting, encroachment	Severe	250	Light	Origin of seedlot unknown	*
Tha34	16	10	No problems		700	None		***
Tha35	12	80	Illegal cutting, encroacment	Severe	>1000	None	Heavy pressure on the stand.	**
Tha36	3	80	Fire	Severe	200	None		**
Tha43	4.8	50	Fire	Severe	400	Very light		**
Tha46	8	50	Fire	Moderate	>1000	None	Poor soil	**
Tha47	8	50	Fire	Moderate	>1000	?	Poor soil	**
Tha48	1.6	80	Fire	Medium	>1000	None		**
Tha58	8.8	50	Fire, encroachment	Moderate	100	Heavy	Many large gaps	**
Tha59	8.8	50	Fire, encroachment	Moderate	100	Heavy	Many large gaps	**

8. Conclusions

8.1 Survival

Eight of 36 FAO/UNEP stands were lost (22%) together with 12 of the 99 national stands (12%), bringing the overall loss to 20 stands (15%). These stands were lost at an early stage within the first five years of establishment.

Fire was the primary cause in loss of stands destroying 14 of 20 lost stands. Fires originated from human activities outside the conservation areas (generally shifting cultivation), then spread, intentionally or unintentionally, into the conservation areas. Direct encroachment into stands only accounted for the loss of five stands. This is a surprisingly low figure considering that most stands are situated in areas with high human pressure on forests and forest resources. Most stands were established close to research stations with permanent guarding and protection, which is probably a main reason for their good survival.

In summary, 115 stands out of a total of 135 contributing to the study still existed, showing a strong commitment from the national institutes in charge of the stands. Approximately half of these stands were undisturbed the other half disturbed to varying degrees. The situation was the same in both the FAO/UNEP stands and the national stands. Fire was the primary causal agent of damage followed by illegal cutting. Problems with resin tapping, wind, drought, and termites were encountered in some locations. Damage from wildlife or domestic animals was largely restricted to the establishment phase. Most of the disturbed stands suffered slight to moderate damage and only a few stands were disturbed to the extent that their conservation value was compromised.

8.2 Establishment and management

Stands were well established and well managed in the initial stages during which external funding were available. Appropriate techniques were applied in stand establishment, weeding and fire management. Establishment was in general done in accordance with the agreed guidelines issued for the FAO/UNEP stands.

However, long-term management, especially thinning, was neglected which substantially reduced the conservation value and success of the project. It is believed to be partly due to a low demand for seeds from the stands, which provided little incentive for undertaking costly operations that would not pay back in the short term.

Regarding stand size, 25% of the stands fulfilled the minimum size of 10 ha recommended by the FAO/UNEP project. Most stands were considerably smaller. The recommended minimum size of 10 ha, based on a number of biological/genetic considerations, can be considered to provide a broad guideline to secure a viable conservation stand in the long run. Smaller stands may, however, go some way towards securing conservation values, their value depending on local circumstances. It is not clear which factors determined the size of the stands in local decision-making, however, it is likely that land availability, and success in seedling propagation, may both have played important roles, as may financial resources available.

8.3 Matching of seed source to planting site

Careful matching of seed source to planting site is an important factor to ensure successful plantation establishment. Climatic conditions at the planting sites in many cases differed significantly from the conditions in the natural range of the species and provenance. While it seems that poor matching did not have a major influence on stand survival, health and growth, it seems to have negatively affected the reproductive potential of the trees. This is not entirely surprising, as it is generally known that certain types of sites are required for good cone production in conifers, and these may or may not be good for general growth. The clearest example is provided by the lowland provenances of *P. caribaea*, which did not produce cones and set seeds when planted at higher altitudes (in cooler, subtropical climates). For the other species the effect is less clear, and they were in general established at planting sites more similar to those of the natural range.

At the time of stand establishment, there was little knowledge of, and insufficient attention paid to, seed setting in tropical pines. Problems with flowering and seed set, especially in *P. caribaea*, were documented in many tropical countries in the years following the establishment of the conservation stands.

