

*Conservation & Testing of Tropical &
Subtropical Forest Tree Species
by the CAMCORE Cooperative*



Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative

Pinus caribaea

Pinus chiapensis

Pinus greggii

Pinus herrerae

Pinus jaliscana

Pinus maximartinezii

Pinus maximinoi

Pinus oocarpa

Pinus patula

Pinus pringlei

Pinus tecunumanii

Cover photo: Natural stand of *Pinus caribaea* var. *hondurensis* in Honduras being burned and cleared for cattle grazing and agricultural crops. Loss of valuable forest gene pools like these jeopardizes the potential for increasing the productivity of forests planted in the future.

Back Cover: Map showing the locations of CAMCORE seed collections made from 1980 to 2000 in Mexico and Central America (Mesoamerica) and other countries from natural stands of various forest tree species. CAMCORE has collected seeds from approximately 10,000 trees from nearly 400 provenances representing 36 species.

Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative

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PREFACE

Comments by Dr. Bruce J. Zobel

Professor Emeritus, Department of Forestry, North Carolina State University

Foresters have recognized for many years that the genetic base of a few pine species, and particularly, ecotypes of some species, were dangerously eroded and little was being done to preserve them. I first noted this during seed collection trips to Nuevo León, Mexico in 1952 and 1953. Twenty-five years later, Carl Gallegos (formerly with International Paper Company) and I made a trip to Guatemala hosted by Willi Mittak (FAO) and Jesse Perry (Rockefeller Foundation) to assess the conservation status of pine populations in the highland regions of the country. We located one beautiful stand of *Pinus tecunumanii*, but when we returned the following year to collect seeds, the stand had been cut for firewood.

Based on this incident and other observations, Carl Gallegos and I thought action was needed to preserve the genetic base of several species in Central America, and Willi Mittak and Jesse Perry urged us to do something. Carl and I went to international organizations for support of a Central American pine conservation program, and although there was some interest, agencies did not want to commit funds. Since we had strong ties with forest industry, we went to the private sector in early 1980 to promote the concept of an international gene conservation cooperative. Four companies were interested and pledged financial support: Aracruz Florestal (Brazil), Smurfit Cartón de Colombia, International Paper Company (USA) and the Weyerhaeuser Company (USA). We named the Cooperative CAMCORE (Central America and Mexico Coniferous Resources Cooperative), and established it at the College of Forest Resources, North Carolina State University, with the help of Dr. Eric Ellwood, the Dean of the College at that time.

After we saw that CAMCORE had start-up funding, we hired Bill Dvorak as director in 1980. Under his direction CAMCORE has developed beyond our initial fondest hopes. It is now recognized throughout the world that CAMCORE is the leader in collecting, establishing and testing genetic material, much of which would otherwise have been lost.

The four of us who initially started the efforts are very proud of CAMCORE's contribution and pleased that we were able to play a small part in starting a most successful and beneficial organization.

Comments by Mr. Juan Jurado-Blanco

General Manager, Industrial Fiber, Smurfit Cartón de Venezuela and Chairman, CAMCORE Advisory Board

It is remarkable that in the late 1970s, when forest gene conservation was not in vogue or as popular as it is today, that the vision of a few scientists could persuade several companies from the forestry private sector and government agencies in Central America and Mexico to work together to protect forest species growing in the tropics and subtropics. For the past 20 years, CAMCORE members (government and private forest enterprise) on four different continents have established hundreds of field conservation and breeding banks of forest species. This has assured the ex situ conservation of many populations of forest species that unfortunately no longer exist in their native environments today.

For many companies, membership in the CAMCORE Cooperative has been an indispensable and positive part of their forestry program regardless of their level of development. CAMCORE expertise ranges from supplying accurate information about the potential utilization of different pine and hardwood species, to identifying provenances and seed sources most useful for plantation projects, as well as designing applied strategies for advanced generation breeding programs. Recent work merges applied conservation activities with biotechnology tools to better understand species evolution and genetic diversity. The CAMCORE Cooperative annual meetings and short courses have created the opportunity for forest managers and scientists from distant places or competitive arenas to be able to meet with the common objective of supporting the growth of CAMCORE. At the same time it gives members the opportunity to share information and to learn from the experience of others throughout the world.

The progress made in conservation, testing, and breeding by members of the Cooperative over the last 20 years has been extraordinary. The CAMCORE program demonstrates the important role the private sector has in forest gene conservation and especially the value of cooperative research.

Comments by Dr. Fredrick W. Cubbage
Professor and Head, Department of Forestry,
North Carolina State University

CAMCORE has been part of the Department of Forestry at North Carolina State University for twenty years. It has pioneered in practical, on-the-ground gene conservation and tree breeding throughout its history contributing to forest protection and management, as well as forestry research and education. This overview summarizes the substantial mutual benefits received by CAMCORE, the Department of Forestry, and NC State University.

CAMCORE has been supported mostly by membership dues, with some foundation grants, and direct and indirect university support. Members of the CAMCORE staff are employees of NC State, and contribute directly to our research and education programs and reputation. The College of Natural Resources and the Department of Forestry house CAMCORE, contribute modest operating funds to the program, and provide administrative support.

NC State University provides a wealth of technical expertise that contributes to the success of CAMCORE. First, CAMCORE is a progeny of our successful domestic Tree Improvement Program, and was formed with the active collaboration of Bill Dvorak and Bruce Zobel 20 years ago. Scientists in the Tree Improvement Program and CAMCORE cooperate in teaching an extensive forest genetics curricula, and form a portion of the largest cadre of Tree Improvement professors at one institution anywhere in the world. The NC State Forest Biotechnology Group has cooperated closely with CAMCORE in recent years, using modern techniques to study the population genetics of Mexican pines. Used in conjunction with classical tree breeding, such techniques could greatly accelerate genetic improvement. Vegetative propagation research, such as is being performed in the NCSU Rooted Cuttings Co-op, will play a vital role in the rapid multiplication and deployment of improved material.

NCSU and the Department of Forestry provide strength and depth in related expertise such as genetics, statistics, soils, nutrition, and economics. The Department of Forestry has probably the deepest tradition of graduate education in forest genetics and international forestry of any U.S. institution—including many graduates that are now employed by CAMCORE member organizations. Along with the core biological science disciplines, international forestry social science professors provide knowledge about the increasingly complex context within which sustainable forest management is practiced.

NC State University also benefits greatly from its association with CAMCORE. The CAMCORE staff serve as our representatives every time they visit another country, and provide contacts with the best operational tree improvement programs in the world, as well as direct knowledge about world forest products firms. Professors with CAMCORE teach tropical forestry and forest genetics courses, advise graduate students, and contribute to university service and committees. They periodically teach formal tree improvement short courses in various locations, and teach an international two-week course every other year in Raleigh. The annual CAMCORE technical meetings and tours showcase the state of the art in research and practice of tropical forest management.

In short, it is indeed to our mutual benefit and great pleasure to have CAMCORE as part of the Department of Forestry and College of Natural Resources at North Carolina State University. We have enjoyed productive and collegial relationships, pursuing the common goals of conserving and enhancing the world's forests for society's benefit. I hope that the next two decades will be even more productive in our cooperative research, professional education, and operational tree breeding programs, and will personally pledge my sincere support to achieving those integrated conservation goals.

FOREWORD

The CAMCORE Cooperative is dedicated to the conservation, testing, and breeding of forest tree species in the tropics and subtropics. It is represented by North Carolina State University, the forestry private sector on four continents, and national seed banks in Central America and Mexico. CAMCORE was founded in 1980 and is part of the Department of Forestry, North Carolina State University. The growth and development of CAMCORE over the years are the result of the hard work and dedication of hundreds of people who share the vision and dream that by working together, forest species and populations can be conserved and better utilized by humankind. CAMCORE now has 31 members in 15 countries.

CAMCORE works in the following ways. Research seed collections are made in threatened populations of forest species. The selection of species to be conserved and tested is made in collaboration with personnel at national seed banks in donor countries. Seeds are collected and sent to North Carolina State University where they are redistributed to CAMCORE members in various countries. Members establish provenance/progeny tests and field conservation banks, with each member using the same field design. Data from the field trials are collected at 3, 5, and 8 years for pines and at 1 and 3 years for fast-growing broadleaf species like *Gmelina arborea* and *Eucalyptus urophylla*. The data is analyzed by CAMCORE at North Carolina State University. Results of the tests are published and made available to the members as well as to others through scientific journals. Cooperative tree breeding programs have been initiated for a number of forest species. Fifteen hundred trees have now been selected in CAMCORE progeny trials and some grafted into seed orchards to begin the second generation of breeding. Annual visits by CAMCORE staff are made to members to assist them in breeding and gene conservation strategies and in the development of nursery and vegetative propagation programs. CAMCORE has strong links to the forest biotechnology and tree improvement cooperatives at North Carolina State University. The Cooperative offers three stipends for graduate studies at North Carolina State University in areas that help develop our knowledge about tropical and subtropical species. It also has played an important role in the development of short courses in international tree improvement.

Over the years, the CAMCORE program has changed to meet the needs of its membership while still meeting its goals of conservation, testing, and breeding. Initially the Cooperative only worked to conserve and test Mesoamerican pines, but now it also has intensive conservation and breeding programs with several broadleaf species like *Bombacopsis quinata*, *Gmelina arborea*, and

Eucalyptus urophylla. It works not only in Central America and Mexico, but also in Southeast Asia. Formerly we described the cooperative as the "Central America and Mexico and Coniferous Resources Cooperative" (from which arose the acronym CAMCORE). However, to take into account the expansion of our work, we now describe the program as an "International Cooperative for Gene Conservation and Tree Improvement". However, the name remains the same – CAMCORE.

CAMCORE celebrates its 20th year of operation in the year 2000. Since its beginning it has worked with 36 forest species, conducted seed collections in nearly 400 provenances, and sampled almost 10,000 mother trees (see Appendix 3). The research seed collections were (and still are) a mammoth undertaking that could never have been accomplished without the assistance of the governmental forestry organizations and national seed banks in Belize, Guatemala, Honduras, El Salvador, Mexico, Myanmar, Nicaragua and Thailand, and private industry in Indonesia. The establishment, maintenance, and measurement of nearly 1000 genetic tests and ex situ conservation banks since 1980 has been primarily the responsibility of the private sector. These field trials cover approximately 2500 hectares. These accomplishments demonstrate the valuable role that forest industry can play in the conservation and testing of forest species.

The objective of this book is to summarize the results of 20 years of ex situ conservation and testing efforts of 11 pine species sampled by the CAMCORE Cooperative. The chapters contain information on seed collection efforts in natural stands, results from provenance tests, general descriptions of wood quality, reports on seed orchards, and the conservation status for each species. Published and unpublished information from CAMCORE members has been combined with field observations in natural stands and field trials to provide a better understanding about the genetics, silviculture, and breeding potential of each species. Research results of scientists at other institutions have also been included to make the species summaries as complete as possible. A second volume is envisioned in the near future that would summarize results of the CAMCORE broadleaf testing program.

The findings listed in this book supersede results presented in the "1980-92 CAMCORE Review" written by Dvorak and Donahue (1992). More detailed information is now available from the provenance collection sites. For example, many of the latitude and longitude coordinates in this book are based on GPS rather than map values and therefore have been revised slightly. One of the many strengths of CAMCORE is access to data from a large number of well-designed tests to accurately predict

performance of both populations and families. When available, provenance effects for productivity have been calculated using best linear unbiased prediction (BLUP). Explanations about the CAMCORE test design, the BLUP analyses and the method for calculating genetic parameters are presented in Appendix 4. The *in situ* conservation rankings presented in the book (**low risk, vulnerable, endangered, and critically endangered**) are based on our observations in the field and follow The World Conservation Union (IUNC) guidelines on conservation categories presented in the excellent work by Farjon and Page (1998).

Many people in the CAMCORE membership or associated with the program through collaborative projects have contributed information to the species overviews. Information on the authors and contributors is presented at the end of the book.

It is our hope that the book will stimulate further interest in the conservation, propagation, and breeding of these forest species. Specifically, our desire is that the provenance results will be used to guide national seed banks in identifying populations where *in situ* conservation programs are most desperately needed in their respective countries.

The overviews for the 11 species presented in the following chapters are not intended to be complete literature reviews on all aspects of each taxon. Informational gaps still remain for a number of species and there is still much fieldwork to do. However, it is hoped that the activities of the CAMCORE Cooperative over the last 20 years, summarized in this compendium, demonstrate what can be accomplished when private industry, government agencies and universities work together to further our knowledge about tropical and subtropical forest species.

W. S. Dvorak
Director, CAMCORE &
Research Professor of Forestry
North Carolina State University
September 2000

Chapter I

THE EVOLUTIONARY HISTORY OF THE MESOAMERICAN OOCARPAE

W. S. Dvorak, A. P. Jordan, G. R. Hodge, J. L. Romero and W. C. Woodbridge¹

INTRODUCTION

Approximately 40% of the 110 pine species in the world occur in Mexico. Of these, the species that have been the most widely studied and established as exotics are those in the *Oocarpa* subsection (Table I-1). The taxonomy of this subsection has been debated for years but generally encompasses two groups: the Mesoamerican closed-cone pines (*Oocarpa* or *Oocarpa*) which include *Pinus greggii*, *P. jaliscana*, *P. oocarpa*, *P. patula*, *P. pringlei* and *P. tecunumanii*, and the California closed-cone pines (*Patula* or *Attenuatae*) which include *Pinus attenuata*, *P. muricata*, and *P. radiata* (Little and Critchfield 1969, Perry 1991). Recent taxonomic arrangements based on both morphologic

and molecular marker assessments (Farjon and Styles 1997, Price et al. 1998) have moved several species (*P. herrerae*, *P. lawsonii*, and *P. teocote*) from Perry's (1991) *Teocote* subsection into a *Teocote* group within the *Oocarpa* subsection (Table I-1). Furthermore, recent molecular marker research indicates that *P. caribaea* var. *hondurensis* is genetically intermediate between the *Oocarpa* and *Australes* subsections (Grattapaglia et al. 1993, Furman et al. 1997). The placement of Caribbean pine closer to the *Oocarpa* species than in previous taxonomies is supported by numerous field observations of naturally occurring hybrids between *P. caribaea* and *P. oocarpa* in Central



Photo I-1. Mountain ranges like the Sierra Madre del Sur in Mexico served as the migration route for plant species between the western and eastern parts of the country.

¹ This chapter is taken mostly from Dvorak et al. 2000.

America (Williams 1955, Denevan 1961, Barrett and Golfari 1962, Johnson et al. 1973, Styles et al. 1982, Squillace and Perry 1992) and by successful artificial crosses between the two species in Australia (Nikles 1989, 2000). Ancestry and genetic relatedness of species are important to foresters because they help in developing comprehensive gene conservation strategies, and are useful in determining what interspecific combinations of genetic material are likely to be successful. Any study of the evolutionary history of the *Oocarpace* also should consider species from Little and Critchfield's *Australes* subsection and Perry's *Teocote* subsection.

CAMCORE has made seed collections for all the above mentioned species (except *P. attenuata*) and embarked upon such an evolutionary study in the late 1990s. The objective of the work was to improve the understanding of historic developments of the Mesoamerican *Oocarpace* and

to assess the group's basic taxonomy (Dvorak et al. 2000). The phylogeny work was an extension of that initiated by Furman et al. (1996, 1997) and utilized Random Amplified Polymorphic DNA (RAPD) marker technology which has proven to be both a stable and powerful tool for delineating differences among closely related taxa (Dvorak et al. 2000).

GEOLOGY AND CLIMATE

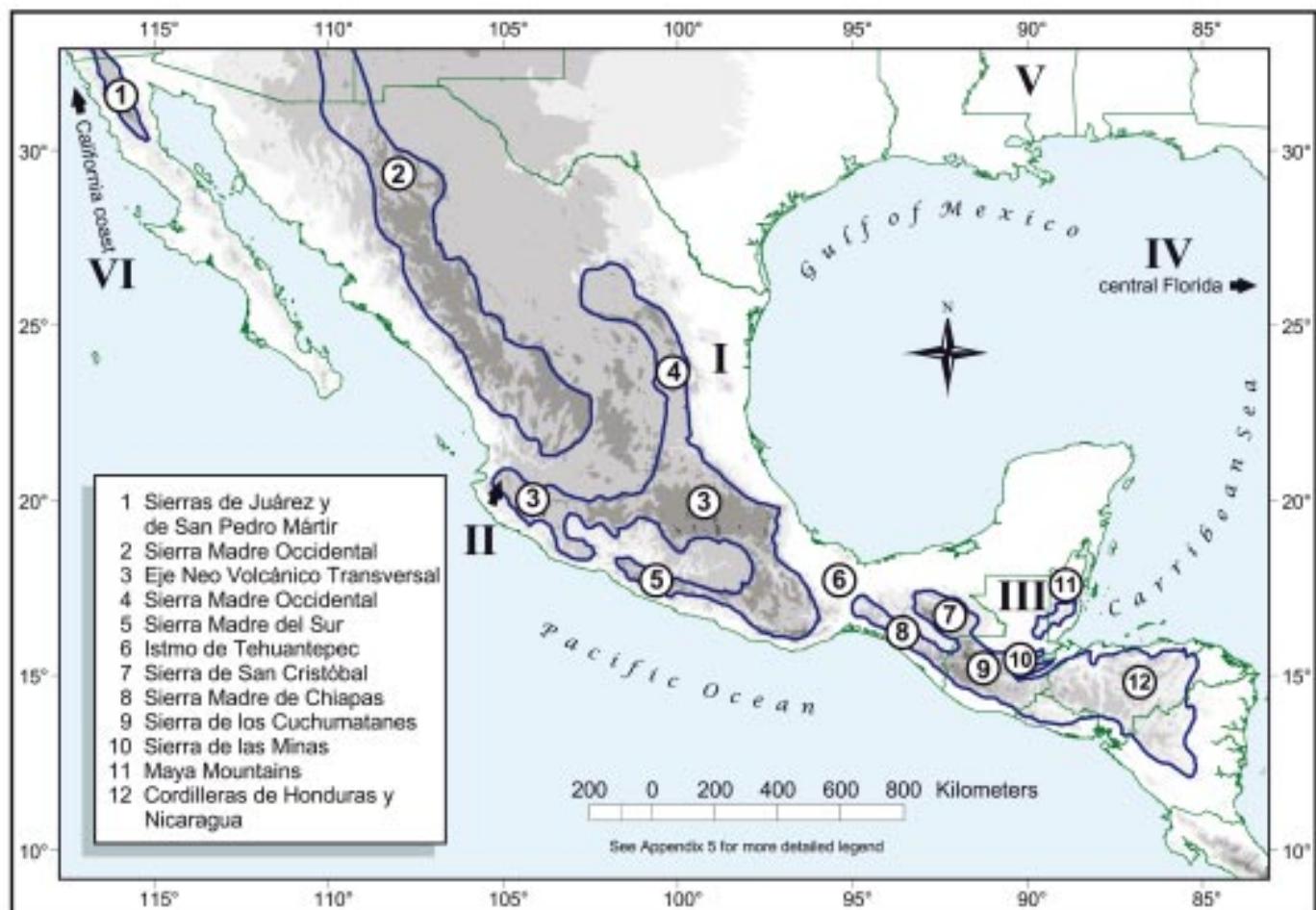
A discussion of the evolutionary history of the Mesoamerican *Oocarpace* should be viewed within the context of the geological and climatic processes that influenced development, migration, and distribution of species since the Cretaceous and Tertiary periods. For details on theories of pine evolution and the paleogeology of Mexico and Central America, readers are referred to the works by Mirov (1967), Eguiluz-Piedra (1985), Millar (1993), and Farjon (1996). Pines, like other plant species in the

Table I-1. Species in the *Oocarpace* and *Australes* subsections as suggested by Little and Critchfield (1969) and amendments to the *Oocarpace* by (Perry 1991), Farjon and Styles (1997) and Price et al. (1998).

Little and Critchfield 1969		Perry 1991	Farjon and Styles 1997	Price et al. 1998
AUSTRALES	OOCARPAE	OOCARPA	OOCARPAE	OOCARPAE
<i>P. palustris</i>	<i>P. oocarpa</i>	<i>P. oocarpa</i> vars. <i>oocarpa</i> * <i>trifoliata</i> <i>microphylla</i> <i>ochoterenae</i>	<i>P. oocarpa</i> vars. <i>oocarpa</i> <i>trifoliata</i>	<i>P. oocarpa</i> vars. <i>oocarpa</i> <i>trifoliata</i>
<i>P. taeda</i>				
<i>P. echinata</i>				
<i>P. elliotii</i> vars. <i>elliotii</i> <i>densa</i>	<i>P. patula</i>		<i>P. patula</i> vars. <i>patula</i> <i>longipedunculata</i>	<i>P. patula</i> vars. <i>patula</i> <i>longipedunculata</i>
<i>P. glabra</i>				
<i>P. rigida</i>				
<i>P. serotina</i>	<i>P. pringlei</i>	<i>P. pringlei</i> *	<i>P. pringlei</i> (+)	<i>P. pringlei</i>
<i>P. pungens</i>		<i>P. tecunumanii</i> *	<i>P. tecunumanii</i>	<i>P. tecunumanii</i>
<i>P. caribaea</i> vars. <i>hondurensis</i> <i>bahamensis</i> <i>caribaea</i>		<i>P. jaliscana</i> *	<i>P. jaliscana</i>	<i>P. jaliscana</i>
<i>P. occidentalis</i>			<i>P. praetermissa</i>	<i>P. praetermissa</i>
<i>P. cubensis</i>			<i>P. durangensis</i> (+)	<i>P. greggii</i>
				Teocote group
			<i>P. teocote</i> * (+) <i>P. lawsonii</i> (+)	<i>P. teocote</i> <i>P. lawsonii</i> <i>P. herrerae</i>
		PATULA	ATTENUATAE	ATTENUATAE
	<i>P. radiata</i>	<i>P. radiata</i> vars. <i>radiata</i> * <i>binata</i> *	<i>P. radiata</i> vars. <i>radiata</i> <i>binata</i>	<i>P. radiata</i> vars. <i>radiata</i> <i>binata</i> <i>cedrosensis</i>
	<i>P. attenuata</i>	<i>P. attenuata</i> *	<i>P. attenuata</i>	<i>P. attenuata</i>
	<i>P. muricata</i>	<i>P. muricata</i> *	<i>P. muricata</i>	<i>P. muricata</i>
		<i>P. greggii</i> *	<i>P. greggii</i>	
		<i>P. patula</i> vars. <i>patula</i> * <i>longipedunculata</i>		
			<i>P. coulteri</i>	

Species marked with * are those used in the study. Species marked with (+) have been provisionally included in the subsection by the authors.

Figure I-1. Location of major landforms in Mexico and Central America (amended from Eguiluz-Piedra 1985) and the general location of the six clades generated from the RAPD analysis (after Dvorak et al. 2000).



region, migrated along the major mountain chains in Mexico and Central America including: the Sierra Madre Occidental, the Eje Neo Volcánico Transversal, the Sierra Madre de Sur, the Sierra Madre de Chiapas, the Sierra de los Cuchumatanes, the Sierra de las Minas and the Cordilleras de Honduras and Nicaragua (Figure I-1). These mountain chains arose at different geologic periods and have been completely rearranged by volcanism or uplifting at various times during their development. Depending on the nature of geologic processes and the severity of climate changes, pine communities along these mountain ranges either thrived or declined. Speciation and migration of most pine species in Mexico were probably driven by the drier climates that developed during periods of mountain building (Axelrod 1980). Low lying areas, such as the Isthmus of Tehuantepec, the Mexican Yucatan and present-day southern Florida were underwater for millions of years (Schuchert 1935) and may have hindered or served as barriers to pine migration. The exact timing of such geologic events is speculative, but their effect on pine evolution and migration must have been far reaching. The pine forests of present-day Mexico are more like those in the western rather than in the eastern United States (US). The forests of Chiapas, east of the Isthmus of Tehuantepec,

are more similar to those in the rest of Central America than to those in northern and western Mexico. There are approximately 45 pine species endemic to Mexico and then their number decreases south and eastward into Nicaragua, which has only four pine species. Of the many pine taxa in the region, *P. oocarpa* has the largest natural distribution, stretching 3000 km from northern Mexico to Nicaragua, and is presumably the most ancient of the species in the *Oocarpace* subsection.

DEVELOPMENT OF THE PHYLOGENETIC TREE

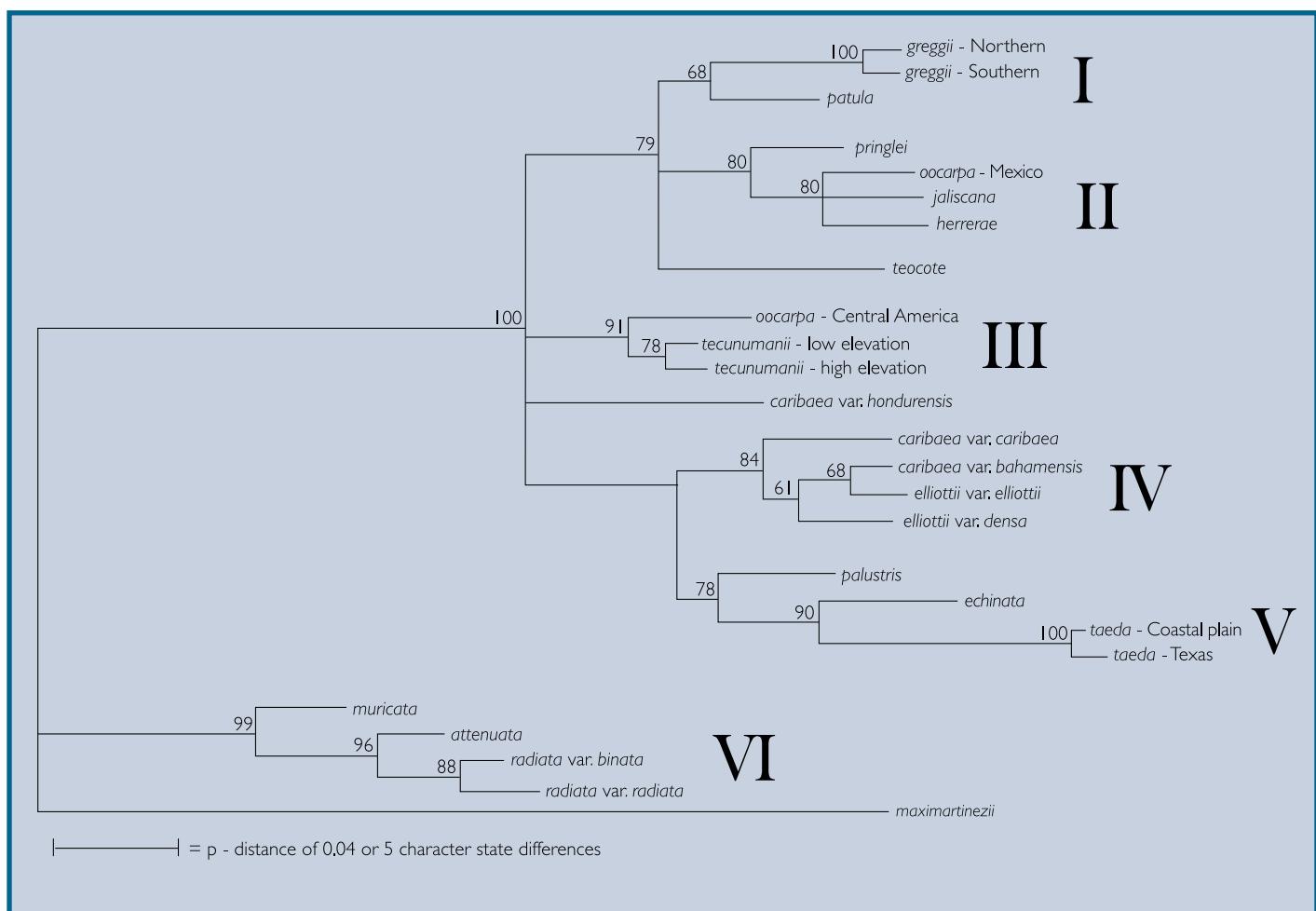
CAMCORE used RAPD markers to assess the relatedness of various pine species. Ten taxa from the *Oocarpace*, eight from the *Australes* and two from the *Teocote* subsection were included in the phylogeny study (Table I-1). *Pinus oocarpa*, *P. greggii*, *P. tecunumanii* and *P. taeda* were subdivided by geographic region to take into account morphological differences observed in natural stands and variation exhibited in provenance trials. Seed samples of *P. oocarpa* from northern and western Mexico were analyzed separately from those collected in Central America. *Pinus greggii* samples from northern Mexico, now referred to as *P. greggii* var. *greggii*, were kept separate from

those in central Mexico, now referred to as *P. greggii* var. *australis* (Donahue and López-Upton 1999) (Chapter 4, *Pinus greggii*). *Pinus taeda* collections from the US coastal plain east of the Mississippi River were separated from collections originating in Texas. *Pinus tecunumanii* populations representing high elevation sources above 1500 m elevation were kept separate from those originating below 1500 m elevation in Central America.

A DNA pooling strategy was used to determine the presence or absence of RAPD fragments. The bulked species samples were constructed from a variety of provenances and relied on collections made by CAMCORE, as well as a number of other organizations (see Dvorak et al. 2000 for a complete description of provenances included in the species bulks along with contributing organizations). Conditions for PCR amplifications were based on the RAPD protocol of

Williams et al. (1990) and are described fully in the Dvorak et al. (2000) paper. A matrix of pairwise distances (*p*-distances) generated from the character data was constructed and subjected to neighbor-joining (NJ) analysis (Saitou and Nei 1987) using the MEGA (Molecular Evolutionary Genetic Analysis) software (Kumar et al. 1993). The *p*-distance represents the percentage of character state differences (CSD) between pairs of taxa. Missing data was handled by pairwise deletion. Branch topology confidence was assessed using bootstrap resampling (Felsenstein 1985). A bootstrap confidence level (BCL) was determined from 10,000 bootstrap trees by MEGA. Branch points with a BCL less than 50% were not retained on the phylogeny tree. From the 110 decamer primers tested, 76 yielded intense, scorable RAPD bands. A total of 127 markers were assessed for band presence or absence in the pooled DNA samples.

Figure 1-2. Phylogenetic tree showing the relationships among 24 pine taxa rooted with *Pinus maximartinezii* as the outgroup. The tree was constructed by neighbor-joining analysis of a *p*-distance matrix (MEGA v 1.10). Bootstrap confidence levels (BCL) in % are shown for internal branches. Groups with a BCL less than 50% were not retained on the consensus map. Major clades are identified by Roman numerals. Only horizontal (not vertical) distances are indicative of genetic distances (after Dvorak et al. 2000). The northern *P. greggii* taxon is var. *greggii* and the southern group is var. *australis*.



RESULTS

The NJ analysis of the RAPD marker data identified two distinct phylogenetic groups: a small cluster into which the Californian closed-cone pines grouped and a larger cluster that contained the Mesoamerican *Oocarpace* and the *Australes* (Figure 1-2). The mean p-distance (genetic) between the species of these groups was 0.418.

Five distinct clades formed within the large cluster; three for the Mesoamerican and two for the US/Caribbean group (Figure 1-2). Clade structure approximately reflects the current geographic positions of the taxa. For the Mesoamerican subgroup, the clades are: (I) the Sierra Madre Oriental (*P. patula*, *P. greggii*), (II) the Sierra Madre Occidental (*P. oocarpa*, *P. jaliscana*, *P. herrerae* with *P. pringlei* as an outlier), and (III) Central America (*P. tecunumanii*, *P. oocarpa*, native to Guatemala and Honduras). The *Australes* clades are: (IV) Florida/Caribbean (*P. elliottii* vars. *elliottii* and *densa*, *P. caribaea* vars. *bahamensis* and *caribaea*) and (V) southern US coastal plain (*P. palustris*, *P. echinata*, *P. taeda*). *Pinus teocote* is represented as a branch between clades I and II, as is *P. caribaea* var. *hondurensis* between clades III and IV. The mean p-distance between species of the Mesoamerican group and the *Australes* was 0.247.

THE CALIFORNIAN CLOSED-CONE PINES

The Californian closed-cone cluster separates from the other major group (which contains all of the remaining taxa considered in the study) with a BCL of 100%. *Pinus radiata* var. *binata* and *P. attenuata* were equidistant from *P. muricata* (p-distance = 0.092, CSD = 12). *Pinus radiata* var. *radiata* and *P. radiata* var. *binata* (Cedros Island) were most closely aligned within the Californian closed-cone group (p-distance = 0.40, CSD = 5).

THE MESOAMERICAN CLOSED-CONE PINES

Pinus oocarpa from northern and western Mexico grouped in a different clade than Central American *P. oocarpa* (Figure 1-2). The genetic distance between the *P. oocarpa* bulks (p-distance = 0.135) was as great as that found between well-established species, such as *P. echinata* and *P. elliottii* var. *elliottii* of the southern US.

Pinus oocarpa from western Mexico was found to be very closely related to *P. herrerae* (p-distance = 0.056) and to *P. jaliscana* (p-distance = 0.071) and was more aligned with *P. patula* (p-distance = 0.135) than with *P. greggii* (p-distance = 0.168) (Figure 1-2). *Pinus patula* was closely related to *P. greggii* and was equidistant from the northern and southern populations of the species (p-distance = 0.95)

(Figure 1-2). The two varieties of *P. greggii* were associated with a p-distance = 0.024, which is the same level of differentiation that was observed between the two subpopulations of *P. tecunumanii* and much smaller than that observed between the two *P. oocarpa* bulks.

Pinus pringlei appears to be nearly the same distance from *P. oocarpa* from western Mexico (p-distance = 0.096), *P. jaliscana* (p-distance = 0.089), *P. herrerae* (p-distance = 0.073) and *P. patula* (p-distance = 0.088). *Pinus oocarpa* from Central America was closely aligned to high and low elevation populations of *P. tecunumanii* (p-distances of 0.057 and 0.072, respectively).

PINES IN THE TEOCOTE SUBSECTION

Pinus teocote did not show a particularly close relationship with any other species in the study. The distance from *P. teocote* to *P. herrerae* was smaller than to any other taxa (p-distance = 0.138). However, *P. herrerae* appears to be in closer genetic proximity to *P. jaliscana* and to *P. oocarpa* from western Mexico than to *P. teocote*. The positioning of *P. herrerae* and *P. teocote* indicates that these two species may not be as closely related to one another as to some other members of the Mesoamerican *Oocarpace*.

THE AUSTRALES PINES

An ancestral form of *P. caribaea* var. *caribaea* appears to be the founder species for the Florida/Caribbean taxa in clade IV (Figure 1-2). *Pinus caribaea* var. *caribaea* was more closely related to var. *bahamensis* (p-distance = 0.065) and *P. elliottii* var. *elliottii* (p-distance = 0.088) than it was to *P. elliottii* var. *densa* (p-distance = 0.096). Similarly, *P. elliottii* var. *elliottii* was more closely aligned to *P. caribaea* var. *bahamensis* (p-distance = 0.032) than to *P. elliottii* var. *densa* (p-distance = 0.052). *Pinus echinata* and *P. palustris* both exhibited a closer relationship with *P. elliottii* var. *densa* (p-distance approximately 0.113) than with *P. elliottii* var. *elliottii* (p-distance approximately 0.136). As mentioned previously, *P. caribaea* var. *hondurensis* was positioned on a branch of the NJ tree that contained no other species. This branch occurs at a position between the Mesoamerican *Oocarpace* and *Australes* clades. *Pinus caribaea* var. *hondurensis* was more closely related to var. *caribaea* (p-distance = 0.139) than to any taxa in clades IV or V but was distinctly separate from it.

An ancestral *P. palustris* type appears to be the progenitor of other species in clade V, with *P. echinata* and subsequently *P. taeda* evolving from it. The two *P. taeda* samples from east and west of the Mississippi grouped closely together; as was expected (p-distance = 0.016).

DISCUSSION

GENETICS WITHIN THE MESOAMERICAN OOCARPAE

The finding that *P. oocarpa* from northern and western Mexico is notably different from its Central American counterpart raises important evolutionary questions. Eguiluz-Piedra (1985) suggests that ancestral *P. oocarpa* evolved in eastern Mexico and most likely migrated south through Chiapas into Central America. Present-day *P. oocarpa* from eastern Mexico and Central America are very similar morphologically (J. Pérez de la Rosa, personal communication), suggesting a common lineage. The migration route from eastern Mexico into Central America also has been noted for a number of angiosperms and gymnosperms (Miranda and Sharp 1950).

We propose that the differences between *P. oocarpa* from the eastern Mexican Sierras and Central America and the western Mexican Sierras observed in the CAMCORE RAPD study reflect either different migration times for the same species or represent genetically different species that are morphologically quite similar (Photos 1-2a and b). The data supports the conclusion that the western *P. oocarpa* originated from *P. pringlei*, which in turn evolved from

ancestral *P. oocarpa* from the eastern Sierras of Mexico. Regardless of the evolutionary path, *P. oocarpa* from western Mexico, *P. herrerae* and *P. jaliscana* appear to be younger than *P. oocarpa* from eastern Mexico and Central America. This scenario offers an explanation as to why the more ancient line of *P. oocarpa* from Central America in the study had a closer genetic relationship to the Californian closed-cone pines than did the race from western Mexico.

The relationships observed among taxa in clade II are complex because they include species from two recognized subsections, *Oocarpace* and *Teocote* (*sensu* Perry 1991). Critchfield (1967), after obtaining sound seeds from crosses of *P. patula* × *P. teocote* and *P. patula* × *P. lawsonii* at the Institute of Forest Genetics (Placerville, CA), was the first researcher to propose a genetic relationship between the Mesoamerican *Oocarpace* and the *Teocote* subsections. However, the validity of these crosses was never confirmed through chemical or molecular analyses (J. Duffield, personal communication). CAMCORE's field observations in Mexico suggest that *P. patula* hybridizes with both *P. teocote* and *P. herrerae* in sympatric zones (Photo 1-3). Krupkin et al. (1996) also demonstrated a close relationship



Photo 1-2a and b. *Pinus oocarpa* from Central America (left) appears to be the progenitor of *P. oocarpa* from western Mexico (right). The line of descent may have passed through *P. pringlei*.



Photo 1-3. Needles of a group of trees morphologically intermediate between *Pinus teocote* and *P. patula* var. *longipedunculata*. These trees are located several km past the town of Latuvi, Oaxaca, Mexico.

between *P. teocote* and the Mesoamerican *P. patula* and *P. oocarpa* taxa in chloroplast DNA evaluations.

Furthermore, *P. pringlei* (*Oocarpace*) and *P. lawsonii* (*Teocote*) share many morphologic similarities in sympatric areas in Oaxaca and Michoacán, Mexico (Dvorak et al. unpublished data). Perry (1991) comments on the difficulty in distinguishing the two taxa on dry sites in southern Mexico.

Pinus jaliscana exhibits morphologic traits of both *P. oocarpa* and *P. herrerae*, sharing bark characteristics, needle number and internal needle morphology with *P. oocarpa* and tree form, needle architecture, cone size and shape, and microsite requirements with *P. herrerae*. The present-day geographic ranges of *P. herrerae* and *P. jaliscana* come within 500 m of each other at Monte Grande, Jalisco (Chapter 6, *P. jaliscana*).

CAMCORE's marker work suggests that *P. herrerae*, *P. jaliscana* and *P. oocarpa* from western Mexico are all closely related and were derived from the same ancestral species. *Pinus herrerae* (and probably *P. lawsonii*) belong to the same taxonomic group as the *Oocarpace* species, as was first intimated by van der Burgh (1973) and supported by Farjon and Styles (1997) and Price et al. (1998). Although the results conclusively show that *P. herrerae*, *P. pringlei*, *P. jaliscana* and *P. oocarpa* are closely related, the data neither support nor contradict the suggestion that *P. teocote* should be included in the *Oocarpace* subsection. A more diverse sample of *P. teocote* than was used in this

study presumably would move this species closer to both *P. oocarpa* from western Mexico and *P. herrerae* rather than farther away (our samples came only from Veracruz in eastern Mexico). It also should be noted that the number of missing data points for *P. teocote* ($n = 10$) was higher than for any other taxa, which could obscure genetic relationships.

Pinus tecunumanii in Chiapas and Central America appears to have evolved recently from *P. oocarpa* (Photo 1-4). Its divergence from *P. oocarpa* is more pronounced at low elevation sites in Honduras and Nicaragua than in the mountains of Guatemala and Chiapas. Although this greater separation at lower latitudes is often considered to be a consequence of increased hybridization between *P. tecunumanii* and *P. caribaea* var. *hondurensis*, RAPD analyses do not seem to support this premise. The genetic relationship between *P. tecunumanii* from high altitudes and *P. oocarpa* from eastern Mexico and Central America is so close that RAPD markers have failed to distinguish them (Furman et al. 1997). Trees intermediate between *P. oocarpa* and *P. tecunumanii* often are seen together in the field, and are nearly indistinguishable on dry sites in the southern areas of these species' ranges.

These results are in agreement with the taxonomic classification of Price et al. (1998), in which the Mesoamerican *Oocarpace* includes both closed and open cone species.

SEPARATION OF AUSTRALES AND THE MESOAMERICAN OOCARPAE

Our findings indicate that Mesoamerican *Oocarpeae* and *Australes* subsections share a common ancestral origin. We propose that an ancestral "oocarpa" species was not only the progenitor of *P. oocarpa* in eastern Mexico and Central America, as well as the remainder of the Mesoamerican *Oocarpeae*, but that this species also functioned as the progenitor to many of the *Australes* species. The status of this ancestral species as the common progenitor for both groups readily explains why *P. oocarpa* naturally hybridizes with species in both the *Oocarpeae* and *Australes* (Squillace and Perry 1992).

The ancestral relatedness of the Mesoamerican *Oocarpeae* and *Australes* found in this study is supported further by artificial hybridizations between more distantly related species such as *P. tecunumanii* × *P. taeda* and *P. greggii* × *P. taeda* (Photo 1-5) (CAMCORE Annual Report 1998), which have been reported to be successful when conducted in tropical and subtropical environments in Brazil and South Africa. Verification of hybridization in the field and laboratory would support more strongly the common heritage theory between *Australes* and *Oocarpeae*. Currently, field studies are too young to make assessments. Although Mesoamerican *Oocarpeae* and *Australes* may have a common origin, the divergence of these subsections could be from a common ancestral species or one group could have served as a progenitor to the other.

DIVERGENCE TIMES

Using the data obtained from the RAPD study, an evolutionary scenario is proposed to explain the results. In developing the evolutionary scenario, it is assumed that genetic distances (Figure 1-2) are directly related to time since divergence. Obviously, such an assumption is not always appropriate, particularly when comparing migration patterns across landmasses subject to differing geological processes. We determined general time sequences for evolutionary events using "molecular clock" information generated from fossil assessments presented by

Krupkin et al. (1996). The fossil-based clock suggests that Californian and Mesoamerican clades diverged approximately 22 million years ago and *Australes* separated approximately 10 to 12 million years ago. Although these divergence times may not be completely accurate, they are useful reference points and demonstrate that *Australes* originated more recently than both the Californian taxa and many of the Mesoamerican *Oocarpeae*.