8.4 Regeneration of *ex situ* stands

The stands produced few cones and little seed. The present survey and analysis, which was confounded by the fact that few stands had been thinned as compared to those not thinned, does not provide sufficient material to clarify this situation better. The effects of poor seed production are however fairly easy to predict; it will be difficult to ensure regeneration of the *ex situ* stands. Thinning at this stage of stand development may or may not induce flowering and seed set. The situation is even more difficult or impossible to correct in stands in which the reproductive potential is reduced because of poor site matching.

For the purposes of *ex situ* conservation and seed production it is essential that stands are properly isolated from outside, contaminating pollen sour-

ces. This important aspect was neglected in the layout of many stands, and only approximately 50% of the stands had what may be considered a satisfactory isolation. FAO/UNEP stands were in general better isolated than national stands, and there were also differences between countries. The recommendation of the FAO/UNEP project is an isolation zone of a minimum of 330 m.

In view of the lack of isolation, seeds collected in the conservation stands might have resulted from crosses between different provenances or species. Uncontrolled pollination will also reduce the value of the seed source in general terms, as seed from the stands may no longer possess the special characteristics of the provenance sought. Lack of isolation of stands was thus one of the major shortcomings of the *ex situ* conservation stands established and assessed in the present study.

It is not known what caused the lack of adherence to the guidelines regarding isolation of the stands. The importance and above all the reasons for the need for isolation might not have been conveyed strongly enough to the collaborating institutions, or proper isolation might simply not have been considered possible because of lack of suitable planting sites.

8.5 Seed production and seed demand

As mentioned earlier, cone production and seed setting were low. In some countries, the tropical pines have not played the significant role they were envisaged to do in the national plantation programme. This is especially true for Thailand and Côte d'Ivoire. Pines have been important in some countries, e.g. Australia, Brazil and Tanzania, but in these countries other sources, often imported and improved seed, have been used for plantation establishment, rather than managing the conservation stands for this purpose.

8.6 »The forgotten stands«

The 135 *ex situ* conservation stands covered by this study have helped ensure that reproductive materials of species and provenances, which may otherwise be difficult to obtain, are available for use in the countries in which the stands were established. However, the stands have to date not played a significant role in the provision of seed. Stand management has generally been neglected and this, in combination with the little seed produced, has led to few national benefits from the stands. Many of the stands may be characterised as the »forgotten stands«; they were established, but not actively managed or used. At present, many stands are in danger of being a 'dead-end', because of the likely biological and financial problems in regeneration at the end of the rotation.

The participating institutions had varying objectives in mind when establishing the stands. While it is not possible to analyse the initial situations in countries concerned, it is clear that institutional set-up, long term policy level commitment, and perceived benefits have played an important role. These are important aspects to consider and discuss when planning *ex situ* conservation programmes at national and international level.

8.7 Future management

The responsibility for future management of the *ex situ* conservation stands included in this study rests with the national institutions in charge of the stands. The present study has shown that although many of the stands have been successfully established and managed in the early stages, long-term management was often neglected. Some technical options and recommendations are presented below:

It is recommended that institutions in charge carefully assess the national situation, define national conservation priorities, and take action in accordance with these priorities. Specifically, the species and stands located in each country should be further evaluated for the **potential use** (not current). The present analysis provides information on the actual conservation value of the stands. If complemented with data on planned plantation programmes, and expected demand for seed at national level, the present information can be used to assess the value of the stands from a *national* perspective.

If a stand has only limited conservation value from a national perspective it may still be valuable from an *international* point of view (e.g. if the genetic resource is threatened in its natural range and no other conservation initiatives have been initiated). An assessment of the conservation value from an *international* perspective could therefore be useful. This assessment would give an idea of how each stand may fit into an overall conservation network and thereby contribute to the conservation of genetic resources of the species. This activity would need to include an evaluation of the present status of the *in situ* populations from which the material was collected, complemented with information on any *ex situ* conservation activities that may have been carried out since the inception of this current project (e.g. plantations or conservation stands). The latter point would entail some »detective work«, but it is believed that it could largely be carried out as a desk study. A study describing the present status of conservation and evaluation of the three pine species within the CAMCORE Cooperative has recently been published by CAMCORE (2000). This information could serve as a basis for carrying out the assessment of international conservation value.

If a stand is considered of national interest, or is recognised for its international conservation value, management steps such as the following could be considered:

- evaluate the biological value of the stands according to fitness and genetic integrity (i.e., isolation and size), based on data in this report;

- thinning measures to attempt to develop some crown structures of better phenotypes left in the stand;
- slowly, over several years, attempt to build up seed production from the better phenotypes;
- once stands appear to be failing (e.g., breakage, mortality), it would be desirable to grow offspring from the collected seed and replant the block to the same number or larger. It is likely, however, that the effective population size of any re-established block may be substantially reduced from the original stand size, perhaps in the order of 1/2 to 1/3 of the original number of trees which provided seed for the conservation stand. So it is desirable to collect seed from as many trees as possible in order to avoid the negative effects of poor sampling. Relatively few individuals are required to maintain the quantitative genetic variation whereas conservation of low frequency alleles will require larger population sizes. If the number of trees from which open-pollinated collections have been made in the conservation stands themselves, can be maintained in mid-hundreds (e.g. 400+ range), then it is likely that very high levels of quantitative genetic variation will be maintained as well as adequate conservation of lower frequency alleles.

In most cases a management mechanism (e.g., coordination and funding) would need to be established to support countries and national institutions in the implementation of the above general steps.

8.8 Lessons learned

None of the stands in this study represent ideal candidates for successful *ex situ* conservation. Lack of thinning, poor isolation from contaminating pollen sources and poor matching of seed source to planting sites were the most important factors substantially reducing the value of stands for *ex situ* conservation. Dual - and conflicting - objectives of growth evaluation and seed production did not allow for the most desirable outcomes of each. Thus technical aspects, which in theory can be controlled by planners, have been more important to the overall success than factors less easily controlled, i.e. encroachment, fires, illicit felling, locating the most appropriate sites for establishment, disturbance by domestic animals and other damage to the stands. An important experience from this study is thus that *ex situ* conservation in live collections is an option for conserving forest genetic resources, provided that appropriate techniques and knowledge are available and, above all, systematically applied. The study also showed that long-term management and regeneration is likely to be the main obstacles for successful *ex situ* conservation in living stands.

The programme allowed the formulation and testing of methods to conserve a genetic resource in *ex situ* stands - not so advanced in forestry at the time. It has contributed to finalise some prerequisites for *ex situ* conservation of forest tree species in the field. Among the possible methods of *ex situ* conservation, living stands provide an option for provenances of proven value. The present study supports the findings of Dvorak *et al.* (1996) that collaboration within the international forestry community can result in successful conservation of species and populations. However, sustained participation, interest and support of both local and international agencies are essential for the long-term *ex situ* conservation of forest tree species. The experience gained by national and international partners from the *ex situ* programme will contribute to the development of practical guidelines[2] for *ex situ* conservation of forest genetic resources.

[2]FAO, IPGRI, DFSC and other partners are presently developing practical guidelines for *in situ* and *ex situ* conservation of forest genetic resources. For further information please contact DFSC.

Picture 21. Villagers near Huey Bong, Thailand. *Ex situ* stands are under pressure from shifting cultivation for cash crops like cabbage, tomatoes and chilli.