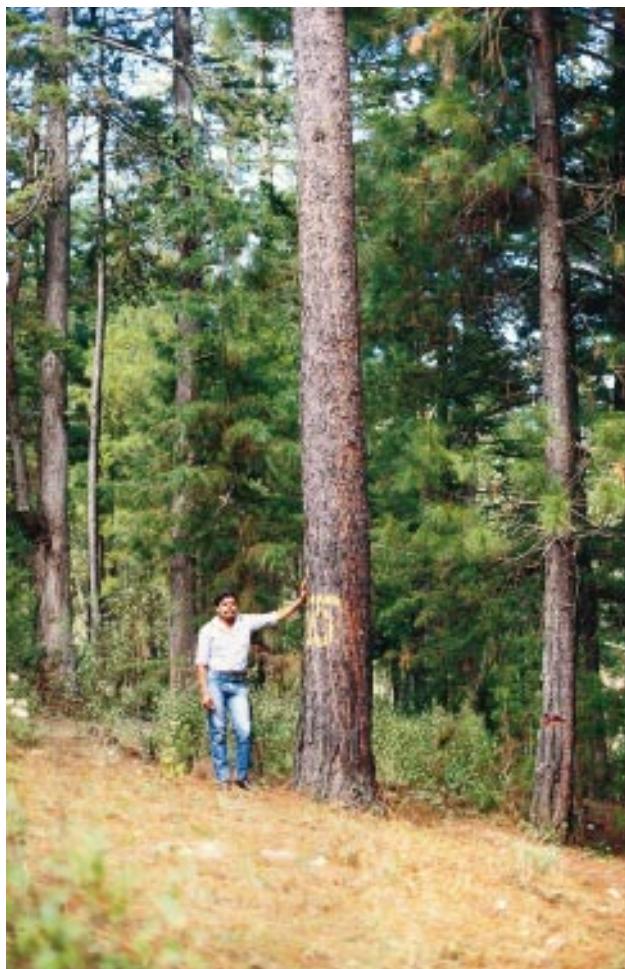


Photo 1-4. *Pinus tecunumanii* is a close genetic descendant of *P. oocarpa* from Central America. CAMCORE technician Elmer Gutiérrez marks a selected *P. tecunumanii* tree at Cabricán, Guatemala.

EVOLUTIONARY SCENARIO

The California closed-cone pines evolved separately but in the same general region as ancestors of the Mesoamerican *Oocarpeae* in northern Mexico or the southwestern US. As the Californian cluster moved north, elements of the Mesoamerican *Oocarpeae* subsection presumably moved east, south and southeast into the central and eastern US and Mexico. *Pinus oocarpa* from eastern Mexico and Central America (EM and CA) and a cohesive *P. greggii*/*P. patula* group diverged first from the cluster and then radiated south into the Sierra Madre Oriental. *Pinus teocote* also migrated into the Sierra Madre Oriental with

Mesoamerican *Oocarpeae*, but its origin is speculative. The inception of *P. teocote* may have been in the southern Rocky Mountains along with ancestral *Contortae* and *Ponderosae*, some elements of which are presumed to be much older than *Oocarpeae* (see Krupkin et al. 1996). *Pinus oocarpa* continued its migration south into Central America, occupying mid-elevation areas that were marginally dry part of the year. The *P. patula*/*P. greggii* cluster initially occupied the more humid highlands of eastern Mexico but eventually diverged as drier conditions gained prevalence in the Sierra Madre Oriental valleys. Two



Photo 1-5. Eric Kietzka, Mondi Forests, stands next to a *Pinus taeda* × *P. tecunumanii* hybrid grown in South Africa. Genetic distances between the two species are great so hybrid crosses presumably will produce, on average, only a few sound seeds.

possibilities exist with respect to the evolution of *P. greggii*. One scenario suggests that the ancestral *P. greggii* cluster diverged and migrated as a group from a *P. patula* type but the *P. greggii* range was subsequently partitioned into two subpopulations by geologic or climatic events. An alternate scenario suggests that the two subgroups diverged independently and migrated to their present-day position. Although populations of *P. greggii* var. *greggii* no longer occur sympatrically with *P. patula*, some populations of *P. greggii* var. *australis* do (López-Upton and Donahue 1995) (Photo 1-6). *Pinus patula* var. *patula* migration continued south through Oaxaca and then much later moved eastward in the form of *P. patula* var. *longipedunculata* along the Sierra Madre de Sur into Guerrero (CAMCORE, unpublished data).

Pinus oocarpa (EM and CA) from the Sierra Madre Oriental migrated into central Mexico and later the Sierra Madre Occidental after traveling across the Eje Neo Volcánico Transversal, the mountain range that was the highway for movement of many plant communities between the Atlantic and Pacific Oceans (Eguiluz-Piedra 1985). The entrance of *P. oocarpa* into the western part of the country presumably occurred during a time when volcanism had subsided and when more arid climates drove speciation, which was likely millions of years after the taxa migrated through the eastern Sierras (Figure 1-1).

Pinus pringlei originated from the more ancient eastern elements of *P. oocarpa* in association with *P. patula* and *P. teocote*, occupying relatively dry, eroded sites in southwestern Mexico. *Pinus pringlei* exhibits a modified grass stage, a refinement of the adaptability to dry conditions exhibited by *P. teocote*, which, after planting, develops slowly until the root system is established (Dvorak and Donahue 1992). *Pinus herrerae*, *P. oocarpa* (western Mexico) and *P. jaliscana* share close evolutionary ties but the exact relationship and order of divergence remain unclear. *Pinus herrerae* appears to be of direct genetic descent from *P. pringlei*, although the species are morphologically distinct (CAMCORE, unpublished data). The western Mexico *P. oocarpa* evolved directly from eastern elements of *P. oocarpa* or *P. pringlei* and migrated along the dry western coast of Mexico as far north as Chihuahua. *Pinus jaliscana* is a derivative of *P. oocarpa* and *P. herrerae*. It now occurs in areas too low in elevation for *P. herrerae* but maintains its need for moisture and often is found along streambeds in Jalisco, Mexico. *Pinus oocarpa* is sympatric with *P. jaliscana* but tends to occupy the drier slopes (Dvorak et al. 1998).

As *Oocarpace* species evolved and migrated within Mexico, the ancestral *P. oocarpa* cluster migrated east and a tropical element subsequently separated from it. This tropical element migrated south along the western Gulf Coast of



Photo 1-6. *Pinus patula* and *P. greggii* var. *australis* occur together at several locations in central Mexico. This is a scene from Carrizal Chico, Veracruz, Mexico.

Mexico, across the southern Yucatan into Central America and eventually evolved into the present-day *P. caribaea* var. *hondurensis*. The genetic constitution of *P. caribaea* var. *hondurensis* contains elements from both the *Australes* and *Oocarpace* subsections. We propose that ancestral *P. caribaea* separated prior to the divergence of *Australes*, based on its distinctness from clade V, and then migrated into Central America from the West Gulf of Mexico (rather than from the east through Florida and the Caribbean). The geographic distribution of *P. caribaea* var. *hondurensis* is sufficiently large to presume an ancient (i.e., western) rather than a geologically recent (i.e., eastern) origin (Mirov 1967). *Pinus caribaea* var. *hondurensis* inhabited lower, coastal altitudes than *P. oocarpa* and *P. tecunumanii* and introgressed with them occasionally during periods of extreme drought (expansion of the *oocarpa* range) or abundant moisture (expansion of the var. *hondurensis* or *P. tecunumanii* range). *Pinus caribaea* var. *hondurensis* appears to have arrived in Central America before the separation of *P. tecunumanii* from *P. oocarpa*. Had *P. caribaea* arrived from the west after the divergence of *P. tecunumanii*, one would expect it to be more closely related to high altitude subpopulations in Chiapas and Guatemala (where it first made contact), than to the low elevation subpopulations in Honduras and Nicaragua. We presume var. *hondurensis* and *P. tecunumanii* evolved together in Middle America. Clusters of hybrids and introgressed *P. tecunumanii* and *P. caribaea* var. *hondurensis* trees can be found at several locations in

Central America, most notably in the Maya Mountains at Mountain Pine Ridge, Belize (Figure 1-1).

Other ancestral elements of northern Mexico/southwestern US *Oocarpace* migrated east along the northern Gulf Coast of the US to form precursors to *P. palustris*, *P. echinata* and *P. taeda*. Undoubtedly, during this 5- to 10-million-year period of evolution *Oocarpa/Australes* grew in association with elements of *Contortae*. As the continental *Australes* cluster formed and moved east, *P. palustris* (or a *P. palustris*-like species) was likely the first to diverge. *Pinus oocarpa* chloroplast genotypes have been found in both *P. palustris* and *P. echinata* (Nelson et al. 1994), which supports the supposition of ancient associations and migration from the west (Photo 1-7).

As speciation was occurring in the southern US to form species in clade V (Figure 1-2), an early form similar to *P. caribaea* var. *hondurensis* made its way from Central America to the Caribbean and eventually to peninsular Florida. The species that diverged from ancestral *P. caribaea* var. *hondurensis*, a prototype of *P. caribaea* var. *caribaea*, was the precursor to the species in clade IV (Figures 1-2). Migrations of ancestral *P. caribaea* to and from Cuba and the Bahamas were likely slow and infrequent. The existence of an island and coral reef land bridge connecting Central America with Cuba has been suggested by Schuchert (1935), with seed dispersal via migratory birds and tropical storms proposed (Nikles 1966, Mirov 1967, Eguiluz-Piedra 1985) as a means of gene movement.

Pinus caribaea var. *caribaea* eventually migrated to the central peninsula of Florida by route of the Bahamas, Cuba or Hispaniola. Because southern Florida was submerged until the recent geologic past (Pleistocene) (Schuchert

1935, 1955), early pine establishment of this area was not possible. *Pinus elliottii* var. *elliottii* evolved from *P. caribaea* var. *caribaea* and migrated north into the US coastal plain and then south after the seas retreated in southern Florida.

IMPLICATIONS

The results found in this study have broad implications for gene conservation. Progenitor species may contain genes that are useful and important in maintaining genetic base populations of currently endangered or intensively bred descendant species. Can genes from Mesoamerican *Oocarpaceae* be useful in advanced-generation breeding populations of *P. taeda*? For example, in seedling screening studies, *P. oocarpa*, *P. pringlei*, *P. jaliscana* and low elevation *P. tecunumanii* (Clades II and III) are much more resistant to *Fusarium subglutinans* f. sp. *pini* (pitch canker) than are *Australes* species in Clades IV and V (Hodge and Dvorak 1999).

The genetic distances between species found in this study and presented in Dvorak et al. (2000) can be used to explain why seed set is good for some hybrid crosses and low for others. Furthermore, the results can be used to predict which hybrid crosses should be successful. Based on CAMCORE RAPD results, crosses between *P. palustris* and *P. tecunumanii* should produce sound seeds.

Photo 1-7. *Pinus palustris* growing on coastal sands in North Carolina, USA. The species, a representative of the *Australes* subsection, represents the closest genetic link from the southern US pines to some of the Mesoamerican *Oocarpaceae*.



CONCLUSIONS

The Mesoamerican *Oocarpaceae*, as defined by Little and Critchfield (1969), evolved separately from the California closed-cone pines. The Mexican and Central American branch includes species that previously were classified as part of the Teocote subsection, and therefore, the *Oocarpaceae* subsection contains both "open" and "closed" cone pines. The evolutionary scenario proposed suggests that the Mesoamerican *Oocarpaceae* were the ancestors of the present-day pines in the *Australes* subsections, such as *P. elliottii*, *P. palustris* and *P. taeda*, and that *P. caribaea* var.

hondurensis forms the genetic link between the two subsections. The evolutionary scenario suggested is speculative but represents our best attempt to explain the phylogenetic patterns generated by RAPD markers. These patterns are, in many respects, in agreement with those generated by researchers using different molecular marker systems (see Wu et al. 1999, Schmidling and Hipkins 2000). Our understanding of the evolution of the Mesoamerican *Oocarpaceae* undoubtedly will be improved as more data become available.

CONTRIBUTORS

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C h a p t e r 2



PINUS CARIBAEA VAR. *HONDURENSIS*

W. S. Dvorak, E. A. Gutiérrez, G. R. Hodge, J. L. Romero, J. Stock and O. Rivas

OVERVIEW

TREE DESCRIPTION

Pinus caribaea Morlet var. *hondurensis* (Sénéclauze) W.H. Barrett & Golfari is a medium to large tree that ranges in height from 15 to 38 m with dbh (outside bark) from 30 to 60 cm. Stem form and crown architecture vary with soil type and depth. On fertile soils the species develops a relatively straight stem with a pyramidal to rounded crown (Photo 2-1). On shallow soils or heavy clays, the stem is often crooked and the crown irregular. The bark of the tree is thick and reddish-brown with rough plates formed by deep vertical and horizontal fissures (Perry 1991). Needles are dark green, thick, stiff and erect, 15 to 25 cm long and occur primarily in fascicles of three. Cones range in size from 5 to 12 cm and are usually borne singly and occasionally in pairs. The cone scales carry a sharp persistent prickle. Cones ripen from mid-May to mid-July throughout the species' natural range in Mesoamerica. In natural stands the average seed potential per cone is approximately 166 seeds. There are about 50,000 seeds per kg. The wood is of moderate density, high in extractives, and suitable for a number of wood and paper products.

CONSERVATION STATUS

Based on CAMCORE fieldwork in Central America and Mexico, the conservation status of *Pinus caribaea* var. *hondurensis* is **vulnerable** in its natural range. Although large areas of the species exist in Poptún, Guatemala and eastern Honduras and Nicaragua, other regions of the species are severely threatened. These include the extremely productive populations of Guanaja Island and Limón in northern Honduras, the interior dry site provenances in central Honduras extending into El Salvador, the extreme southern populations at Karawala,

Pine Ridge Point, and Laguna del Pinar; Nicaragua, and coastal Belize provenances.

TEST STATUS

Since 1981, CAMCORE has collected seeds from 29 provenances in Belize, Guatemala, Honduras, El Salvador, Nicaragua and Mexico and has sampled 1414 mother trees. The Cooperative has established 84 provenance/progeny tests and conservation banks in seven countries.

BEST PROVENANCES

Results from CAMCORE provenance/progeny test data indicate that the best populations for planting sites in Latin America based on productivity are: Limón (not to be confused with Los Limones), Guanaja, and Gualjoco, Honduras, Alamikamba, Nicaragua and possibly Melinda, Belize.

SUITABLE PLANTING SITES

An estimated 1.0 million ha of *P. caribaea* var. *hondurensis* have been established in the tropics and subtropics, 60% of which are in Venezuela (Dieters and Nikles 1997). The variety has been grown successfully at latitudes from approximately 18° N to 28° S on a wide range of soil types across areas that receive 900 to 2500 mm of annual rainfall. Average growth rates of 25 m³/ha/yr over a rotation of 9 to 20 years have been observed on sites of different quality. The variety lacks frost tolerance. It has failed on shrink-swell clays (Vertisols) in northern Colombia where annual rainfall is approximately 900 mm and soil pH is about 7.0, on deep sands in eastern Venezuela, and on heavy wet clays in valley bottoms in Kalimantan, Indonesia and Malaysia.

Photo 2-1. *Pinus caribaea* trees growing at Alamikamba, Nicaragua.

ADVANTAGES OF *PINUS CARIBAEA*

- Grows rapidly on most sites.
- Is well adapted to a wide range of sites.
- Can withstand moderate weed competition.
- Possesses thick crowns that shade out most understory weeds after crown closure.
- Hybridizes with other Mesoamerican and southern US pines.
- Is easy to propagate as a seedling cutting.
- Good provenance information is available.
- Improved seeds are available on the world market.
- Wood is acceptable for many uses.
- Produces a valuable resin.
- More wind firm than *P. oocarpa* or *P. tecunumanii*.

DISADVANTAGES OF *PINUS CARIBAEA*

- Unimproved material often foxtails or develops many forks.
- More insect susceptible than other *P. caribaea* varieties.
- Less wind firm than other *P. caribaea* varieties.
- Moderately susceptible to *Cylindrocladium* spp. when planted in the Brazilian Amazon region and Southeast Asia.
- Will not resprout after intense fires.
- Poor seed producer near the equator.

NATURAL STANDS

EVOLUTION

Taxonomists place *Pinus caribaea* var. *hondurensis* in the *Australes* subsection. However, phylogenetic assessments by CAMCORE indicate that *P. caribaea* var. *hondurensis* is intermediate between taxa in the *Oocarpace* and *Australes* subsections (Dvorak et al. 2000), suggesting that the species has genetic characteristics of both the “closed-cone pines” and the “southern yellow pines.” Ancestors of *P. caribaea* apparently migrated, perhaps during the Miocene, around the western edge of the Gulf of Mexico into Central America (see Chapter 1). *Pinus caribaea* var. *caribaea* and *bahamensis* apparently evolved from var. *hondurensis*.

DISTRIBUTION

As var. *hondurensis* evolved, it established dominance in the humid lowlands of the Atlantic Coast in extreme eastern Mexico, Belize, Guatemala, Honduras and Nicaragua. It has penetrated inland along valleys as far as 300 km into Honduras and Nicaragua and is now found in the drier interior highlands (Greaves 1978). Recent collections by CAMCORE sampled a mixed *P. caribaea* var. *hondurensis*, *P. oocarpa* and *P. tecunumanii* population in eastern

El Salvador (Figure 2-1). More populations of Caribbean pine probably exist there.

The current distribution of *P. caribaea* var. *hondurensis* ranges from 18° 15' N at Ejido Caobas, Quintana Roo, Mexico to 12° 13' N at Laguna del Pinar, Zelaya, Nicaragua (Table 2-1). Although the variety can be found from sea level to approximately 1000 m elevation at Monteca, El Salvador; it is most prominent below 500 m altitude. The geographic range is naturally discontinuous with occurrences in bands of varying widths along the Atlantic coast (Greaves 1978). The largest and most impressive area of *P. caribaea* is the region of La Mosquitia in eastern Honduras and Nicaragua, where it grows on scattered ridges in varying densities, separated by savanna and bush vegetation along rivers and creeks (Fahnestock and Garratt 1938). Isolated populations of *P. caribaea* var. *hondurensis* are surrounded by tropical broadleaf vegetation at Popotún and El Pinal, Guatemala. True insular populations occur on Guanaja and Roatán Islands off the northern mainland of Honduras. Population size ranges from thousands of hectares in eastern Honduras and Nicaragua to just a few hectares with approximately 150 trees at Ejido Caobas.



Photo 2-2. The inland, dry-site population of *Pinus caribaea* var. *hondurensis* at El Porvenir, Honduras.

CLIMATE

Pinus caribaea var. *hondurensis* is adapted to a wide range of precipitation regimes. For example, at the southern extreme of its range at Laguna del Pinar, Nicaragua, annual rainfall amounts in excess of 4000 mm have been recorded with no dry season. At Los Limones, in central Honduras, annual precipitation is approximately 670 mm with a dry season of six months. The general trend is for precipitation to decrease from north to south along the coast in the species range (Greaves 1978). Rainfall also tends to decrease from coastal to inland areas, although there are exceptions. For example, Lanquín, Guatemala and Santa Cruz de Yojoa, Honduras, both inland populations, receive in excess of 2400 mm of precipitation annually. *Pinus caribaea* var. *hondurensis* is not subject to frosts in any part of its natural range, with mean annual temperatures averaging between 22 and 27 °C at most locations. Rainfall and temperature patterns at Caribbean pine sites are shown in Table 2-2.

SOILS

Pinus caribaea var. *hondurensis* grows across a wide range of locations in Mesoamerica. Consequently, it is not possible to quantify a typical “*P. caribaea*” site accurately with a single description. Generally the variety occupies relatively infertile and eroded red-yellow sandy clay soils (Ultisols and Inceptisols) that are moderately well drained. It also has been found on poorly drained shrink-swell clays on an

old lakebed at El Pinal, Guatemala (Gutiérrez and Donahue 1987) and on well drained, high gravel content soils derived from marine sediments in eastern Nicaragua (Taylor 1962). The variety has also survived periodic flooding in Ejido Caobas, Mexico (Chavelas 1981) and Laguna del Pinar (Greaves 1978, Donahue 1993). Populations in southern Nicaragua and coastal Belize (see Romero 1999) are situated in clumps on small rises surrounded by mangrove swamps. Soil pH ranges from 4.2 on the eroded Ultisols to 6.5 on the limestone-derived soils of the lower Petén near Poptún.

A composite soil sample taken by CAMCORE on a relatively good site at Lanquín, Guatemala (meteorological data shown in Table 2-2) revealed a sandy-clay A horizon 10 cm deep overlying a sandy-clay to clay B horizon more than 85 cm deep (Gutiérrez and Donahue 1986). Soil pH ranged from 5.0 to 5.5. This location is at the upper end of the elevational distribution of Caribbean pine, and is the only location where *P. caribaea* has been found growing in association with *P. maximinoi* (discussed later). A similar series of soil samples were taken at Las Trincheras, Guatemala in a highly degraded stand of Caribbean pine that is subject to annual fires. There was no litter or organic layer or A horizon. Trees were growing on an exposed B horizon of a reddish clay loam that was about 1.0 m deep and with rocks. Soil pH was approximately 6.5.

Table 2-1. *Pinus caribaea* collections made by the CAMCORE Cooperative in Central America and Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	Cabbage Haul	Stann Creek	Belize	16° 47' N	88° 25' W	190 - 220	2500	8
2	Deep River	Deep River	Belize	16° 19' N	88° 40' W	150 - 200	2750	7
3	Mountain Pine Ridge	Cayo	Belize	16° 58' N	89° 00' W	400 - 690	1558	50
4	San Pastor Pine Ridge	Cayo	Belize	16° 40' N	88° 57' W	600 - 800	1558	0*
5	Swasey-Bladen	Stann Creek	Belize	16° 29' N	88° 33' W	190 - 210	2500	7
6	Trio Camp	Stann Creek	Belize	13° 34' N	88° 40' W	190 - 210	2500	8
7	Monteca	La Unión	El Salvador	13° 53' N	87° 52' W	560 - 790	1500	20
8	El Pinal (Tikal)	El Petén	Guatemala	17° 18' N	89° 29' W	210 - 230	1688	16
9	Lanquín	Alta Verapaz	Guatemala	15° 33' N	89° 58' W	370 - 630	2401	18
10	Poptún	El Petén	Guatemala	16° 21' N	89° 25' W	470 - 580	1688	77
11	Trincheras	Izabal	Guatemala	15° 27' N	89° 03' W	150 - 500	2000	50
12	Araslaya	Gracias a Dios	Honduras	15° 42' N	84° 47' W	5 - 15	2528	50
13	Culmí	Santa Bárbara	Honduras	15° 06' N	85° 33' W	400 - 600	1441	60
14	Dursuna	Gracias a Dios	Honduras	15° 00' N	84° 54' W	15 - 25	2750	50
15	El Marañón	Cortés	Honduras	15° 22' N	88° 02' W	310 - 420	1373	19
16	El Porvenir	Fco. Morazán	Honduras	14° 23' N	87° 25' W	560 - 600	805	50
17	El Venado	Cortés	Honduras	15° 16' N	88° 04' W	590 - 610	1446	20
18	Gualjoco	Santa Bárbara	Honduras	14° 55' N	88° 14' W	240 - 355	1200	49
19	Isla de Guanaja	Gracias a Dios	Honduras	16° 28' N	85° 54' W	60 - 165	2447	150
20	La Brea	Colón	Honduras	15° 46' N	86° 02' W	10 - 400	2630	50
21	Limón	Colón	Honduras	15° 51' N	85° 23' W	20 - 85	2452	234
22	Los Limones	El Paraíso	Honduras	14° 05' N	86° 53' W	660 - 750	616	89
23	Pinalejo	Santa Bárbara	Honduras	15° 23' N	88° 26' W	290 - 650	941	40
24	Puerto Lempira	Gracias a Dios	Honduras	15° 15' N	83° 41' W	10 - 15	3043	50
25	San Patricio	Comayagua	Honduras	14° 55' N	87° 44' W	300 - 600	1604	40
26	San Pedro de Catacamas Olancho		Honduras	14° 39' N	85° 51' W	200 - 600	1441	40
27	Santa Cruz de Yojoa	Cortés	Honduras	14° 53' N	86° 56' W	530 - 720	2758	50
28	Zacapa	Santa Bárbara	Honduras	14° 45' N	88° 10' W	300 - 650	1714	50
29	Ejido Caobas	Quintana Roo	Mexico	18° 15' N	89° 00' W	110 - 130	1280	12
30	Alamikamba	Zelaya	Nicaragua	13° 34' N	84° 17' W	20 - 40	2610	50
31	Karawala	Zelaya	Nicaragua	12° 58' N	83° 34' W	5 - 10	3897	0*
32	Laguna del Pinar	Zelaya	Nicaragua	12° 13' N	83° 42' W	5 - 10	4184	0*
33	Pine Ridge Point	Zelaya	Nicaragua	12° 29' N	83° 38' W	5 - 10	4000	0*
29	Provenances	17 State/Depts.	6 Countries	12 - 18° N	83 - 90° W	5 - 800	2115	1414

* Site visited, collections not made.

Map key does not correspond to CAMCORE provenance codes.

Figure 2-1. CAMCORE collections of *Pinus caribaea* var. *hondurensis* in Mexico and Central America.

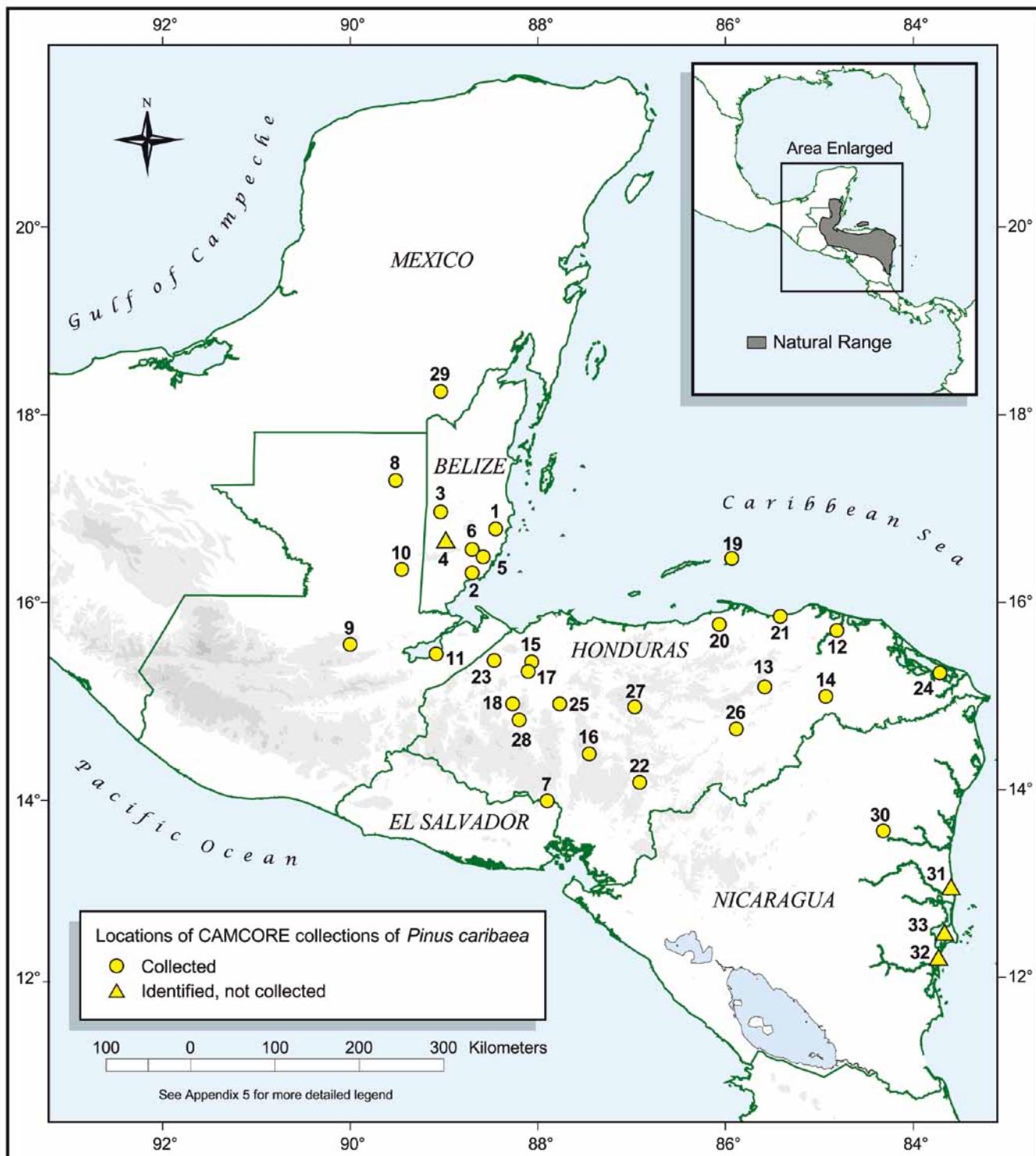


Table 2-2. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus caribaea* humid coastal site at Limón, Honduras (top) and a drier inland site at Los Limones, Honduras (bottom).

Limón, Wet	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	26.0	26.6	27.7	28.2	27.7	26.6	27.1	26.6	26.0	26.0	25.4	25.4	26.6
Mean Rain mm	286	103	124	120	169	285	444	262	150	279	377	480	3079

Based on 7 years of data recorded at Sicó, Colón, elevation 20 m, approximately 19 km from Limón. Data provided by ESNACIFOR.

Los Limones, Dry	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	26.1	27.4	28.8	29.8	29.8	27.9	26.9	28.1	28.3	27.1	26.2	25.8	27.7
Mean Rain mm	2	2	3	8	80	149	69	102	113	101	31	3	663

Based on 10 to 13 years of data recorded at Moroceli and El Zamorano, Honduras, at 650 m elevation, approximately 6 km from the collection site (Greaves 1978).

REPRODUCTIVE BIOLOGY

Production of male and female strobili usually occurs from November to January (Styles et al. 1982) and occasionally as late as early February at Alamikamba, Nicaragua (Gutiérrez 1993). As Robbins and Hughes (1983) state, although there is a single, defined flowering period, strobili on individual trees can mature almost any time in the year. Cone crops mature approximately 18 to 20 months after pollination in late May to early June in Honduras and Nicaragua and in late June or early July at the Mountain Pine Ridge, Belize and Poptún, Guatemala. Cones are collected when the scales begin to turn brown. Cone crops, which are often sporadic, are affected by local weather patterns and vary from one provenance to another. For example, Ordoñez (1981) found seed yield per volume of cones to be three times greater in Poptún (ann. precip. 1688 mm) than at Lanquín, Guatemala (ann. precip. 2401 mm). The cone collection period in any one provenance lasts only about two weeks. It is typical to find a high proportion of empty seeds in *P. caribaea* cones collected in natural stands. This may be a consequence of abundant cone-boring insect populations (see Carlin and Nuñez 1985) or an extended pollination period that could sometimes result in poor synchronization of female receptivity and pollen dispersal. For example, 10 sacks of cones (800 to 900 cones per sack) yielded 1 kg of seeds in collections at Alamikamba, Nicaragua by the National Seed Bank (Gutiérrez 1993), which is roughly equivalent to 7 to 10 filled seeds per cone. Yields in Honduras are slightly better. The average seed potential for *P. caribaea* is approximately 166 seeds per cone.

ECOLOGY AND ASSOCIATED SPECIES

The distribution and ecology of *P. caribaea* is very much defined by the frequency of fires and the site elevation (which affects temperature). Hurricanes also may play a major role along the eastern part of the Caribbean pine range in opening gaps in broadleaf forests for the expansion of pines. The wet savannas in eastern Honduras

and Nicaragua, where Caribbean pine is the dominant overstory species, were thought to be rain forests before fire eradicated the broadleaf ecosystem (Taylor 1962). Caribbean pine also occurs on the drier savannas of the lower Petén, Guatemala, and as a remnant population on the "Sabana de Jaguactal" in Quintana Roo, Mexico. These savannas have a history of fire that is particularly prominent during periods of severe drought. Unlike *P. oocarpa*, Caribbean pine seldom resprouts after exposure to fire. Its mechanism for co-existence with fire is fast growth and rapid development of a thick bark.

Pinus caribaea grows in association with *P. oocarpa* at Las Trincheras, Guatemala, San Pastor Pine Ridge, Belize, Monteca, El Salvador and a number of locations in Honduras and Nicaragua, primarily in areas between 400 and 1000 m elevation. The taxa grow mixed with *P. tecunumanii* (low elevation sources) at San Pastor Pine Ridge and Monteca, El Salvador, and on the fringes of *P. tecunumanii* at San Esteban and Culmí, Honduras and Mountain Pine Ridge, Belize. In these areas of sympatry, trees with morphology intermediate between *P. caribaea* var.*hondurensis* and *P. tecunumanii* are often found (Styles et al. 1982, Squillace and Perry 1992). At Lanquín, *P. caribaea* grows in association with *P. maximinoi* at approximately 1000 m elevation. Caribbean pine occasionally merges with sporadic scrub oak (*Quercus* spp.) forests in drier valleys in Honduras, but it is only at El Pinal, Guatemala that the oak competition (*Quercus oleoides*) threatens to eradicate Caribbean pine because of lack of fires (Photo 2-3). At Guanaja Island, it occurs on the ocean shore in association with coconut palms (*Cocos nucifera*).

A number of authors have described the secondary and understory vegetation associated with Caribbean pine in natural stands (Greaves 1978, Chavelas 1981). Understory vegetation type is influenced by the severity of the dry season, temperature, and soil, as well as the presence or absence of fire (Robbins and Hughes 1983). Only the predominant understory species are mentioned here. At

many sites, *Byrsonima crassifolia* (sometimes locally called "Nance") and *Pteridium aquilinum* (bracken ferns) are found, especially after recent fires. Collectors on the Mountain Pine and San Pastor Pine Ridges must fight their way through *Dicranopteris pectinata* (tiger bush) and *Tripsacum latifolium* (dumb cane) in order to select trees and collect cones. At the wetter, lower lying areas in eastern Nicaragua and coastal Belize, *Acoelorraphe wrightii*, an endemic palm, is found in association with *P. caribaea*.

Although Caribbean pine is relatively disease-free in natural stands, it is susceptible to several pests and pathogens. It is sometimes affected by *Cronartium conigenum* (cone rust). Like most pine species in Mesoamerica, it is occasionally attacked by *Dendroctonus* spp. (pine bark beetles). Cone- and seed-boring insects are also a common problem (Carlin and Nuñez 1985).

WOOD QUALITY IN NATURAL STANDS

Removal of *P. caribaea* var. *hondurensis* for use as sawtimber has a long history in Central America. *Pinus caribaea* var. *hondurensis* trees were initially harvested in eastern Nicaragua in the 1930s and exported to Great Britain and the United States for structural timber and general millwork. Fahnstock and Garratt (1938) conducted wood studies on mature trees in eastern Nicaragua and describe the heartwood of Caribbean pine as reddish-brown with a distinct pale yellow sapwood. The wood is straight grained and rather coarse in texture and has a high extractive content that increases its weight. The primary difference between wood properties of *P. palustris* and *P. elliottii* in the southern United States and *P. caribaea* var. *hondurensis* is the distribution of latewood in the growth rings. Rather than a band of earlywood followed by a single band of latewood, in *P. caribaea* var. *hondurensis* several bands of each are present and the number and thickness of the bands varies considerably. In a study in Belize, Hunt (1970) suggests that varied ring thickness resulted from seasonal water stress. The wood of Caribbean pines is perfectly suited for structural lumber in most cases. On rare occasions the dense latewood rings were nearly or completely absent on trees in eastern Nicaragua.

(Fahnstock and Garratt 1938). Such trees are not recommended for structural uses. Tracheid length of mature trees studied in Dolores, Guatemala averaged 6 mm in length with a range of 4 to 10 mm. Density of the trees was 590 kg/m³ but no age was given (CETEFOR 1972). The wood of Caribbean pine is used in its native range for construction, pallets, paintbrush and broomstick handles, and firewood; it is also exported for a number of overseas uses.



Photo 2-3. *Pinus caribaea* var. *hondurensis* is being outcompeted by broadleaf vegetation at El Pinal (Tikal), Guatemala.

PLANTATIONS

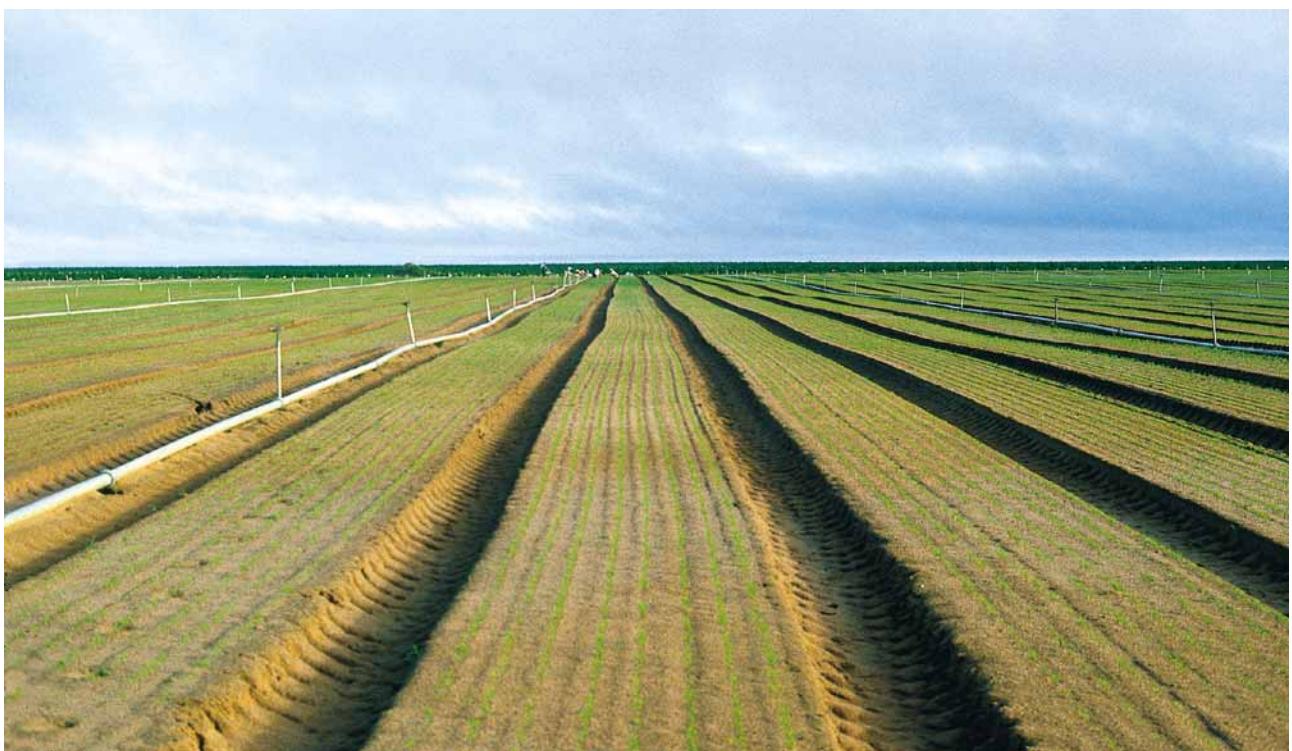
There are approximately 1.0 million ha of Caribbean pine planted worldwide. Six hundred thousand ha are established in Venezuela. The average productivity (over bark) of unimproved *Pinus caribaea* assessed in 48 CAMCORE trials was 14 to 15 m³/ha/yr in Brazil and Venezuela and 4 to 5 m³/ha/yr in sandy soils of western Colombia at 8 years of age (Hodge et al. 2001). The highest average growth rate recorded at any one

CAMCORE test site was approximately 27 m³/ha/yr at 11 years of age (based on outside bark dbh).

NURSERY PRACTICES

Seed Handling

Caribbean pine seeds can be stored at 4 °C with 6 to 9% moisture content for a number of years without problems. The relative humidity of the storage facility should be



maintained at approximately 60%. Because seeds purchased from Central America are collected during the rainy season, their moisture content should be checked when shipments arrive. In Central America, sun drying of cones on cement patios will usually bring seed moisture content down to 6 to 10% (CAMCORE, unpublished data).

Pinus caribaea, like *P. tecunumanii* and *P. oocarpa*, has a relatively thin seed coat that can be easily damaged during extraction; consequently, care must be used during processing. No pretreatment or cold stratification of seeds is necessary prior to sowing. However, most commercial nurseries in Venezuela soak seeds in water at 25 °C for 24 hours before sowing to promote even germination. Germination capacity of well-cleaned seed lots from Central America is normally better than 80%.

Containers and Growth Media

Seedling production of Caribbean pine in Venezuela is mainly bare root (Photo 2-4a). The sandy soils of the eastern Llanos of this country make them ideal for large bare-root nurseries with capacities for more than 20 million seedlings per year. Containerized operations are becoming more popular (Photo 2-4b). Smurfit Cartón de Venezuela in the west central part of the country uses tubettes 4 x 12 cm and approximately 80-cm³ capacity for its commercial Caribbean pine operation. Seeds are directly sown into a commercial medium consisting of 50% composted coconut fibers, 40% burnt rice husks and 10% organic matter, with a pH between 4.5 and 5.0. Terranova S.A. in the eastern part of Venezuela grows its Caribbean pine seedlings in 100% composted pine bark in tubettes 5 x 15 cm and approximately 140 cm³ capacity. Seeds are sometimes germinated under shade and then seedlings are moved to full sunlight.

Photos 2-4a and b. Above, bare-root *Pinus caribaea* nursery established by PROFORCA in eastern Venezuela. Below, Alexis Wainer of Terranova S.A. shows the type of container the company is using to grow *P. caribaea* in the sandy soils of eastern Venezuela.



Seedling Management

At the PROFORCA bare-root nurseries, approximately 150 seedlings are grown per square meter of nursery bed. In container research nurseries, spacing is not an important issue since containers or tubettes can be moved to allow for additional space. Local bird populations have destroyed germinants of Caribbean pine in CAMCORE tests by pulling at the seed coats on emerging cotyledons. The problem seems to be most severe between 5:30 and 6:30 a.m. when birds actively feed. Mice also have caused damage to new germinants. *Fusarium* spp. (damping-off) is ever present and can be controlled by proper irrigation management and fungicide application. Since many plantings of Caribbean pine occur on savanna-type environments devoid of useful mycorrhizae, application of mycorrhizae are needed in the nursery beginning three to four weeks after sowing seeds in the nursery (see Davey 1981). Fertilizer application often begins at the same time. The most needed nutrient in Caribbean pine nurseries is nitrogen (Davey 1981), which should be applied using ammonium nitrate as the source when medium is less than pH 5.8 and ammonium sulfate when pH values are ≥ 5.8 . In situations where ammonium nitrate cannot be used, only ammonium sulfate is applied and the low pH values are adjusted by adding lime to the soil between nursery crops. Iron deficiencies were noted in Caribbean pine seedlings in a CAMCORE test at one nursery in East Kalimantan. The juvenile foliage was a strong yellow color. Soluble ferrous iron (FeSO_4) was sprayed on the foliage and within two weeks the green color of the new foliage was restored. It takes approximately four to six months to produce a Caribbean pine seedling with a shoot height of 25 cm and a root collar diameter of 4.0 to 5.0 mm, which is suitable for outplanting. Seedling growth and quality in the nursery often vary by provenance making seed source selection important. In Venezuela, seeds are sown in bare-root nurseries or in containers in November and seedlings are outplanted in June at the onset of the rainy season. Research is being conducted at Terranova S. A. in eastern Venezuela to see if the three-month "planting window" can be extended by planting higher quality seedlings on well-prepared beds with state of the art weed and ant control.

Vegetative Propagation

Many areas where *P. caribaea* var. *hondurensis* is planted as an exotic are well suited for tree growth, but not for cone and/or seed production. Many growers have been forced to establish their seed orchards in conditions very different from, and sometimes very distant to their operational plantations. Vegetative propagation allows pine growers to obtain many cuttings (plants) from single seeds. This is an extremely valuable tool when seed production is expensive or physiologically difficult.

Because the variety does not produce stump sprouts, hedges or stock plants must be established for cutting production. Seedlings, usually from the best genetic quality

possible, are grown in the nursery and then outplanted into a hedge garden or into pots if they will be managed in greenhouses and shade houses. The seedlings are grown to a height of 30 to 50 cm and then cut back to a height of 18 to 20 cm; alternatively, seedlings can be clipped (hedged) as soon as they reach a height of 18 to 20 cm in the nursery. Hedges are maintained at 18 to 20 cm height for sprout production, and typically are managed for 3 to 4 years before being replaced. Sprout harvest can start from one to two months after hedging. Sprout size and physiological state (i.e., lignification, primary versus secondary needles, etc) vary from program to program, but are generally in the vicinity of 10 cm height with 50% juvenile needles and 50% secondary needles.

Rooting protocols are quite varied for *P. caribaea* var. *hondurensis*. Some programs use containers in mist houses, some root directly in the field as bare-root cuttings, some use rooting hormones (such as IBA + NAA) and some root without auxins. Whatever the protocol, cuttings must be harvested from hedges, rooted, grown out in the nursery and then outplanted to the field.

Pioneering work on the vegetative propagation of Caribbean pine from seedling cuttings was done by the Queensland Forestry Research Institute (Haines et al. 1993). CAMCORE member Arauco experimented with propagation procedures of Caribbean pine and found that techniques used for *P. radiata* in Chile worked very effectively for *P. caribaea* (Balocchi 1996). From 128 seedlings per provenance, Balocchi was able to obtain 1200 usable cuttings per year. CAMCORE members SAFCOL, Sappi and Smurfit Cartón de Venezuela have modified the Queensland protocol to propagate hybrids of *P. elliottii* x *P. caribaea* var. *hondurensis* in South Africa and pure *P. caribaea* in Venezuela. The Smurfit Cartón de Venezuela cutting program began in 1997 and methods of propagation have been described by Stock et al. (2000) as follows. Seedlings are grown in tubettes for six months and then transplanted into hedge beds (approx. 40 m long, 1.4 m wide and about 15 cm high). The beds are 60% sandy clay, 20% washed river sand, and 20% burnt rice husks. The rice husks are added to improve drainage. Three rows of seedlings are transplanted down each bed at approximately 50-cm spacing. Two weeks after transplanting, each seedling receives 120 g of diammonium phosphate. Seedlings are allowed to grow in the cutting beds for about four months until shoot height is approximately 50 cm, at which time they are cut to 20 cm above the ground line. The plants produce new sprouts that can be harvested approximately every 40 to 60 days. Approximately 20 cuttings can be obtained from each stock plant per harvest period.

The cuttings are transported in water to a shade house, where they are cut to a uniform length of 10 cm. They are then submerged in a fungicide solution of Captan



Photo 2-5. Rooted cutting of *Pinus caribaea* var. *hondurensis* produced by Smurfit Cartón de Venezuela in its nursery near Acarigua.

(200 ppm) for one minute. The cutting base is then dipped into a rooting hormone. Research by Smurfit Cartón de Venezuela indicates the best rooting hormone for their conditions is a treatment of Indolebutyric acid (250 ppm) and Naphthalacetic acid (NAA) diluted in alcohol (Stock et al. 2000).

After the hormone application, cuttings are transferred to a misting house and planted in plastic tubettes containing a medium of 70% burnt rice husks and 30% loamy sand. Fungicides are applied on a weekly basis. The cuttings are grown under 70% shade with relative humidity 75 to 95% using mist irrigation. Roots begin forming in about 25 days and are sufficiently developed by 40 to 45 days. Rooting success using this system is approximately 90%. After the root system is formed, the cuttings are placed outside under shade for three days and then grown in full sun for 60 more days prior to field planting (Photo 2-5).

STAND MANAGEMENT

Site Selection and Establishment

Caribbean pine grows best in areas receiving more than 1500 mm of annual precipitation with loamy clay soils that are at least 1.0 m deep. Trees reach massive sizes in Misiones, Argentina and the Nausori Highland, Fiji on deep fertile Alfisols (Photo 2-6). However, the value of the species lies in its ability to produce a productive crop on poor sandy soils. On deep infertile sandy clays (Oxisols) near Brasilia, average growth of the (unimproved) Guanaja

source was 16 m³/ha/yr (outside bark) at 10 years of age Moura and Dvorak (1997). Unimproved Caribbean pine in CAMCORE tests planted at Aracruz Florestal on a deep sandy Ultisols in eastern Espírito Santo was producing 27 m³/ha/yr at 11 years of age (unpublished data CAMCORE). The variety also grows reasonably well on the sandy soils of the eastern Llanos of Venezuela, Queensland, Australia and Zululand, South Africa. It has shown mortality due to drought on shallow, gravelly soils at Santo Tomás, Venezuela, and on deep sands at Chaguaramas, Venezuela in areas characterized by strong dry season. It has also failed on deep fertile Vertisols near Zambrano, Colombia where annual rainfall is 920 mm and soil pH is neutral. During the dry season at Zambrano, cracks 2 cm wide develop in the clay to a depth of 1.0 m that presumably break pine lateral roots causing seedlings to die. The exotic species *Gmelina arborea* and the native species *Bombacopsis quinata* are better suited for these locations. Caribbean pine has not survived well in East Kalimantan, Indonesia and Sabah, Malaysia on the heavy clays in valley bottoms, but does acceptably well on better drained soils on hilltops and ridges.

Pinus caribaea responds well to a number of site preparation methods. It has been planted successfully both with and without bedding. Relative to *P. tecunumanii* and *P. oocarpa* the species is deep rooted and has exhibited stability on sandy soils along the east coast of Australia, Brazil and South Africa. Wind resistance of coastal sources



Photo 2-6. Large tree of *Pinus caribaea* var. *hondurensis* near the headquarters of Alto Paraná S.A. in Misiones, Argentina.

(with the exception of Guanaja) is generally better than inland sources (Nikles et al. 1983). In hurricane or typhoon belts, var. *hondurensis* demonstrated less wind resistance than var. *bahamensis* and *caribaea* (Fiji Islands, Baylis and Barnes 1989) but better resistance than *P. oocarpa* (Puerto Rico, Liegal 1984).

Caribbean pine seedlings are sturdy and lend themselves well to machine planting. Normal spacing is 3 x 3 m. CAMCORE member Terranova S.A. has recently begun planting at 4 x 2 m spacing in the dry eastern Llanos of Venezuela. In this same region, PROFORCA plants seedlings deep, with only the top 5 to 10 cm of the plant above ground, to protect them from desiccation in the hot sun. Even though young Caribbean pine seedlings will survive in heavy grass and weeds, removal of weed competition around seedlings at time of planting is highly recommended.

Silviculture

Pinus caribaea usually grows slowly the first year (0.3 to 1.0 m), but much more rapidly after its root system becomes established. Weed control around plants is highly recommended during the first couple of growing seasons. Observations in Venezuela suggest that as much as 2 years growth can be lost in a 15-year rotation when weed competition is not controlled in the first 18 months after planting. Weed and grass control during the first two years resulted in a 30% increase in volume at age 6 years in

studies in Queensland, Australia (Costantini et al. 1990). Although overuse of glyphosate was found to cause deformities in Australia, in Portuguesa, Venezuela, Smurfit Cartón de Venezuela found that glyphosate provided excellent weed control with no symptoms of phytotoxicity to Caribbean pine (Kane 1992). Grass-killing herbicides applied directly over the pines did not damage the trees.

Application of fertilizer to Caribbean pine, especially on sandy soils, is very important on some sites. Smurfit Cartón de Venezuela applies 80 grams of 14-13-16 NPK fertilizer 15 days after planting. Application of 250 kg/ha of phosphorous, 60 kg/ha of potassium, and 12.4 kg/ha of boron in bands between rows eight weeks after planting produced volume gains of 25% at age 4 years in PROFORCA plantations (González and Longart 1995). Studies in Australia in Caribbean pine plantations indicate that application of phosphorus was essential for good growth on the relatively infertile coastal lowland soils (Simpson et al. 1998). Studies by Pizano/Monterrey on the wet Colombian Llanos indicate that the addition of a micronutrient such as manganese made the difference between whether trees grew or remained stunted. The lack of some trace elements, especially copper, caused stem deformities in some Caribbean pine families growing in coastal soils in Queensland, Australia (Simpson et al. 1996). More information on the nutritional needs of Caribbean pine on different soils is urgently needed.

Pinus caribaea often produces a single leader, but in some locations generates multiple forks at the base during the first year after planting. Multistem percentage was 25% in one test of the Guanaja seed source near Brasilia (Moura and Dvorak 1997); this percentage was even higher in a CAMCORE trial of the Alamikamba, Nicaragua source in west central Venezuela. Seedlings had a single stem when transplanted from the nursery. One hypothesis is that when Caribbean pine is planted on bare soil in some areas of the tropics, the terminal leader can be scalded and killed by heat reflected off the soil, and is replaced by sprouts that form at the base. Some families were more prone to producing multiple stems than others.

Pinus caribaea begins to show evidence of foxtailing at 1.5 years after planting and seems to reach its maximum in plantations at 5 to 8 years of age. The degree of foxtailing is dependent on the planting site and the seed source. Two of the worst provenances were Poptún, Guatemala and Araslaya, Honduras which foxtail approximately one-and-a-half to two times as frequently as the average provenance (Hodge et al. 2001). Foxtail trees are the first to die out or die back during periods of stress. Selection against foxtailing and forking in breeding programs has produced remarkable results.



Photo 2-7. Terranova S.A. is growing *Pinus caribaea* var. *hondurensis* on 50-cm-high beds with good weed control in the eastern Llanos of Venezuela.

Crown closure begins at age 5 to 7 years on fertile sites and from 7 to 10 years on sandy dry sites. The crowns of Caribbean pine are dense enough to limit understory vegetation from accumulating to high levels after crown closure, thus reducing the danger of fire.

Pests and Other Limiting Factors

Animals: Rodents girdled the cambium of 1-year-old plants in a CAMCORE test southern São Paulo State in Brazil. Removing weed cover and placing baits reduced the problem. Hawks occasionally land on the terminal leader of 1 to 3-year-old saplings and break branches. In areas with high bird populations, artificial perches built above the tallest trees have proven effective. No other animal problems have been observed on a regular basis.

Disease: Occasional trees in CAMCORE tests at Jari, Brazil and East Kalimantan, Indonesia are attacked by *Cylindrocladium* spp. At Jari, the disease killed the smaller trees. *Pinus oocarpa* was much more susceptible than Caribbean pine. The susceptibility of Caribbean pine to *Cylindrocladium* has been reported by a number of authors (e.g. Hodges et al. 1974, Ahmad and Ahmad 1982). Other needle diseases, such as *Dothistroma* needle blight, that have been frequently reported in the literature have not been noted on CAMCORE trees, probably because the Cooperative has not planted Caribbean pine at high altitudes in the tropics. *Pinus caribaea* var. *hondurensis* appeared resistant to *Sphaeropsis sapinea* (*Diplodia*) at Klabin, while *P. patula* and *P. greggii* were very susceptible.

Insects: *P. caribaea* var. *hondurensis* appears to be more susceptible to insect attacks in Southeast Asia than var. *bahamensis* and var. *caribaea* (Baylis and Barnes 1989). However, insects have not posed major problems for trees in CAMCORE tests in Latin America. Leaf-cutting ants (*Atta laevigata*) have caused some damage to CAMCORE trials of *P. caribaea* in eastern Colombia, Venezuela, and central Brazil. Entire trees have been stripped of needles overnight. The best protection from the ants is control prior to planting followed by continued treatment during tree development. Observations in the Llanos of Venezuela suggest the ants were more attracted to the Mountain Pine Ridge, Belize provenance or seed sources derived from Mountain Pine Ridge than to sources from Honduras. The terpene composition of trees from Mountain Pine Ridge and Honduran provenances differs (Squillace and Perry 1992), which may explain the observed trends. Even though Caribbean pine has been reported to be susceptible to termites in Malaysia (Tho and Kirton 1998), no problems have been reported in CAMCORE trials in Latin America. Other potential insect pests include an aphid (*Eulachnus rileyi*) that was identified on Caribbean pine in the eastern Llanos of Venezuela in 1988 (Rosales and Cermeli 1995), and *Rhyacionia frustrana* (pine tip moth), which has been reported in Costa Rica (Ford 1986) and in other places in the tropics. However, neither of

these insects has caused problems in CAMCORE trials to date.

Drought: Caribbean pine is moderately susceptible to droughts when established on shallow soils, but is much more tolerant to such conditions than *P. oocarpa* and *P. tecunumanii*. In one case at Smurfit Cartón de Venezuela, mortality due to drought was exacerbated when competing herbaceous vegetation was removed around the stressed pines. No one provenance of Caribbean pine has demonstrated better drought resistance than others.

Other Limitations: Young *P. caribaea* trees established near Brasilia exhibited "crinkled needle" disease, a malady that occurs when needles on an entire shoot do not penetrate the fascicle sheath. Similar symptoms have been reported on Caribbean pine in Africa (Lamb 1973) and Malaysia (Slee et al. 1976). The reason for this abnormal needle development has been attributed to several causes, including dry winds, low relative humidity, and high nighttime temperatures in conjunction with short day lengths in the tropics (Slee et al. 1976, Lamb 1973). The condition does not appear to cause problems for the tree.

WOOD QUALITY IN PLANTATIONS

The wood of Caribbean pine from plantations has been used for particle board, medium density fiberboard, Parrallam (parallel strand lumber), charcoal, fuelwood, fence poles, telephone poles, wood cement blocks and boards, plywood, moldings, furniture, structural lumber and a number of paper products. Most wood studies of Caribbean pine are from unimproved plantations with poor uniformity consisting of mostly juvenile wood. Many published studies used sample sizes of less than 10 trees. Provenance differences exist in bark percentages and wood density. The bark percentage and wood density of the Guanaja Island was consistently high in Oxford Forestry Institute (OFI) tests (Wright et al. 1994, Crockford et al. 1990). The wood of Caribbean pine is relatively susceptible to termite attack in some locations (Grace et al. 1998) and is very susceptible to the blue stain fungus caused by *Lasiodiplodia theobromae* (Cendeno-Mujica et al. 1996).

Density

Wood density, which is highly correlated to strength properties, varies greatly across Caribbean pine planting sites. High densities of approximately 600 kg/m³ at 15 years of age in western Fiji (Palmer 1985) and 510 kg/m³ at 12 years of age in Amapa, Brazil (J. Mikhos, personal communication) have been reported. Mid-range density values are found in the large plantation areas of eastern Venezuela. For example, trees 14 to 15 years of age grown at PROFORCA average 425 kg/m³ (Rivas and Bentacourt 1995). Wood density is lowest in coastal South Africa where trees 15 years of age can have values around 350 kg/m³, even with large, higher-density resin pockets in the heartwood (Falkenhagen 1979). The general trend is



Photo 2-8. In South Africa, it is common for some *Pinus caribaea* trees to produce large resin pockets yet have low wood density.

for the wood density of Caribbean pine to decrease with increasing elevation (Wright 1990, Silinge and Iddi 1990). Latewood bands in mature wood are sometimes absent (Falkenhagen 1979), as is occasionally the case in natural stands of Mesoamerica.

Fiber Quality and Spiral Grain

Average tracheid length in 6-year-old trees in eastern Venezuela was 3.0 mm (Moschler et al. 1985). Average tracheid length midway between the bark and the pith of 16 to 17-year-old trees was approximately 4.5 mm and increased to 5.2 mm near the bark in South Africa (Falkenhagen 1979). Overall, strength properties of trees derived from improved seeds and planted on "normal" sites are acceptable for structural lumber at 15 to 16 years. However, spiral grain can be a problem at some locations (Cown et al. 1983). Wood properties, especially density, are highly heritable in *P. caribaea*, and can be readily improved by selection and breeding.

Wood Quality of Foxtail Trees

Foxtail trees are characterized by long sections of the stem without branches, thus, upon first glance, they may appear to be well suited for some types of products. However,

foxtail trees pose milling problems because they possess lower strength properties than normal trees and lack within-family uniformity. One sawmiller in Venezuela described processing foxtails trees as like “cutting through cheese.” Areas of compression wood often form along the stem of foxtail trees in response to wind-induced bending. When cut and kiln dried, longitudinal and tangential shrinkage can be excessive. Boards cut from foxtails are permeated with needle traces. In an Indonesian study, foxtail trees (dbh 15 cm) had fewer and shorter tracheids, thinner cell walls and longer intercellular canals than normal trees (Scharai and Budiarso 1988). In a study utilizing trees grown in Minas Gerais, Brazil, wood sampled from foxtails had thinner cell walls, larger diameter and greater flexibility than normal wood (Colodette et al. 1981). Interestingly, foxtail and normal wood had similar density, but foxtail wood had less hemicellulose, was easier to delignify and produced pulps with higher strength properties. For some wood properties, or for some products, the effects of foxtails may be minimal. In a Venezuelan study, no differences were found in tracheid length between foxtailed

and non-foxtailed trees in a 6-year-old plantation (Moschler et al. 1985). In Indonesia, no differences were found in strength properties of particleboard made from foxtail and non-foxtail trees (Sastradimadja 1988).

Pulp Quality

A number of pulping studies have been conducted on Caribbean pine. The tree produces an acceptable pulp with low tear and high burst strength. Tracheid structure of Caribbean pine grown at Jari was especially well suited for products requiring high water absorption capacity such as napkins, paper towels and diapers (B. Redko, personal communication). In a representative wood study by Palmer (1985), yields of 44 to 52% and kappa numbers 40 to 64 were obtained using trees from Fiji and Uganda pulped by the sulfate process. CAMCORE studies of CTMP and TMP using 8-year-old Caribbean pine from Venezuela indicated that that CTMP pulps had superior tear and tensile indices, TEA, physical sheet brightness and ISO brightness compared to TMP pulp (Wright et al. 1995). Juvenile pulp in this study met quality criteria for industrial application.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

CAMCORE has visited 33 populations of *Pinus caribaea* in Belize, Guatemala, Honduras, El Salvador, Nicaragua, and Quintana Roo, Mexico (Table 3-1, Figure 3-1). Seed collections have been made in 29 provenances from 1414 mother trees of *P. caribaea* var. *hondurensis* since the first collection of the variety in 1981. Initially collections were divided into wet and dry provenance sources and distributed to members in an effort to identify drought hardy populations of the species (Dvorak et al. 1993b). Priorities in the early collections were based on the pioneering work of the OFI. More recently, efforts have concentrated on sampling the most remote and isolated populations of the variety for *ex situ* gene conservation purposes. CAMCORE members in Argentina, Brazil, Colombia, Costa Rica, Indonesia, South Africa, and Venezuela have established 84 provenance/progeny tests.

PROVENANCE VARIATION

There have been two across-site analyses on the CAMCORE provenance tests of Caribbean pine. Dvorak et al. (1993b) presented results on 16 provenances from 29 tests based mainly on 5-year results. Hodge et al. (2001) subsequently analyzed a larger subset of 48 trials that included a combination of data from tests assessed at 5 and 8 years. Both manuscripts, as well as one by Vásquez and Dvorak (1996), discuss trends in genetic parameters of Caribbean pine. Results from these three works are summarized in the following sections.

The OFI has done two major across-site analyses on their series of Caribbean pine tests. One assessment was conducted by Birks and Barnes (1990) and included 17 seed sources, seven of which were similar to those in the CAMCORE studies (Karawala, Alamikamba, Poptún, Ganja Island, Los Limones, Culmí, and the Queensland control). This analysis looked at provenance variation for a number of traits in 16 countries. The second assessment was conducted by Crockford et al. (1990) and looked at both provenance and family variation in *P. caribaea* established on 13 sites. It included six seed sources common to the CAMCORE trial series (Alamikamba, Araslaya, Culmí, Guanaja, Los Limones and the Queensland control).

Survival

Based on results from CAMCORE tests, there is little difference in survival between dry site sources (<1250 mm of ann. precip.) and sources from wet locations (>1250 mm ann. precip.) when planted in deep sandy soils in the eastern Llanos of Venezuela. The only exceptions are the wet site sources of Santa Cruz de Yojoa and Guanaja Island. At the Santo Tomás, Venezuela planting site (lat. 10° N, elev. 300 m, ann. precip. 1287 mm) which has shallow, gravelly soil and where pines are often subjected to drought stress, the Santa Cruz de Yojoa and Guanaja Island sources had survival rates of 48 and 34%, respectively. The other Caribbean pine provenances tested at this site exhibited 55% survival. At Aracruz, Brazil, (lat. 19° S, elev. 25 m, ann. precip. 1518 mm) on a compacted Spodosol, the survival of the Santa Cruz de



Yojoa source was 75 versus 92% for the other sources at 5 years of age. Examination of the data from 12 tests with trees that were ≥ 8 years indicates that survival patterns of provenances from wet and dry locations do not change much after crown closure (unpublished data, CAMCORE).

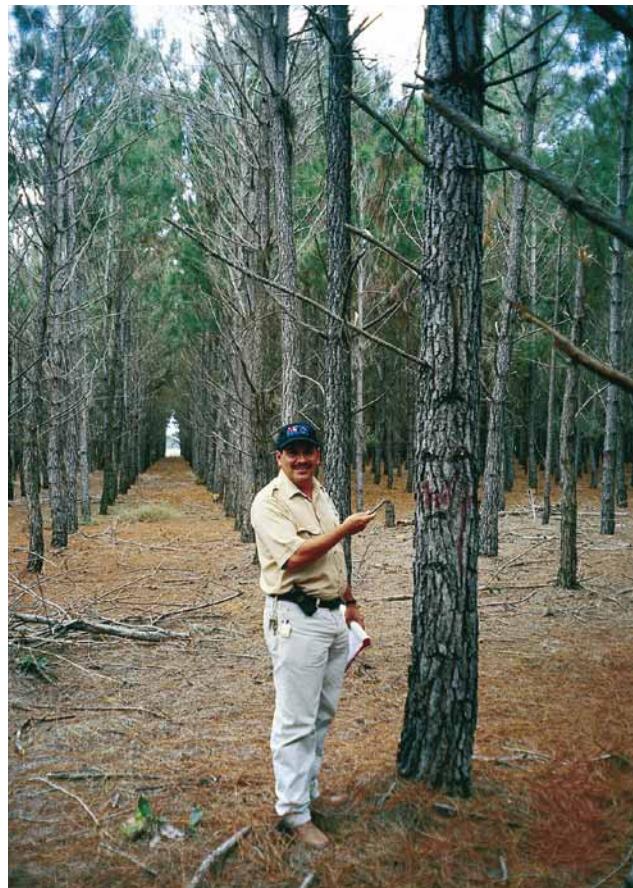
Productivity

In Brazil and Venezuela, mean height and diameter growth in CAMCORE tests at 8 years of age were 12 m and 18 cm, respectively, resulting in an average productivity of 14 to 15 $m^3/ha/yr$. In the Llanos of eastern Colombia, mean height and diameter were 8 m and 13 cm, respectively with a yield of approximately 4 to 5 $m^3/ha/yr$. The Colombian tests were planted in the wet Llanos (2200 mm of ann. precip.) in the eastern part of the country on soils that were 90% sand and 10% clay.

Provenance Performance

Best Linear Unbiased Predictions (BLUP) of provenance effects for volume are shown in Table 2-3. The best provenance sources for volume in the CAMCORE tests across Brazil, Colombia, and Venezuela were Limón, Guanaja, and Gualjoco, Honduras and Alamikamba, Nicaragua. Overall, coastal sources grew better than inland sources on wetter sites, and did as well as inland sources on dry sites (with the possible exception of Gualjoco). Limón, Guanaja and Alamikamba are coastal sources, while Gualjoco is an inland provenance. The performance of the inland Gualjoco source is surprising. The site receives 1200 mm of annual rainfall, and the stand is of average phenotypic quality. The soils appear to be quite fertile

Photo 2-9a. Above, a good tree of *Pinus caribaea* var. *hondurensis* from Guanaja Island in a CAMCORE test 13 years of age at Aracruz, Brazil. **2-9b.** Below, Orlando Rivas, PROFORCA, stands next to a tree from Limón, Honduras in a 10-year-old CAMCORE test established on a dry, sandy site in eastern Venezuela.



based on the size of the broadleaf vegetation in and around the stand. Melinda, Belize, a provenance obtained from the OFI in a seed exchange with CAMCORE, also shows promise (data not shown, see Hodge et al. 2001), but results are based only on a few families.

First generation control lots from Queensland, Australia and Zululand, South Africa were 6 to 13% better than the average of all provenances, as expected, but not better than the most productive unimproved source (although they did have much better stem form). Differences in volume of 18 to 35% were found between the best and the worst provenances.

The high performing provenances from Central America did not group by geographical region, with the exception of

Guanaja and Limón. The two locations are separated by about 60 km. The Bay Islands were connected to the Honduras mainland when ocean levels were low which may have allowed for gene exchange in the past.

The three provenances most widely planted in plantations in the 1970s and early 1980s were Mountain Pine Ridge (MPR), Belize, Poptún, Guatemala, and Alamikamba, Nicaragua. The MPR source has been shown to be of below average quality in the Oxford tests (Gibson et al. 1983); Poptún is below average to average in volume and is of very poor quality; and Alamikamba, although slightly above average, ranks far below the best sources of Limón and Guanaja. Information on previously untested provenances of relatively small geographic size will be available from CAMCORE members in the near future.

Table 2-3. Volume performance (Gain) of *Pinus caribaea* var. *honurensis* assessed at 5 and 8 years of age in Brazil, Columbia, and Venezuela. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean. Foxt33 expresses the percentage of foftailing expected in a provenance when the average provenance has 33% foftailing (from Hodge et al. 2001). Two first-generation control lots of Caribbean pine from Queensland, Australia and Zululand, South Africa were also included.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA			Foxt 33
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests	
<i>Guatemala</i>	10	Poptún	3.6	55	11	2.8	16	1	0.0	50	5	53
<i>Honduras</i>	12	Araslaya	-3.3	21	3	-2.0	1	1	-1.8	.	.	56
	13	Culmí	-0.7	38	5	-1.2	.	.	-2.3	16	2	30
	14	Dursuna	-1.5	14	2	6.5	7	1	2.8	5	1	44
	16	El Porvenir	-10.0	11	3	-12.2	7	1	-9.9	6	1	21
	18	Gualjoco	4.3	25	6	6.5	8	1	2.9	26	4	39
	19	Isla de Guanaja	9.0	98	7	0.6	34	1	7.9	52	3	38
	20	La Brea	-0.3	15	2	0.1	.	.	0.6	16	2	34
	21	Limón	7.1	38	3	11.9	.	.	23.5	39	3	30
	22	Los Limones	0.1	48	14	-0.3	8	1	0.8	53	7	23
	23	Pinalejo	-5.5	27	8	-4.7	.	.	-6.6	30	3	18
	24	Puerto Lempira	3.6	17	2	0.5	.	.	-2.3	5	1	49
	25	San Patricio	-5.0	27	8	-5.0	.	.	-7.9	35	3	26
	26	S. Ped. de Catacamas	-1.7	33	8	-2.8	.	.	-5.4	34	3	18
	27	Santa Cruz de Yojoa	-4.8	20	6	-3.4	9	1	-3.9	19	4	38
	28	Zacapa	-2.4	27	4	-2.9	.	.	-5.0	19	2	31
<i>Nicaragua</i>	30	Alamikamba	3.1	14	2	2.1	.	.	2.3	.	.	.
	31	Karawala	1.9	16	2	1.4	.	.	1.6	.	.	.
<i>Australia</i>	-	Queensland	9.7	14	2	6.3	.	.	6.5	.	.	.
<i>S.Africa</i>	-	SAFRI Zululand	8.4	62	6	8.2	41	1	12.8	36	3	24

Map key does not correspond to CAMCORE provenance codes.

Even though the majority of provenances in CAMCORE and OFI tests were different there were some similar trends in productivity. In the assessment of volume in the Birks and Barnes (1990) analysis, the ranks of the best five sources across all sites in descending order were: Laguna del Pinar (Nicaragua), Queensland (Australia), Guanaja Island (Honduras), Santa Clara (Nicaragua) and Alamikamba (Nicaragua). In the Crockford et al. (1990) analysis, the ranks of the five best sources across all sites in descending order were: Queensland (Australia), Guanaja Island (Honduras), Mountain Pine Ridge (Belize), Culmí (Honduras) and Alamikamba (Nicaragua).

Quality Traits

Forking, and in some respects foxtail percentages, are very much related to site. Forking of trees at 5 years of age in CAMCORE tests was only 6% at Santo Tomás, Venezuela (site described previously) versus values that ranged from 34 to 45% in some areas of Brazil. Foxtail percents were only 5% at 5 years at Santo Tomás and 2% at Planaltina, Brazil at 12 years of age (Moura and Dvorak 1997) versus values of 45% at some other locations. Planaltina occupies a tropical savanna (15° S, elev. 1100 m, ann. precip. 1554 mm) characterized by a distinct dry season, and well drained but infertile Oxisols. On dry sites, inland sources such as Los Limones, El Porvenir; Pinalejo and San Pedro de Catacamas had less forking and foxtailing than did sources from wetter regions. *Pinus oocarpa* also occurs at the Los Limones site (J. Perry, personal communication). One possible reason for the low percentage of foxtails of the Los Limones source is introgression of some *P. oocarpa* genes into the *P. caribaea* population. Limón, which is the best source for volume, exhibits slightly less foxtailing (30%) than the average across provenances (Table 2-3). The worst provenances with regards to foxtailing were Poptún, Guatemala and Araslaya, Honduras, both with values above 50%. These findings are consistent with Crockford et al. (1990). No trends were discernable with regards to provenance variation and stem straightness across sites. The Limón source, which has relatively good stem form for an unimproved source when grown in Latin America, is reported as being quite crooked in Australia (G. Nikles, personal communication).

Provenance x Site Interactions

Provenance by site interaction was important in Caribbean pine for both volume and quality traits in CAMCORE tests through at least age 8 years. Type B genetic correlations for provenance effects for pairs of tests within and between countries in 48 international trials averaged 0.54, which is not significantly less than family type B genetic correlations of 0.59 for the same group of trials (Hodge et al. 2001). This is in contrast with *P. tecunumanii* (Hodge and Dvorak 1999) and *P. maximinoi* (Gapare 1999), for which provenance by site interactions were much less important. Provenance variance for volume in Caribbean pine was

equivalent to 25% of the additive variance at age 8 versus 13% in *P. tecunumanii* at the same age (Hodge and Dvorak 1999, Hodge et al. 2001).

Foxtailing appears to exhibit less provenance x site interaction than does forking. Type B genetic correlations for foxtails and forking were 0.96 and 0.56, respectively (Hodge et al. 2001). Greater genetic gains should be obtainable in selections against foxtails than forking because of its higher heritability and lower degree of interactions.

Family x Site Interactions, Genetic Growth Parameters and Quality Traits

Family x site interactions were more pronounced between pairs of tests in different countries than between pairs of tests in the same country. Within-country type B genetic correlations for volume were 0.64 versus 0.53 between countries for a sample of 48 tests reported on by CAMCORE. Even though family x site interactions were significant, type B genetic correlations were sufficiently high to warrant the value of continued exchange of genetic material across location coupled with testing. Family x site interactions were greater in forking than foxtailing and followed trends described above for provenance effects.

Single-site heritabilities for volume and foxtailing at age 8 years were 0.16 and 0.16, respectively. Interestingly, volume heritabilities did not increase over time as they do in most species (see Vásquez and Dvorak 1996). Single-site heritabilities for stem straightness and forking were 0.11 and 0.10, respectively.

Age-age genetic correlations for volume were 0.53 ± 0.11 across five tests for ages 3 to 8 and 0.93 ± 0.04 across four tests for ages 5 to 8. Since mean single-site heritabilities for volume at ages 5 and 8 were nearly identical and age 5 to 8 correlations were very high, selection for age 8 volume using age 5 data would essentially be as effective as selection at age 8. The only exception to this may be on dry sites (approx. 1000 mm of annual rainfall) where crown closure does not begin until age 7 or 8 years.

DEVELOPMENT OF IMPROVED MATERIAL

Orchard Composition and History

Five major Caribbean pine orchards have contributed plant material to plantation programs in Latin America: the QFRI orchards in Queensland, Australia, the PROFORCA orchard at Santa Cruz (Lara), Venezuela, International Paper orchard (previously owned by Champion and by Jari) at Morada Nova de Minas, MG, Brazil, the Duratex (previously CAFMA) orchard at Agudos, SP, Brazil, and the Aracruz Florestal orchard at Aracruz, ES, Brazil. Although Queensland's first generation orchard was mostly Mountain Pine Ridge, Belize selections, advanced generation orchards contain a mixture of selections with origins from coastal Honduras and Nicaragua that showed superior form, wind resistance, and growth (Nikles 1980, 1996).



Photo 2-10. INPACEL researchers stand in a full-sib progeny test of *Pinus caribaea* in northern Brazil. Seeds for the trial came from the orchard at Morada Nova de Minas. Great improvement can be made in productivity and stem form of *P. caribaea* after only one generation of breeding.

The PROFORCA orchard contains clones from trees selected at Uverito in eastern Venezuela. The plantation trees at Uverito originally were planted in the middle to late 1970s and probably are of Poptún origin. Also included in the PROFORCA orchard are several CAMCORE clones from Gualjoco, Los Limones, Santa Cruz de Yohoja and El Porvenir.

Genetic material of two distinct origins comprises the International Paper orchard in central Brazil: 20% of the orchard is material of Mountain Pine Ridge origin collected in seed orchards and seed stands from South Africa and Queensland, Australia. The remaining 80% of the orchard are plantation selections from Jari Florestal (Pará, Brazil). The Jari plantations were established primarily with seed from Alamikamba, along with a small amount of seed from Mountain Pine Ridge. Subsequent orchard roguing that was based on progeny tests established at AMCEL (Amapá State) has heavily favored clones of the Alamikamba origin.

The Duratex orchard consists of selections from São Paulo and Paraná States. The seed for many of these plantations came from collections of Mr. Horst Schuckar, who worked for the Freudenberg family, the owners of CAFMA who eventually sold their company to Duratex. Schuckar made his first seed collections in Poptún, Guatemala in 1959 only after he was unable to obtain Caribbean pine seeds from Belize because Brazil was not a member of the British Commonwealth (H. Schuckar; personal communication).

Introductions of Caribbean pine from Poptún into the Agudos area of Brazil continued through 1972 and initially were quite promising. However, as selective logging continued at Poptún, the quality of the seeds decreased.

The Aracruz orchard is an extension of the Duratex orchard, and was planted at Aracruz to take advantage of the early and heavy cone and seed production in that area. Because of management changes, both the Duratex and Aracruz orchards will apparently cease to distribute Caribbean pine seeds in the future (G. Rezende, personal communication, H. Schuckar; personal communication). Therefore, the remaining viable Latin American orchards, International Paper and PROFORCA, are of predominantly Alamikamba and Poptún origin, with some Mountain Pine Ridge, Belize and Honduran material. Efforts are being made by CAMCORE members in Venezuela to establish a breeding orchard of the best Guanaja and Limón selections from Cooperative trials in the country.

The most advanced breeding and production seed orchards of Caribbean pine are in Queensland, Australia. Tree improvement programs began there in the 1950s.

Flowering

Male and female strobili are produced as early as 3 years after grafting in optimum seed orchard locations and in areas that are extremely stressed. In the latter situation, heavy flowering may not occur again until age 8 or 9 years.



Photo 2-11. The best source of *Pinus caribaea* in Central America is Limón, Honduras, and is in great danger of being destroyed.

Normally, moderate flowering begins at age 5 years and the first cone collections are made around age 7. Generally, grafted trees do not produce flowers earlier than plantation trees. The seed orchard at Aracruz Florestal, Espírito Santo is exceptional in that it began producing heavy cone crops only 5 years after grafting. Flowering of Caribbean pine in Venezuela, when planted near 1000 m elevation, occurs from November to January (Rivas et al. 1995), much like in the natural stands of Central America. Cone collections are 19 to 20 months later in September. Flowering of Caribbean pine occurs in central Brazil in June, July and August, and cone collections are in December and January, approximately 18 months later (L. Duda, personal communication).

Seed Production

Seed production in Caribbean pine is practically nonexistent at low elevations near the equator but

improves with increasing latitude and with increasing elevation of the seed orchard site (Gallegos 1981). For example, seed production averaged one to two filled seeds per cone at 15 years in PROFORCA seed stands established at 10° N latitude and 50 m elevation in eastern Venezuela. A seed orchard was subsequently established in the west central part of the country at approximately 11° N and 950 m elevation; seed production at this site was approximately 70 filled seeds per cone 8 years after orchard establishment. Low seed yields in the eastern llanos appear to be a consequence of poor synchronization between release of pollen and female flower receptivity. The most copious seed production in Caribbean pine orchards appears to be along the east coast of Brazil in the states of Espírito Santo and Bahia and coastal Queensland. On a poor flowering site, Caribbean pine seed orchards may produce only 3 kgs of seed/ha at 10 years, while on good sites this value may reach 40 kg of seed/ha.

CONSERVATION

IN SITU CONSERVATION

Genetic Diversity

Molecular marker work using RAPD technology on a small number of Caribbean pine provenances did find broad regional differences in genetic diversity patterns between the northern and central part of the Caribbean pine range (Furman 1997). Rangewide genetic diversity studies based on marker data are needed in order to assist the

prioritization of *in situ* efforts. Current information on the physical status of the stand and/or provenance performance suggests that the priorities for *in situ* conservation should include Guanaja, Roatán, Limón, Gualjoco, Ejido Caobas, El Pinal, and Laguna del Pinar.

Conservation Status

CAMCORE classifies the conservation status of *P. caribaea* var. *hondurensis* in natural stands as **vulnerable**. The two

largest contiguous areas of the species, Poptún, Guatemala and the La Mosquitia region of eastern Honduras and Nicaragua, are still relatively intact despite the continued operation of sawmills, annually occurring fires and extreme hurricane damage in some coastal areas. The road to the Petén has been improved over the last 20 years, making it easier to transport timber from Poptún to markets in Guatemala City. Some areas of La Mosquitia remain at a **low risk** simply because they are so far from major cities and because roads for transport are so poor. The exception is from Karawala south through Laguna del Pinar, the southernmost extent of *P. caribaea* var. *hondurensis*. Concerns were expressed 30 years ago about the conservation status of populations located on the extremes of their geographic ranges by Lamb and Cooling (1970). Laguna del Pinar, the southernmost site, is **critically endangered**. Only isolated tall spindly trees too thin to climb remain on the slight rises between swamps (Donahue 1993). Cone crops are small to nonexistent.

Coastal Belize populations of *P. caribaea* var. *hondurensis* are **endangered** or **critically endangered**. For example, the Melinda population in Belize exists only in the form of a few isolated trees because it has been logged and replaced by plantations. A number of roads have been constructed in coastal Belize in the last 10 years, making the pines more accessible to loggers and transport to the market easier (Romero 1999b). The Mountain Pine Ridge *P. caribaea* remains in relatively good condition but some areas may be opened to contractors for timber extractions in the near future. The San Pastor Pine Ridge stand, which was selectively harvested in the 1980s, is relatively open and has a high fuel content in the understory. The conservation status of this area is **vulnerable** because it can be accessed easily by future harvesting ventures.

Hurricane Mitch ravaged a number of populations along the northern and eastern coast of Honduras in 1998. The two most productive *P. caribaea* provenances, Guanaja Island and Limón, are **endangered** to **critically endangered**. Although the Guanaja stands were about 1700 ha in size before the hurricane, the areas were being reduced in size each year (Cornelius et. al. 1994). The best stands on the island were on the wetter draws, which were protected somewhat from fire. The hurricane destroyed much of the pine forests on both Guanaja and Roatán Islands. The Limón stands were being selectively harvested prior to Hurricane Mitch, and the only desirable remaining stands were situated on private property. When CAMCORE made its last cone harvest in July 1998, these landowners were in the process of converting some of the pine forests to oil palm plantations. After the hurricane, little remained of the Limón stands where CAMCORE made its original collections in 1993 and 1998. After a reconnaissance trip in February 2000, CAMCORE estimated that Hurricane Mitch destroyed 60 to 75% of the Limón stand. Replanting

efforts are underway at both locations. There is concern that in the rush to reforest the regions, foreign seed sources may be used as planting stock.

The inland dry sources of *P. caribaea*, such as Los Limones, El Porvenir and Pinalejo, Honduras, have been substantially degraded by constant overgrazing, annual fires and repeated resin tapping. The conservation status of these stands is **vulnerable** to **endangered**. The fate of these provenances is further complicated by the low productivity of these sources in international trials and the difficulty in convincing groups to increase their conservation efforts.

The isolated populations of Ejido Caobas, El Pinal, and Monteca, El Salvador are somewhat protected. Ejido Caobas, which is only about 4 ha in size and contains about 150 trees, is practically inaccessible during the wet season (J. Diaz, personal communication). Fires remain a problem during the dry season. The El Pinal, Guatemala stand, which is approximately 1.0 km² in size, is on the property of Tikal National Park and is under no immediate threat from humans. However, it is being encroached upon by broadleaf species and unless managed with controlled burns may cease to exist in the next 20 years. The Monteca, El Salvador, source, which was discovered by following a new road into the area, will be subject to increased colonization and the human pressures that follow improved access.

EX SITU CONSERVATION

If one considers the seed collections of the OFI, DANIDA, and CAMCORE together, some representation of most provenances of Caribbean pine in Mesoamerica are found in trials somewhere in the world. CAMCORE alone has a number of conservation plantings established worldwide, all maintained by individual pedigrees. One estimate suggests that 99% of the genetic diversity of Caribbean pine had been conserved ex situ (CAMCORE Annual Report 1996). The estimate was based on the following assumptions: a) a seed collection every 75 km within the species natural distribution is necessary to ensure a good sampling of the genetic diversity throughout the range, b) a sample of 10 trees per provenance captures alleles present at middle to low frequencies (CAMCORE typically samples 25 trees per provenance), and c) progeny from at least 10 mother trees per provenance are established in at least three locations with survival of at least 80%. Assumption: (b) was based on isozyme data from small populations of *P. tecunumanii* in Guatemala (Dvorak et al. 1999). It will be important to develop a long-term strategy on how to handle old provenance tests and conservation plantings once they have reached rotation age. The highest priority in ex situ conservation is more comprehensive collections of sources of limited geographic extent (e.g., El Pinal, Ejido Caobas, Laguna del Pinar; and Roatán) that are unlikely to become important constituents in breeding populations of commercial Caribbean pine.

CONTRIBUTORS

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C h a p t e r 3



PINUS CHIAPENSIS

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OVERVIEW

TREE DESCRIPTION

Pinus chiapensis (Mart.) Andresen (syn. *Pinus strobus* var. *chiapensis* Mart.) is a long-lived, medium to very large tree that ranges from 25 to 50 m in height and from 60 to 120 cm dbh at maturity. When young, the species exhibits a pyramidal crown that becomes rounded as it matures. This white pine is characterized by long, horizontally spreading branches that occur in regularly spaced whorls with clear internodes up to 1.0 m long (Loock 1950). Juvenile trees have smooth, gray to green bark, which becomes rough, highly fissured and a darker gray as the tree matures. The foliage of *P. chiapensis* is yellow-green at the juvenile stage and grayish-green when mature. Needles are 5 to 15 cm long (mean = 10 cm) and occur in fascicles of five. Throughout most of its natural distribution in Mesoamerica, cones for this species mature from mid-August to mid-September (Donahue et al. 1991). The cones are cylindrical in shape when closed, 6 to 18 cm long (mean = 11 cm), and resinous (Hernández 1986). Average seed potential for *P. chiapensis* is 188 seeds per cone with approximately 60,000 seeds per kg. However, seed size changes depending on the location of the collection site. The wood is white and of low but uniform density, and is used by local villagers for a wide range of products, including light construction, pallets, furniture, wood carvings, and interior wood work.