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Annex 1. Stand in the Study

Stand	Site	Species	Provenance	Seedlot
aus1	Imanawuti	Pinus tecunumanii	Mt. Pine Ridge Ridge	DFSC1118/83
aus2	Imanawuti	Pinus tecunumanii	Mt. Pine Ridge Ridge	DFSC1118/83
aus3	Yapilika	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
aus4	Yapilika	Pinus caribaea var. hondurensis	Guanaja	DFSC1143/83
aus5	Yapilika	Pinus caribaea var. hondurensis	La Mosquitia	DFSC1060/82
aus6	Yapilika	Pinus caribaea var. hondurensis	La Brea Colon	DFSC5517
aus7	Yapilika	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
aus8	Yapilika	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
bra1	Luiz Antonio	Pinus tecunumanii	San Rafael	IRENA002
bra2	Luiz Antonio	Pinus tecunumanii	San Rafael	OFI7/77
bra3	Luiz Antonio	Pinus caribaea var. hondurensis	Santa Clara	DFSC1049/82
bra4	Luiz Antonio	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
bra5	Luiz Antonio	Pinus caribaea var. hondurensis	Culmi	OFI15/76
bra6	Luiz Antonio	Pinus caribaea var. hondurensis	Karawala	OFI48/78
bra7	Luiz Antonio	Pinus tecunumanii	Yucul	OFI2/76
bra8	Luiz Antonio	Pinus caribaea var. hondurensis	Alamicamba	OFI7/79
bra9	Luiz Antonio	Pinus tecunumanii	Yucul	IRENA001
bra10	Angatuba	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
bra11	Angatuba	Pinus caribaea var. hondurensis	Culmi	OFI15/76
bra12	Angatuba	Pinus tecunumanii	Yucul	OFI2/76
bra13	Angatuba	Pinus caribaea var. hondurensis	Alamicamba	OFI7/79
bra14	Angatuba	Pinus tecunumanii	San Rafael	OFI7/77
bra15	Angatuba	Pinus caribaea var. hondurensis	Karawala	OFI48/78
bra16	Itirapina	Pinus caribaea var. hondurensis	Alamicamba	OFI7/79
bra17	Itirapina	Pinus tecunumanii	San Rafael	OFI7/77
bra18	Itirapina	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
bra19	Itirapina	Pinus caribaea var. hondurensis	Culmi	OFI15/76
bra20	Itirapina	Pinus tecunumanii	Yucul	OFI2/76
bra21	Itirapina	Pinus caribaea var. hondurensis	Karawala	OFI48/78
bra22	Itapetininga	Pinus tecunumanii	Pachoc	CAMCORE15
bra23	Itapetininga	Pinus tecunumanii	Napite	CAMCORE37
bra24	Itapetininga	Pinus tecunumanii	Rancho Nuevo	CAMCORE38
bra25	Itapetininga	Pinus tecunumanii	Chanal	CAMCORE31
bra26	Batatais	Pinus caribaea var. hondurensis	Guanaja	DFSC1143/83
bra27	Luiz Antonio	Pinus tecunumanii	Mt. Pine Ridge Ridge	DFSC1118/83
bra28	Bento Quirino	Pinus caribaea var. hondurensis	Culmi	DFSC5515
bra29	Bento Quirino	Pinus tecunumanii	San Rafael	DFSC1022/82
ind1	BK_Gudda	Pinus caribaea var. hondurensis	Culmi	DFSC5526
ind2	BK_Gudda	Pinus caribaea var. hondurensis	Los Limones	DFSC1056/82
ind3	BK_Gudda	Pinus tecunumanii	San Rafael	DFSC1022/82
ind4	BK_Gudda	Pinus caribaea var. hondurensis	Culmi	DFSC1058/82
ind5	BK_Gudda	Pinus caribaea var. hondurensis	Los Limones	DFSC1137/83
ind6	BK_Gudda	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
ind7	Kurandih	Pinus caribaea var. hondurensis	Poptun	OFI12/78
ind8	Kurandih	Pinus caribaea var. hondurensis	Poptun	OFI12/78
ind9	Mangra	Pinus caribaea var. hondurensis	Los Limones	DFSC1137/83
ind10	Deoghati	Pinus tecunumanii	Yucul	OFI2/76
ind13	Janijuda	Pinus oocarpa	Las Crusitas	DFSC1059/82
ind14	Mumbar	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
ind15	Neratoor	Pinus caribaea var. hondurensis	Unknown	xxx004India