CONSERVATION STATUS

Based on field observations, the overall conservation status of *P. chiapensis* in its natural range is **endangered**. Populations of the species in the Sierra Madre del Sur in

Oaxaca and Guerrero, and the Sierra Madre Oriental in Puebla and Veracruz are **vulnerable** to **critically endangered**. Populations in Chiapas and Guatemala are less than 15 ha in size and are **critically endangered**.

TEST STATUS

Sixteen provenances and 380 mother trees of *P. chiapensis* were sampled in southern Mexico and Guatemala in the 1980s. Seeds for 24 *P. chiapensis* tests were distributed and planted by CAMCORE members in Brazil, Colombia, South Africa and Venezuela. Five- and 8-year results are available from nine tests.

BEST PROVENANCES

Results from 8-year-old tests in Brazil, Colombia and South Africa suggest that the La Trinidad, Chiapas, and Teotlaxco, Oaxaca provenances are some of the most productive. Poor performance by some sources seems to be directly related to inbreeding as a consequence of small natural population size.

SUITABLE PLANTING SITES

A good *P. chiapensis* site has well-drained, fertile soils, is located at altitudes ranging from 550 to 2000 m, and receives at least 1100 mm of annual rainfall. Precipitation should be evenly distributed throughout the year. *Pinus chiapensis* also will perform acceptably on infertile soils as long as they are deep and well drained and rainfall amounts are adequate and well distributed. Levels of soil moisture, rather than levels of soil fertility, determine species survival. The species has failed on sandy soils with well-defined dry seasons. *Pinus chiapensis* is not frost resistant.

Photo 3-1. Pocket of *Pinus chiapensis* trees at Barillas, Guatemala.

ADVANTAGES OF *PINUS CHIAPENSIS*

- After the root system is established, it is one of the fastest growing Mesoamerican pines.
- Shades out weed competition in plantations within 5 years on most sites.
- Is relatively disease free.
- Produces a white wood of uniform quality that can be used for a number of interior construction purposes, as well as for decorative roofing shingles, wood carvings, etc.
- Some provenance results are available.
- Is easy to graft.

DISADVANTAGES OF *PINUS CHIAPENSIS*

- May require as long as one year in the nursery before outplanting size is reached.
- Grows slowly the first three years and needs good weed control.
- Performs best on very fertile sites, thus must compete with agricultural crops or eucalypts for land use.
- Occasionally exhibits top dieback during periods of rapid growth.
- Wood is well suited for special products but produces low pulp yields and may not be acceptable for some structural products.
- Is not frost resistant.
- Is not drought resistant in the juvenile stage.

NATURAL STANDS

EVOLUTION

Pinus chiapensis is a white (soft) pine that apparently evolved from *P. strobus* in eastern North America. It is considered an ancient species, and present-day populations are viewed as relictives of what was once a much broader natural distribution. It has probably been separated from *P. strobus* for millions of years. As is the case with *P. strobus*, current climatic conditions in Mesoamerica are against the maintenance of *P. chiapensis* as a major species (see Wilson and McQuilken 1965). However, if recent trends in global warming continue, this situation may change.

DISTRIBUTION

Pinus chiapensis is found in a series of disjunct, often highly degraded, populations in Chiapas, Guerrero, Oaxaca, Puebla and Veracruz, Mexico and in the departments of Huehuetenango and El Quiche, Guatemala (Figure 3-1). It is most abundant on the lower slopes and foothills of the Sierra Madre del Sur in Oaxaca and Guerrero, which receive moisture from the Pacific Ocean, in warm valleys and canyons that surround the highlands of Chiapas, and on the eastern slopes of the Sierra Madre Oriental where moisture is received from the Gulf of Mexico (Rzedowski and Vela 1966). The species is most prominent at elevations from 1200 to 1800 m throughout southern Mexico and Guatemala, but occurs as low as 150 m altitude in the Isthmus of Tehuantepec, Oaxaca

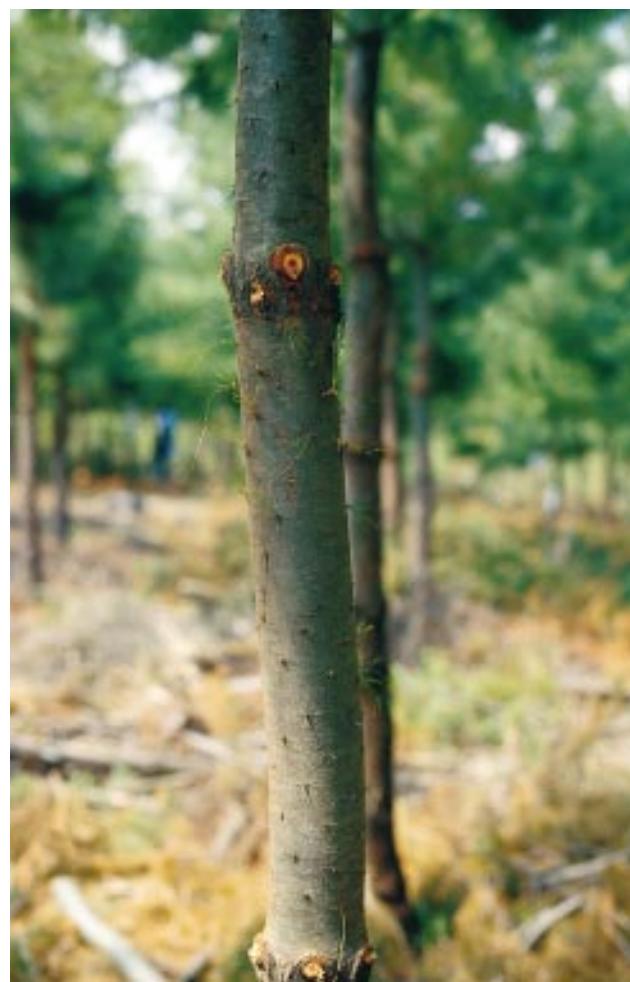


Photo 3-2. Juvenile *Pinus chiapensis* with pyramidal crowns in a natural stand in Guatemala. *Pinus chiapensis* is very similar morphologically to its North American relative, *P. strobus*.

(Donahue et al. 1991). The upper altitudinal limit for the species is 2300 m.

The populations of *P. chiapensis* in northwestern Guatemala and Chiapas are less than 15 ha in size. In southern and eastern Mexico, populations are sometimes as large as 50 ha but are broken into small pockets or bands of trees of less than 10 ha in a pattern that follows the topography of the humid valleys and canyons. Some of these very small stands are only several hectares in size and have been separated from the rest of the population by overcutting and grazing.

CAMCORE began a rangewide collection of the species in the mid-1980s. Populations that were found during explorations were sampled whenever feasible. Because of poor cone crops and the extreme isolation of some natural populations, cone collections were not possible at every site. Stands that were identified by CAMCORE but from which no collections were made are listed in Table 3-1. After the main *P. chiapensis* collection efforts in southern Mexico and northwestern Guatemala in the mid-1980s, several additional large populations were located in Guerrero during explorations for other species, such as *P. patula* var. *longipedunculata* (Donahue 1995). Collections from these populations still need to be made. Additional small populations of the species undoubtedly exist. Recently, a 3-hectare stand was discovered at San Francisco Coatlán, Miahuatlán, Oaxaca by a local forester (Dominguez-Alvarez 1996). Sixteen provenances and 363 mother trees were sampled during CAMCORE's collection effort, making it the largest and most complete collection made for this species (Table 3-1).



Photos 3-3a and b. Above, green bark of juvenile *Pinus chiapensis* tree. Below, Claudio Balocchi (Arauco) stands next to a mature *P. chiapensis* tree with thick, gray bark in a natural stand in Oaxaca, Mexico.

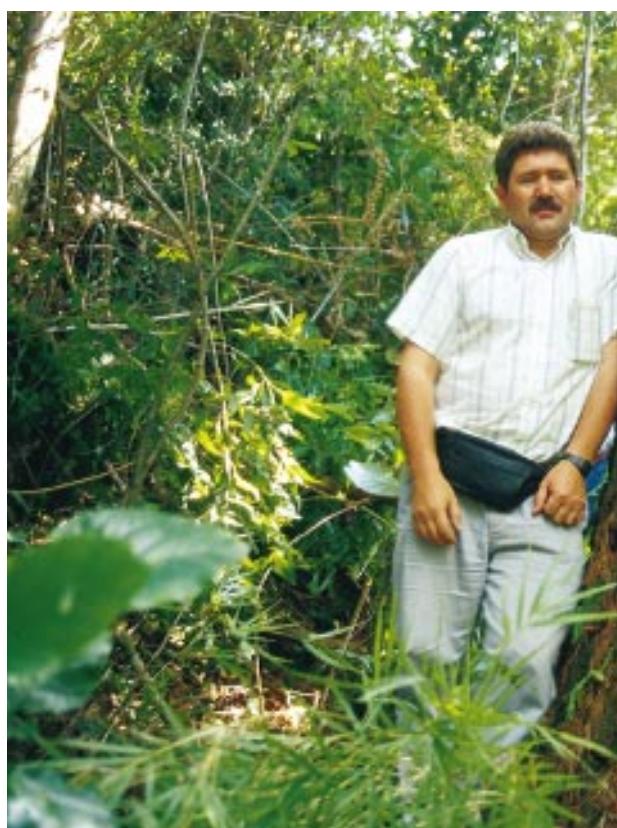


Table 3-1. *Pinus chiapensis* collections and explorations made by the CAMCORE Cooperative in Mexico and Guatemala.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/year)	No. of Trees
1	Barillas	Huehuetenango	Guatemala	15° 48' N	91° 18' W	1450 - 1740	2326	35
2	Guevea de Humboldt	Oaxaca	Mexico	16° 48' N	95° 22' W	823 - 1010	1300	19
3	La Libertad	Chiapas	Mexico	16° 53' N	92° 32' W	1800 - 2025	1975	24
4	La Trinidad	Chiapas	Mexico	17° 02' N	92° 45' W	1162 - 1530	1975	20
5	Larrainzar	Chiapas	Mexico	16° 52' N	92° 41' W	1725 - 1860	1975	29
6	Pohlo	Chiapas	Mexico	16° 56' N	92° 32' W	1340 - 1380	1975	39
7	Pueblo Nuevo	Chiapas	Mexico	17° 06' N	92° 52' W	1740 - 1780	1500	20
8	Santa Cruz de los Pinos	Chiapas	Mexico	16° 49' N	93° 27' W	850 - 1015	1500	23
9	San Gabriel Mixtepec	Oaxaca	Mexico	16° 11' N	97° 05' W	1250 - 1800	1750	26
10	Yerbabuena	Oaxaca	Mexico	17° 58' N	96° 45' W	1070 - 1560	2450	39
11	Santiago Tutla	Oaxaca	Mexico	17° 11' N	95° 25' W	470 - 690	2718	29
12	San Juan Cotzal	El Quiché	Guatemala	15° 27' N	91° 13' W	980 - 1430	2225	20
15	Highway 175	Oaxaca	Mexico	17° 36' N	96° 23' W	2000 - 2030	1893	8
16	Nopoala	Veracruz	Mexico	19° 54' N	97° 13' W	710 - 960	2287	22
17	Hierba Santa	Guerrero	Mexico	17° 31' N	99° 58' W	1850 - 1940	2052	5
18	Teotlaxco	Oaxaca	Mexico	17° 28' N	96° 20' W	1150 - 1400	2517	22
19	Guaquitepec	Chiapas	Mexico	16° 59' N	92° 14' W	1200 - 1400	1750	0*
20	Tenejapa	Chiapas	Mexico	16° 52' N	92° 28' W	1290 - 1490	1750	0*
21	Pantelhó	Chiapas	Mexico	17° 01' N	92° 28' W	1120 - 1320	1750	0*
22	San Cayetano	Chiapas	Mexico	16° 59' N	92° 48' W	1110 - 1310	1350	0*
23	Los Angeles	Chiapas	Mexico	16° 16' N	93° 38' W	1000 - 1300	1350	0*
24	Tierra y Libertad	Chiapas	Mexico	16° 12' N	93° 40' W	1210 - 1410	1750	0*
25	Fco. I. Madero	Chiapas	Mexico	16° 49' N	93° 46' W	850 - 1050	2300	0*
26	Ciénaga de León	Chiapas	Mexico	16° 41' N	94° 00' W	1000 - 1300	2300	0*
27	Jilguero	Guerrero	Mexico	17° 30' N	100° 00' W	2000 - 2300	1750	0*
28	El Guajolote	Guerrero	Mexico	17° 09' N	94° 41' W	1500 - 1700	1500	0*
29	Sierra el Conejo	Guerrero	Mexico	17° 38' N	100° 36' W	2000 - 2200	1800	0*
30	Sta. Ma. Chimalapa	Oaxaca	Mexico	16° 54' N	94° 41' W	150 - 200	2300	0*
31	San Pedro Teutila	Oaxaca	Mexico	17° 58' N	96° 43' W	1100 - 1200	1750	0*
32	San Miguel Copala	Oaxaca	Mexico	17° 13' N	97° 59' W	1520 - 1720	1700	0*
33	Zapotitlán	Veracruz	Mexico	19° 50' N	97° 09' W	700 - 1800	1700	0*
16	Provenances	6 State/Depts.	2 Countries	15 - 20° N	91 - 100° W	470 - 2030	2021	380

* Site visited, collections not made.

Map code does not correspond to CAMCORE provenance code for sites only visited.

Figure 3-1. CAMCORE collections of *Pinus chiapensis* in Mexico.

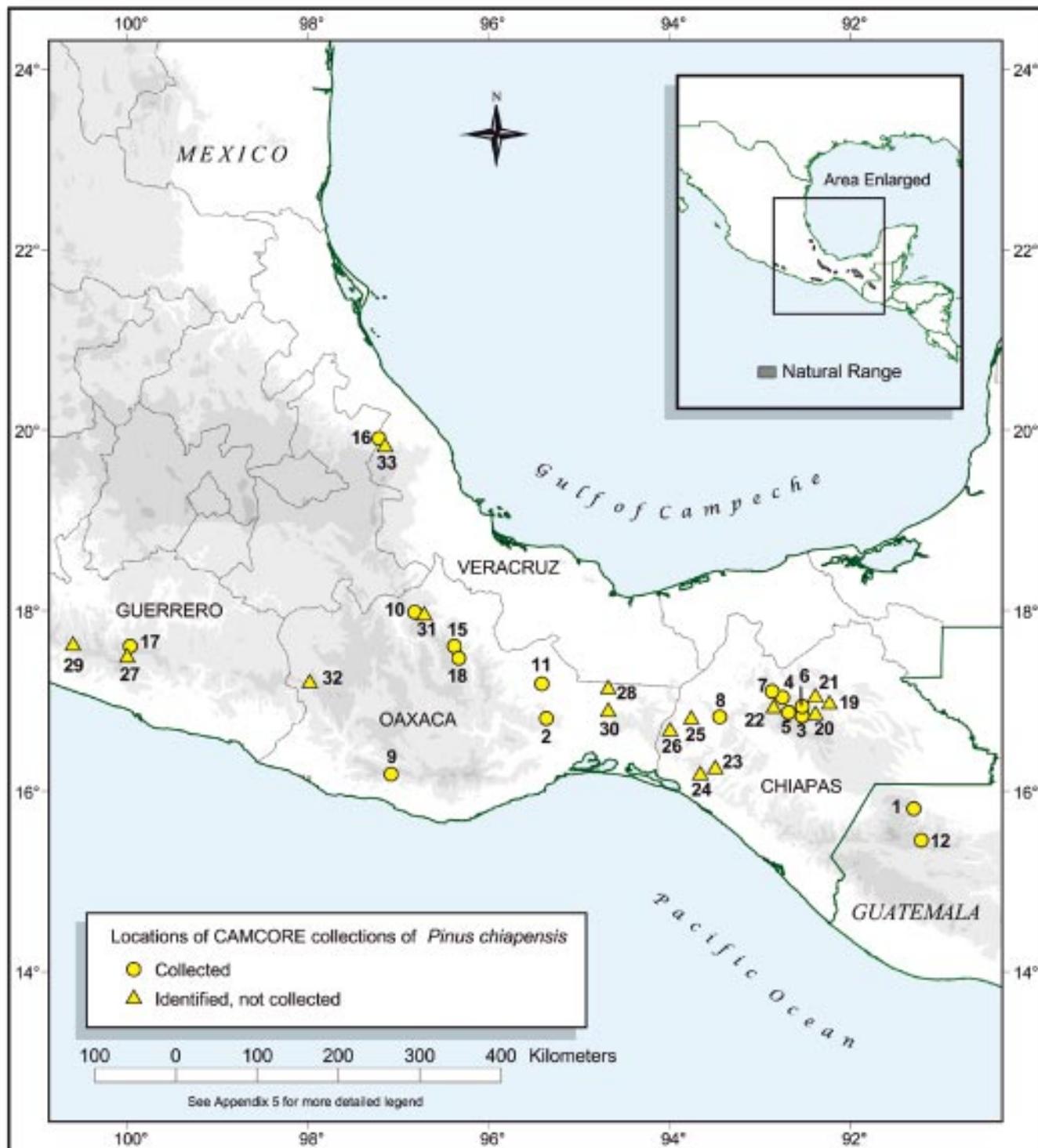


Table 3-2. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus chiapensis* site at Nopoala, Veracruz.

Nopoala	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	18.7	19.2	21.2	24.0	25.6	26.5	25.6	25.9	25.1	23.6	20.9	18.9	22.9
Mean Rain mm	75	82	112	130	148	205	275	190	438	287	214	131	2287

Based on 40 years of data taken at Puente Henríquez (510 m elev.) located 4 km from the collection site.

CLIMATE

Pinus chiapensis occurs mainly in areas that are under the influence of tropical and subtropical climates. These areas receive an average of 1500 to 2000 mm of annual rainfall with an average temperature between 18 to 23 °C. Rainfall is heaviest from May to October, with a dry season of three to five months (< 40 mm of rain per month) occurring from December through April. Some locations receive additional precipitation from morning and evening fogs. Maximum temperatures reach 40 to 42 °C, with minimums of 4 to 6 °C at collections sites in southern Mexico (SPP 1970).

Accurate precipitation and temperature information is difficult to obtain for individual *P. chiapensis* collection sites because populations are often isolated and located far from meteorological stations. Based on CAMCORE field observations, *P. chiapensis* does not occur on sites that are subject to frosts. In areas where the species is found above 2000 m altitude, site aspect is southerly, or the topography promotes cold air drainage away from the stands (Donahue et al. 1991). On rare occasions, mature trees in plantations in southern Brazil and South Africa have been known to withstand air temperatures near the ground of -3 to -5 °C without problems. However, any apparent resistance is probably due to avoidance (good air drainage at crown level) rather than an ability to survive subfreezing temperatures. In an assessment of cold tolerance of *P. chiapensis* in Argentina, Picchi (1967) found the species very sensitive to frost damage. All 5-year-old trees were killed when nighttime temperatures dropped to -8 °C for several hours during a one-week cold spell.

SOILS

Pinus chiapensis occurs predominantly on well-drained sandy loams and sandy clay loams, with subsoils that are loams to clay loams (Donahue et al. 1991). Soils associated with *P. chiapensis* have pH values ranging from 4.5 to 6.0, and are more than 1.0 m deep. The species tends to occupy some of the most naturally fertile sites in all of Central America and Mexico. Andisols and Alfisols are the predominant soil orders on which the species occurs. Unlike species such as *P. caribaea* var. *hondurensis*, which grows on a broad range of sites, *P. chiapensis* is found at locations that are ecologically similar throughout its natural range.

CAMCORE conducted a detailed soil assessment at the Barillas, Guatemala site, which is thought to be

representative of most *P. chiapensis* locations. At Barillas, there is an organic layer of 4 cm, an 18 cm sandy clay loam A horizon (pH 5.1), and a 125 cm loamy B horizon (pH 5.3) that is underlain by parent material (pH 7.1). The base saturation level of the mineral horizons ranged from 41 to 100%. The phosphorus level in the mineral horizons is limiting (1 to 2 kg per hectare), but nutrients occur in amounts that are ample to compensate for any deficiencies (Donahue et al. 1991). Locally, *P. chiapensis* sites are highly sought after by farmers for crops that demand high fertility like coffee, plantain, and cardamom.

REPRODUCTIVE BIOLOGY

Flowering of *P. chiapensis* begins during March and April in Mesoamerica (Patiño 1973). Female flowers are found most often in the upper portion of the crown. In northern North America *P. strobus* has a tendency to produce a much greater proportion of female rather than male flowers during its first 20 to 30 years (Wendel and Smith 1990). The same trend likely exists in *P. chiapensis* natural stands, but more observations are needed to confirm this phenomenon. Cones mature in August, about 18 months after pollen flight. In natural stands, cone production probably does not begin before age 15 years. In studies in southern Mexico, Martínez (1998) found that cones and seeds were produced only on trees with a dbh greater than 26 cm. Cones occur on long, thin peduncles, are not persistent, and can be removed by simply shaking a tree's branches. They are 6 to 18 cm long (mean = 11 cm) and 1 to 2 cm wide (Hernández 1986). Cones turn brown at maturity and exude a great deal of resin when ripe. Throughout the natural distribution of the species, cones usually ripen from mid-August to mid-September. Seed dispersal begins around mid-September, which is during the height of the rainy season (Donahue et al. 1991). Cone crops are generally heavy, with mature trees frequently producing as much as 2 kg of cleaned seed each. Individual cones have between 47 and 73 filled seeds per tree (Martínez 1998). Average seed potential is 188 seeds per cone, yielding a seed efficiency rate of approximately 32%. There are approximately 60,000 seeds per kg.

Like most Mesoamerican pines, *P. chiapensis* has its share of cone and seed pests. Insects observed on the species in the field include *Megastigmus* spp. (seed chalcids), wasps that oviposit through the cone scales into developing seeds, and an assortment of moth and beetle larvae that feed on developing seeds (Donahue et al. 1991).



Photo 3-4. CAMCORE field teams take wood samples from a *Pinus chiapensis* tree in Guatemala. Average wood density of trees in most populations is about 350 kg/m³.

ECOLOGY AND ASSOCIATED SPECIES

Altitude, soil moisture, and frequency of fire define the distribution of *Pinus chiapensis*. The most important of these defining characteristics may be soil moisture (Donahue et al. 1991). *Pinus chiapensis* cannot withstand long periods of drought, especially in the early stages of its development.

As mentioned previously, *P. chiapensis* occurs in warm, moisture-laden valleys and canyons on fertile soils, which may be shallow or deep. It is common to see large, mature trees surrounded by dense broadleaf vegetation. Apparently, fires occasionally enter these areas, destroying broadleaf species and exposing mineral soils. *Pinus chiapensis* naturally regenerates into pine thickets, much like *P. patula*, and, by its dense stocking, prevents the establishment of invading vegetation. The species appears to be partially shade tolerant in the juvenile stages of development and can grow in disturbed areas in hardwood forests. However, light intensity becomes critical to the survival and growth of the pine seedlings after the establishment period. Studies on the effects of light intensity on *P. strobus* probably apply to *P. chiapensis* as well. Wendel and Smith (1990) suggest that at light intensities below 10 to 13% of full sunlight, *P. strobus* survival is uniformly poor and that at least 20% sunlight is needed to keep seedlings alive. By about age three years, the root system of *P. chiapensis* is well established. At this time, the tree enters a period of rapid terminal shoot growth that

lasts for several years. During this period, height growth occurs at a rate of 2 to 3 m per year, which places *P. chiapensis* above the hardwood canopy. The large, solitary *P. chiapensis* trees in tropical broadleaf forests are not necessarily remnants from selective logging operations but instead may represent the species' capability to establish itself in the openings of hardwood forests (Dvorak 1990). When large areas of mineral soil are exposed and pine thickets form, pure stands of the species develop, with both broadleaf and other pine species occurring on the fringes. The pine thickets maintain a high level of humidity and reduce the risk of intense fire; the dense crowns and close spacing keep sunlight to a minimum, thus reducing understory competition and the accumulation of potential fuel. As *P. chiapensis* trees mature, the bark thickens and offers some additional protection from fires.

Above 2300 m, the distribution of *Pinus chiapensis* is limited by frost. Large amounts of herbaceous competition, poor drainage and lack of fires may limit its distribution below 150 m altitude.

Pinus chiapensis trees grow rapidly in natural stands. CAMCORE sampled 15 trees at Barillas, Guatemala with an 11-mm increment borer. At 30 years of age, height growth averaged approximately 1.0 m/year and diameter increment about 1.6 cm/yr (Dvorak and Brouard 1987). Loock (1950) reported even more impressive diameter growth rates of 2.5 cm/yr measured on cut stumps in Mexico.

Conifer species found growing with *P. chiapensis* on coarser soils at middle to low elevations include *P. maximinoi*, *P. devoniana*, *P. oocarpa* and *P. pringlei*. On high elevation mesic sites, *P. ayacahuite*, *P. patula* var. *longipedunculata*, *P. pseudostrobus*, *P. tecunumanii*, and *P. teocote* have been observed. *Liquidambar styraciflua*, a broadleaf species that originated in eastern North America and is an indicator of fertile soil, is found at many *P. chiapensis* sites (Donahue et al. 1991). The tree fern *Cyathaea mexicana* is commonly found in association with *P. chiapensis* at the more humid sites.

WOOD QUALITY IN NATURAL STANDS

Pinus chiapensis produces a wood that is white and of uniformly low density. In a study that included 135 trees sampled from three provenances in Chiapas, Oaxaca, and Veracruz, Yañez and Caballero (1982) found wood density in 30- to 35-year-old trees to range from 330 to 360 kg/m³, a difference of about 10%. More variation in density was found within than between provenances. In a 12-tree

sample from Barillas, Guatemala, CAMCORE found that mean wood density ranged from 344 kg/m³ in the juvenile core (rings 1 to 10) to 358 kg/m³ in the mature wood (rings 11 to 40), a difference of only 4% (Dvorak and Brouard 1987). Tracheid length ranged from 2.7 to 6.9 mm (mean = 3.7 mm) for trees from San Juan Cotzal, Guatemala (CETEFOR 1972). Because of its relatively uniform density from pith to bark, the *P. chiapensis* wood does not shrink or warp appreciably during kiln drying. Local woodcutters like the species because of its stability during the process of making wood carvings and furniture and because the trees are easier to cut with an ax than are the hard pines. At Barillas, Guatemala, it takes three men seven days to chop down a large *P. chiapensis* tree and cut it into planks with a two-man hand saw. The wood is also used for light construction, window frames and doors, and interior moldings. It accepts paint, stains well and does not easily split when nailed. The species has occasionally been used for Christmas trees (Lara-Rubio 1994).

PLANTATIONS

NURSERY PRACTICES

Seed Handling

Storage and handling of *P. chiapensis* seed can be more difficult than for other pine species. As mentioned previously, seed collection in Mesoamerica occurs at the height of the rainy season. Consequently, the moisture content of the seeds should be reduced to between 6 and 9% before they are placed in cold storage (approx. 4 °C). Lamb (1965) recommends against dewinging seeds because of their susceptibility to fungal attack. CAMCORE has not found fungal attack to be a major concern, but such problems could develop in areas of high humidity. Average germination of seeds collected in natural stands in Guatemala is 66% (Donahue et al. 1991).

A major problem in handling *P. chiapensis* seed is the speed at which it loses its viability when maintained in cold storage. After one year of storage, viability may fall to 50% and after 3 years may be less than 5%. Storing seeds at moisture content above 10% may contribute to rapid loss in viability. However, more research is needed to determine the actual cause of this problem.

Containers and Growth Media

Pinus chiapensis has been raised in trays, Jiffy® pellets and plastic bags of varying dimensions. In Guatemala and southern Mexico, it is common to raise seedlings in large black plastic bags using rich topsoil from nearby fields. Smurfit Cartón de Colombia uses 40-tube trays, each tube with 125-cm³ capacity. They also use a Jiffy® peat pellet with a capacity of 34 cm³. Tubes are filled with a media composed of equal parts composed sawdust, carbonized ash from boilers at the mill, and mineral subsoil mixed with

organic matter (M. Arce and V. Betancur; personal communication). The pH of the medium ranges from 5.5 to 6.0. Seeds are germinated first and then pricked into containers. SAFCOL (South Africa) successfully uses composted pine (*P. patula*) bark. At Klabin, seeds are sowed in tubes with 56-cm³ capacity filled with a media composed of 25% vermiculite and 75% composted pine bark (I. Fier; personal communication).

Seedling Management

Some nursery managers have had difficulty raising *P. chiapensis* seedlings because they have failed to realize that the species develops differently from the fast growing tropical hard pines like *P. caribaea* var. *hondurensis* and *P. tecunumanii*. *Pinus chiapensis* grows to a height of approximately 10 cm and then slows or stops aboveground growth to allow for the development of critical mass of lateral roots. After the root system is established, shoot growth resumes. In contrast, most tropical hard pines grow continuously in the nursery. Nursery managers, not understanding the growth phases of *P. chiapensis*, have applied heavy doses of fertilizer to the plants during their resting stage, which can burn and/or kill the seedlings, and have overwatered and flooded their root systems.

CAMCORE has examined root system development in *P. chiapensis*. Dvorak (1990) found that *P. chiapensis* produces fewer but longer lateral roots than the hard pines. Consequently, larger rather than smaller container sizes seem better for the species. Fibrous short roots of *P. chiapensis* comprise approximately 12% of the lateral root surface area of 25-cm-tall seedlings versus the 36% observed for subtropical hard pines of the same height

(Dvorak 1992). The root architecture in *P. chiapensis* may explain the lack of response to fertilizer treatments in the nursery and suggests that shoot height in the nursery is not a good indicator of belowground root development. The root architecture of this species may also explain why mortality is often high the first year after field planting in many locations (see Survival).

Pinus chiapensis responds well to root pruning. In a study at North Carolina State University, seedlings were root pruned when they reached a 23.5-cm shoot height (Dvorak 1992). The root pruning reduced shoot height growth below that of seedlings that were not root pruned in the first month. After the initial month, however, root pruned seedlings grew faster than nonpruned ones (Dvorak 1992). Possibly the greatest effect of root pruning was on mycorrhizae; pruned seedlings had 70% more mycorrhizae per mm² than nonpruned seedlings.

The species requires 10 to 12 months to reach plantable size under Smurfit Cartón de Colombia's nursery conditions, which is almost double the amount of time required for other pine species (Wright et al. 1996a). Many of the seedlings forked near the root collar in the nursery in Colombia and had to be correctively pruned to form a single stem. It is not known if the forking is due to nutrient deficiencies or other nursery related problems. At SAFCOL, the goal is to raise seedlings to a height of 30 cm with a root collar diameter of 10 mm.

Vegetative Propagation

It is possible to root *P. chiapensis* from seedling cuttings (Wright et al. 1996a) but work in the early 1990s at Smurfit Cartón de Colombia indicated that the species was more difficult to propagate than *P. maximinoi*, *P. patula* and *P. tecunumanii*. With the developments of improved facilities and better technology, Colombian researchers now believe that there would be little difficulty in propagating young *P. chiapensis* seedlings. In Brazil, Klabin has produced hedges of *P. chiapensis* and reports that cuttings root satisfactorily. It may also be possible to root cuttings from mature *P. chiapensis*, as cuttings from 17- and 30-year-old trees in the closely related species *P. strobus* have produced roots in experiments in New Hampshire, USA (Kiang et al. 1974).

STAND MANAGEMENT

Site Selection and Establishment

Pinus chiapensis has been established in genetic tests and trial plots in as many as 20 countries throughout the tropics and subtropics (see Dvorak and Brouard 1987). Plantings either have performed very well or have failed miserably. The two factors limiting growth of *P. chiapensis* are drought and freezing weather. Plantings that are even slightly off site can result in stocking levels of 50 to 70% several years after planting.

A good *P. chiapensis* planting site consists of well-drained, fertile soils, a location between 550 and 2000 m elevation, and at least 1100 to 1200 mm of well-distributed annual rainfall (Dvorak and Brouard 1987). In the eastern highlands of South Africa (lat 24° to 25° S), SAFCOL researchers look for loamy to sandy loam soils that are more than 1.0 m deep with a pH of about 4.5. The species is best suited to the mist belts in the highlands between 1000 and 1300 m altitude in areas with more than 1100 mm of rain and a dry season that is shorter than three months (H. L Strydom, personal communication).

In the highlands of Colombia (lat. 2° N), researchers at Smurfit Cartón de Colombia consider a good *P. chiapensis* site to be one that has sandy loam soil nearly 1.0 m deep (Andisol) with a pH value of about 5.1 (J. B. Urrego, personal communication). An optimum altitude would be 1800 m in an area with approximately 2100 mm of annual precipitation and no dry season. Researchers believe that the species needs deep, well-drained soils with good fertility, and high organic matter content.

Experience in growing *P. chiapensis* in Brazil now suggests that soil fertility is not as important as soil depth or moisture. Klabin has successfully established *P. chiapensis* on an infertile but deep Oxisol in an area of abundant rainfall in southern Brazil (lat. 24° S). However, when established in Goiás or Minas Gerais, Brazil (lat. 13° to 18° S) on similar Cerrado soils, but in an area with a very well defined dry season of four to six months, *P. chiapensis* has failed or has done poorly.

Silviculture

There has been very little written on the silviculture of *P. chiapensis* because operational plantations of the species have never been established. However, the silvicultural management of this tropical white pine is assumed to be very similar to that of *P. strobus*. One exception is that *P. chiapensis* begins its juvenile growth spurt at 3 years of age (Dvorak et al. 1996) while its more temperate cousin does so from ages 6 to 10 years (Wendel and Smith 1990). For the most part, the growth phases of *P. chiapensis* mimic those of *P. strobus* but on a reduced time frame.

Pinus chiapensis is usually planted at 3.0 × 3.0 m spacing. At one year of age, trees are about 0.9 m tall. Weeding is needed frequently the first year and occasionally the second or even third years at some sites. At some locations, especially on volcanically derived soils, seedlings turned a yellowish color several months after planting and remained that way for 18 months. The exact cause of the problem was never determined but was probably associated with a nutrient deficiency. Baseline nutrient information is needed for *P. chiapensis*. At most locations, height growth doubles between the ages of 3 and 5 years as roots become established and the dominant terminal leader develops. This growth spurt signifies capture of the



Photo 3-5. Maintaining good stocking is sometimes difficult for *Pinus chiapensis* growers. A group of trees in this young CAMCORE trial established in South Africa was killed by frosts.

site by the species. The only location in the CAMCORE plantings where the growth spurt was not pronounced was in South Africa (Dvorak et al. 1996). At age 5, average tree height is between 8 and 10 m and crowns have begun to close. The crowns are dense and shade out most understory vegetation. By age 8, the trees average 13.5 to 15 m in height with dbh of 17 to 20 cm. The species is very susceptible to fires in the juvenile stage because its bark is still thin.

Pinus chiapensis has been correctively pruned by several CAMCORE organizations at approximately 3 years of age. The species has a propensity to produce one main stem with one or more smaller stems protruding from the base, pruning has been used to remove the smaller stems. Some attribute the basal forking to nursery management practices (Wright et al. 1996a), but the problem occurs in several countries, suggesting that it may also have a genetic component. For example, the San Juan Cotzal, Guatemala source appeared much more prone to the problem than other sources when planted in Colombia. Although not studied in *P. chiapensis*, rate of healing after pruning was related to seed source in studies of *P. strobus*. Those with rapid rate of growth and/or small branches healed most quickly (Wright et al. 1980).

Height-to-diameter ratios for *P. chiapensis* differ significantly across location (Dvorak et al. 1996). The same trend was also observed for *P. strobus* across the eastern United States (Wright 1970). Independent volume formulas for *P. chiapensis* will have to be derived in the different countries where the species is planted.

Top dieback is common in the species at some locations. The terminal leader grows rapidly, is devoid of lateral branches and looks like a foxtail shoot before turning brown and being replaced by another leader. Terminal leader death is sometimes attributed to dry weather but may also signify a nutrient imbalance in the tree.

Thinning will be needed in most *P. chiapensis* stands prior to final harvest. Based on limited experience in the CAMCORE program, the species responds well to thinning.

Pests and Other Limiting Factors

Pinus chiapensis appears to be generally resistant to pests when planted as an exotic species but its true tolerance will not be known until more areas of the species are established. Exotic plantings have not contracted damaging diseases like *Cronartium ribicola* (white pine blister rust) that plagues eastern white pine in areas of Canada and the

United States. It has also shown resistance to *Pineus pini* (woolly aphid) in southern and eastern Africa (Odera 1974, Darrow and Coetzee 1983), while some of the Mesoamerican hard pines show susceptibility to the insect.

Pinus chiapensis has suffered mortality from *Bursaphelochus xylophilus* (pine nematodes) in Zhejiang Province, China (Li et al. 1997). Pine nematodes are also a common problem on *Pinus strobus*. There is one report of *P. chiapensis* being attacked by *Armillaria mellea* (*Armillaria* root rot) in Zimbabwe (Poynton 1977), but the root disease does not seem to cause problems on *P. strobus* in the United States (Gerlach et al. 1997). Possibly, the spread of root diseases are a greater concern with *P. chiapensis* than with the Mesoamerican hard pines because of the tendency for the white pine to form root grafts with neighboring trees of the same species (see Ferreira et al. 1999). Root grafting has also been reported in *Pinus strobus* (Bormann 1962).

WOOD QUALITY IN PLANTATIONS

The wood of *Pinus chiapensis* is different from that of the hard pines primarily because of its low density, which raises a number of questions about its potential uses. In the 1870s and 1880s, *P. strobus*, a close relative to *P. chiapensis*, was the most important commercial lumber species in North America. The wood was used for window frames, doors, roofing shingles, and all types of construction. Readers are referred to some of the literature written at the turn of the last century on potential uses of *P. strobus* (see Spalding 1899), which has wood properties nearly identical to *P. chiapensis*.

Physical Properties

Malan (1994) conducted one of the most complete wood property studies on *P. chiapensis* growing in CAMCORE tests in South Africa. He harvested a total of 20 trees that were approximately 9 years of age in three provenances planted in sister trials at Wilgeboom and Tweefontein South Africa. The three provenances were La Trinidad, La Libertad and Pueblo Nuevo (see Table 3-1). A control of *P. elliottii* was also used in the study. He found the wood of *P. chiapensis* to be light and uniform with a poorly defined ring structure. There were no statistical differences in latewood percent among *P. chiapensis* provenances, but the value was markedly lower than that of *P. elliottii*. Interestingly, latewood percent did not increase with distance from the pith in *P. chiapensis* as it does with many other pine species; as a result, there was little change in density from pith to bark in *P. chiapensis*. Average density of trees sampled at Wilgeboom was approximately 350 versus 360 kg/m³ for Tweefontein. Pueblo Nuevo had slightly higher density than La Trinidad and La Libertad. The general conclusion is that La Trinidad and La Libertad had average densities below 360 kg/m³, which is the minimum

standard for structural lumber in South Africa. Therefore, trees will have to be selected above this threshold for use in breeding programs if sawtimber is to be produced.

Tracheid length increased from pith to bark in *P. chiapensis*. Average tracheid length was about 2.0 mm at ring two and about 3.0 mm at ring eight. *Pinus chiapensis* and the *P. elliottii* control differed little in terms of tracheid length.

Pinus chiapensis demonstrated significantly less radial shrinkage than *P. elliottii*, and at one site, Tweefontein, exhibited much less tangential shrinkage (Malan 1994). There were no differences in amount of shrinkage by *P. chiapensis* provenance.

Fifteen of the 20 *P. chiapensis* trees sampled by Malan (1994) exhibited high levels of spiral grain with angles above 5°. However, there was much tree-to-tree variation in this trait and improvements could be made through selection.

Wood from *P. chiapensis* possesses uniform density that results in little shrinkage or warping when dried. *Pinus chiapensis* makes high quality veneers (Jankowsky 1978) and likely can be used in the same manner as *P. strobus* which has been used for plywood (Zanutini 1994), oriented strand board (Avramis and Smith 1989), and finger jointed products (Fisette and Rice 1988). Some genetic improvement in wood density and grain angle may be necessary.

Pulp Quality

CAMCORE and Smurfit Cartón de Colombia conducted a laboratory kraft pulping study on *P. chiapensis* at North Carolina State University (Wright et al. 1996b). Trees were sampled in CAMCORE trials at 8 years of age. *Pinus chiapensis* required higher active alkali charges to achieve a given kappa number than *P. patula*, *P. maximinoi* or *P. tecunumanii*. *Pinus chiapensis* also had the lowest screened yield of the four species.

In a study in Brazil, the kraft pulp quality was determined for different mixtures of *P. chiapensis* and *E. urophylla* (Chaves de Oliveira et al. 1979). For *P. chiapensis*, wood density was 361 kg/m³ and tracheid length was 4.2 mm, while for *E. urophylla* wood density was 503 kg/m³ and tracheid length was 1.0 mm. In general, *P. chiapensis* had more lignin and was more difficult to delignify than *E. urophylla*. *Pinus chiapensis* had 4.3% extractives. The authors concluded that mixing the two species was not economical because of the higher wood consumption per ton of pulp caused by the low density of *P. chiapensis*. In a different study also conducted in Brazil, compression wood of *P. chiapensis* contained more lignin and less holocellulose than normal wood (Tomazello et al. 1985). The kraft pulp yield from *P. chiapensis* is approximately 25% less than that of the higher density hard pines.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

Sixteen provenances and 380 mother trees of *Pinus chiapensis* were sampled in southern Mexico and Guatemala in the 1980s. CAMCORE members have planted seeds in Brazil, Colombia, South Africa and Venezuela. Five- and 8-year results are available from nine tests.

There have been two across-site analyses of CAMCORE *P. chiapensis* tests. Dvorak et al. (1996) summarized (mainly) 5-year results from six tests established in Brazil, Colombia and South Africa. Recently, analyses have been completed for nine tests, eight of which had 8-year measurements (CAMCORE unpublished data). Three of the tests were established in the Colombian highlands (lat. 2° to 4° S), three trials were planted in the eastern highlands of South Africa (lat. 25° S) and three tests were established in Brazil, but at widely different locations. Specifically, the Brazilian tests were established at Fazenda Primavera, Minas Gerais (18° S, elev. 850 m, ann. precip. 1400 mm), Grão, Mogol, Minas Gerais (16° S, elev. 810 m, ann. precip. 1080 mm) and Imbauzinho, Paraná (24° S, elev. 780 m, ann. precip. 1443 mm) and will be referred to as eastern, central, and southern Brazil, respectively. Information from the nine tests forms the basis for the following section and the results presented in Table 3-3.

PROVENANCE VARIATION

Survival

Overall survival at 8 years of age in the *P. chiapensis* tests was 74% in Colombia, 67% in South Africa and 35, 52 and 93% in eastern, central, and southern Brazil. Survival was best at locations where rainfall was very evenly distributed (Colombia and southern Brazil). The poor survival in eastern Brazil (Fazenda Primavera) was due to planting trees during a period of drought. Ninety percent of the mortality in the trials occurred in the first three years after planting. Therefore, if planting stock is good, the timing of the planting coincides with the rainy season, and frost pockets are avoided, it should be possible to maintain stocking levels above 85%. Once established, *P. chiapensis* appears to be relatively hardy. There was less than 1% additional mortality in the trials from ages 5 to 8 years.

Choice of provenance appears to be very important to obtain good survival, especially on marginal sites. In central Brazil (Grão Mogul) the San Juan Cotzal source from Guatemala had 30% poorer survival than the rest of the provenances being tested. The soils at Grão Mogul are deep, well drained Oxisols that dry out quickly when rainfall is infrequent. Survival of San Juan Cotzal was also poor in Colombia (63%). The provenance is extremely

degraded in Guatemala and only contains a few trees.

Poor survival may be due to a combination of poor adaptability plus high levels of inbreeding. Interestingly, the *P. chiapensis* control lot collected from young trees in Zimbabwe included in several of the CAMCORE tests also exhibited poor growth and survival (Dvorak et al. 1996). The Barillas, Guatemalan source also survived more poorly in eastern Brazil and Colombia than did other sources. The soils at Fazenda Primavera are of high quality and suitable for planting *Eucalyptus grandis*. However, only 29% of the trees from Barillas survived the drought at time of planting; survival for trees in the other *P. chiapensis* populations was 45%. Therefore, mortality of *P. chiapensis* at Grão Mogul and Fazenda Primavera in central and eastern Brazil was caused by two different events. At Grão Mogul, the extended dry season and low soil moisture killed the plants; at Fazenda Primavera, an unusual drought on a good soil at time of planting caused heavy mortality.



Photo 3-6. Typical *Pinus chiapensis* growth at 3 years of age in Colombia. The species grows slowly initially, but once the root system has become established, it is one of the fastest developing Mesoamerican pines.

Productivity

Average productivity in the CAMCORE tests at 8 years of age was 3 m³/ha/yr in central Brazil, 21 m³/ha/yr in southern Brazil, 20 m³/ha/yr in the Colombian highlands, and 11.5 m³/ha/yr in the eastern highlands of South Africa (Table 3-3). These values are very much in line with productivity found in other *P. chiapensis* pilot plantings established around the world (see Dvorak and Brouard 1987). By choosing the best provenance in CAMCORE tests at each of these sites, productivity would be: 5 m³/ha/yr in central Brazil, 23 m³/ha/yr in southern Brazil, 31 m³/ha/yr in the Colombian highlands and 14 m³/ha/yr in the eastern highlands of South Africa. It appears that the Colombian highlands and southern Brazil offer the best combination of soil and rainfall for the development of *P. chiapensis*.

Volume Performance

Individual provenance performance across countries is shown in Table 3-4. There was a 16, 27 and 8% difference between the best and worst provenances in Brazil, Colombia, and South Africa. Provenance differences were most pronounced on sites that were most productive. Two provenances appear to show promise: La Trinidad (formerly called Bochil) and Teotlaxco. There is no geographic pattern associated with the best sources, nor anything particularly noteworthy about the best performing populations in their natural range. The La Trinidad population is a highly degraded source located in rolling hills in southern Chiapas. The Teotlaxco provenance occurs in one of the wettest regions of the species' natural distribution.

The large provenance differences found for survival and metric traits for *P. chiapensis* are somewhat surprising because the species occurs in similar ecological niches throughout its natural range in Mesoamerica. As mentioned previously, provenance differences may be as much a reflection of different levels of inbreeding in individual stands as the result of varying degrees of adaptability of provenances to environment (Dvorak et al. 1996).

Quality Traits

Provenance differences in straightness were most apparent on sites where growth was the best. Trees from Guevea

de Humboldt, Guerrero were much straighter than those from San Juan Cotzal and Barillas, Guatemala and Larrainzar, Chiapas when planted in Colombia.

Percent forking for trees of *Pinus chiapensis* ranged from 3 to 38% with the lowest values being recorded in South Africa and the highest values in Colombia (Dvorak et al. 1996). There was significant provenance variation for forking in Colombia but not in South Africa. Percent foxtails followed the same trend as forking; they were highest (11%) in Colombia and lowest (3%) in South Africa. Provenance trends in foxtailing were not apparent.

Malan (1994) found that variability in stem diameter of *P. chiapensis* increased with increasing altitude in the highlands of South Africa. Such trends have not been noticed in Colombia or Brazil possibly because the CAMCORE tests have all been planted at similar altitudes in each country. However, Smurfit Cartón de Colombia has established a number of species x site interaction trials at different altitudes that include *P. chiapensis*, and it will be possible to observe such trends in the future if they exist.

Provenance x Site Interactions

The CAMCORE tests are too few to obtain good information about provenance x site interaction for growth traits in *P. chiapensis*. Results from an assessment of three trials in two countries by Dvorak et al. (1996), and those presented from a larger data set in Table 3-3, suggest that there are no important provenance x site interactions (i.e. major rank changes) for volume production. However, Dvorak et al. (1996) found important provenance x site interaction for basal forking and foxtailing.

Family x Site Interactions, Genetic Parameters for Growth and Quality Traits

Spearman family rank correlations for volume were determined between two tests in the eastern highlands of South Africa located 20 km apart and one test in the highlands of Colombia at 8 years of age. The two South African tests were planted at Wilgeboom (lat. 25°, elev. 1071 m and ann. precip. 1297) and at Mac-Mac (lat. 25° S, elev. 1371 m, ann. precip. 1608 mm). The test in Colombia was planted at San Jose (lat. 3° N, elev. 1750 m, ann. precip. 2046 mm). There were 38 to 47 open-pollinated families

Table 3-3. Survival and productivity (over bark) for *Pinus chiapensis* at 8 years of age grown in nine tests in Colombia, South Africa, and three regions of Brazil.

Region	Num. of Tests	Survival (%)	Height (m)	Diameter (cm)	Productivity (m ³ /ha/yr)
Colombia	3	74	16.0	19.0	19.7
South Africa	3	67	13.7	16.1	11.5
Eastern Brazil	1	35	-	-	-
Central Brazil	1	52	10.5	10.9	3.1
Southern Brazil	1	93	15.2	18.0	21.0

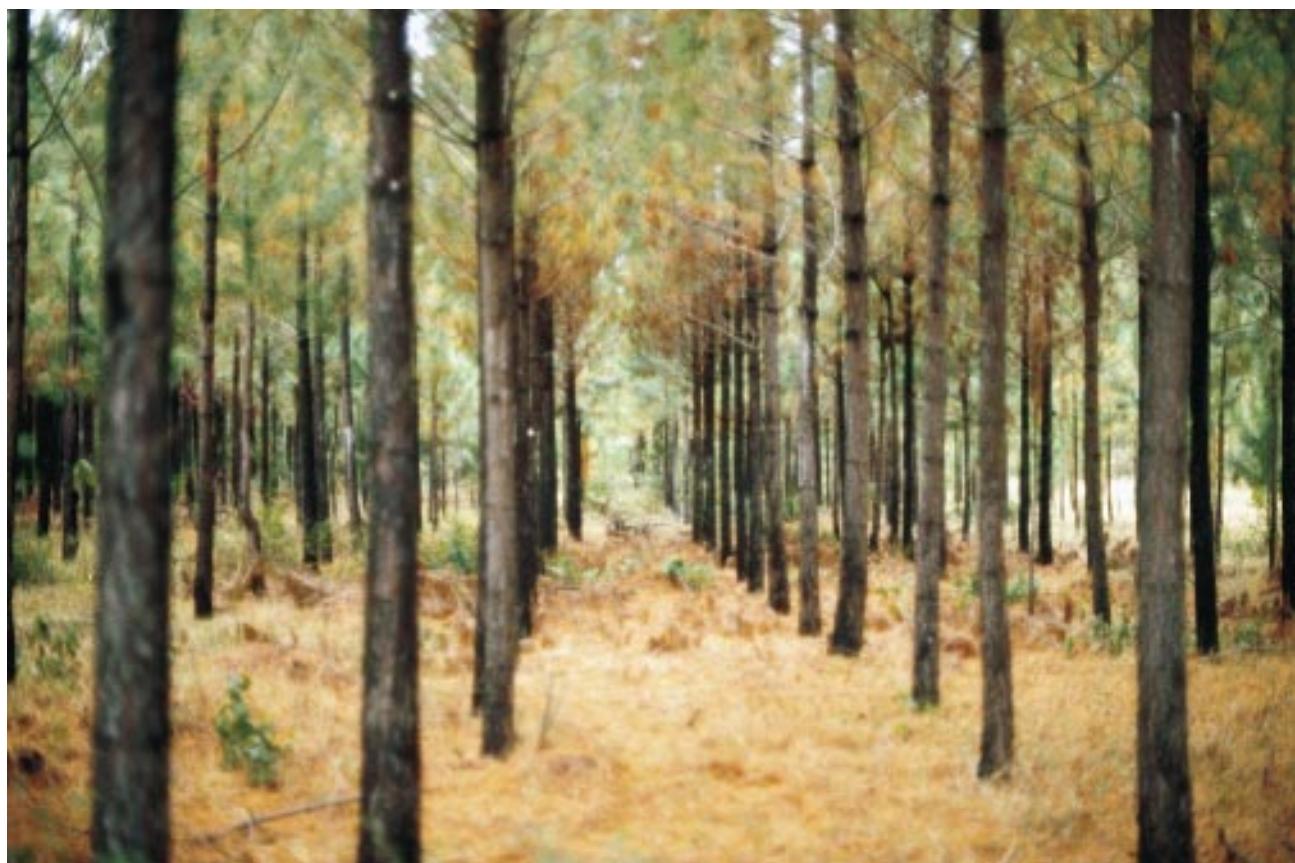


Photo 3-7. A CAMCORE *Pinus chiapensis* trial. Trees often have straight stems and produce a heavy litter layer on the forest floor.

Table 3-4. Volume performance (Gain) of 13 provenances of *Pinus chiapensis* tested in Brazil, Colombia, and South Africa. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests
<i>Guatemala</i>	12	San Juan Cotzal	0.0	.	.	0.0	7	1	0.0	8	1
	1	Barillas	-4.8	.	.	-11.1	32	1	-4.8	.	.
<i>Mexico</i>	3	La Libertad	-5.9	3	1	-12.2	22	2	-2.0	23	2
	6	Pohlo	2.4	.	.	5.6	5	1	2.4	.	.
	5	Larraínzar	1.2	.	.	2.8	8	1	1.2	.	.
	4	La Trinidad	5.6	.	.	14.5	13	1	3.9	14	2
	7	Pueblo Nuevo	-1.4	1	1	1.8	13	2	-1.1	14	2
	11	Santiago Tutla	4.2	6	1	1.8	.	.	1.8	.	.
	2	Guevea de Humboldt	-1.5	.	.	-3.4	3	1	-1.5	.	.
	18	Teotlaxco	8.3	20	1	3.6	.	.	3.6	.	.
	10	Yerbabuena	1.7	4	1	0.7	.	.	0.7	.	.
	9	San Gabriel Mixtepec	-1.5	4	1	-0.7	.	.	-0.7	.	.
	16	Nopoala	-8.3	19	1	-3.6	.	.	-3.6	.	.



Photo 3-8. Trees in a number of CAMCORE trials produced multiple stems at the base. This picture is from a CAMCORE planting in south-central Brazil at 4.5 years of age.

common to the pairs of tests. Rank correlation between Colombia and both tests in South Africa was $r = 0.52$ and highly significant. Rank correlation between the two South African tests was $r = 0.41$ and was also significant. The general conclusion is that families of *P. chiapensis* are relatively stable across site for volume.

Vásquez and Dvorak (1996) examined the trends in heritability for height in two *P. chiapensis* tests in Colombia and South Africa established by Smurfit Cartón de Colombia and SAFCOL. The general trend was for individual tree heritability to decrease with age through 8 years. Examination of a larger CAMCORE data set that included eight of the nine tests described above (eastern Brazil was omitted) showed more mixed results. Heritability for height increased through age 8 in four tests, while heritability decreased after age 5 in the other four tests. Mean heritability values across all eight sites for height at ages 1, 3, 5 and 8 years were 0.12, 0.16, 0.18 and 0.20. Mean heritability values for volume at ages 3, 5 and 8, were 0.13, 0.21 and 0.21, and for straightness at ages 5 and 8 were 0.15 and 0.14 (CAMCORE, unpublished data).

Trends in age-age genetic correlations across sites were interesting. At the Klabin study at Imbauzinho (southern Brazil) the age-age correlation between height at age 5 and volume at age 8 was 0.96. For the same age classes and traits at the other sites, genetic correlations were much lower: in Colombia 0.71, central Brazil 0.83, and South Africa 0.84. The Imbauzinho site was different from the

others in one important aspect: at 8 years of age its average survival was 20 to 30% better than the other sites. One theory to explain these results is that when stocking is good in *P. chiapensis*, development of the trees is relatively uniform within the stand and across ages at least through age 8. Every tree in the stand is competing equally for sunlight, nutrients and moisture. However, when an opening occurs in the stand due to mortality (e.g. from frost, droughts etc.), development patterns change as trees aggressively compete for additional space and the age-age correlations drop. The developmental pattern described is the same as that which occurs in natural stands when *P. chiapensis* tries to outcompete broadleaf species in Mesoamerica. Drastic rank changes due to changes in levels of competition (due to row thinning) have also been observed for *Gmelina arborea* in Costa Rica. Until data proves to contrary, CAMCORE recommends making *P. chiapensis* selections at approximately half rotation age (i.e., not before 8 years of age).

DEVELOPMENT OF IMPROVED MATERIAL

Flowering and Seed Production

There is relatively little information available on the flowering and seed production of *P. chiapensis* when planted as an exotic. Flowering occurs in June in the plateau region near Popayán (lat. $2^{\circ} 30' N$, elev. 1800 m, ann. precip. 2000 mm) in the highlands of Colombia. At 17 years of age, a seed stand with 30 trees per hectare was averaging only four filled seeds per cone with less

than five cones per tree (N. Isaza, personal communication). In a different assessment made on 12-year-old trees located in the same vicinity, only two filled seeds per cone were found.

Flowering of *P. chiapensis* began as early as 8 years in the Wilgeboom/Mac-Mac region (25° S, elev. 945 to 1250 m, ann. precip 1100 to 1550 mm) of Mpumalanga, South Africa. The first cone crop in CAMCORE trials was noted at 10 years of age in stands that had approximately 70% survival (i.e., there were some open spaces in the stand to allow light to enter). Cones mature in March and April (V. Ximba, personal communication). Definite differences in timing of cone maturity were noted at the two locations at the provenance, family, and within-family levels.

Pinus chiapensis flowers early in southern Brazil. Researchers at Klabin noted flowers on trees in CAMCORE trials at 6 years and cone crops by 8 years. The flowering time for the species is at the end of winter, in August and September.

The only grafted clonal bank of *P. chiapensis* in the Cooperative is one established by Smurfit Cartón de Colombia using selections from CAMCORE trials (Wright et al. 1996a). The species has been found to be very easy to graft.

Hybrids

Pinus strobus × *P. chiapensis* hybrid crosses were made by the Weyerhaeuser Company in the early 1990s in the southern United States but no fertile seeds were obtained. One theory is that the pollen tubes may have frozen during the temperate winters. The other theory is that even though *P. chiapensis* and *P. strobus* are morphologically similar, they may be genetically distinct after millions of years of separation, making successful hybrid crosses difficult. Because CAMCORE has found that hybrid crosses between temperate and tropical pine species are usually more successful when conducted in the tropics, our intent is to try this cross again in the future, possibly in Brazil or Colombia. The advantage of making a *P. strobus* × *P. chiapensis* cross is to produce hybrids that are faster growing than the *P. strobus* parent.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

There is little information on genetic diversity in the remaining populations of *P. chiapensis* in southern Mexico and Guatemala. However, researchers at the University of Edinburgh, Scotland are conducting studies on CAMCORE populations of *P. chiapensis* using RAPD, mtDNA, RFLP and nuclear microsatellite molecular markers; results should be available in the near future.

Genetic diversity studies have been conducted in natural populations of *P. strobus* in Canada. Isozymes were used to examine the effect of harvesting on genetic diversity in two natural populations of *P. strobus* (approx. 250 years old). Removal of 75% of the trees by harvesting reduced the total and mean number of alleles by 25%, and reduced the percentage of polymorphic loci by about 33% relative to preharvest levels (Buchert et al. 1997). These results provide some indication of how man-made disturbances might affect *P. chiapensis* populations.

Conservation Status

Unlike most pine species in Mexico and Central America, *P. chiapensis* is selectively sought after by local woodcutters because it is soft (i.e., it is easy to cut with an ax) and its workability. After harvesting, areas are often replanted to agricultural crops with demanding fertility requirements like coffee, or to more common crops like maize and beans. Most of the crude furniture one buys at roadside stands and in local markets in northwestern Guatemala and southern Mexico are either *P. ayacahuite* or *P. chiapensis*. Zamora-Serrano and Velasco-Fiscal (1977) warned about

the destruction occurring in natural stands of *P. chiapensis* in Chiapas as a result of wood harvesting and agriculture nearly a quarter century ago, as have a number of other authors (e.g. Veblen 1976, Perry 1991, Donahue et al. 1991).

Local and state governments have placed restrictions on cutting *P. chiapensis* in several locations in southern Mexico. Furthermore, small planting programs of the species have begun in several towns and villages, although they are sometimes hampered by the difficulty in obtaining seeds from good sources. The reaction to protecting *P. chiapensis* by restricting harvesting has not always been met with universal approval. Villagers burned some natural stands of *P. chiapensis* to protest the local laws once a ban on harvesting was announced (M. Arizmendi, personal communication). The situation points to the complexity of implementing *in situ* conservation in developing countries (Dvorak 1996) and the realization that if important social, economic, and political questions are not addressed, conservation activities seldom succeed.

Pinus chiapensis stands are **critically endangered** in Guatemala and Chiapas and may be eradicated within two decades. The conservation status of *Pinus chiapensis* is **vulnerable** to **critically endangered** in the rest of southern and eastern Mexico. The overall conservation status of the species based on CAMCORE field experience is **endangered**. Based on provenance results, priority should be given to *in situ* conservation efforts at the La Trinidad (formerly called Bochil) population in Chiapas and the Teotlaxco, Oaxaca population. However, protection of any natural population, regardless of its performance in trials, is



Photos 3-9a and b. Typical scenes of agricultural encroachment in *Pinus chiapensis* provenances. Natural stands of *P. chiapensis* at Larrainzar, Chiapas, Mexico (above) and Barillas, Guatemala (below) are being replaced by maize.



regarded as important step forward for the *in situ* conservation of the species.

EX SITU CONSERVATION

In some respects, *P. chiapensis* is a difficult species to conserve *ex situ*. Because of the species' site requirements, not many organizations in the tropics and subtropics have the right type of land to establish field conservation plantings. If there is land available, it is usually not in sufficient quantities to make establishing large-scale plantations worthwhile. At high latitudes (above 24°), the occasional frost can cause high levels of mortality in the field. As mentioned earlier, *P. chiapensis* competes for the same kinds of land as fast growing eucalypts, especially *E. grandis*. Finally, markets are not developing to encourage

growers to plant more *P. chiapensis*, and long-term seed storage is not currently feasible, which further limits conservation approaches.

CAMCORE members have very actively tried to conserve the species. At Smurfit Cartón de Colombia, the best trees in the first-generation field trials have been selected and grafted into a gene conservation bank. SAFCOL in South Africa is collecting seeds from its CAMCORE studies and distributing these to other South African members to establish second-generation conservation banks. Klabin in Brazil has CAMCORE studies of *P. chiapensis* that have been well maintained. Ultimately, the long-term *ex situ* conservation of the species is going to depend on finding markets for the wood. Without such interest, the future of the species is very uncertain.

CONTRIBUTORS

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C h a p t e r 4



PINUS GREGGII

W. S. Dvorak, J. E. Kietzka, J. K. Donahue, G. R. Hodge and T. K. Stanger

OVERVIEW

TREE DESCRIPTION

In the early 1990s, the varying growth and morphology of *Pinus greggii* trees in CAMCORE field trials led foresters to begin recognizing that the species' northern and southern populations in Mexico represented distinct taxa.

Subsequent taxonomic and monoterpenoid studies by Donahue and López-Upton (1996) and Donahue et al. (1996) culminated in the classification of *P. greggii* as two varieties. Trees in northern populations from Nuevo León and Coahuila, Mexico are known as *P. greggii* Engelm. ex Parl. var. *greggii*, and those 360 km to the south in the states of Hidalgo, Puebla, Querétaro, San Luis Potosí and Veracruz are known as *P. greggii* Engelm. ex Parl. var. *australis* Donahue & López-Upton (Donahue and López-Upton 1999).

Pinus greggii var. *greggii*

Pinus greggii var. *greggii* is a small tree that is typically 6 to 15 m in height with dbh of 22 to 40 cm at maturity. Mature trees have a rounded and sometimes irregular crown. The lower trunk has thick, grayish-brown bark that is divided into scaly plates by deep vertical fissures (Perry 1991). The bark tends to become smooth midway up the trunk. Young trees have a uninodal branching pattern and a pyramidal crown that becomes rounded at an early age on shallow soils. The bark of young trees is gray and smooth. The needles on trees from northern populations are dark (and sometimes silvery) green, stiff and erect, occur primarily in fascicles of three and range from 104 to 118 mm (mean = 113 mm) in length (López-Upton and Donahue 1995). Cone clusters contain from three to twelve cones and are borne on the main stem and on branches. Cones range in length from 96 to 114 mm (mean = 106 mm) and are held tenaciously to the branches. Average seed potential is 91 seeds per cone (López-Upton and Donahue 1995). There are approximately 55,550 seeds per kg. The wood is resinous and of moderate density, and is used for construction, mining timbers and fuelwood.

Pinus greggii var. *australis*

Pinus greggii var. *australis* is a small to medium-sized tree that ranges from 9 to 20 m in height with a dbh from 25 to 40 cm at maturity. The crown of var. *australis* is not as

compact as that of var. *greggii*. On humid sites in its native range, trees of this variety exhibit internode distances of up to 2 m. The bark characteristics of var. *australis* are similar to those of var. *greggii*. The needles on trees from the southern populations are medium green, erect to slightly drooping, occur mainly in fascicles of three, and range in length from 120 to 133 mm (mean = 125 mm). In addition to having longer needles than var. *greggii*, var. *australis* has more stomata per unit of needle length and more resin canals in the internal position. Furthermore, var. *australis* essentially lacks the terpene longifolene (Donahue et al. 1996, Donahue and López-Upton 1996). The cone size of var. *australis* is approximately the same as that of var. *greggii*. However, the average seed potential of var. *australis* is 117 seeds per cone, versus 91 for var. *greggii*. *Pinus greggii* var. *australis* has an average of 67,100 seeds per kg. The wood quality of var. *australis* appears to be approximately the same as that of var. *greggii*.

CONSERVATION STATUS

Based on CAMCORE field observations, the conservation status for *P. greggii* var. *greggii* is **endangered**. The remaining populations of the variety are small to very small in size (some with only 10 to 20 trees) and stands are being genetically depleted. The conservation status for *P. greggii* var. *australis* is **vulnerable** with some stands **endangered** to **critically endangered**. Its conservation status needs to be closely monitored over the next few years.

TEST STATUS

Seeds have been collected from eight provenances and 183 trees of *Pinus greggii* var. *greggii* and seven provenances and 180 trees of var. *australis*. Fifty-two *P. greggii* tests have been established in Brazil, Chile, Colombia, Mexico, New Zealand, South Africa, and Zimbabwe. Approximately half of these tests are at least 5 years of age.

BEST PROVENANCES

Across all planting sites, the best provenance of *Pinus greggii* var. *greggii* is La Tapona. The best source of *P. greggii* var. *australis* varies depending on the country in which it is planted. Laguna Atezca performs well in Brazil, Laguna Seca shows promise in Colombia, and El Madroño is productive in South Africa. Preliminary results also suggest that Valle Verde is a good source of var. *australis*.

Photo 4-1. *Pinus greggii* var. *australis* at Laguna Atezca.

SUITABLE PLANTING SITES

Pinus greggii var. *greggii* does well on sites that are too cold and dry for *P. patula*. It seems to be best adapted to sites above 1500 m elevation that are between 25° and 31° S latitude. The variety can tolerate heavy freezes but does poorly on wet sites. *Pinus greggii* var. *australis* is best suited to areas from 900 and 1500 m elevation and 24° and

31° S latitude in Brazil and South Africa. It appears to have broad adaptability and has shown promise in CAMCORE studies at 200 m elevation in Chile (40° S) and at an elevation of 2450 m in Colombia (2° N). Variety *australis* appears to have more drought tolerance than *P. patula*, but both var. *australis* and *P. patula* are equally sensitive to the cold.

ADVANTAGES OF *PINUS GREGGII*

- Easy to raise in the nursery.
- Slightly (var. *australis*) to very (var. *greggii*) cold tolerant.
- Moderately (var. *australis*) to very (var. *greggii*) drought tolerant.
- Early and prolific producer of female strobili.
- Will hybridize with other *Oocarpaceae* species, as well as with *P. taeda* from *Australes*.
- Provenance information is available.
- Var. *greggii* is wind firm.
- Var. *greggii* may be more resistant to hail-induced *Sphaeropsis sapinea* (*Diplodia*) than *P. patula* in South Africa.
- Var. *greggii* is less susceptible to goat browsing than var. *australis* or *P. patula* in South Africa.
- Propagates easily from seedling cuttings.
- Has good wood properties for TMP, CTMP and newsprint.

DISADVANTAGES OF *PINUS GREGGII*

- Thirty-three-month reproductive cycle lengthens time required for breeding.
- Very susceptible to *Pineus pini* (woolly aphid) and moderately susceptible to attacks by other aphid species in southern Africa.
- Performs poorly on wet sites (especially var. *greggii*).
- Var. *australis* develops speed wobble and foxtails in humid locations.
- Very susceptible to non-hail-induced *Sphaeropsis sapinea* in Brazil and on off-site plantings in South Africa.
- Wounds from pruning heal slowly on var. *greggii* relative to var. *australis* and *P. patula*.
- Has shorter tracheids than *P. patula*, which may affect strength properties of some paper products.

NATURAL STANDS

EVOLUTION

Based on RAPD marker studies conducted by CAMCORE at North Carolina State University, *Pinus greggii* appears to have evolved from *P. patula* (see Chapter 1). One proposed evolutionary scenario suggests that progenitors of *P. greggii* originated from *P. patula* as a response to drier climates during the Eocene and subsequent periods. *Pinus greggii* var. *greggii* may represent an original migration from the progenitor cluster and var. *australis* a subsequent one. *Pinus greggii* var. *australis* still occurs sympatrically with *P. patula* at Laguna Atezca, Jalamelco and El Madroño, and

natural introgression appears to be occurring at some locations, suggesting a close genetic relationship. Another scenario proposed suggests that the distribution of *P. greggii* was continuous from northern to central Mexico at one time, and for reasons still not well understood, there is now a gap of 360 km between present-day var. *greggii* and var. *australis*. Geographic separation of the two subpopulations has resulted in genetic and morphologic divergence between them. Interestingly, La Taponia, the most southern of the northern populations, exhibits morphological characteristics (Donahue and López-Upton 1996) and



Photos 4-2a and b. Natural stands of *Pinus greggii* var. *australis* (above) at Carrizal Chico and var. *greggii* (below) at La Tapona. Trees in southern populations (var. *australis*) grow on acidic soils while those in northern populations (var. *greggii*) are usually found on calcareous soils.



developmental growth patterns in field trials (long internode lengths) that are intermediate between the two varieties.

DISTRIBUTION

Pinus greggii var. *greggii* occurs in a series of disjunct populations across canyons and ridges in the states of Coahuila and Nuevo León (Figure 4.1). Most var. *greggii* sites are located in dry regions (about 700 mm ann. precip.) at altitudes between 2300 to 2800 m. The distance between populations in the region is small, with some located in adjacent canyons only a few kilometers apart. Population size ranges from a few hectares (about 20 trees) at Cerro El Potosí to several hundred hectares at La Tapona and Las Placetas. All of the major populations of var. *greggii* in Coahuila and Nuevo León have been sampled by CAMCORE. There is now a report of *P. greggii* near Conrado Castillo in Tamaulipas (J. López-Upton, personal communication), where CAMCORE collected

P. patula in the 1980s. This area will be explored in the near future to verify the existence of another var. *greggii* source.

The distribution of var. *australis* is confined to the states of Hidalgo, Puebla, Querétaro, San Luis Potosí and Veracruz (Figure 4-1). Like var. *greggii*, var. *australis* also occurs in disjunct populations throughout its range but at lower elevations (from 1200 to 2300 m). The sites range from warm subtropical in summer months (see Climate) to cool during the winter. Several populations, such as Laguna Seca, can be dry. Population size ranges from about 75 to 10,000 ha.

CAMCORE has sampled 183 trees of var. *greggii* from eight provenances and 180 trees of var. *australis* from seven provenances since the late 1980s for testing and ex situ conservation (Table 4-1). The collections are the first to be conducted by provenance and mother tree and sample the entire natural range of the species.

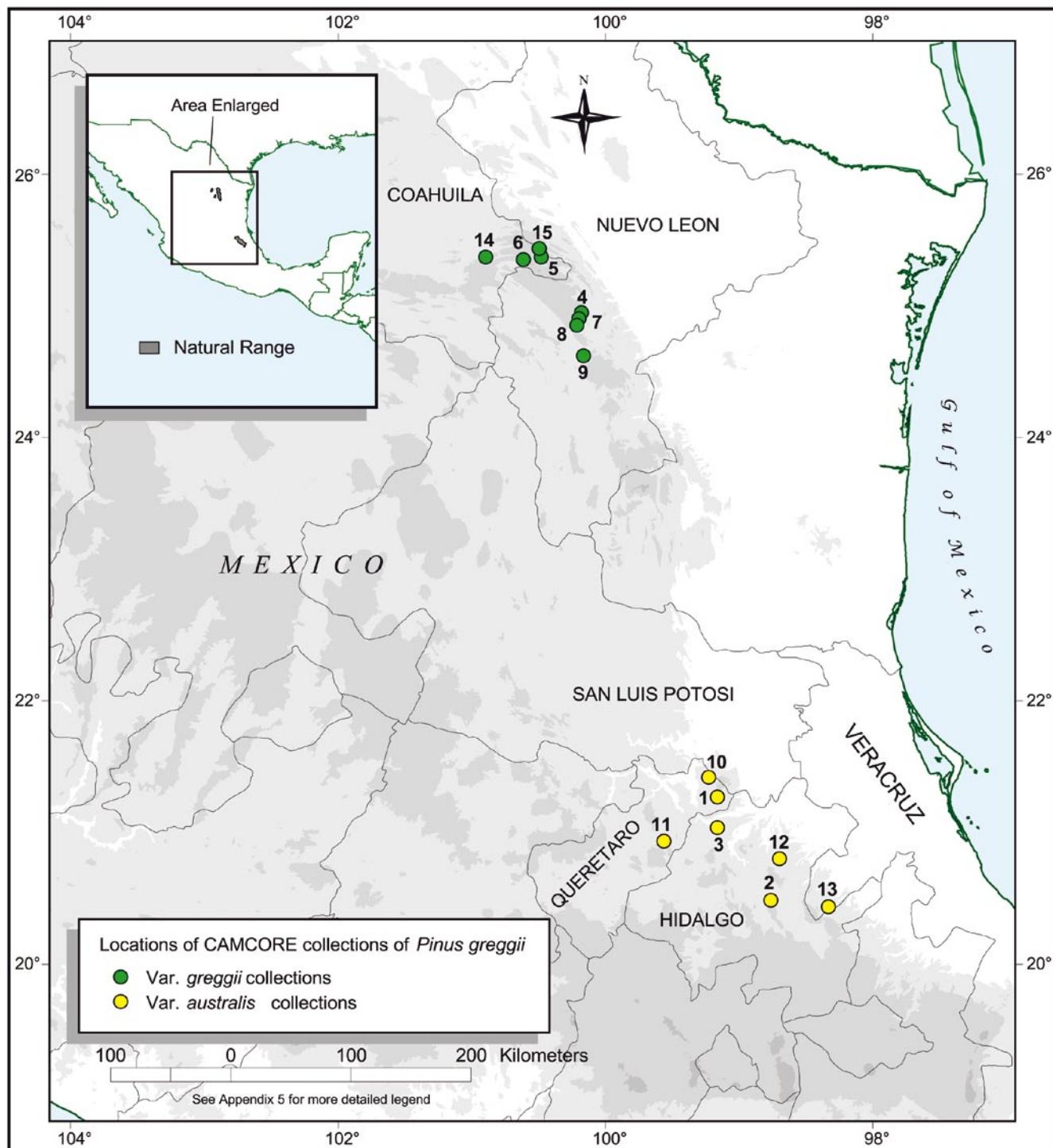
Table 4-1a. *Pinus greggii* var. *greggii* collections made by the CAMCORE Cooperative in Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
4	Las Placetas	Nuevo León	Mexico	24° 55' N	100° 11' W	2370 - 2520	750	25
5	Los Lirios	Coahuila	Mexico	25° 22' N	100° 29' W	2300 - 2400	650	13
6	Jamé	Coahuila	Mexico	25° 21' N	100° 37' W	2500 - 2590	650	9
7	Cerro El Potosí	Nuevo León	Mexico	24° 54' N	100° 12' W	2430 - 2500	750	5
8	Ojo de Agua	Nuevo León	Mexico	24° 53' N	100° 13' W	2115 - 2400	750	28
9	La Tapona	Nuevo León	Mexico	24° 37' N	100° 10' W	2090 - 2350	650	54
14	Loma el Orégano	Coahuila	Mexico	25° 22' N	100° 54' W	2270 - 2430	600	19
15	Sierra el Tarrillal	Coahuila/N. León	Mexico	25° 26' N	100° 30' W	1960 - 2540	650	30
8	Provenances	2 States	I Country	20 - 25° N	100 - 101° W	1960 - 2590	681	183

Table 4-1b. *Pinus greggii* var. *australis* collections made by the CAMCORE Cooperative in Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	El Madroño	Querétaro	Mexico	21° 16' N	99° 10' W	1500 - 1660	1100	55
2	Laguna Atezca	Hidalgo	Mexico	20° 29' N	98° 46' W	1250 - 1420	1642	21
3	Laguna Seca	Hidalgo	Mexico	21° 02' N	99° 10' W	1750 - 1900	820	19
10	Valle Verde	Querétaro	Mexico	21° 29' N	99° 10' W	1150 - 1250	1400	25
11	San Joaquín	Querétaro	Mexico	20° 56' N	99° 34' W	2130 - 2350	1109	15
12	Jalamelco	Hidalgo	Mexico	20° 48' N	98° 42' W	1800 - 1880	1642	20
13	Carrizal Chico	Veracruz	Mexico	20° 26' N	98° 20' W	1360 - 1770	1855	25
7	Provenances	3 States	I Country	20 - 21° N	98 - 99° W	1150 - 2350	1367	180

Figure 4-1. CAMCORE collections of *Pinus greggii* in Mexico.



CLIMATE

There are distinct climatic differences between northern and central Mexico, where the two varieties of *P. greggii* occur. *Pinus greggii* var. *greggii* occupies sites that are very dry most of the year (680 mm ann. precip.) and cold in winter (Table 4-2a). *Pinus greggii* var. *australis* occurs on sites that are moist to semidry during the year (1365 mm ann. precip.) and mild to cold during the winter (Table 4-2b). Accurate temperature and precipitation data is difficult to obtain for most locations because sites are so far away from meteorological stations. The available climatic information was compiled by Donahue and López-Upton (1996).

Pinus greggii var. *greggii*

Pinus greggii var. *greggii* occurs on sites that fall into the broad climatic classification of subhumid temperate using the Köppen Classification System as modified by García (1973). Annual rainfall ranges from 600 to 750 mm and falls mainly from May to October. Annual rainfall can be less than 500 mm during drought periods. The driest site on which the variety occurs may be Loma El Orégano (600 mm ann. precip.), where the average height of mature trees is only 8 to 15 m (Donahue 1994). Average annual temperature at collection sites is about 14 °C.

Within the subhumid temperate group, there are two var. *greggii* climatic subgroups. La Taponia and Las Placetas experience summer rains, but precipitation is less than 40 mm for a number of months. The other five var. *greggii* populations (Table 4-1a) grow in regions where rainfall is classified as scarce throughout the year (Table 4-2a).

All of the var. *greggii* sites experience numerous frosts throughout the winter. At Loma de Orégano and Sierra Tarrillal, an average of 74 frost days per year were recorded between 1942 and 1970 (SARH 1982). Local farmers in the area also talk about the occasional heavy snow at some sites (e.g., La Taponia) during winter.

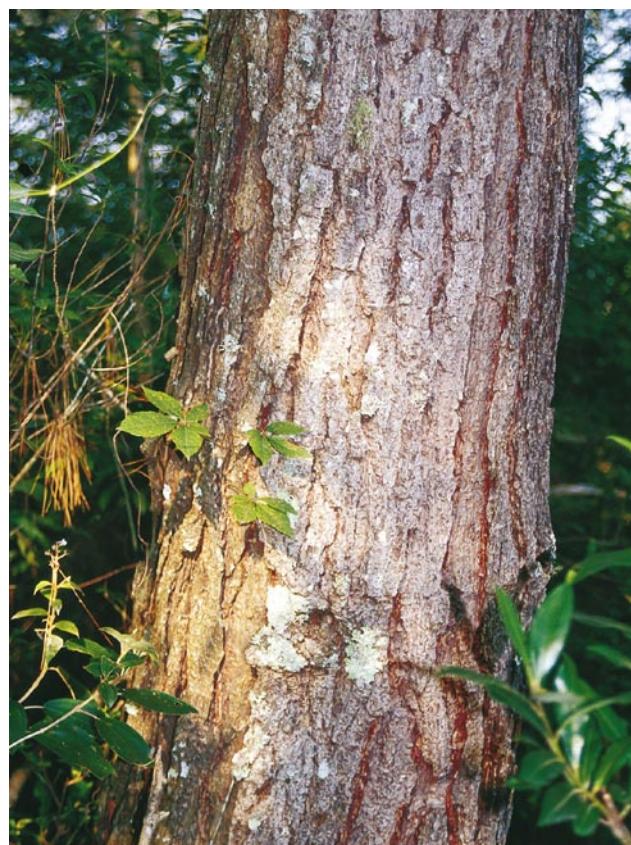


Photo 4-3. Bark on a mature *Pinus greggii* var. *australis* tree.

Pinus greggii var. *australis*

Pinus greggii var. *australis* occurs in areas that are classified as subhumid subtropical, subhumid temperate and humid temperate (García 1973). Summer rainfall at places like Carrizal Chico, Jalameco, Laguna Atezca, and Valle Verde can be abundant. Annual rainfall varies from 820 mm at Laguna Seca to 1855 mm at Carrizal Chico and falls mainly from May to November. Average annual temperature in the region is about 17 °C. At some of the lowest elevation sites, such as Laguna Atezca, several years may pass without a killing frost. Carrizal Chico has five frost days per year (SARH 1982). The coldest var. *australis* sites likely average 10 to 15 frosts per year.

Table 4-2a. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus greggii* site at Loma El Orégano, Coahuila.

Loma El Orégano	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	8.2	9.1	11.3	13.5	15.8	15.6	14.9	15.2	14.8	12.3	12.1	9.9	12.7
Mean Rain mm*	20	22	10	19	46	55	76	69	59	42	30	22	470

Based on 27 years of data recorded at San Antonio Alazanas (elev. 2138 m), approximately 33 km from the collection site (SARH 1982).

* Isohyetal charts indicate that the average rainfall at this site is closer to 600 mm (INEGI 1986).

Table 4-2b. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus greggii* site at Laguna Atezca, Hidalgo.

Laguna Atezca	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	16.2	17.7	20.0	21.8	22.4	22.3	21.3	21.8	20.8	19.5	17.6	16.0	19.8
Mean Rain mm	57	60	58	60	71	237	204	203	359	189	91	53	1642

Based on 27 years of data recorded at Molango (elev. 1650 m), approximately 5 km from the collection site (INEGI 1986).



Photo 4-4. Mature cone cluster on *Pinus greggii*.

SOILS

General soil maps for the region show that the two varieties occur on three soil types: shallow soils over limestone, thin calcareous, high-base-status soils over unconsolidated material, and hard rock or shallow soils (Donahue and López-Upton 1996). At most sites, soils are well drained. Southern populations of var. *australis* occur on more acidic soils (pH 4.2 to 6.1) than var. *greggii* (pH 6.8 to 7.7).

Soils in northern Mexico where var. *greggii* occurs can be very shallow (40 to 45 cm deep) and rocky. Soil texture is mostly sandy clay, clay loam, or clay. For example, the soils at Los Lirios were described as follows by Donahue (1988): "top soils are shallow (5 to 20 cm) and mostly clays; subsoils are also shallow (20 to 35 cm), clay in texture with many rocks."

Soils in central Mexico, where var. *australis* occurs, are generally deeper than those in northern Mexico and in some cases may be heavier (more clays) but are still well drained. At Laguna Atezca, one cluster of trees occurred on a deep clay soil (1.0 to 1.5 m) that consisted of a brown clay surface horizon underlain by a deep yellowish clayey B horizon. At Valle Verde, Donahue (1994) reports "the soils are mostly clay with a high percentage of stones. The parent material is of maritime sediment origin."

REPRODUCTIVE BIOLOGY

In natural stands, *P. greggii* flowers precociously. Production of male and female strobili probably begins by age 5 years. Flowers are usually produced on var. *australis* in April and

May and on var. *greggii* in May and June. In explorations for *P. greggii* var. *greggii* at Sierra Tarrillal in 1993, Donahue (1994) noted that pollen dispersal had not yet begun on June 1st, while it occurred between April 15th and April 30th on var. *australis* at Valle Verde and San Joaquín in the same year. The reproductive cycle for *P. greggii* was once thought to be approximately 22 months. However, examination of controlled crosses made between *P. greggii* parents by Mondi in South Africa conclusively shows that the reproductive cycle is 33 months. Additional flower phenology studies need to be conducted on *P. greggii* in natural populations in Mexico to determine if this pattern holds true elsewhere.

Cones are borne in clusters of three or four; occasionally up to 14, and occur on both branches and the main stem. Most cone collectors prefer to conduct *P. greggii* collections from January to mid-March, although some cones begin to open in late February (Donahue 1994). In 1993, many cones on var. *australis* and var. *greggii* did not open until June. In detailed studies conducted by López-Upton and Donahue (1995), vars. *greggii* and *australis* had average seed potentials of 91 and 117 seeds per cone, respectively. The number of filled seeds per cone was 57 for var. *greggii* and 74 for var. *australis*, for a seed efficiency rate of approximately 63% for both varieties. Populations sampled at extremes of the altitudinal or precipitation ranges for the species had fewer filled seeds per cone (López-Upton and Donahue 1995). There are approximately 55,550 and 67,100 seeds per kg for vars. *greggii* and *australis*, respectively.

ECOLOGY AND ASSOCIATED SPECIES

Pinus greggii var. *greggii* occurs in a temperate semihumid to semidry forest ecosystem that occasionally merges with almost desert-like species such as the pinyon pine *P. cembroides*. Six of the eight var. *greggii* collection sites in Nuevo León and Coahuila were located on the northern aspects of mountains, suggesting that the variety prefers the moister sites in what is otherwise a very harsh environment. Species like *P. cembroides* occupied the southern slopes at some of these locations. At Los Lirios and Loma El Orégano, var. *greggii* occupied or was adjacent to ravines and draws, while even more drought tolerant species, such as *P. arizonica* var. *stormae*, occupied the upper slopes (Donahue 1988, 1994).