Stand	Site	Species	Provenance	Seedlot
ind16	Gorgod	Pinus tecunumanii	San Rafael	DFSC1022/82
ind17	Behalli	Pinus caribaea var. hondurensis	Los Limones	DFSC1056/82
ind19	Madenoor	Pinus tecunumanii	San Rafael	DFSC1022/82
ind20	Sydoor	Pinus caribaea var. hondurensis	Poptun	xxx003India
ind22	Talavata	Pinus caribaea var. hondurensis	Culmi	DFSC5526
ind23	Devala	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
ind24	Marappalam	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
ind25	Silver Cascade	Pinus oocarpa	Bonete	OFI7/74
ind26	Maredumilli	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
ind27	Korapur	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
ind28	Perumalmalai	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI30/71
ind30	Gorgod2	Pinus caribaea var. hondurensis	Los Limones	DFSC1137/83
ind31	BK Gudda	Pinus tecunumanii	Yucul	DFSC1021/82
ivo1	Rapide Grah	Pinus caribaea var. hondurensis	Poptun	OFI29/70
ivo2	Rapide Grah	Pinus tecunumanii	Yucul	OFI2/76
ivo3	Rapide Grah	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
ivo4	Rapide Grah	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
ken1	Katende Hill	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
ken2	Katende Hill	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
ken3	Katende Hill	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
tan1	Kwamarukanga	Pinus caribaea var. hondurensis	Karawala	OFI29/77
tan5	Ruvu	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
tan6	Ruvu	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
tan7	Ruvu	Pinus tecunumanii	Yucul	OFI6/71
tha1	Nong Krating	Pinus oocarpa	Jocotan	PIC3130
tha2	Nong Krating	Pinus caribaea var. hondurensis	La Brea Colon	DFSC5517
tha3	Nong Krating	Pinus caribaea var. hondurensis	La Mosquitia	DFSC1060/82
tha4	Nong Krating	Pinus caribaea var. hondurensis	Culmi	DFSC1058/82
tha5	Nong Krating	Pinus oocarpa	Mal Paso	DFSC5519
tha6	Nong Krating	Pinus caribaea var. hondurensis	Lololo Islands	PIC2047
tha7	Nong Krating	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
tha8	Nong Krating	Pinus caribaea var. hondurensis	Culmi	DFSC1058/82
tha9	Khong Chiam	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
tha10	Huey Bong	Pinus tecunumanii	Yucul	OFI2/76
tha11	Huey Bong	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
tha12	Huey Bong	Pinus oocarpa	Mal Paso	DFSC5519
tha13	Huey Bong	Pinus oocarpa	Dipilto	OFI10/73
tha14	Huey Bong	Pinus oocarpa	Bucaral (El Castaño)	OFI3/71
tha15	Huey Bong	Pinus tecunumanii	Yucul	OFI2/76
tha16	Huey Bong	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
tha17	Huey Bong	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
tha18	Huey Bong	Pinus caribaea var. hondurensis	Los Limones	PIC2277
tha19	Huey Bong	Pinus caribaea var. hondurensis	La Mosquitia	DFSC1060/82
tha2	Nong Krating	Pinus caribaea var. hondurensis	La Brea Colon	DFSC5517
tha21	Huey Bong	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
tha22	Huey Bong	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
tha23	Huey Bong	Pinus caribaea var. hondurensis	Culmi	DFSC1058/82
tha24	Huey Bong	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
tha25	Huey Bong	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
tha26	Huey Bong	Pinus caribaea var. hondurensis	Santa Clara	DFSC1049/82
tha27	Huey Bong	Pinus caribaea var. hondurensis	Los Limones	PIC2277