Perhaps the best example of var. *greggii*'s association with other species can be seen at Sierra Tarrillal. Donahue (1994) reports that,

"At 1950 m altitude, var. *greggii* occurs as scattered individuals, growing in association with *P. pseudostrobus* and *P. cembroides*. At 2000 m altitude, a few individuals of *P. teocote* and *P. montezumae* can be seen mixed with more dense stands of *P. greggii*. At the highest elevations of 2500 to 2600 m, *P. greggii* grows in mixed stands with *P. ayacahuite*, *P. pseudostrobus*, *Pseudotsuga menziesii*, *Abies* sp. and *Populus* sp."

The natural stocking of *P. greggii* in these northern locations can be as low as 20 trees per hectare. In addition to the species mentioned above, *Quercus* spp. are common at some locations, as are *Cupressus arizonica*, *Pseudotsuga flahoulti* and *Juniperus* spp. Possibly the most intriguing question concerning the ecology of var. *greggii* is why it is the only pine species that occurs at some locations. The ecology of the variety needs to be better studied.

The ecological settings that define the occurrence of *P. greggii* var. *australis* are more varied than they are for var. *greggii*. At Carrizal Chico, Laguna Atezca, and Jalamelco, var. *australis* is found in what can be described as moist temperate to subtropical forests. It occurs with *P. patula* at Carrizal Chico and Jalamelco. Although *P. patula* is not found at Laguna Atezca, it does occur only a few kilometers from the site at 1490 m elevation. Large *Liquidambar styraciflua* (sweetgum) trees are also found in association with *P. greggii* at Jalamelco and Laguna Atezca, a sign that

moisture content and/or humidity is high. *Pinus oocarpa* also has been seen at Carrizal Chico (Donahue 1994).

The remaining populations of var. *australis* occur in mesic environments that are drier and cooler than those at Jalamelco and Laguna Atezca. *Pinus patula* is occasionally present on some *P. greggii* sites (e.g., El Madroño). As the soils become more shallow and the climate drier, *P. teocote*, *P. pseudostrobus*, *Quercus* spp. and *Juniperus* spp. tend to become more common.

Cone- and seed-boring insects are common on *P. greggii* in natural stands, particularly on var. *greggii* (López-Upton and Donahue 1995). One of the more damaging cone insects is *Leptoglossus occidentalis* (Hemiptera). Several Lepidoptera defoliators have been identified on *P. greggii* in natural stands as well (Cibrián-Tovar et al. 1995).

WOOD QUALITY IN NATURAL STANDS

The majority of information available on the wood quality of *P. greggii* in natural stands comes from assessments of var. *australis* trees. Martínez (1948) describes the wood of var. *australis* as pale yellow and light in weight. Pérez-Olvera and Olvera-Coronel (1981) state that color changes little from juvenile to mature wood. The earlywood is a pale yellow and the latewood is a pale brown. The annual rings are very well defined.

CAMCORE took wood samples from 36 trees that averaged 25 years of age at Laguna Atezca and El Madroño and analyzed 11-mm cores for wood density (Murillo 1988). Results indicate that the transition from juvenile to mature wood occurred between the ages of 12 and 18 years. Mean wood density of juvenile and mature samples was 458 and 515 kg/m³, respectively. There were no differences in wood density between the two provenances. It was concluded that *P. greggii* var. *australis* has a low density compared to many of the other pine species studied in Mexico (Murillo 1988).

The wood of var. *australis* is not singled out for any specific purpose by local sawmillers. It has been used for railroad ties, mining timber, fence posts, furniture and fuelwood (Pérez-Olvera and Olvera-Coronel 1981).

Because most *P. greggii* var. *greggii* trees are very small, sawmillers sometimes overlook them and cut larger trees of different species to maximize economic returns. This is not to say that farmers do not harvest var. *greggii* locally, but the wood is not highly sought after.

PLANTATIONS

Currently, *Pinus greggii* is only being planted commercially in South Africa, but the species has been examined on a field trial basis in a number of countries in subtropical and temperate regions around the world (Chaturvedi and Dwivedi 1982, Leslie 1992, Neil 1991). Much of what is known about *P. greggii* plantation management comes from

these field trials and commercial plantings, as well as from CAMCORE genetic tests in Brazil, Colombia, Chile, South Africa and Zimbabwe, and species introduction studies established by the South African government (Darrow and Coetze 1983) and Mondi Forests in the 1970s.



Photo 4-5. Johan Vermaak, Mondi Forests, next to containerized *Pinus greggii* seedlings in South Africa. On average, it takes about 28 weeks to grow seedlings to plantable heights.

NURSERY PRACTICES

Seed Handling

The seeds of var. *greggii* are larger and have thicker seed coats than those of var. *australis* (López-Upton and Donahue 1995). Most organizations handle the seeds of both varieties in the same way. Seeds are placed in cold storage (2 to 4 °C) at a moisture content of 8 to 10%. Viability of var. *australis* has been maintained for as long as 60 months under these conditions. Information is not available on the viability of var. *greggii* seed maintained in storage for more than two years. However, the assumption is that seed storage of the variety does not differ much from other hard pines.

In a laboratory study at North Carolina State University, Donahue (1990) found that var. *greggii* reached maximum germination in 14 days, versus 21 days for var. *australis*. Cold stratification of *P. greggii* seeds is not used by CAMCORE organizations at present. However, researchers at SAFCOL report that seed germination may take as long as four to six weeks. Donahue (1990) did find that a 30-day cold stratification improved *P. greggii* var. *australis* germination rates. In Donahue's study, seeds were soaked in a 10% bleach solution for 10 minutes, followed by a water soak at 3.0 °C for 24 hours. Afterwards, excess water was drained, and the seeds stored for 30 days at 3.0 °C. Even though the 30-day stratification improved the germination rate for var. *australis* it had little effect on var. *greggii*. Donahue recommended the 30-day

stratification to improve the germination of var. *australis* and suggested the need for a 60-day stratification for var. *greggii* to produce a similar effect.

Several CAMCORE members use pregermination treatments prior to sowing. Mondi places *P. greggii* seeds in a water bath through which compressed air is bubbled for 24 hours; the bath is maintained at 28 °C with a pH of 5.6. In Zimbabwe, seeds are subjected to a 24-hour soak and are then maintained at 4 °C for 12 days (H. Mhongwe, personal communication).

Most organizations sow *P. greggii* seeds directly into tubes rather than pricking out from germination beds. Some CAMCORE members are concerned that pricking out damages root radicals and leads to spiral rooting in the field. This problem is not restricted to *P. greggii*; it occurs in most tropical and subtropical pines.

Containers and Growth Media

Most organizations use tubes with a capacity of approximately 60 cm³ when raising *P. greggii* seedlings. RIGESA uses slightly larger tubes with capacity of 110 cm³ (H. Guimaraes, personal communication), and Smurfit Cartón de Colombia uses tubes with a capacity of 125 cm³, as well as Jiffy® pellets of 34 cm³.

Several different media have been used to grow *P. greggii* seedlings successfully. All of the South African organizations use 100% composted pine bark that has pH values ranging from 4.9 to 5.6. In Zimbabwe, the Forest Research Centre

uses topsoil mixed with soil from pine plantations (pH 6.0) that contains mycorrhizae (H. Mhongwe, personal communication). RIGESA uses equal parts of composted pine bark, topsoil and vermiculite. Klabin uses 75% composted pine bark with 25% vermiculite. Smurfit Cartón de Colombia uses equal parts composted sawdust, carbonized ash from the mill, and topsoil (M. Arce and V. Betancur, personal communication).

Seedling Management

The goal of organizations in southern Africa and Colombia is to raise seedlings that are 10 to 15 cm tall with root collar diameters of 3 to 4 mm. The Brazilian organizations generally opt for seedlings that are 25 cm tall. To grow seedlings to a height of 10 to 15 cm in South Africa and Colombia, 20 to 36 weeks may be required. Growing seedlings to a height of 25 cm in the humid environments of southern Brazil may require 20 to 24 weeks for var. *australis* and 30 to 36 weeks for var. *greggii*. Because var. *greggii* takes longer to reach the desired height, careful planning is needed to time outplanting of this variety with the onset of the rainy season.

Pinus greggii requires nursery practices typical of most pines. Normal fungicide and fertilizer applications are recommended, but care must be taken not to overwater. Most nurseries in South Africa grow seedlings under a shade cloth to protect plants from hail and damage by birds. Seedlings planted by CAMCORE members do not appear to be susceptible to any specific diseases.

Vegetative Propagation

Research conducted by CAMCORE members suggests that *P. greggii* is relatively easy to vegetatively propagate. *P. greggii* var. *greggii* is easier to propagate than var. *australis*, and both varieties are easier to propagate than *P. patula*. The tendency to coppice found in young var. *greggii* trees is not present in var. *australis*, corroborating the high potential for vegetative propagation of var. *greggii*. Using the Arauco system in Chile, which involves the use of bottom heat in the rooting beds, Balocchi (1996) obtained more than 1000 rootable cuttings from 128 seedlings of both var. *australis* and var. *greggii* in one year of propagation.

Several of the South African CAMCORE members have established *P. greggii* cuttings in the field. They used the propagation system described in Chapter 10 (*Pinus patula*). Mondi propagates *P. greggii* using potted hedges and uses microcuttings to mass produce *P. greggii* × *P. patula* hybrids. Microcuttings are harvested from minihedges grown under intense management in Unigro® trays. The hedges remain in trays for 18 months before they are planted out into 10 liter black plastic bags for macrocutting production.

STAND MANAGEMENT

Site Selection and Establishment

***Pinus greggii* var. *greggii*:** *Pinus greggii* var. *greggii* seems well suited to areas that are too cold and dry for *P. patula*, but

the variety can not tolerate the wet, humid sites that seem ideal for such species as *P. taeda* and *P. elliottii*. Before planting var. *greggii*, growers need to be aware of the elevation and climate of the planting site (not too warm), the length of the dry season (five to seven months of pronounced dry weather) and the soil drainage characteristics (must be well drained).

CAMCORE's South African members have the most experience growing *P. greggii* var. *greggii*. Based on their recommendations, an optimal planting site for this variety is between 25° and 31° S, located above 1500 m elevation, and receives approximately 800 mm of annual precipitation. Sites should experience well-defined cold and dry periods that are too harsh for var. *australis* or *P. patula*. Variety *greggii* appears most adapted to sandy clay loams or sandy clays that are approximately 60 cm in depth. Variety *greggii* exhibits great stability on slopes exposed to strong winds.

The variety also has survived and grown relatively well in field trials established by Arauco and Forestal Mininco on well-drained volcanic soils between Concepción (37° S) and Valdivia (40° S), Chile. In a species trial near Valdivia that included both varieties of *P. greggii*, average height growth at 4 years was 2.6 m, compared to the 2.8 and 3.4 m heights of *P. patula* and *P. radiata*, respectively (P. Crespell, personal communication).

In a Smurfit Cartón de Colombia planting at Romerillo, Colombia (lat. 2° N, elev. 2450 m, ann. precip. 2090 mm), *P. greggii* var. *greggii* has grown very poorly relative to

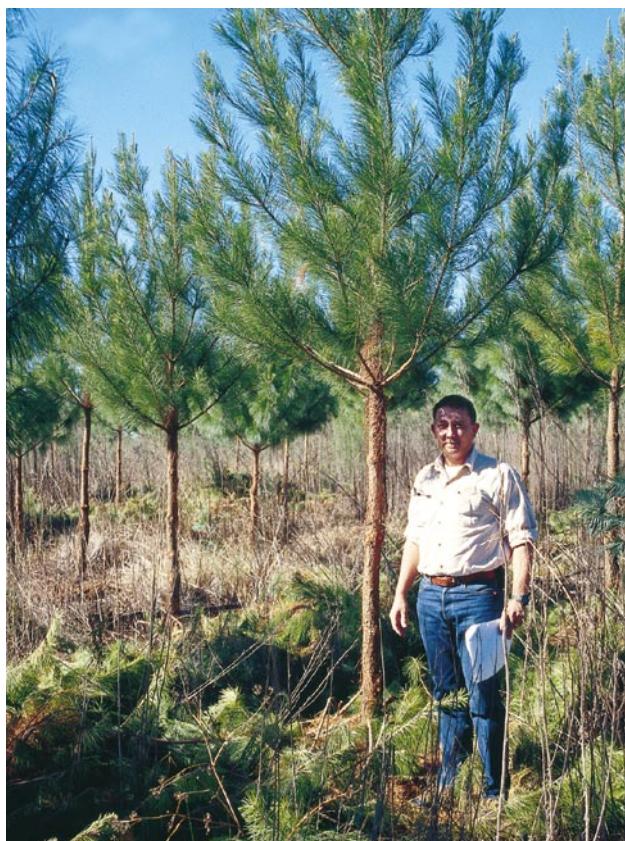


Photo 4-6. Eric Kietzka, Mondi Forests, standing next to a pruned *Pinus greggii* tree produced from cuttings. Early stem form of the cuttings has been very good.

P. patula, possibly because the altitude is too low and there is no well-defined dry season at this site. The northern variety has also done poorly when planted between 880 and 920 m elevation in southern Brazil (24° to 27° S). In this area, the rainfall is evenly distributed throughout the year, humidity is high and the variety is severely attacked by *Sphaeropsis sapinea* (see Disease and Insects).

Pinus greggii var. australis: *Pinus greggii* var. *australis* requires slightly more moderate conditions with respect to cold and dryness than var. *greggii* and is suited to lower elevations. Relative to *P. patula*, var. *australis* seems to withstand drier conditions and poorer soils, but is not significantly more cold hardy.

In South Africa (25° to 31° S), an optimum *P. greggii* var. *australis* planting site is one between 800 and 1500 m elevation located in areas with 800 mm of annual rainfall (Stanger 1998, Kietzka et al. 1996). Foresters are impressed with the variety's early growth in plantings around 1000 m elevation, which is off site for *P. patula*. Although var. *australis* performs well as high as 1800 m, it generally does not outgrow *P. patula* at this altitude. The exception may be on very dry sites in both Lesotho (Leslie 1992) and possibly the northeastern Cape, South Africa (see Provenance Variation). The variety has performed well on moist sites between 1800 and 2000 m elevation in Uttar Pradesh, India (27° N) but is no better than *P. patula* in these areas (Chaturvedi and Dwivedi 1982).

South African foresters suggest that *P. greggii* var. *australis* prefers acidic, sandy clay loams to sandy clays with a soil depth of at least 70 cm. The variety can tolerate 40 frosts per year, probably at temperatures no more severe than -10 °C. When planted above 1500 m in South Africa, the variety seems to foxtail with greater frequency and produces extremely large internodes. It suffers from needle scorch due to cold winds in the northeastern Cape region of South Africa above 1500 m elevation and should not be planted in hail belts because of its susceptibility to *Sphaeropsis sapinea*.

On a site near Lages, (Santa Catarina) Brazil (27° S), the provenance of Laguna Atezca, has performed well at 920 m elevation on a moist Inceptisol that is high in organic matter. However, when planted on a deep Oxisol in Paraná, Brazil at (24° S) at 880 m elevation, the variety performs poorly relative to the southern pines. In Zimbabwe (19° S), researchers have found that var. *australis* grows very well at approximately 1490 m elevation. In Romerillo, Colombia (2° N), the Smurfit Cartón de Colombia plantings of var. *australis* showed promise on a volcanically derived soil at an altitude of 2450 m.

Site preparation for the species differs little from that of other tropical pines. Seedling blow down was exacerbated when plants were established on well-prepared beds in a windy region of the northeastern Cape, South Africa, but not more so than *P. patula*. *Pinus greggii* var. *australis* and

P. patula were more susceptible to wind damage than var. *greggii*. As a word of caution, like *P. radiata* and *P. patula*, *P. greggii* var. *australis* is an early sprinter; even when planted off site. Decisions on widespread use of the species should not be made until adequate testing has been completed.

Silviculture

CAMCORE members have established the species at 3.0 × 2.5 m to 3.0 × 3.0 m spacings. Most CAMCORE organizations do not use fertilizer at time of planting. However, *P. greggii* responded to phosphorus applications in Mpumalanga, South Africa (Freimond 1997). Although urgently needed, no baseline data exist on the nutrient needs of this species.

Pinus greggii var. *greggii* grows slowly and is only about 0.5 m tall at the end of the first growing season and 2.5 m after 3 years. It has a Christmas tree-like appearance at 3 years of age, with dark green foliage, a uninodal branching pattern and a pyramidal crown. After 3 years, terminal shoot elongation becomes more pronounced, and the crown becomes more irregular. Internode lengths for the La Tapona source can be as long as 2 m. Foxtailing is less than 5% at most locations and is only noticeable when the species is established on low elevation, off-site areas. The formation of stem cones on var. *greggii* appeared to cause the terminal leader to fork at some sites in South Africa. By age 5 years, trees are 4.0 to 7.0 m tall.

Pinus greggii var. *australis* grows more quickly than does var. *greggii*, with an average height of 5.0 m by 3 years. This variety often produces long internodes and is prone to foxtailing and top dieback when planted off site. On a wet site with deep fertile soils at 2000 m altitude in Jujuy, Argentina (23° S), 80% of the trees were foxtailing at 3 years of age. However, at most locations above 25° S latitude, foxtailing is about 20%. Malan (1994c) studied branching patterns of *P. greggii* in the Mpumalanga region of South Africa (25° S) and found that *P. greggii* var. *australis* produced twice as many branches per unit of main stem as did *P. patula* or *P. pringlei*. In plantations in the northeastern Cape (31° S), *P. greggii* produced more but thinner branches per unit stem than did *P. patula*.

Several organizations correctively prune *P. greggii* between the ages of 3 and 5 years. Pruning crews in the northeastern Cape commented that it was more difficult to saw through similar-sized branches of *P. greggii* than *P. patula*. At altitudes above 1200 m in South Africa, the wounds resulting from branch removal healed much more slowly on *P. greggii* var. *greggii* than they did on var. *australis* or *P. patula*.

Forty-two percent of 3.5-year-old *P. greggii* trees resprouted after a fire at Langweis, South Africa (lat. 31° S, elev. 1320 m, ann. precip. 832 mm). The fire resistance of the species was classified as average with respect to most pine species, but is much less resistant than *P. leiophylla* (Kietzka et al. 1996).

Pests and Other Limiting Factors

There have been some observations and official reports of several important pest problems on *P. greggii*. On a shallow soil at Nyangui, Zimbabwe (elev. 2200 m), where *P. patula* growth was poor, a 4.5-year-old *P. greggii* var. *greggii* planting was severely infested with *Pineus pini* (woolly aphid). Woolly aphids also were seen at a lower elevation several years later in CAMCORE trials of *P. greggii* var. *australis*. In addition to woolly aphids, *Cinara cronartii* (black aphid) and *Eulachnus rileyi* (leaf aphid) have been observed on *P. greggii* in South Africa, but these pests did not result in tree mortality. In southern Brazil, leaf-cutting ants have attacked *P. greggii* trees in CAMCORE tests. In Uttar Pradesh, India, two beetle species defoliated var. *australis* (Gupta 1980). Interestingly, plants shaded by tall grasses escaped the attacks.

Non-hail-induced *Sphaeropsis sapinea* (*Diplodia*) severely infected *P. greggii* var. *greggii* and moderately infected var. *australis* in the humid environments of southern Brazil (Auer and Grigoletti 1997); off-site var. *australis* plantings in South Africa are affected much less by this pest (Stanger 1998). The southern Brazil plantings (24° to 27° S) of *P. greggii* established between 800 and 900 m altitude began to show symptoms at 3 years of age. Families of var. *greggii* show varying levels of resistance to *S. sapinea* in CAMCORE studies in southern Brazil, but further testing is not recommended because the taxon grows so slowly in the region. However, the performance of var. *australis* in southern Brazil is very promising, especially in Santa Catarina and Paraná States (see Provenance Variation). Sources of *P. greggii* var. *australis* also vary by provenance and family with respect to their level of resistance. For example, at the Klabin planting at Tributos, Santa Catarina (lat. 27° S, elev. 920 m, ann. precip. 1464 mm), mean family infestation rates ranged from 0 to 70%. Some of the most resistant families were also the fastest growers. When assessed at 5 years, Laguna Atezca, the var. *australis* source most adapted to that region of Brazil, had significantly fewer problems with the disease than the slowest growing source, Laguna Seca (CAMCORE, unpublished data). In some ten-year-old trials of *P. greggii* var. *australis* at Klabin, the trees appeared quite healthy, suggesting that they have recovered from the disease. Nevertheless, continued selection for resistance is warranted because early infection may reduce survival.

Interestingly, in hail-induced *Sphaeropsis sapinea* events in South Africa, *P. greggii* var. *greggii* has demonstrated more resistance at several locations in South Africa than has var. *australis* or *P. patula* (Kietzka et al. 1996). Studies are now underway to look at the resistance patterns of both varieties in South Africa.

In Nepal, *P. greggii* var. *australis* was more resistant to *Mycosphaerella gibsonii/Cercoseptoria pini-densiflorae* (brown needle disease) than *P. patula* and some of the local pines (Neil 1989). In India, *P. greggii* was susceptible to the

disease in the nursery but resistant in plantations (Singh 1982).

Antelopes and goats sometimes preferentially browse young *P. greggii* var. *australis* shoots in southern Africa. Variety *greggii* appears to be less palatable, possibly as a consequence of terpene difference between the two varieties (Kietzka et al. 1996). In South Africa, baboons and monkeys have stripped the bark from and killed trees in *P. greggii* seed orchards.

WOOD QUALITY IN PLANTATIONS

The wood of var. *australis* is straw-white in color, relatively homogeneous between juvenile and mature sections, and is similar in appearance to that of *P. patula* (Poynton 1977). It is comparable to *P. patula* in terms of hardness but tends to be weaker, stiffer, and tougher. Annual rings are well defined (Malan 1994c). The general appearance of var. *greggii* wood is similar to that of var. *australis*, but little information is available on its quality.

Physical Properties

Three studies have examined physical properties of *P. greggii* var. *australis* in South Africa. The kraft and thermomechanical pulping properties of two 10-year-old *P. greggii* and *P. patula* trees were compared in South Africa



Photo 4-7. When *Pinus greggii* trees are planted off site in a humid climate, they are often attacked by *Sphaeropsis sapinea*. This picture shows a tree dying at a planting site in southern Brazil.

(du Plooy and Venter 1981). Domisse (1994) looked at the wood and pulping properties of five var. *australis* trees at age 16 and compared results to those obtained from nine other pine species. Malan (1994c) analyzed the wood and sawmilling properties of 20 trees at approximately 22 years of age at Tweefontein (lat. 25° S, elev. 1152 m, ann. precip 1298 mm) and Mac-Mac (lat. 25° S, elev. 1250 m, ann. precip 1546 mm). There also have been several kraft and TMP pulping studies conducted on 9- to 12-year-old *P. greggii* trees in India; physical properties were reported in these studies (Sharma and Bhandari 1986, Sharma et al. 1987). One study of wood from *P. greggii* var. *greggii* has been conducted by Mondi on 6-year-old trees.

Density

du Plooy and Venter (1981) found that the density of 10-year-old *P. greggii* var. *australis* trees in the George-Knysna area (lat. 34° S, elev. 232 m, ann. precip. 884 mm) was 373 versus 332 kg/m³ for *P. patula*. Domisse (1994) found that var. *australis* has strength properties similar to those of *P. patula*. The mean wood density (unweighted) of *australis* was also similar to that of *P. patula* (360 vs. 356 kg/m³). Malan (1994c) found the density of var. *australis* to be 453 kg/m³ at Tweefontein and 508 kg/m³ at Mac-Mac. There were large differences in density between earlywood and latewood in var. *australis*, as is the case in *P. elliottii*. Planting site had a large effect on mean wood density and on the pith-to-bark wood density in Malan's study. Wood studies conducted by Mondi on very young (6-year-old) var. *greggii* trees in South Africa showed the variety to be slightly more dense than *P. patula* (372 vs. 353 kg/m³).

Fiber Quality

In the study by du Plooy and Venter (1981), tracheid length was approximately 30% shorter in *P. greggii* than in *P. patula* (2.6 vs. 3.2 mm). In the study by Domisse (1994), var. *australis* tracheid length was 5 to 15% shorter than that of *P. patula* (2.42 vs. 2.72 mm). Malan (1994c) also found that var. *australis* produced shorter tracheids than either *P. patula* or the *P. elliottii* × *P. caribaea* hybrid. There was no correlation between tracheid length and site. Average tracheid length at the 20th ring measured near dbh was 3.41 and 3.51 mm at Tweefontein and Mac-Mac, respectively. Sharma et al. (1987) found that *P. greggii* had an average tracheid length of 2.2 mm, which is shorter than *P. pseudostrobus* but the same as *P. taeda* in northern India. *Pinus greggii* had the largest tracheid diameter of the three species. Tracheid length in 6-year-old var. *greggii* trees from South Africa was 1.4 versus 1.7 mm for *P. patula* trees of a similar age.

Sawmilling Properties

Malan (1994c) found that spiral grain angle was very different at two sites he studied in South Africa. Mean grain angle was 4.9° at Tweefontein versus 3.1° at Mac-Mac. He concluded that the difference was due in part to excessive wandering pith (speed wobble) at the low

elevation Tweefontein site.

Pinus greggii wood can be high in extractives, a characteristic that seems to be greatly affected by planting site. At Tweefontein extractive percent was 5.0% for *P. greggii* var. *australis* versus 1.8% for *P. patula*. At Mac-Mac, extractive percent dropped to 2.9% for *P. greggii* var. *australis*. (Malan 1994c). In the study by du Plooy and Venter (1981), extractive percents for *P. greggii* and *P. patula* were 3.7 and 3.0, respectively. Domisse (1994) found that *P. greggii* and *P. patula* exhibited the same percent extractives.

From a structural point of view, *P. greggii* wood is characterized by a well-defined ring structure and large density differences between earlywood and latewood (Malan 1994c). Because it has a higher concentration of knots and a poorer stem form than *P. patula*, a larger portion of *P. greggii* var. *australis* boards were rejected for commercial use in the sawmilling study conducted by Malan (1994c). Stem form and branchiness need to be improved if it is to be a useful solid wood species.

Pulp Quality

Pinus greggii var. *australis* was found to have sufficiently high α-cellulose content for the manufacture of filament rayon and tire cord yarn in Uttar Pradesh, India (Dhawan et al. 1990). In a pilot study in Uttar Pradesh, India, 10- to 12-year-old *P. greggii* trees were kraft-pulped along with samples of *P. pseudostrobus* (Sharma et al. 1987). There were no differences between the two species in screened pulp yield (43%) at kappa number 38.6 for unbleached pulps. The study indicated that *P. greggii* had better bonding properties than *P. pseudostrobus* at a comparable tearing strength.

In the kraft and TMP studies initiated by du Plooy and Venter (1981), the kraft pulp yields for both *P. greggii* and *P. patula* at a given kappa number were very similar. Furthermore, the TMP strength properties of the two species were almost identical.

In TMP studies conducted by Domisse (1994) in South Africa (described previously), *P. greggii* and *P. patula* required the least amount of energy of the 10 pines evaluated to refine to the same level of freeness. *Pinus greggii* had the 3rd highest strength properties, following *P. radiata* and *P. patula*. The tensile index in *P. greggii* was only 10% less and the burst index only 3% less than that of *P. patula* (Domisse 1994). *Pinus greggii* had considerable brightness, second only to *P. leiophylla*, but exhibited the lowest opacity of the species tested. In TMP studies conducted in northern India by Sharma and Bhandari (1986), *P. greggii* exhibited lower brightness values than *P. patula* and *P. caribaea* but higher values than *P. pseudostrobus* and *P. taeda*. Based on the pilot studies in India and South Africa, *P. greggii* var. *australis* produces acceptable kraft and newsprint grade pulps. Kraft pulp yields for 6-year-old *P. greggii* var. *greggii* and *P. patula* were 42 and 43%, respectively.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

Since the late 1980s, CAMCORE has sampled 183 trees from eight provenances of var. *greggii* and 180 trees from seven provenances of var. *australis* for use in testing and ex situ conservation (Table 4-1). The collections are the most complete ever made and sample across the entire known distribution of the species.

The Cooperative has established 52 tests with *P. greggii*. In the first series of tests, the two varieties were grouped together in the same trials. However, after the considerable difference in growth rate between the northern and southern sources was noted, the two varieties were planted separately but with common control lots in subsequent genetic tests.

There are three reports assessing the CAMCORE *P. greggii* studies in the literature. Dvorak et al. (1996a) and Kietzka et al. (1996) summarized three-year results, with the former summarizing global responses of *P. greggii* across sites in different countries and the later emphasizing developments of Mondi Forest plantings in South Africa. Hodge (1998) generated information on genetic parameters from Cooperative-wide assessments that measured tests at 3, 5 and 8 years from 17, 28, and 3 tests, respectively.

PROVENANCE VARIATION

Survival

***Pinus greggii* var. *greggii*:** On sites receiving an excess of 1000 mm of rainfall in Brazil and South Africa, var. *greggii* survival is poorer than for *P. taeda*, *P. elliottii* and *P. patula*. Poor survival in Brazil is due to *Sphaeropsis sapinea* (Diplodia), while in South Africa it may be the result of a combination of factors, including Diplodia, wet soils and excessive weed competition. *Pinus greggii* var. *greggii* showed good survival on well-drained, moist sites at Romerillo, Colombia (lat. 2° N, elev. 2450, ann. precip. 2090 mm) but grew much slower than the *P. patula* control (see Productivity). There were no detectable differences in survival among provenances of *P. greggii* var. *greggii* in Brazil, Colombia, and South Africa, with the exception of Cerro El Potosí, which was the poorest performing source at several locations.

On sites in South Africa receiving less than 1000 mm annual rainfall, *P. greggii* var. *greggii* survival varies with respect to other species. In a group of four tests established by Sappi at Helvetia, South Africa (lat. 25° S, elev. 1700 m, ann. precip. 770 mm), var. *greggii* survival (79%) was superior to var. *australis* (72%) and *P. patula* (66%) in one trial, there were no differences among the three taxa in a second trial, and *P. patula* exhibited survival superior to that of var. *greggii* at 3 and 5 years in the other two tests.

Two *P. greggii* tests were also established by Mondi Forests in low rainfall areas at Jessievale, South Africa (lat. 26° N, elev. 1745 m, ann. precip. 836 mm). The survival of var. *greggii* (98%) was better than var. *australis* (92%) and *P. patula* (88%) at 5 years of age in one test. In the other test, which only included var. *greggii* and *P. patula*, the survival of northern *greggii* was vastly superior to that of *P. patula*.

A consistent pattern of survival for var. *greggii* emerged in Mondi high elevation plantings in the northeastern Cape of South Africa. A number of tests were planted at two locations, Bendoran (lat. 31° S, elev. 1480 m, ann. precip. 834 mm) and Rush Valley (lat. 31° S, elev. 1780 m, ann. precip. 844 mm). Age 5 survival of var. *greggii* was much better than *P. patula*, generally around 20 to 25% higher. Survival of var. *australis* was intermediate, generally around 7% higher than *P. patula*. CAMCORE's experience suggests that *P. greggii* var. *greggii* does not survive well on wet sites at low elevations, but does progressively better at higher elevations that are cold and dry.

***Pinus greggii* var. *australis*:** On wet sites in Brazil, the survival of Laguna Atezca was often as good as that of *P. taeda* and *P. elliottii* and better than the other two var. *australis* provenances of Laguna Seca and El Madroño. Laguna Atezca occurs on a moist site in Hidalgo, Mexico. Survival of the three var. *australis* provenances tested in southern Brazil was perfectly correlated ($r = 1.0$) to amount of rainfall received by populations in natural stands in Mexico.

On sites in South Africa receiving more than 1000 mm of rainfall per year, var. *australis* typically survives as well as *P. patula* and slightly better than var. *greggii*. On sites receiving less than 1000 mm at Helvetia and Jessievale, the survival trend has been inconsistent and could have been confounded by the variability in seedling quality at time of planting; at the northeastern Cape the survival of var. *australis* is better than that of *P. patula*.

Productivity

Four CAMCORE tests have reached 8 years of age. The tests were planted at Romerillo, Colombia (lat. 2° N, elev. 2450 m, ann. precip. 2090 mm) and Boa Esperança, Brazil (lat. 24° S, elev. 880 m, ann. precip. 1473 mm) by Smurfit Cartón de Colombia and Klabin, respectively.

In Colombia, mean productivity of the best var. *australis* population, Laguna Seca, was 12 m³/ha/yr at 8 years. The control lots of improved *P. patula*, *P. maximinoi* and *P. tecunumanii* had mean productivities of 18, 13 and 7 m³/ha/yr, respectively. The productivity values for Laguna Seca were based on measurements of approximately 1000 trees.

At Boa Esperança, Brazil, mean productivity of the best provenance, Laguna Atezca, was 17 m³/ha/yr at 8 years of

age, versus 22 m³/ha/yr for *P. taeda* and 10 m³/ha/yr for *P. elliottii*. The values for Laguna Atezca were based on the measurements of 1100 trees. All values from the Klabin tests are biased upwards because the trials were interplanted with provenances of *P. greggii* var. *greggii*, which grew much slower or died out because of *Sphaeropsis sapinea* attack.

Mean annual increment at 20 years was estimated from measurements taken at age 10 for *P. greggii* var. *australis* planted at four sites in the Mpumalanga region of South Africa (Darrow and Coetze 1983). Average estimated productivity at 20 years ranged from 10 to 24 m³/yr, depending on the site. Volume increment increased with site elevation. Belfast, South Africa (lat. 25° S, elev. 1888 m, ann. precip. 842 mm) emerged as one of the most promising locations for planting *P. greggii* var. *australis*.

Preliminary results from the CAMCORE tests, along with other introduction trials, suggest that *P. greggii* var. *australis* has the potential to grow nearly as fast as *P. taeda* and *P. elliottii* at latitudes between 25° and 27° S at sites above 880 m in southern Brazil, assuming an appropriate provenance is used and that the Diplodia problem can be controlled. Likewise, the variety can grow as quickly as *P. patula* in the dry zones of South Africa between 28° and 31° S latitude on sites below 1500 m elevation. Specifically, *P. greggii* var. *australis* may be best suited for areas between 1000 and 1500 m elevation that are too warm for *P. patula*. The variety does well above 1500 m but often demonstrates no growth advantages over *P. patula* in these areas.

In terms of productivity, the only locations at which var. *greggii* was competitive with var. *australis* and *P. patula* were in the northeastern Cape above approximately 1400 m altitude. Although var. *greggii* often had individual-tree volume lower than the other two taxa, its better survival compensated for the slower growth.

Volume Performance

Volume (over bark) performance across locations for both *P. greggii* var. *greggii* and var. *australis* is presented in Tables 4-3a and b. The source from La Tapona produced significantly more volume than the other northern sources of *P. greggii* that were tested. In the 5-year assessment, trees in La Tapona exhibited longer internode lengths than those in neighboring populations.

Five-year results are only available for three var. *australis* sources: Laguna Atezca, Laguna Seca and El Madroño. The Laguna Atezca source, which is from a humid site in the state of Hidalgo (Mexico), performed the best on wet sites in southern Brazil. El Madroño, a source from a relatively cold and dry site, performed the best on similar sites in South Africa. The relatively good performance of Laguna Seca, a dry-site source, when planted in Colombia is not well understood.

Three-year results from a *P. greggii* planting at Helvetia, South Africa indicated that the Valle Verde provenance was superior to other var. *australis* populations, including El Madroño, as well as improved sources of *P. patula* (data not presented). The growth of the Valle Verde source was also outstanding at an early age in the Eastern Highlands of Zimbabwe.

Table 4-3a. Volume performance (Gain) of six provenances of *Pinus greggii* var. *greggii* tested in Brazil, Colombia and South Africa. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests
MEXICO	1	Cerro el Potosí	-17.6	4	2	-20.9	4	1	-24.4	4	4
	2	Jamé	-21.6	8	2	-3.6	8	1	4.1	8	4
	3	La Tapona	35.7	24	4	30.4	.	.	33.0	23	9
	4	Los Lirios	0.0	8	2	6.0	8	1	3.3	8	4
	5	Las Placetas	7.4	8	2	-5.7	8	1	-6.1	8	4
	6	Ojo de Agua	-3.9	27	4	-6.1	.	.	-9.9	25	9

Table 4-3b. Volume performance (Gain) of three provenances of *Pinus greggii* var. *australis* tested in Brazil, Colombia and South Africa. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests
MEXICO	7	El Madroño	0.5	25	4	-6.9	16	1	5.8	16	4
	8	Laguna Atezca	9.5	21	4	-1.0	16	1	-6.3	15	4
	9	Laguna Seca	-10.0	16	3	7.9	14	1	0.5	16	4



Photo 4-8a. Top left, Luis Fernando Osorio, Smurfit Cartón de Colombia, stands next to a 2-year-old *Pinus greggii* var. *australis* tree in a CAMCORE planting in the highlands of Colombia. **4b and c.** Top right, Victor Sierra, Forestal Mininco, and bottom left, Claudio Balocchi, Arauco, pose next to young *P. greggii* trees in two separate CAMCORE trials established in Chile. **4d.** Bottom right, Carlos Mendez, Klabin, assesses the early growth of *P. greggii* var. *australis* in a trial near Lages in southern Brazil.

Quality Traits

In most of the CAMCORE trials, *P. greggii* var. *greggii* exhibited a straighter stem form than var. *australis*. However, there were no noticeable trends by provenance or by location with respect to this characteristic. There were high levels of forking in several of the CAMCORE trials, but no specific trends by provenance were noted.

Provenance x Site Interactions

Results from CAMCORE studies indicate that provenance x site interaction for volume in var. *greggii* is quite limited. La Tapona and Cerro el Potosí were consistently the best and worst sources, respectively; there were some changes in rank of the intermediate provenances. Type B provenance correlations for volume for pairs of tests within and between countries were 0.74 and 0.58, respectively (Hodge 1998). These values are similar to those of most species in the CAMCORE testing program.

The var. *australis* populations behaved somewhat differently. Type B provenance correlations for volume for pairs of tests within and between countries were 0.73 and 0.18, respectively (Hodge 1998). The very low provenance correlation between countries is atypical. Results from additional var. *australis* provenances and more CAMCORE tests will be available in the near future to better quantify



Photo 4-9. Andre Nel, Sappi, standing next to 5-year-old *Pinus greggii* selection in South Africa. CAMCORE members have selected 168 trees in tests of *P. greggii*.

the magnitude of the provenance x site interaction for growth traits across sites. The magnitude of provenance differences in var. *australis* was exacerbated somewhat by the high incidence of disease in southern Brazil.

Family x Site Interactions, Genetic Parameters for Growth Traits

Hodge (1998) also examined the magnitude of family x site interactions for volume. He reports that Type B genetic correlations for var. *greggii* between pairs of tests in the same and different countries were 0.57 and 0.45, respectively; the values were 0.70 and 0.54, respectively, for var. *australis*. These results suggest that family performance is more similar within than between countries. Estimates of age-age correlations for volume between 3 and 5 years was 0.75 and 0.81 for northern and southern varieties, respectively (Hodge 1998).

Estimates of single-site heritability for volume in *P. greggii* var. *greggii* at 3, 5 and 8 years of age were 0.25, 0.26 and 0.20, respectively (Hodge 1998). For var. *australis* these values were 0.14, 0.20 and 0.21.

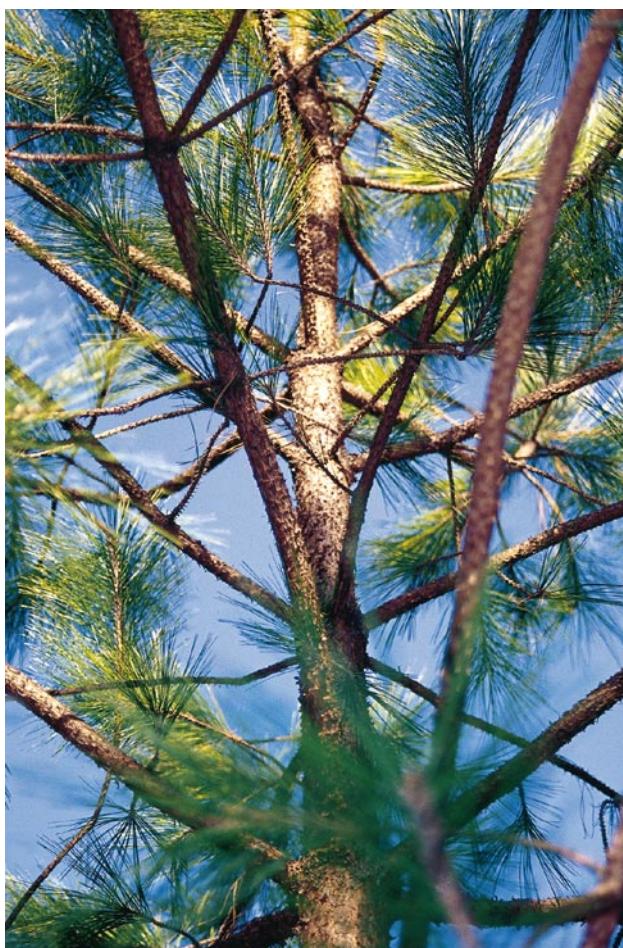
DEVELOPMENT OF IMPROVED MATERIAL

Flowering and Seed Production

Pinus greggii var. *greggii* produces a heavy female flower crop between 18 and 36 months after planting when it is planted in southern Brazil and South Africa. The female flowers on var. *greggii* are usually larger and more purple than those of var. *australis*.

Trees of var. *australis* may produce female strobili as early as 18 months after field planting, but more often a light to moderate crop of flowers emerges at approximately 24 to 36 months (Dvorak 2000a). The onset of male strobili production is somewhat delayed; they may not develop until approximately 48 months after planting, depending on the site. In South Africa and some locations in Zimbabwe, *P. greggii* flowers twice a year. The main flowering period for the southern populations of the species occurs from September through November; with a second flush of predominantly female strobili in February and March in South Africa and January through April in Zimbabwe (Nyoka et al. 2000). Critchfield (1967) also noted that *P. greggii* had two periods of flowering in California, USA, once in November and again in June. Interestingly, at Mukandi, Zimbabwe (lat. 18° S, elev. 1268 m, ann. precip. 1760 mm), female strobili on var. *australis* were produced throughout the year, with only brief interruptions of up to three weeks (Nyoka et al. 2000).

Researchers in Zimbabwe concluded that flowering production was greatest at the highest altitude site (1850 m) and poorest at the lowest site (950 m), and that male flower production was earliest in the year at the high altitude site and began progressively later with decreasing elevation (Nyoka et al. 2000). Female and male flowering were most synchronized at the high altitude site (1850 m).



Photos 4-10a and b. Unimproved *Pinus greggii* var. *australis* can have large branches (left) or can sometimes exhibit a “speed wobble” (right). The speed wobble is thought to be the result of planting the variety on sites that are too humid and also may be related to nutrient imbalances. Stem and branch quality in *P. greggii* var. *australis* are two traits that will be improved through breeding.

Variety *greggii* flowers from November to January in South Africa and produces a second flush with female flowers in April to May. Heavy cone crops can be found on trees in some plantations at 4 to 5 years of age. In southern Brazil, flowering time for female strobili is April and May (H. Guimaraes, personal communication).

Seed Orchards

Based on experience in South Africa, an ideal location for a var. *greggii* orchard is above 1400 m altitude, at 25° to 32° S latitude, and with annual rainfall above 800 mm. Site specifications for a var. *australis* orchard in South Africa are slightly different. A location between 1200 and 1400 m altitude receiving at least 1000 mm of annual precipitation appears to be best.

Pinus greggii has successfully been grafted onto both *P. greggii* and *P. patula* rootstock. Cones of *P. greggii* are ready to harvest 32 to 33 months after pollination. In

South Africa, cones of *P. greggii* var. *greggii* mature from August to September and for var. *australis* from July to August. Based on CAMCORE experience, it appears that var. *greggii* orchards come into full production at 6 years and var. *australis* orchards at 8 years. Seed orchards of both varieties have been established in South Africa and a clonal bank (var. *australis* only) that includes 48 of the best selections from CAMCORE tests has been grafted in Colombia.

Hybrids

Pinus greggii var. *australis* was first crossed successfully with *P. patula* in Australia 40 years ago (Fielding 1960). CAMCORE members have recreated that hybrid and have also successfully crossed *P. greggii* var. *australis* with *P. tecunumanii*, *P. radiata* and *P. taeda*. Crosses of *P. greggii* var. *greggii* with var. *australis* and with *P. patula* have also been tried and results will be available shortly. The greatest contribution of *P. greggii* to a hybrid cross would be an improvement in cold and drought hardiness.



Photo 4-11. Both varieties of *Pinus greggii* produce an abundance of female flowers at an early age.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

Herrera et al. (1997) examined the genetic diversity of *P. greggii* in 10 natural populations (four of var. *australis* and six of var. *greggii*). Using isozymes, they assessed 16 loci, and found an average of 1.5 alleles per locus. There was an average of 44% polymorphic loci, but this value varied greatly by population. At Paltotecoya, Puebla, which is a southern source with only a few trees, there were only 19% polymorphic loci. The larger stand of El Madroño had 68% polymorphic loci. The percentage of polymorphic loci for *P. greggii* is considered low. As an example, a small, 30-tree natural stand of *P. tecunumanii* in Guatemala had 74% polymorphic isozyme loci (Dvorak et al. 1999). Observed heterozygosity for *P. greggii* was greater in northern populations (0.234) than in southern ones (0.185). The results of Herrera et al. (1997) suggest that genetic diversity within *P. greggii* is lower than in many of the other pines in the *Oocarpae* subsection.

Donahue et al. (1996) found that the genetic variation in monoterpenes in var. *australis* was greater than in var. *greggii*. Genes affecting the production of the five terpenes studied appear to be fixed in the northern populations, but only two terpenes tended towards fixation in the southern populations.

Conservation Status

The size of natural populations of *P. greggii* var. *greggii* ranges from about 250 ha at La Tapona, Las Placetas, and other locations, to only a few hectares at Cerro El Potosí. The smallest populations are **endangered** to **critically endangered**. Regeneration is nonexistent at some sites because of overgrazing and uncontrolled burning. Because of the small size of the populations, their degradation by human influences and the variety's small geographic distribution, the conservation status of *P. greggii* var. *greggii* is classified as **endangered**.

Pinus greggii var. *australis* has a slightly broader geographical distribution (Figure 4-1). Like most populations of trees in the region, var. *australis* is under pressure from agricultural enterprises, especially cattle grazing. In rare situations, stands are being harvested to accommodate housing developments (e.g., at Laguna Atezca). In situations where they occur in close proximity to *P. patula*, *P. greggii* var. *australis* is sometimes overlooked as a timber species because of its average stem form and large branches. However, several stands, like El Madroño, are being cut rather intensively at present. Some conservation efforts have been established indirectly. A small seed stand does exist at El Madroño. Trees of *P. greggii* var. *australis* are being sold at commercial nurseries near Mexico City and can be seen in gardens and along the new expanses of toll roads



Photo 4-12. Harvesting trees for the operation of small sawmills like this one at El Madroño (Querétaro, Mexico) slowly reduces the size of native populations of *Pinus greggii*. CAMCORE has conserved much of the genetic base of the species *ex situ*, but *in situ* conservation efforts are still needed.

being built in the central part of the country. At the present time, the conservation status of var. *australis* is classified as **vulnerable**, but population condition needs to be closely monitored.

Until genetic diversity studies based on molecular markers prove otherwise, La Taponia should be considered as a priority for *in situ* conservation of *P. greggii* var. *greggii*. The stand is several hundred hectares in size, is the most productive of the northern sources, and is being well cared for by the local landowner.

Because of its relatively high levels of genetic diversity and good performance in provenance/progeny tests (Dvorak et al. 1996a, Kietzka et al. 1996, Hodge 1998), as well as local efforts to create a seed production area, El Madroño may be a good candidate for *in situ* conservation of var. *australis*.

EX SITU CONSERVATION

Results from *Pinus greggii* tests by CAMCORE have generated enough interest from foresters in South Africa

to begin small-scale plantings of the species. As a result, the Forest Genetics Center in Mexico has made more explorations for undiscovered populations of the species in Mexico and has sold commercial amounts of seeds to interested parties. Several thousand hectares of the species have now been planted as an exotic, and a number of small scientific studies have been conducted within and outside of Mexico in an effort to learn more about the evolution and genetic diversity of the species. CAMCORE members have established conservation plantings in a number of countries. Since there is such a great difference between the best and worst seed sources, especially for var. *greggii*, there could be some concern that future genetic bases might contain representatives from only a few sources. However, in CAMCORE's selections at 5 years of age, a concentrated effort was made to include good trees from some of the poorest provenances, such as Ojo de Agua and Cerro El Potosí, to ensure that a broad genetic base is maintained for future adaptability.

CONTRIBUTORS

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C h a p t e r 5



PINUS HERRERAE

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OVERVIEW

TREE DESCRIPTION

Pinus herrerae Martínez is a medium to very large tree that is 17 to 40 m tall with dbh ranging from 25 to 70 cm at maturity. Specimens in old-growth forests in Michoacán once reached heights of 55 m with diameters at breast height of more than 1.0 m, but nearly all of these large trees have been harvested. Mature trees have a rounded crown with thick, rough, grayish bark that is divided into plates by longitudinal fissures. The bark becomes somewhat scaly and smoother on the upper stem and tends to be smooth, thin and reddish-gray on the branches. Juvenile trees have a pyramidal crown. Their bark is typically scaly and gray but is occasionally smooth and exfoliating with a reddish-brown color; much like that of juvenile *P. patula*. Usually the needles of *P. herrerae* are dark green, erect to slightly drooping, occur in fascicles of threes, and are 10 to 20 cm long (Perry 1991). However, at some locations in Jalisco, Guerrero, and Oaxaca, trees have mainly drooping needles that occur predominately in fascicles of four and occasionally five (mean = 4.1). The cones, which are yellowish-brown, are most often borne singly or in twos, but do occur rarely in threes. Cones are 22 to 57 mm long (mean = 38 mm). Average seed potential per cone is approximately 75 seeds with approximately 150,000 seeds per kg. The wood is pale yellow in color, of moderate density and is used locally for sawtimber, paper products, construction and firewood.

CONSERVATION STATUS

Because both the northern and southern ranges of *P. herrerae* are poorly defined, the conservation status of this species is uncertain. In Durango and Sinaloa, where large areas of *P. herrerae* exist, the species is at **low risk**. In the central part of the species range in Jalisco and Michoacán, local sawmillers are cutting the species heavily

and populations are **vulnerable**. In Guerrero and Oaxaca, which is in the southern portion of the species distribution, stand sizes are very small and/or harvesting is intensive. The population of Palo Blanco, Guerrero is **critically endangered** and Juquila, Oaxaca is **endangered**.

TEST STATUS

Seeds have been collected from 317 mother trees across 12 provenances. Eight tests have been planted in Brazil, Chile, South Africa and Zimbabwe. Another large series of CAMCORE tests is being planned for distribution in 2000.

BEST PROVENANCES

Although results are still preliminary, the provenance of Pino Gordo, Durango appears to be the most promising of the northern sources that have been tested. The Juquila, Oaxaca source also appears to be a good volume producer but may be better suited to subtropical sites that do not experience frosts.

SUITABLE PLANTING SITES

Trial results still need to be evaluated in order to determine which sites are most suitable for *P. herrerae* plantings. Based on CAMCORE experience, the species performs well on sites between 20° and 30° S latitude that occur from approximately 800 to 1700 m elevation. Near the equator planting sites should be around 2000 m elevation. Soils should be well drained, of average fertility, and at least 60 cm deep. The northern sources of *P. herrerae* will grow in areas that receive at least 800 mm of annual precipitation, while the southern sources perform best in regions where annual rainfall is at least 1000 mm. Most populations appear well suited to dry seasons of four to five months. Some sources should be able to withstand freezing temperatures of -5 °C. Because *P. herrerae*'s initial growth is rather slow, weed control is necessary the first few years after planting.

Photo 5-1. *Pinus herrerae* at Dos Aguas, Michoacán, Mexico.

ADVANTAGES OF *PINUS HERRERAE*

- Large north to south distribution in Mexico suggests the possibility of important provenance differences in growth.
- Has very straight stem form and is self-pruning in natural stands.
- Based on its use in Mexico, appears to have good wood quality.
- Recent molecular marker data suggest that the species will hybridize easily with many of the Mesoamerican closed-cone pines.
- Seems to withstand light frosts and moderate droughts.
- Shows better resistance to *Sphaeropsis sapinea* (Diplodia) in areas of southern Brazil than *P. patula* and *P. greggii*.
- Can be easily propagated from seedlings.

DISADVANTAGES OF *PINUS HERRERAE*

- Initial growth of some provenances is slow compared to that of commercial species.
- Shows moderate susceptibility to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in greenhouse trials.
- Poor seed yields in natural stands may suggest low seed production in exotic environments.

NATURAL STANDS

EVOLUTION

Pinus herrerae appears to be a genetic descendent of *P. pringlei* and is closely related to *P. jaliscana* and *P. oocarpa* from western Mexico (see Chapter 1, Evolution). Although *P. herrerae* is morphologically similar to *P. teocote*, the evolutionary relationship between these two species needs to be clarified. Phylogeny results based on RAPD markers suggest that *P. herrerae* should be included in the *Oocarpace* subsection with the Mesoamerican closed-cone pines, rather than in the *Teocote* subsection.

DISTRIBUTION

Pinus herrerae is primarily confined to the Sierra Madre Occidental and the Sierra Madre del Sur of western and southwestern Mexico. It has been identified as far north as Sonora and Chihuahua, Mexico (28° N) by some authors (see Farjon and Styles 1997) and as far south as 17° N in Guerrero (Perry 1991). Its exact distribution in these areas is poorly defined.

Recently, CAMCORE confirmed the existence of *P. herrerae* in Oaxaca. RAPD marker studies show that the population at Juquila, Oaxaca (16° N), once thought to be *P. tecunumanii* (Farjon and Styles 1997) or an atypical form of *P. patula* var. *longipedunculata* (Dvorak and Raymond 1991), has a strong genetic link to *P. herrerae* (Dvorak et al. 2001). More populations of *P. herrerae* undoubtedly occur in the Sierra Madre de Sur in both Oaxaca and Guerrero.

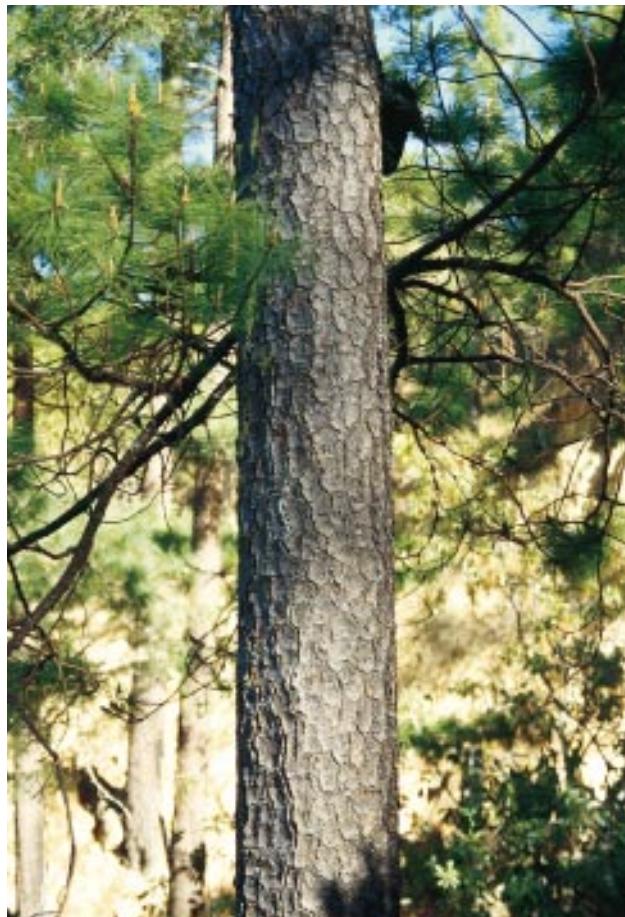
Pinus herrerae is found from elevations of approximately 1200 to 2600 m, but is most common between 1800 and

2400 m. Populations occur on land with flat to rolling topography and often grow in association with a number of other pine species. CAMCORE has sampled 12 provenances and 317 mother trees since the cooperative's first collection of the species in the early 1990s (Table 5-1). These CAMCORE collections mark the first time that the species has been studied at the provenance and family levels. The stands in Durango and Sinaloa are dispersed but are thousands of hectares in size. Those in the central and southern part of the species distribution are much smaller. The smallest population, Monte Grande, Jalisco, was less than 0.5 ha and contained about 20 mature trees (Table 5-1).

CLIMATE

Pinus herrerae occurs in warm, temperate to subtropical climates with some locations experiencing pronounced dry seasons of four to six months. Annual rainfall amounts increase from north to south throughout the species' natural range, but exact values are difficult to obtain because of the large distances between the collection sites and recording meteorological stations (Table 5-2). Estimates indicate that several of the Durango sites at which CAMCORE made collections may receive as little as 850 mm annual precipitation, while sites in Guerrero and Oaxaca may receive as much as 1500 mm. Mist from fog adds to the moisture in the southern populations. Average temperature ranges from 12 to 17 °C at Santa Lucía, Durango, and La Nieve and Dos Aguas, Michoacán to 18 to 20 °C at La Lobera, Sinaloa. Two of the coldest sites

Photo 5-2a. Left, gray bark of a mature *Pinus herrerae* tree in Jalisco. **5-2b.** Right, exfoliating reddish-brown bark of juvenile trees in Michoacán.



at which *P. herrerae* occurs are at La Nieve and Dos Aguas, Michoacán. Some frosts are recorded at these locations each year; with extreme minimums that are around -5 °C.

SOILS

Pinus herrerae occurs on soils of varying depths. In Durango, the soils are calcareous with depths ranging from 35 cm to more than 1.0 m. These soils, which are primarily Entisols, have poorly defined A and B horizons. At Dos Aguas, the soils range in color from yellowish to reddish to a grayish-brown (Photo 5-3) and have an average soil pH of 5.7 (Donahue 1995). In some places, the soils are more than 1.5 m deep and are predominantly clays. Soils at Dos Aguas are mostly Inceptisols, Ultisols and Alfisols. At Palo Blanco, Guerrero, the soils are clay loams to clays, are relatively fertile and are mainly Alfisols. One characteristic common to all *P. herrerae* sites is good drainage.

REPRODUCTIVE BIOLOGY

CAMCORE researchers have noted that female and male strobili on *P. herrerae* are produced the third week of March at Monte Grande, Jalisco. Farjon and Styles (1997) also saw flower production in March in both Michoacán and Jalisco. Information on sites further north and south of these areas is not available. Cones occur singly or in twos and rarely in threes; their length ranges from 22 to 57 mm. Although



Photo 5-3. *Pinus herrerae* occurs on soil of average fertility and moderate depth. This soil profile is at Dos Aguas, Michoacán, Mexico.

Table 5-1. *Pinus herrerae* collections made by the CAMCORE Cooperative in Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	La Puerta	Durango	Mexico	23° 24' N	105° 23' W	2000 - 2450	927	40
2	Pino Gordo	Durango	Mexico	23° 36' N	105° 40' W	2200 - 2300	927	40
3	El Llano	Durango	Mexico	23° 17' N	105° 00' W	2400 - 2450	927	40
4	Guajolota	Durango	Mexico	23° 13' N	105° 11' W	2050 - 2150	927	40
5	Dos Aguas	Michoacán	Mexico	18° 49' N	102° 56' W	2150 - 2250	1090	30
6	La Nieve	Michoacán	Mexico	18° 49' N	103° 03' W	2050 - 2150	1100	20
7	Sierra Lalo	Jalisco	Mexico	19° 12' N	103° 12' W	2000 - 2200	980	35
8	Palo Blanco	Guerrero	Mexico	17° 25' N	99° 31' W	2170 - 2350	1220	15
9	Juquila	Oaxaca	Mexico	16° 15' N	97° 13' W	2090 - 2260	1325	21
10	La Lobera	Sinaloa	Mexico	23° 29' N	105° 51' W	1594 - 2025	1000	15
11	Santa Lucía	Durango	Mexico	23° 37' N	105° 31' W	1985 - 2020	1000	10
12	Los Negros	Durango	Mexico	23° 39' N	105° 47' W	1744 - 2000	1000	11
13	Monte Grande	Jalisco	Mexico	20° 15' N	104° 51' W	2180 - 2190	1500	0*
14	Sierra de Cuale	Jalisco	Mexico	20° 22' N	104° 59' W	2410 - 2430	1500	0*
12	Provenances	6 State/Depts.	1 Country	16 - 23° N	97 - 106° W	1600 - 2450	1102	317

* Site visited, no collections made.

CAMCORE has made cone collections in Mexico from the end of December to as late as February 10th. January appears to be the optimum harvest time. Cones are collected as they turn from green to brown; care must be taken not to collect cones too early. Many of the seeds produced are empty, especially in the northern part of the species range. In the 1996 collection in Michoacán and Jalisco, there was an average of 10 filled seeds per cone. During seed collections in Durango and Sinaloa in 1999 and 2000, only two to four filled seeds per cone were obtained. *Pinus herrerae* trees with small cones (22 to 25 mm long) generally tend to have low seed yields of only one or two filled seeds per cone. Cones begin to open slowly on the tree in mid-February and seed is dispersed over a period of six to 10 weeks (Photo 5-4). By the first of May all cones have opened completely. On some trees, cones fall within several months after seed dispersal. On others, cones persist on the branches for more than a year. *Pinus herrerae* has an average seed potential of 75 seeds, and therefore, one of lowest seed efficiency rates of any pine species studied in Mexico. There are approximately 150,000 seeds per kg.

ECOLOGY AND ASSOCIATED SPECIES

Pinus herrerae occurs across a wide range of ecological conditions. Southern populations in Oaxaca and Guerrero in the Sierra Madre del Sur occur in a moist subtropical cloud forest environment that is characterized by dense understory vegetation, an abundance of *Bromelia* spp. and relatively deep, fertile soils. Populations in central Mexico in Jalisco and Michoacán, as well as those further north in Sinaloa and Durango in the Sierra Madre Occidental, grow under conditions that typically have pronounced dry periods. In the north, soils are generally less fertile and sometimes more shallow, and growing conditions are harsher than those found at *P. herrerae* sites in the south. The upper elevational limit of the species distribution is likely defined by frost severity, while the lower limit is determined by the species' ability to compete with faster growing pines and broadleaf species.

Pinus herrerae occurs in both pure and mixed stands. In the northern part of its distribution, it occupies a transition zone between species that can tolerate frosts and snow, such as *P. engelmannii*, and those that are more frost susceptible, such as *P. oocarpa*. In northern Mexico

Table 5-2. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus herrerae* site at Dos Aguas, Michoacán.

Dos Aguas	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	21.4	21.9	24.4	26.2	25.8	24.3	23.5	23.3	22.3	22.9	23.2	21.7	23.3
Mean Rain mm	18	2	5	3	31	190	234	189	218	105	17	9	1021

Based on 7 and 27 years of data for temperature and rainfall, respectively, taken at Aguililla, Michoacán (elev. 970 m) approximately 17 km southeast of Dos Aguas (DGGM 1970). Average monthly temperature at Dos Aguas is estimated to be 5°C colder than shown in the above table.

Figure 5-1. CAMCORE collections of *Pinus herrerae* in Mexico.

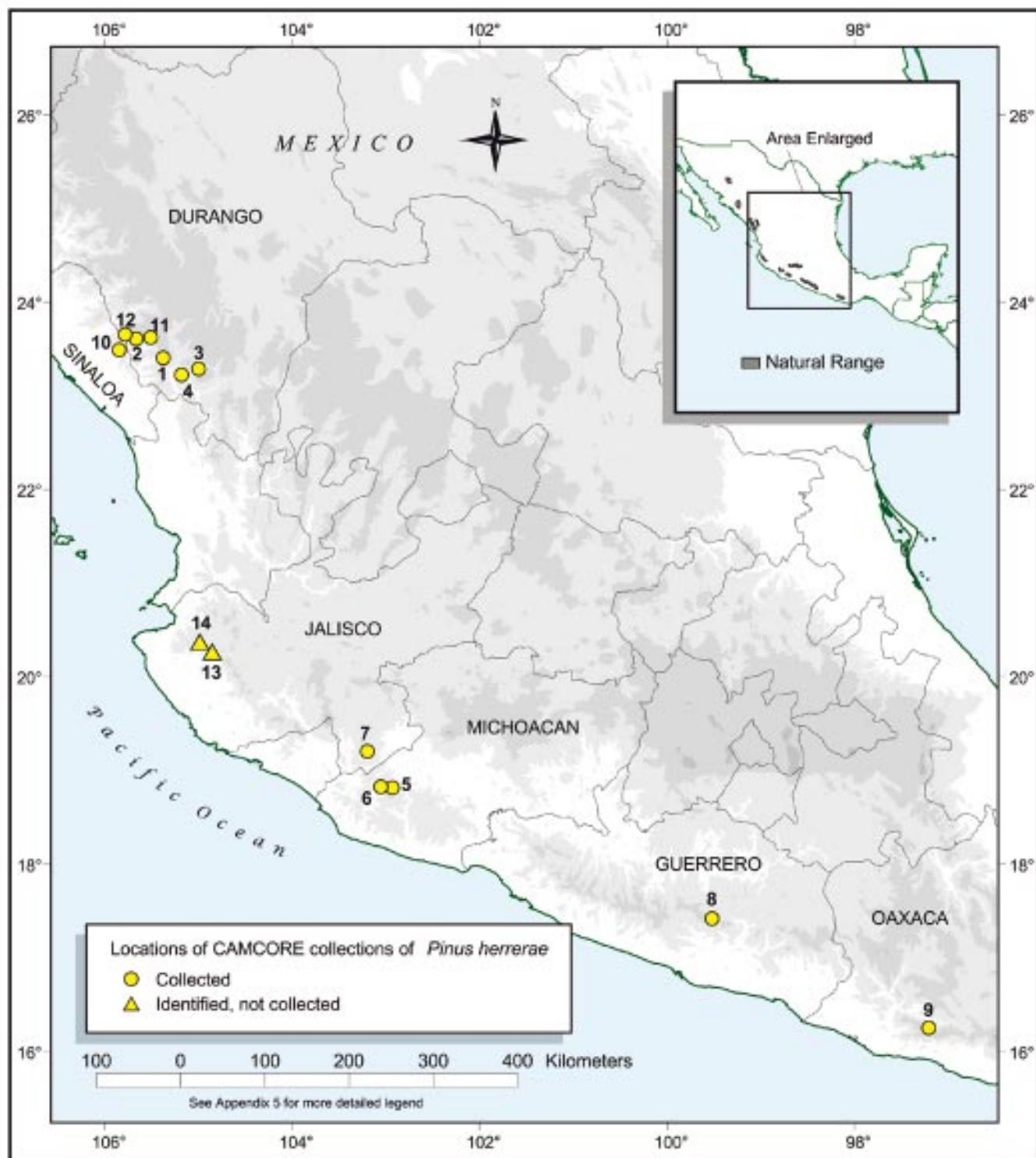




Photo 5-4. Partially opened *Pinus herrerae* cones near the end of March at Monte Grande, Jalisco.

P. herrerae is often seen with such species as *P. engelmannii*, *P. leiophylla*, *P. lumholtzii*, occasionally *P. oocarpa* (in the warmer canyons) and *Quercus* spp. At La Lobera, Sinaloa and Sierra Lalo, Jalisco, *P. herrerae* occupies sites at slightly higher elevations than *P. oocarpa*, but the two species rarely occur together in mixed stands. At Dos Aguas, Michoacán, *P. herrerae* occurs in small patches as a pure species, as well as in mixed stands with *P. devoniana*, *P. douglasiana*, *P. maximinoi*, *P. montezumae* and *Cupressus* and *Quercus* spp. At Monte Grande, Jalisco, *P. herrerae* occurs in a pure stand that is surrounded by *Quercus* spp. *Pinus jaliscana* is found within 500 m of this stand at an elevation that is about 140 m lower. At Palo Blanco, Guerrero, *P. herrerae* is found intermixed with large *P. pseudostrobus* trees that are situated slightly above the occurrence of *P. pringlei*. The transition zone between *P. herrerae*/*P. pseudostrobus* and *P. pringlei* occurs at approximately 2200 m elevation. At Juquila, Oaxaca, *P. herrerae* is intermixed with *P. douglasiana*. Perry (1991) has also seen *P. herrerae* growing with *P. ayacahuite* var. *veichtii*, *P. lawsonii*, *P. montezumae* and *P. teocote*.

Mature *P. herrerae* trees may be quite resistant to fire because of their thick bark. Bark was approximately 30 mm thick at breast height on trees assessed in Durango by the Forest Genetics Center, Texcoco, Mexico. On trees with 65-cm base diameters that were inspected by CAMCORE personnel at Dos Aguas, Michoacán, bark thickness was 70 to 80 mm. *Pinus herrerae*'s resistance to

fire is also supported by the occurrence of the species with such fire-tolerant grass-stage species as *P. engelmannii*, *P. devoniana* and *P. montezumae*. *Pinus herrerae* appears to regenerate rapidly on exposed mineral soils and along road cuts.

WOOD QUALITY IN NATURAL STANDS

Only general information is available on the wood quality of *P. herrerae*. Martínez (1948) described the wood as bland in color and highly resinous, while Loock (1950) states that the timber is light yellow to almost white in color and only slightly resinous. Sawmillers at Dos Aguas, Michoacán say the wood is whiter and less resinous than *P. oocarpa* and makes boards of high quality. CAMCORE observations in Guerrero indicate that the wood is yellowish-white with a relatively low resin content. Sawmillers do not selectively cut *P. herrerae*, but rather consider it one of many pine species available for use in wood production.

Wood density of mature trees sampled at Los Negros and Santa Lucía by Calixto (1996) varied from 430 and 480 kg/m³, respectively. Mature trees sampled by Zobel (1965) in Chihuahua also had an average wood density of 480 kg/m³ (between rings 31 and 40). Average tracheid length found in the two studies was about the same, ranging from 4.2 to 4.4 mm. These limited results suggest that *P. herrerae* wood is of moderate density, has relatively long tracheids and should be well suited for a number of wood and paper products.

PLANTATIONS

NURSERY PRACTICES

Seed Handling

Cones placed in the sun on cement patios in Mexico City took as long as two months to open completely, unlike cones of species such as *P. oocarpa* or *P. tecunumanii*, which open in about a week. Scales at the tops of cones sometimes have to be pried open in order for all of the seeds to be extracted.

As mentioned previously, *P. herrerae* produces a very small seed that has a tendency to be empty. For commercial plantings, careful seed cleaning prior to sowing is especially important.

Based on CAMCORE experience, *P. herrerae* does not need to be cold stratified before sowing, and normal pregermination treatments, like those described for *P. patula* (Chapter 10), should work well.

Seedling Management

CAMCORE members did not make special adjustments to container size or growth medium before planting *P. herrerae*. Seedlings should be treated in the nursery in the same way as *P. patula* or *P. greggii*. Plantable seedlings with a shoot height of 15 cm can be produced in about 28 weeks, but this time may vary depending on individual nursery conditions. There is no evidence to suggest that watering and fertilizer regimes should be any different than those used for *P. patula*.

Vegetative Propagation

CAMCORE member Arauco grew 128 *P. herrerae* seedlings from each of two provenances (El Llano and Guajolota) in their greenhouse near Valdivia, Chile (Balocchi 1996). Cuttings were taken from seedlings six to eight times per year and were propagated using the same system the company employs for *P. radiata*, which involves rooting the cuttings in a misting house using bottom heat. Survival (rooting ability) of the 1700 cuttings after one year was approximately 86 versus 92% for *P. radiata* (Balocchi 1996). These results suggest that there should be no difficulty

in propagating *P. herrerae* from seedling cuttings for commercial operations.

STAND MANAGEMENT

Site Selection and Establishment

Based on current knowledge, *P. herrerae* should be planted at sites from 800 and 1800 m elevation in subtropical to warm temperate regions that receive between 750 and 1500 m rainfall annually. The species needs well-drained, clayey soils and seems to perform best in areas with well-defined wet and dry seasons. *Pinus herrerae* grows reasonably well in soils of average fertility. Although CAMCORE collections from Durango and Michoacán can tolerate freezing temperatures to about -5 °C, sources from warmer areas in Oaxaca, Jalisco and Sinaloa sometimes suffer from such conditions.

Pests and Other Limiting Factors

Because only a few trials of the species have been established, little information is available on the tolerance of *P. herrerae* to pests. In CAMCORE tests at Klabin, *P. herrerae* showed some susceptibility to *Sphaeropsis sapinea* (*Diplodia*). The incidence of infection at 5 years of age varied by provenance and was 42, 25, 18 and 22% for Pino Gordo, Guajolota, La Puerta and El Llano, respectively. The fastest growing provenance, Pino Gordo (Table 5-3), was the most susceptible. There were great differences in susceptibility among families (2 to 67%). Disease symptoms were confined mainly to branch tips and seldom resulted in tree mortality. A general conclusion is that *P. herrerae* is moderately susceptible to *S. sapinea* in southern Brazil but is more resistant than *P. patula* and *P. greggii* at the same location.

In a seedling screening study for resistance to *Fusarium subglutinans* f. sp. *pini* (pitch canker) conducted by CAMCORE in North Carolina, *P. herrerae* generally was found to be as susceptible to the disease as *P. patula* and *P. greggii* (Hodge and Dvorak 2000). More fieldwork is needed to verify laboratory results.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

Between 1992 and 2000, CAMCORE made collections of *P. herrerae* at 12 locations from Durango to Oaxaca, a distance of approximately 800 km. The collections included 317 mother trees and the seeds were distributed to organizations in Brazil, Chile, South Africa and Venezuela. The great difficulty in working with this species is the poor seed yield in natural stands. Yields of less than 5 g of seeds per tree are common.

The Juquila, Oaxaca provenance was classified as *P. herrerae* only after molecular marker and morphological studies confirmed its identity (see Distribution). When seeds were collected from this provenance in the mid-1980s, Juquila was identified and distributed to members as *P. tecunumanii*.

PROVENANCE VARIATION

Because the testing program of *P. herrerae* is new, CAMCORE only has 3-year results from a single planting

by Sappi at Helvetia, South Africa (lat. 25° 32' S, elev. 1700 m, ann. precip. 770 mm) and 3- and 5-year results from a planting by Klabin at Anta Brava (lat. 24° 07' S, elev. 750 m, ann. precip. 1469 mm). Mondi Forests has also established several single-replication studies (six-tree row plots) that include a number of families from each provenance. Two such studies are planted at Hendriksdal (lat. 25° 16' S, elev. 1328 m, ann. precip. 1000 mm) and Jessievale, South Africa (lat. 26° 14' N, elev. 1680 m, ann. precip. 908 mm) and are 5 years old. All results are based on families from CAMCORE's first collection made in Durango, which included the provenances of La Puerta, Pino Gordo, El Llano and Guajolota (see Table 5-1).

Survival

Pinus herrerae has survived well in the dry conditions at Helvetia, South Africa. Survival at 3 years was 95 versus 93% for the *P. patula* controls. However, when planted near



Photo 5-5. Ten-year-old *Pinus herrerae* from Juquila, Oaxaca growing in a CAMCORE test established in South Africa by SAFCOL.

Jessievale at 1680 m altitude, survival of *P. herrerae* was only 60 versus 72% for the *P. patula* control (data not shown). Mortality was thought to be the result of cold temperatures. At Anta Brava, survival of *P. herrerae* on a relatively fertile site with good rainfall was 98% at 3 years, but at 5 years was only 88% while 5-year survival was 98% for the *P. taeda* and *P. elliottii* controls. The drop in survival of *P. herrerae* between ages 3 and 5 was a consequence of attacks by leaf-cutting ants, as well as some loss due to *Sphaeropsis sapinea* (P. Kikuti, personal communication).

Productivity

Pinus herrerae from Durango grew at a rate of more than 1.0 m per year during its first 5 years in both Brazil and South Africa (Table 5-3). In these areas, trees produce a thick diameter relative to height in comparison to other Mexican subtropical pine species. Because *P. herrerae* exhibits a healthy needle color and a straight stem form, the species has an impressive appearance. However, development at an early age is not nearly as rapid as it is for improved sources of *P. patula* or *P. greggii* in South Africa, *P. taeda* or *P. elliottii* in Brazil or *P. radiata* in Chile. Field observations after 5 years suggest that growth of *P. herrerae* relative to other species may be improving as trees get older.

Although direct comparisons are not possible, it appears that the recently identified *P. herrerae* source from Juquila, Oaxaca, would grow substantially faster than the *P. herrerae* provenances from Durango. The Juquila source, which was included in CAMCORE *P. tecunumanii* trials, was represented in seven South African trials with 5-year measurements. Across those seven tests, Juquila averaged 7.7 m in height, substantially larger than the average height of approximately 6.0 m for the Durango provenances at the Mondi Hendriksdal trial. The *P. herrerae* from Juquila, when analyzed with high elevation *P. tecunumanii*, produced 8% more volume than the average *P. tecunumanii* provenance (Hodge and Dvorak 1999), suggesting that the species may have commercial potential in some areas where *P. tecunumanii* is also being considered.

Genetic Parameters for Growth

Individual tree heritabilities (h^2) for height, diameter and volume at 3 years of age were about equal at Anta Brava, Brazil and Helvetia, South Africa. Mean values were 0.29, 0.14, and 0.15, for height, diameter and volume, respectively. These heritability values increased to 0.36, 0.22, and 0.26 at Anta Brava, Brazil, at 5 years. Genetic and age-age corrections will be calculated when 8-year results are available.



Photo 5-6a. Left, Terry Stanger (left) and Andre Nel (right) of Sappi stand next to a 2.5-year-old *Pinus herreriae* tree on a high elevation, dry site at Helvetia, South Africa. **5-6b.** Right, Heuzer Guimaraes, RIGESA, stands next to a 2.5-year-old *P. herreriae* tree grown on a low elevation, wet site in southern Brazil.

Table 5-3. Mean height (m) and diameter (cm) results for provenances of *Pinus herreriae* from Durango, Mexico grown in Brazil and South Africa and assessed at 3 and 5 years.

ORGANIZATION	SAPPI		KLABIN		KLABIN		MONDI	
Test Code	38-07-01B		38-26-01A		38-26-01A		Pv55	
Site	Helvetia		Anta Brava		Anta Brava		Hendriksdal	
Age	3 Years		3 Years		5 Years		5 Years	
Provenance	HT	DBH	HT	DBH	HT	DBH	HT	DBH
La Puerta	4.0	6.8	3.7	6.0	5.7	11.8	6.3	11.9
Pino Gordo	4.2	7.1	4.1	6.5	5.8	12.2	6.4	11.7
El Llano	4.1	7.0	3.7	5.6	5.6	11.3	5.8	10.7
Guajolota	4.1	7.0	4.0	6.3	5.9	12.0	5.8	10.7
Improved Controls								
<i>Pinus taeda</i>	-	-	5.2	3.1	8.6	18.4	-	-
<i>Pinus elliottii</i>	-	-	3.8	6.6	6.3	12.6	-	-
<i>Pinus patula</i>	5.5	8.2	-	-	-	-	8.2	14.0
<i>Pinus greggii</i>	-	-	-	-	-	-	8.7	14.3

CONSERVATION

IN SITU GENE CONSERVATION

Conservation Status

More explorations for *Pinus herrerae* are needed to better determine the extent of the species range, at both the northern and southern extremes of its natural distribution, and to assess conservation status of each of the populations. Based on CAMCORE field observations, the populations in Durango and Sinaloa are extensive and are at **low risk**. The vast quantity of commercially accepted pines in this region, such as *P. cooperi*, *P. durangensis* and *P. engelmannii*, serves as protection for *P. herrerae* stands from exploitation. The stands in Jalisco and Michoacán are being harvested under a forest management system in some cases. Old-growth forests have been cut and trees taller than 50 m have nearly all disappeared. The stand at Dos Aguas is now mainly composed of trees with heights averaging from 18 to 22 m with diameters of approximately 35 cm at breast height. The conservation status of populations in Jalisco and Michoacán is **vulnerable**.

The most threatened *P. herrerae* stands are in Guerrero and Oaxaca. Heavy cutting by the local communities and the planting of agricultural crops has decimated stands at Palo Blanco. The Juquila, Oaxaca source is bisected by a number of small farms and its future is questionable. Some of the largest remaining trees are near the main road. The conservation status of the stands in Guerrero and Oaxaca are **endangered** to **critically endangered**.

Genetic diversity studies based on molecular markers, along with rangewide explorations and seed collections, are needed. Better information on the reproductive biology of the species and its ability to naturally regenerate would help foresters to manage the populations more efficiently *in situ*. Understanding why *P. herrerae* produces so few filled seeds per cone is of great importance.

EX SITU CONSERVATION

Genetic tests and conservation banks have been successfully established in Brazil, Chile, South Africa and

Zimbabwe. The species has grown fast enough to attract the interest of management in some locations. At present, there are no assurances that *P. herrerae* will flower and produce seeds in exotic conditions, but even with a few seeds, plants can be multiplied by vegetative propagation. CAMCORE envisions the establishment of conservation plantings in other countries, with new seed distributions planned for 2000.

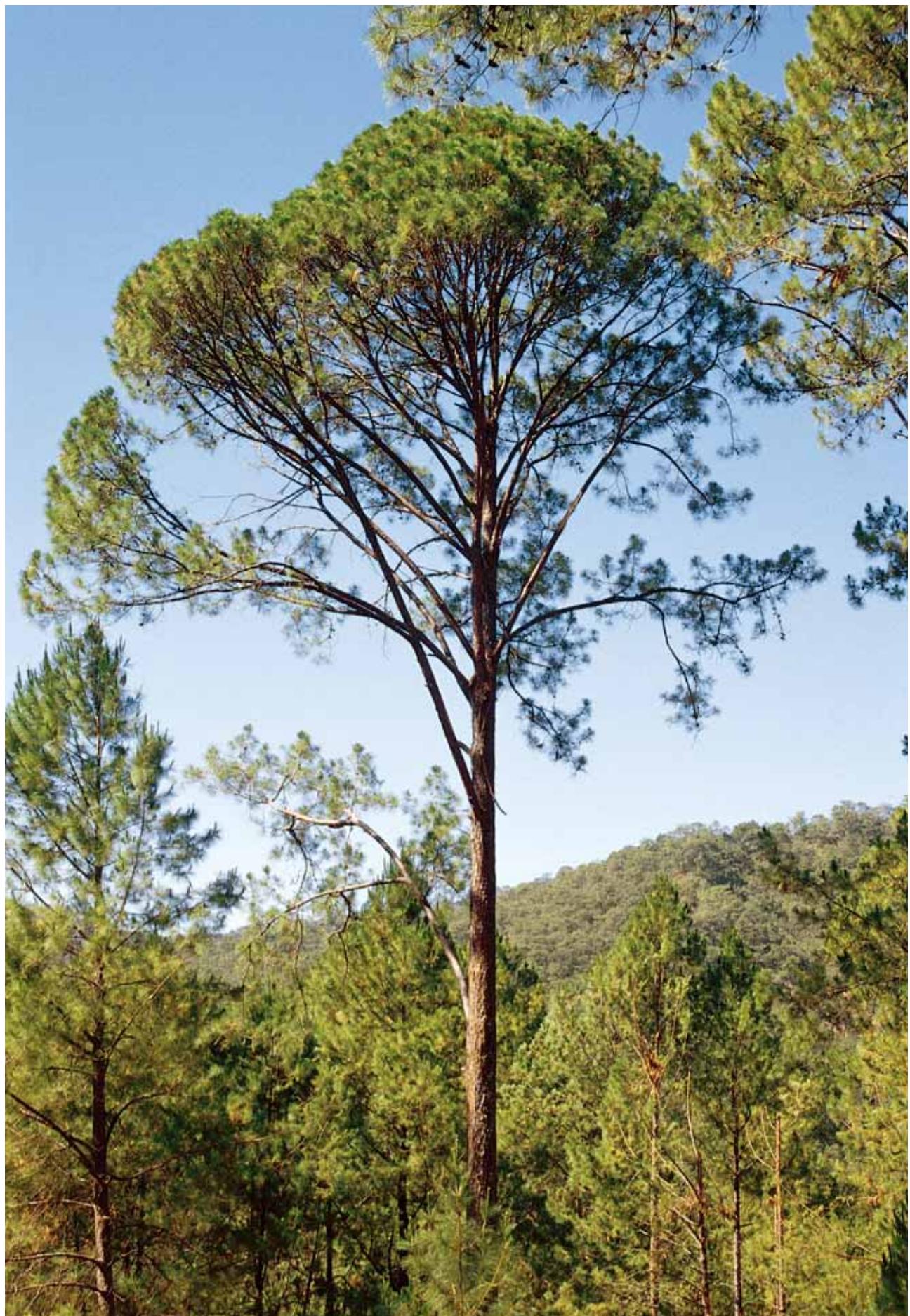


Photo 5-7. CAMCORE plantings of *Pinus herrerae* established by the Forestry Commission in the highlands of Zimbabwe. *Ex situ* conservation will be especially important for the southern Mexican population of this species.

CONTRIBUTORS

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C h a p t e r 6



PINUS JALISCANA

W. S. Dvorak, A. P. Jordan, J. Pérez de la Rosa and G. R. Hodge

OVERVIEW

TREE DESCRIPTION

Pinus jaliscana Pérez de la Rosa is a medium to very large tree with heights ranging from 20 to 42 m and dbh (outside bark) between 40 and 95 cm. The species exhibits a wide-spreading, rounded crown, similar to that of *P. herrerae*, but with distinctive yellow-green foliage. The bark of *P. jaliscana* is rough and platy and on smaller to medium-sized trees is somewhat similar in appearance to *P. oocarpa*. On extremely large, overmature trees, bark plate size may be as much as 15 cm wide and 30 cm long and is quite distinctive from *P. oocarpa*. Needles tend to be very fine and slightly drooping, and occur primarily in fascicles of five. Needle length varies from 123 to 217 mm. Internal needle morphology is similar to *P. oocarpa*, with an average of three resin canals, 95% of which are in the septal position. Cones are conical and borne on strong peduncles, usually singly or in twos, occasionally in threes and rarely in fours. Cone length ranges from 43 to 83 mm (mean = 63 mm). Cones ripen from late January to early April in western Jalisco. The average seed potential per cone is 120 seeds. There are approximately 93,000 seeds per kg. The wood of *P. jaliscana* has a creamy-white juvenile core and yellowish-white mature wood with very pronounced annual rings. The wood is used for sawtimber in Mexico.

CONSERVATION STATUS

Based on CAMCORE field observations, *Pinus jaliscana* is classified as **vulnerable** in its natural range due to increased logging in several populations. Of the nine provenances CAMCORE sampled in 1998 and 1999, one is **critically endangered**, one is **endangered**, five are **vulnerable** and two are at **low risk**.