Stand	Site	Species	Provenance	Seedlot
tha28	Intakin	Pinus tecunumanii	San Rafael	DFSC1022/82
tha29	Intakin	Pinus caribaea var. hondurensis	Alamicamba	DFSC1033/82
tha30	Mae Sanaam	Pinus caribaea var. hondurensis	Guatemala	PIC2028
tha31	Mae Sanaam	Pinus caribaea var. hondurensis	Mixed 15 prov.	PIC2030
tha32	Mae Sanaam	Pinus oocarpa	Mixed	PIC3070
tha33	Mae Sanaam	Pinus oocarpa	Guatemala	PIC3062
tha34	Mae Sanaam	Pinus tecunumanii	Yucul	DFSC1021/82
tha35	Mae Sanaam	Pinus caribaea var. hondurensis	Los Limones	PIC2277
tha36	Mae Sanaam	Pinus tecunumanii	San Rafael	DFSC1022/82
tha43	Huey Bong	Pinus tecunumanii	Yucul	DFSC1021/82
tha45	Mae Sanaam	Pinus caribaea var. hondurensis	Los Limones	DFSC1056/82
tha46	Mae Sanaam	Pinus caribaea var. hondurensis	Los Limones	DFSC1056/82
tha47	Mae Sanaam	Pinus oocarpa	Mal Paso	DFSC5519
tha48	Nongkhu	Pinus tecunumanii	Yucul	OFI2/76
tha49	Huey Bong	Pinus tecunumanii	San Rafael	DFSC1022/82
tha51	Huey Bong	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
tha52	Intakin	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
tha53	Huey Bong	Pinus caribaea var. hondurensis	Poptun	OFI29/70
tha54	Nongkhu	Pinus caribaea var. hondurensis	Alamicamba	OFI6/74
tha55	Nongkhu	Pinus caribaea var. hondurensis	Los Limones	OFI24/75
tha56	Nongkhu	Pinus caribaea var. hondurensis	Poptun	OFI29/70
tha57	Nongkhu	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
tha58	Nong Krating	Pinus oocarpa	Mal Paso	DFSC5519
tha59	Nong Krating	Pinus caribaea var. hondurensis	Poptun	DFSC1134/83
tha61	Intakin	Pinus oocarpa	Unknown	PIC3251
tha62	Intakin	Pinus caribaea var.hondurensis	Unknown	PIC2276
tha63	Intakin	Pinus caribaea var. hondurensis	Culmi	DFSC1058/82
tha64	Intakin	Pinus oocarpa	Mal Paso	DFSC5519
zam1	Chati	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
zam2	Chati	Pinus tecunumanii	Yucul	OFI2/76
zam3	Chati	Pinus oocarpa	Bonete	OFI7/74
zam4	Siamambo	Pinus oocarpa	Bonete	OFI7/74
zam5	Siamambo	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74
zam6	Siamambo	Pinus tecunumanii	Mt. Pine Ridge Ridge	OFI11/74

Annex 2. Calculation of Mean Stand Values

This annex documents the calculation of mean, stand values based on the data measured on individual trees in sample plots.

DG- Diameter corresponding to mean basal area at breast height (1.3 m)

DG for the plot is calculated using the following formula:

where Di is the diameter at breast height of tree No. i in plot (in cm);

$$DG = \left(\sqrt{\frac{\left(\sum_{i=1}^{n} \pi \times \left(Di/2 \right) 2 \right)}{n}} \right) \times 2$$

n is the total number of trees in plot.

Stand mean value is mean of the plot values.

GHA - Basal area per hectare

Basal area in m² per hectare for the plot is calculated using the formula:

where Di is the diameter at breast height of tree no. i (in cm);

$$GHA = \frac{\sum_{i=1}^{n} \pi \times \left(Di/2 \times 100 \right)^2}{n \times sp^2} \times 10000$$

n is the total number of trees in plot; and
sp is the spacing in m;

Stand mean value is mean of the plot values.

HG - Height of tree with diameter corresponding to mean basal area

A linear regression per stand is prepared using the model:

$$Height = \beta + \alpha \times \ln(DBH1)$$

where
DBH1 is the diameter of stem (first stem if more than one stem) in cm;
α is the slope of the regression line;
β is the intercept with y-axis;

α and β are estimated using PROC REG (SAS 1990).

HG for the stand is then calculated using the linear regression estimates (α and β) and stand DG (as previously calculated).

VHA - Volume per hectare

$VHA = 0.5 * HG*((DG/2)^2*\pi);$

Volume per hectare for the plot is calculated from the formula:

Stand mean value is mean of the plot values.

Other assessed traits

For other assessed traits (survival, kraft score, crown percentage, forking, stem form, foxtailing) plot means are simple arithmetic means, which have subsequently been used to calculate stand mean values.

Annex 3 and 4 are very voluminous and are not included in this publication. Data sheets on specific stands or seed sources can be obtained from DFSC.