TEST STATUS

Seeds from nine populations and 88 mother trees were collected by CAMCORE and distributed to organizations in Argentina, Brazil, Colombia, Mexico and South Africa for ex situ conservation and field testing. The first field plantings will be established in 2000.

BEST PROVENANCES

No provenance results are available from tests at this time.

SUITABLE SITES

Based on our understanding, this species is most suited to the mid-elevation sites in the tropics and subtropics that are currently being planted to *Eucalyptus grandis*, *Pinus maximinoi*, *P. patula*, *P. taeda* and *P. tecunumanii*. *Pinus jaliscana* is not frost tolerant and needs well-drained soils.

ADVANTAGES OF PINUS JALISCANA

- May be a fast grower.
- May be relatively easy to propagate from cuttings.
- Should hybridize easily with several other Mesoamerican pine species.
- Seedlings are resistant to *Fusarium subglutinans* f. sp. *pini* (pitch canker).
- Wood appears well suited for solid wood and paper products.

DISADVANTAGES OF PINUS JALISCANA

- Is not frost tolerant.
- May be a shy seed producer.
- Is not tolerant of soils with poor drainage.

Photo 6-1. Natural stand of *Pinus jaliscana* at Monte Grande, Jalisco, Mexico.

NATURAL STANDS

EVOLUTION

It is now known that *Pinus jaliscana* is closely related both morphologically and phylogenetically to *P. oocarpa* from western Mexico and to *P. herrerae* (Dvorak et al. 2000). Molecular assessments indicate that the species also may be ancestrally related to *P. pringlei* (Dvorak et al. 2000).

Photo 6-2. The bark of an overmature *Pinus jaliscana* tree.



DISTRIBUTION

Pinus jaliscana is a closed-cone pine that has been found only in the mountains of western Jalisco, Mexico at latitudes between 20° and 21° N. Initially, botanical specimens of *P. jaliscana* were classified as *P. herrerae*, but further

Photo 6-3. Example of *Pinus jaliscana* forest at Los Lobos.

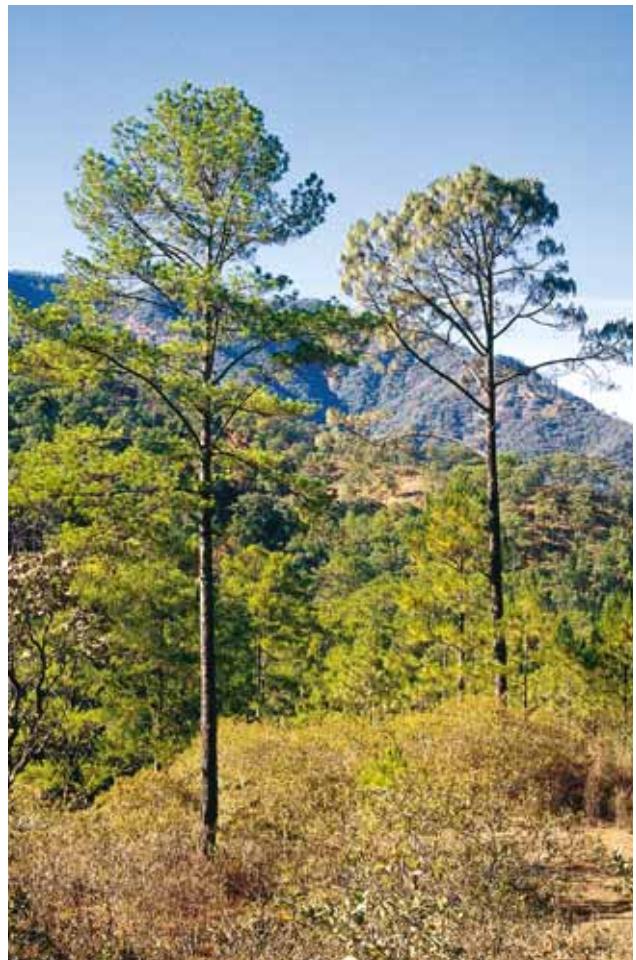
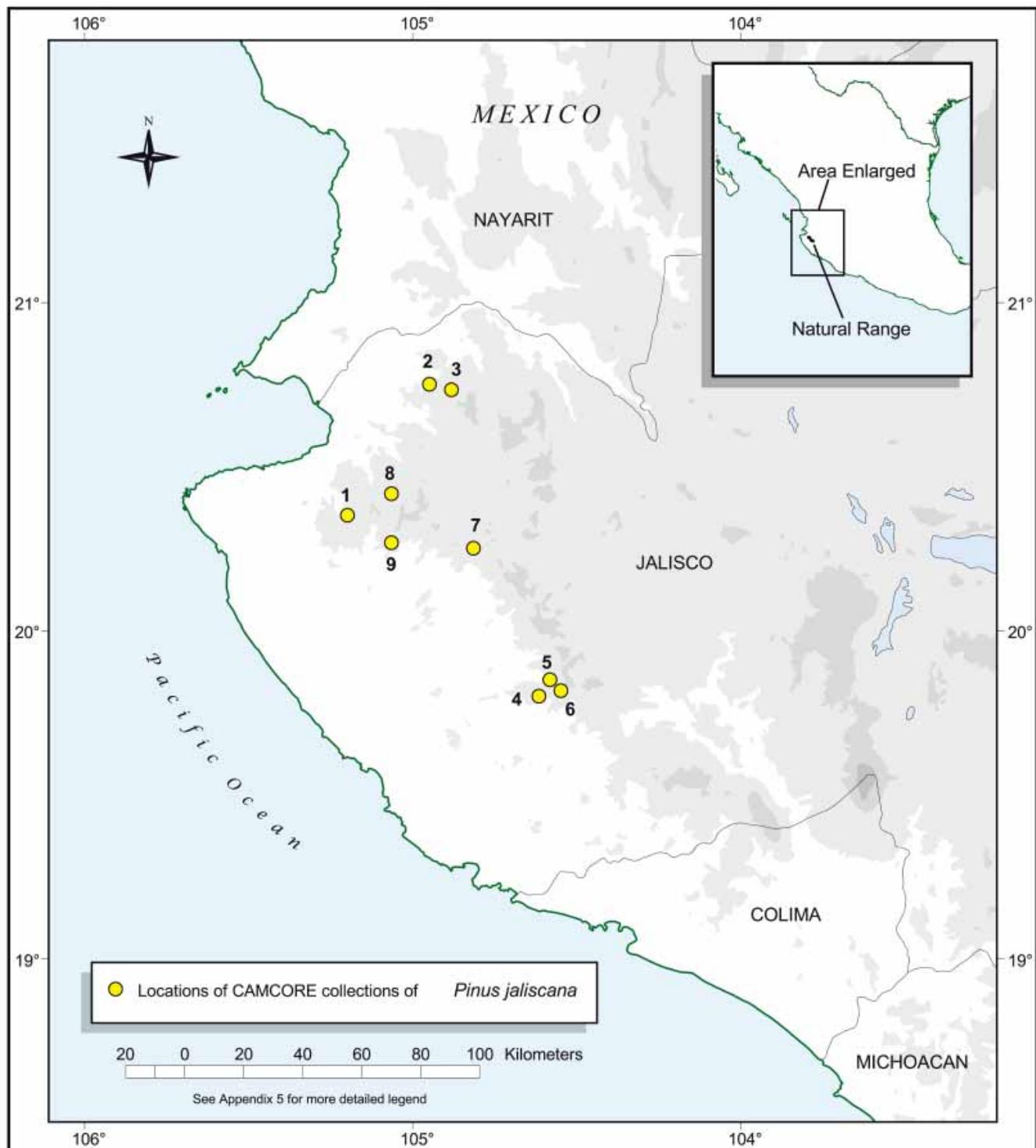


Table 6-1. *Pinus jaliscana* collections made by the CAMCORE Cooperative in Jalisco, Mexico.

Map Key	Provenance	State or Department	Country	Latitude Range (m)	Longitude	Elevation	Rainfall (mm/yr)	No. of Trees
1	El Tuito	Jalisco	Mexico	20° 21' N	105° 12' W	840 - 1460	1900	15
2	La Bulera	Jalisco	Mexico	20° 45' N	104° 57' W	700 - 1100	1600	8
3	Milpillas	Jalisco	Mexico	20° 44' N	104° 53' W	1195 - 1410	1900	7
4	Las Tarimas	Jalisco	Mexico	19° 48' N	104° 37' W	1010 - 1220	1935	10
5	Las Trojes	Jalisco	Mexico	19° 51' N	104° 35' W	1190 - 1245	1935	6
6	El Sauz	Jalisco	Mexico	19° 49' N	104° 33' W	1000 - 1300	1935	4
7	Monte Grande	Jalisco	Mexico	20° 15' N	104° 49' W	1255 - 2050	1500	14
8	Los Lobos	Jalisco	Mexico	20° 25' N	105° 04' W	1020 - 1460	1700	12
9	La Concha	Jalisco	Mexico	20° 16' N	105° 04' W	900 - 1300	1700	12
9	Provenances	1 State	1 Country	19 - 21° N	104 - 105° W	700 - 2050	1789	88

Figure 6-1. CAMCORE collections of *Pinus jaliscana* in Mexico.



taxonomic assessments by Pérez de la Rosa in the early 1980s confirmed the discovery of a new species (Pérez de la Rosa 1983). Nine populations of the species were identified in Jalisco in 1998 and 1999 through joint explorations by CAMCORE, the Forest Genetics Center (Mexico) and the University of Guadalajara (Dvorak et al. 1998).

The geographic range of the nine identified populations of *P. jaliscana* roughly forms a triangle, with La Bulera and Milpillas in the north, La Concha, Los Lobos, El Tuito and Monte Grande in the center; and Las Trojes, El Sauz and Las Tarimas in the south (Figure 6-1, Table 6-1). The distance between the most northern and the most southern populations is about 107 km. Several provenances, such as El Sauz, Las Tarimas and Las Trojes, are within 7 km of each other but are separated by canyons and broadleaf forests. The population at El Salto de Rincón ($19^{\circ} 48.22' N$, $104^{\circ} 35.75' W$) described by Carvajal (1986) was not sampled in the CAMCORE collections because it is only a few kilometers from the Las Tarimas site and is thought to represent the same provenance. Additional populations of *P. jaliscana* likely exist in isolated canyons in the mountain ranges of western Jalisco.

Although *P. jaliscana* is found at elevations from 700 to 2050 m, it occurs most commonly at elevations between 750 and 1550 m. The species is often found on the northern and western slopes of canyons and along the banks of small streams with high humidity or where ground water is available for most of the year. At the lowest elevation within its range, the species is a constituent of a semideciduous, pine-oak ecosystem, while at the highest elevation of its occurrence it is part of a mountain mesofile forest community.

CLIMATE

The climate at a typical *P. jaliscana* site, such as El Tuito, is classified as a rainy tropical savanna [Aw2 (w) (l')] under the Köppen system, with an average monthly temperature less than $18^{\circ} C$ (García 1973). *Pinus jaliscana* is not cold hardy. It prefers areas with tropical climates where annual rainfall ranges from 1500 to 2000 mm. Rainfall is concentrated in a five-month period from June to October while conditions for the remainder of the year are extremely dry (Table 6-2).

SOILS

Pinus jaliscana occurs on two main soil types: 1) those derived from fluvial sediments on valley bottoms along

streams and 2) the more clayey soils on canyon slopes. The soils are often loosely compacted and easily weathered, and erosion is pronounced at most seed collection sites. For example, unpaved roads built through stands at Monte Grande may have as much as 10 cm of fine powdered soil on their surface during the dry season. *Pinus jaliscana* quickly establishes itself in ravine and gully bottoms and is an aggressive colonizer on disturbed mineral soils along road cuts.

The fluvial sediments near streams where *P. jaliscana* often occurs (Entisols and Inceptisols) may be as much as 3 m deep. The silt and sand are loosely compacted and a soil probe can be pushed to a depth of 40 cm with little resistance. The surface of these soils is usually covered with small pebbles and occasionally with large rocks and boulders. At Los Lobos, the number of rocks on the surface is so great that farmers have used them to construct houses and fences.



Photo 6-4. Deep, well-drained, easily erodable clayey soil at the *Pinus jaliscana* collection site at Monte Grande.

Table 6-2. Monthly mean temperature ($^{\circ}C$) and rainfall (mm) recorded at the *Pinus jaliscana* site of El Tuito.

El Tuito	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. $^{\circ}C$	19.6	19.8	21.1	22.5	24.4	25.3	25.1	25.1	24.7	24.1	21.9	20.2	22.8
Mean Rain mm	21	7	8	7	19	219	421	465	482	194	30	27	1900

Based on 32 years of data recorded at El Tuito (elev. 600 m), 6 km from the collection site (García 1973).



Photo 6-5. Cones of *Pinus jaliscana*.

There is little soil horizon differentiation on valley bottom sites. A compacted surface organic (O) horizon 2 to 8 cm deep may be present at some locations. This horizon was most defined at La Bulera, where *P. jaliscana* exists in a tropical rain forest environment with abundant broadleaf flora. The top (A) mineral horizon of valley soils ranged from a grayish-white, sandy clay loam to yellow coarse sand with pH values from 4.8 to 5.2. The subsoil (B) horizon was a grayish-white sandy clay loam to a yellow-brown sandy clay and was extremely acid with pH values from 4.0 to 4.3.

On the steep slopes above the valley bottoms where *P. jaliscana* occurs with other pine species such as *P. oocarpa*, the soils have higher clay content (Ultisols), are sometimes more shallow and often possess more well-defined horizons. The A horizon of the upland soils is often grayish-white sandy clays 40 to 200 cm in depth, underlain by yellowish-brown or red clays. The B horizon may be another 100 cm in depth.

Pinus jaliscana occasionally was found growing directly on eroded red clays (pH 4.8) at Milpillas and La Concha. These soils are more poorly drained than those at other locations. Apparently, availability of soil moisture and high humidity are more important characteristics than soil texture in determining the geographic distribution of *P. jaliscana*.

REPRODUCTIVE BIOLOGY

Female and male strobili are thought to be produced in November and cone collections in natural stands are made from late January through early April, 26 to 28 months later. Cones occur singly or in clusters of twos, occasionally in threes and rarely in fours. Cone length ranges from 43 to 83 mm (mean = 63 mm) and increases with collection site elevation ($r = 0.25, p = 0.04$). When closed, cones have a conical, elongated shape, more similar to *P. patula* var. *longipedunculata* than to the somewhat ovoid shape of *P. oocarpa*. The average seed potential for *P. jaliscana* is about 120 seeds per cone (Dvorak et al. 1998). Approximately five filled seeds per cone were obtained in the January, 1998 collection versus 11 filled seeds per cone in the March, 1999 seed collection (based on a sample size of 2582 and 8000 cones, respectively). There is an average of 93,000 seeds per kg. Squirrel populations are abundant at most sites, as indicated by the number of partially eaten pine cones on the ground, and apparently have an important role in seed dispersal.

ECOLOGY AND ASSOCIATED SPECIES

Pinus jaliscana regenerates prolifically in natural stands after fires have removed the needle layer and mineral soils are exposed. Having evolved to compete with broadleaf species in humid environments, *P. jaliscana* grows quickly

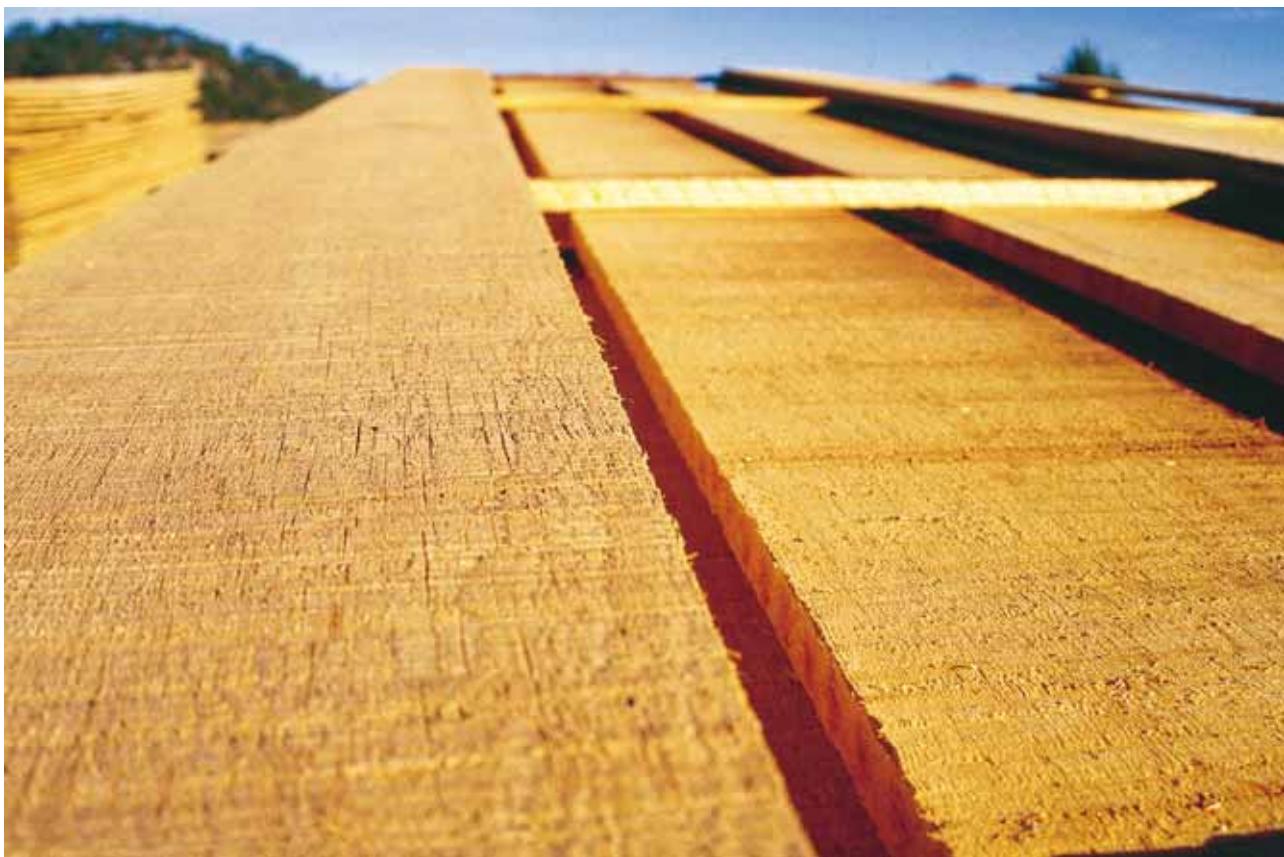


Photo 6-6. Lumber made from mature trees of *Pinus jaliscana* in Jalisco, Mexico.

after germination, much more so than *P. oocarpa*. In canyon bottoms, the intensity and frequency of fires define the distribution and extent of *P. jaliscana* and associated species.

Pinus jaliscana occurs in both pure and mixed stands in pine-oak ecosystems. It is often found in pure stands (Los Lobos, La Bulera) near streambeds or in protected coves on slopes where humidity is high. On exposed slopes where soils are poorer, humidity is lower and fires are more common, *P. jaliscana* is outcompeted by *P. oocarpa*, *P. douglasiana* or *P. maximinoi*. Rarely, *P. devoniana* is seen at the collection sites. *Pinus herrerae* and *P. jaliscana* have not been found growing together, but come within 500 m distance and 140 m elevation of each other near the summit of Monte Grande ($20^{\circ} 15' 29.2''$ N, $104^{\circ} 51' 23.7''$ W).

The composition of the broadleaf forests differs at each *P. jaliscana* site depending on soil, water availability and frequency of fires. At La Bulera and El Sauz, broadleaf trees 20 to 30 m in height are commonly seen in association with *P. jaliscana*. Broadleaf species observed at many locations include: *Arbutus xalapensis*, *Byrsinima crassifolia*, *Comarostaphylis glaucescens*, *Curatella americana*, *Hedosmum mexicanum*, *Juniperus jaliscana*, *Quercus aristata*, *Q. elliptica*,

Q. glaucescens, *Q. insignis*, *Q. magnoliifolia*, *Q. peduncularis* and *Vaccinium stenophyllum*. *Cedrela odorata* has been observed at El Sauz. At the highest elevation site, Monte Grande, *Abies guatemalensis* var. *jaliscana* and *Magnolia pacifica* ssp. *pacifica* have been identified.

Standing dead *P. jaliscana* trees are used as nesting sites by woodpecker populations at Las Trojes. Woodpecker activity was more noticeable on *P. jaliscana* than *P. oocarpa*, likely due to the softer wood of the former species.

WOOD QUALITY IN NATURAL STANDS

The wood of *P. jaliscana* is characterized by a creamy-white juvenile core with poorly distinguished annual rings and yellowish-white mature wood with pronounced annual rings. Local woodcutters in Jalisco do not show preference to *P. jaliscana* over *P. oocarpa* or *P. douglasiana*. However, they do comment that the wood of *P. jaliscana* is softer and produces less resin than wood of *P. oocarpa*. The weighted mean wood density (unextracted) of wood cores taken from 10 trees (average age = 35 years) was 546 kg/m^3 . The juvenile and mature samples had wood density of 464 and 573 kg/m^3 , respectively. These values are similar to those found for *P. greggii* in natural stands in Mexico. The wood of *P. jaliscana* is used for sawtimber.

PLANTATIONS

NURSERY PRACTICES

Seed Handling

Seeds can be stored in cold rooms at 4 °C with few problems as long as moisture content of the seed is maintained from 6 to 9%. No cold stratification of the seed prior to germination is necessary. As is the case for most tropical pines, subjecting seeds to a 24-hour wet soak before sowing should promote more even germination. Seeds germinate seven to 10 days after sowing in moist sand. Germination was 50% for seeds from mother trees in a natural stand in Jalisco in the 1998 collection. Higher germination percentages are expected for the collections made in March, 1999 because cones were more mature when collections were made.

Containers and Growth Media

Pinus jaliscana has been grown successfully in the greenhouse in a mixture containing equal parts decomposed pine bark, perlite and sand. The species requires soils that are well drained. Standard size containers used for species such as *P. tecunumanii* and *P. oocarpa* also work well for *P. jaliscana*.

Seedling Management

Germinants can be pricked into larger containers following standard practices for species such as *P. caribaea* var. *hondurensis*. *Pinus jaliscana* produces seven cotyledons and reaches plantable size (20 cm) in four to five months.

As a word of caution, germinants and seedlings can be killed by overwatering. One organization lost many seedlings by simply germinating seeds in a warm, humid, misting house (set up for rooted cuttings) for two weeks

and then transferring trays with germinants to an outdoor nursery. After the trays were placed outside, rainstorms were heavy and the *P. jaliscana* seedlings began to die, while other species in the nursery were fine.

Vegetative Propagation

Experiments have been initiated at North Carolina State University to develop techniques for vegetative propagation of *P. jaliscana* seedlings. The rooting substrate used was a 2:1 peat to perlite mixture, and 2.5 mM NAA was applied at the base of the cutting prior to sticking. Initial survival of the cuttings was approximately 65%.

STAND MANAGEMENT

Site Selection and Establishment

The first *P. jaliscana* planting of CAMCORE material will be established in 2000 and 2001. Based on our observations, *P. jaliscana* should be established in frost-free areas. The species is likely to perform best at mid-elevations in the tropics and subtropics on sites similar those often planted to *Eucalyptus grandis*, *Pinus maximinoi*, *P. patula*, *P. taeda* and *P. tecunumanii*.

Pest Resistance

Based on greenhouse screenings by Hodge and Dvorak (2000), *P. jaliscana* seedlings appear to be very resistant to pitch canker, *Fusarium subglutinans* f. sp. *pini* (Hodge and Dvorak 1999a). Seedlings have been found to be moderately resistant to *Cronartium quercuum* f. sp. *fusiforme* (Fusiform Rust) as well; *Pinus jaliscana* seedlings exhibited 29% infection versus 72% for the improved *P. elliottii* control (CAMCORE, unpublished data).

CONSERVATION

IN SITU CONSERVATION

Genetic Diversity

CAMCORE conducted a study to determine the magnitude of genetic diversity present in *Pinus jaliscana*. The nine populations sampled (Table 6-1, Figure 6-1) were aggregated into three larger groups according to geographical location: northern populations (provenance codes 2 and 3), southern populations (4, 5, and 6), and central populations (1, 7, 8, and 9). The northern, southern and central regions were represented by 7, 14 and 39 mother trees, respectively. Genomic DNA was extracted from megagametophyte tissue from one seed per mother tree, amplified with eight AFLP primer pairs, and a total of 240 polymorphisms were scored from the resulting fragment profiles.

Nei's genetic diversity (Nei 1978) was calculated for each of the three large groups and was adjusted for sample size assuming no inbreeding. The populations from the central region, El Tuito, Monte Grande, Los Lobos and La Concha were most diverse ($D = 0.301 \pm 0.147$), but only slightly more than the populations from the southern region, Las Tarimas, Las Trojes and El Sauz ($D = 0.297 \pm 0.179$). The northern populations were the least diverse ($D = 0.277 \pm 0.203$).

Aggregating across the entire set of 60 parents, there were 30 markers that had a frequency of 5% or less. Of these 30 markers, eight were represented in the northern region, 11 in the southern, and 26 in the central region.

Accounting for size of samples, these values suggest that low-frequency alleles may be more common in the northern populations. Among the populations of the

central regions, Monte Grande had a genetic diversity $D = 0.278$ and 17 of the 30 low-frequency alleles. The other three provenances in the central region had D ranging from 0.272 to 0.298, and had only seven to nine of the low frequency alleles. Monte Grande is a relatively degraded population approximately 375 ha in size bisected by cattle ranches. Most of the area has previously been harvested. It is noticeably different from other populations only in the fact that trees occur over a wide altitudinal gradient (approx. 700 m) and that it is the only location where *P. herrerae* occurs nearby.

Conservation Status

The nine sampled populations range in size from 6 ha at Las Trojes to more than 2000 ha at Los Lobos (Table 6-3).



Photo 6-7. Burn scar on an old, overmature *Pinus jaliscana* tree at Los Trojes. The conservation status of this population is **vulnerable**.

The provenances of Milpillas, Las Tarimas and parts of La Concha are **endangered** or **critically endangered**. Most other populations are vulnerable to genetic high grading. Logging roads were being constructed in parts of El Sauz, Monte Grande, La Concha, El Tuito and Los Lobos in 1999. Only La Bulera seems to be under little present threat of being exploited for timber. CAMCORE classifies the conservation status of this species as **vulnerable**. Based on the results from the molecular study, *in situ* conservation efforts should be concentrated in the central part of the species range. The most accessible, large population in the central region is Los Lobos (Table 6-3).

Table 6-3. Population size and conservation status of areas of *Pinus jaliscana* sampled by CAMCORE (amended from Dvorak et al. 1998).

Map Code	Provenance	Stand Size (ha)	Conservation Status*
1	El Tuito	1000+	VU & LR
2	La Bulera	1000+	LR
3	Milpillas	< 20	CR
4	Las Tarimas	15	EN
5	Las Trojes	6	VU
6	El Sauz	250	VU
7	Monte Grande	375	VU
8	Los Lobos	2000+	LR
9	La Concha	500+	VU

* CR=critically endangered, EN=endangered, VU=vulnerable, LR=lower risk. See Farjon and Page (1999) for a description of conservation categories.

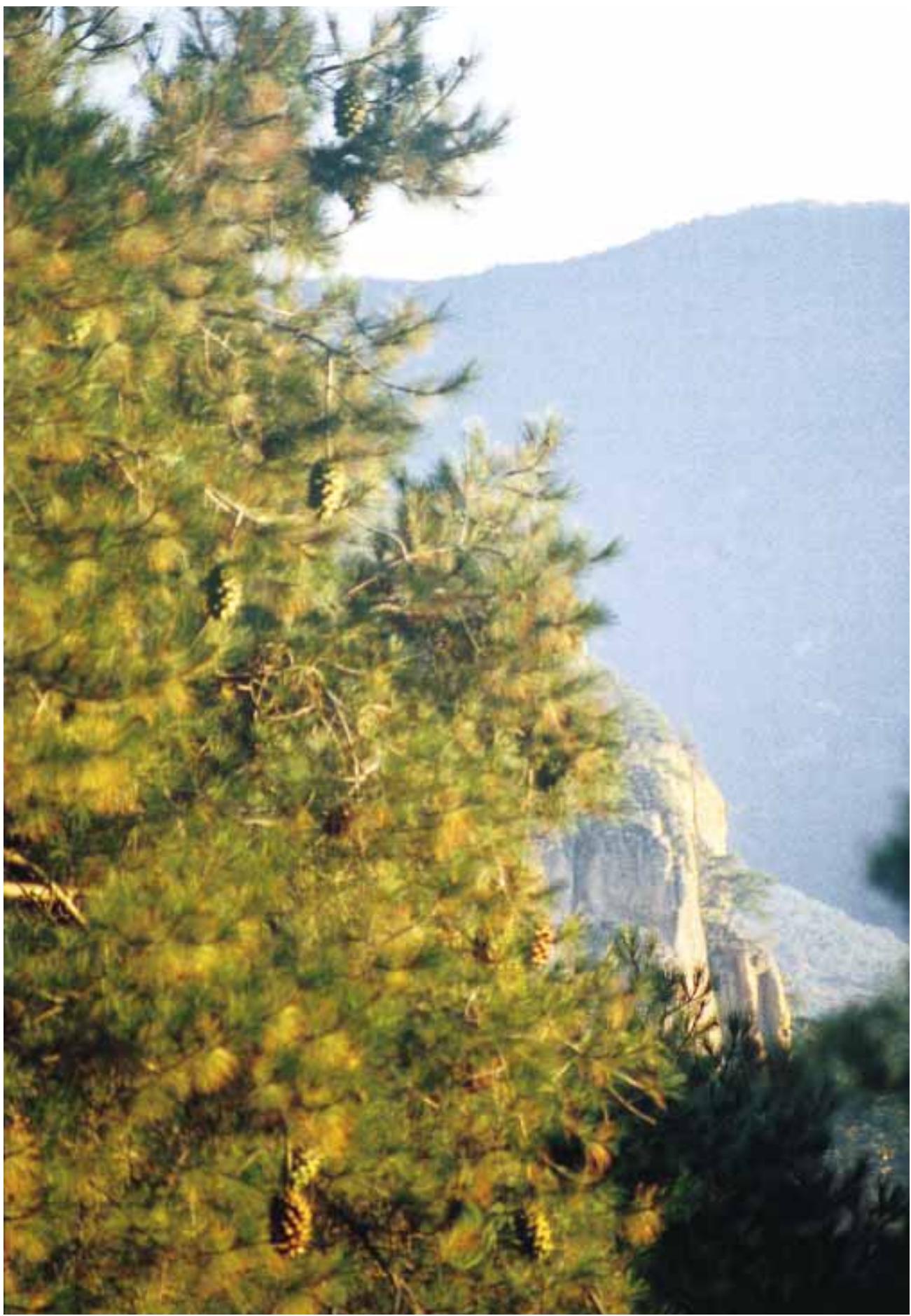
EX SITU CONSERVATION

Seeds from the nine provenances and 88 mother trees were collected by the CAMCORE Cooperative and distributed to agencies in Argentina, Brazil, Colombia, Mexico and South Africa in order to establish *ex situ* conservation plantings. Five field plantings of approximately 1.5 ha each are envisioned. Additional *P. jaliscana* field conservation banks need to be planted to ensure the long-term security of the species.

CONTRIBUTORS

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C h a p t e r 7



PINUS MAXIMARTINEZII

W. S. Dvorak, T. K. Stanger and J. L. Romero

OVERVIEW

TREE DESCRIPTION

Pinus maximartinezii Rzedowski is a rare pinyon pine that occurs naturally at a single location on the Cerro de los Piñones in southern Zacatecas, Mexico. Trees are small, reaching 8 to 13 m in height with dbh from 40 to 60 cm at maturity. Juvenile trees have a smooth, greenish to whitish-gray bark. Mature trees have a gray-brown bark that is fissured in both the longitudinal and the transversal direction (Perry 1991) and an open, irregular crown. There are distinct color differences between juvenile and mature foliage. Needles of juvenile foliage are grayish-blue and become grayish-green as the tree matures. Juvenile foliage can be maintained on the tree for as long as 20 years in natural stands but may only last 3 to 5 years when trees are kept as indoor ornamentals or established as exotics in humid environments. Needles occur in fascicles of five, and range in length from 4 to 9 cm for juvenile foliage and 7 to

11 cm for mature foliage. Cones are large (15 to 25 cm long with diameters of 11 to 13 cm) and are borne on the ends of long branchlets. A single cone may weigh as much as 2 kg (green weight). Cones ripen on the Cerro de los Piñones during the dry season in October and November. The seeds are edible, and range from 22 to 26 mm long and 10 to 12 mm wide, making them among of the largest seeds of any pine species (Rzedowski 1964). The average seed potential per cone is 134 seeds. There are approximately 900 seeds per kg (Eguiluz-Piedra et al. 1985).

CONSERVATION STATUS

CAMCORE observations suggest that *Pinus maximartinezii* is **endangered** at the Cerro de los Piñones due to the frequent destruction of natural regeneration by fires and overgrazing. The annual cone collections made by local landowners, who sell the large edible seeds at local markets, further limit the natural regeneration process. Local landowners are now trying to protect the mature cone-bearing trees because the seed crops provide supplemental income.

TEST STATUS

Two research seed collections of *P. maximartinezii* have been made by CAMCORE in 1993 and 1998. These collections have been used to establish *ex situ* conservation areas, as well as to study within-species diversity patterns. Seeds from the 1993 collection have been used to establish conservation plantings in South Africa and Zimbabwe and are now between 1 and 3 years old.

SUITABLE PLANTING SITES

Pinus maximartinezii survives in areas where frosts are neither frequent nor severe. The species performs best in areas characterized by very well drained soils and well-defined wet and dry seasons, such as those found in southern and eastern Africa. The species may perform well in the frost-free plateau region of central Brazil, from Goiás State south to the more tropical areas of São Paulo State and Paraná State, as well as in the rain shadow areas of the northern Andes. *Pinus maximartinezii* has been planted as an ornamental throughout Mexico, particularly in gardens in Mexico City.



Photos 7-1a and b. Juvenile (left) and mature bark (right) on *Pinus maximartinezii* trees.

Photo 7-2. *Pinus maximartinezii* tree growing on the Cerro de los Piñones.

ADVANTAGES OF *PINUS MAXIMARTINEZII*

- Makes an attractive ornamental, especially when foliage is in the juvenile stage.
- Produces an edible nut that is high in protein.
- Vegetative propagation is relatively easy.

DISADVANTAGES OF *PINUS MAXIMARTINEZII*

- Very susceptible to overwatering in nurseries.
- Does not possess significant cold tolerance.
- Appears to lack high resistance to fire.
- May take as long as 20 years to produce cones and seeds.

NATURAL STANDS¹

DISTRIBUTION

The only known natural population of *Pinus maximartinezii* occurs on the Cerro de los Piñones at the southern extreme of the Sierra de Morones, Zacatecas, Mexico ($21^{\circ} 21' N$, $103^{\circ} 13' W$, Figure 7-1). Although trees can be found from 1600 to 2550 m elevation, the main band occurs from 2100 to 2300 m (see Donahue and Mar-López 1995). The trees are distributed into several subpopulations, which are predominantly on the eastern, southern and southwestern slopes of the Cerro de los Piñones. These subpopulations are separated by a ridge but are not reproductively isolated. The greatest distance between trees in the subpopulations is approximately 3 km. Trees occur in clusters (especially in small valleys and draws) and as isolated trees (Photos 7-3 and 7-7). Perry (1991) and Donahue and Mar-López (1995) found little regeneration

under trees. However, Eguiluz-Piedra et al. (1985) and Romero (1998a) reported abundant regeneration around mature trees during their explorations. Natural regeneration density varies with respect to the number of years since the last fire. Local landowners have controlled wild fires more in recent years, allowing the natural regeneration to flourish.

The size of the *P. maximartinezii* forest at the Cerro de los Piñones has been estimated to be between 400 and 1000 ha (Donahue and Mar-López 1995, Ledig et al. 1998, Arteaga et al. 2000). Reports by local villagers in the area indicate that the *P. maximartinezii* forest is smaller than it was 60 years ago (Ledig et al. 1998). An estimated 2500 to 10,000 mature trees remain on the isolated mesa at Cerro de los Piñones (Donahue and Mar-López 1995, Farjon



Photo 7-3. Small cluster of *Pinus maximartinezii* trees on the Cerro de los Piñones.

¹ Much of the description was derived from Donahue and Mar-López (1995).

Figure 7-1. CAMCORE collections of *Pinus maximartinezii* in Mexico

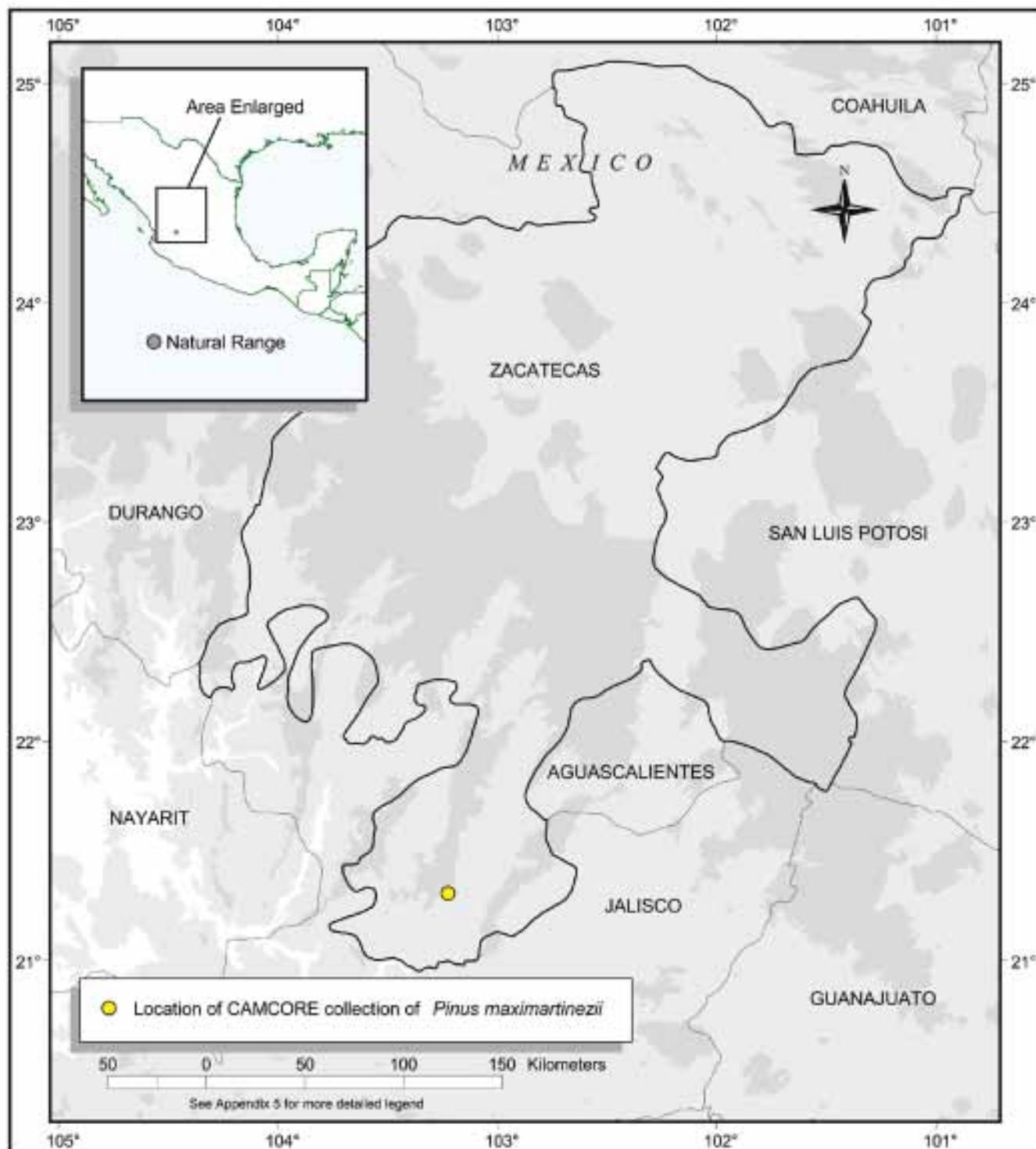




Photo 7-4a and b. *Pinus maximartinezii* cones can weigh as much as 2 kg.

1999). Explorations for *P. maximartinezii* on other isolated mesas in nearby regions by several botanists have not identified other populations (Farjon 1999).

CAMCORE collected cones from 80 trees in 1993 and 50 trees in 1998 on the Cerro de los Piñones. Seeds from the 1993 collection were distributed for the establishment of ex situ gene conservation banks; the 1998 collection was used for genetic diversity studies.

CLIMATE

Meteorological information from the small town of Juchipila, which is 4 km from the pinyon forests but at a lower elevation, indicates that approximately 750 to 800 mm of precipitation falls at the collection site. During drought years, this amount could be as low as 500 mm. Nearly 90% of the rain at Cerro de los Piñones occurs between June and September (Table 7-1). Juchipila (elev. 1350 m) experiences 7.5 frost days per year with a minimum temperature of -3.0 °C (SARH 1988). On top of the mesa where *Pinus maximartinezii* occurs (elev. 2100 to 2300 m), it is reasonable to assume that around 10 frosting days occur each year, with estimated minimum temperatures of about -6 °C. There has been one recorded snowfall (December 1997) in the last 30 years (Arteaga et al. 2000).



SOILS

Pinus maximartinezii is confined to the sandy clay and sandy clay loam soils on the southern part of the Cerro de los Piñones (Donahue and Mar-López 1995). Soils are 25 to 40 cm in depth, very well drained, and have pH values from 4.5 to 5.7 (Arteaga et al. 2000). Organic matter in the soil varies from approximately 0.2 to 7.0 % depending on the sampling location.

REPRODUCTIVE BIOLOGY

Pinus maximartinezii has a four-year reproductive cycle (Donahue and Mar-López 1995). Flower initiation begins in August and September; followed by pollination in May or June of the second year. Fertilization may occur in year two or three, and cones ripen in October to November of year four. Cones are collected when cone scale apophyses

Table 7-1. Mean monthly temperature (°C), extreme minimum temperature (°C) and rainfall (mm) recorded near the *Pinus maximartinezii* collection site at Cerro de los Piñones.

Cerro de los Piñones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	17.7	18.8	21.3	23.8	26.1	26.8	24.8	24.6	24.3	23.0	20.3	18.1	22.5
Extreme Min. °C	-3.0	-3.0	1.5	4.0	8.5	11.0	10.0	12.0	7.0	6.0	-2.0	-3.0	-3.0
Mean Rain mm	8	5	6	7	15	116	194	175	106	46	13	17	709

Based on 28 years of data, recorded at Juchipila (elev. 1350 m), 4 km from the collection site (SARH 1988).



Photo 7-5. Cone and seeds of *Pinus maximartinezii* (center) dwarf those of *P. herrerae* (left) and *P. patula* (right).

turn brown and resin exudates appear on the scales. There are only very subtle differences between immature cones at 3 years and mature cones at 4 years, thus collectors must be very careful (Romero 1998a). Cone number and size decrease from the top of the mesa at approximately 2300 m elevation to the lower slopes at 1600 m (Frankis 1999). Squirrels, birds and other animals (Farjon 1999) disperse the wingless seeds. Seeds are very large, ranging from 22 to 26 mm long and 10 to 12 mm wide (Rzedowski 1964). The average seed potential per cone is approximately 134 seeds. On average, there are 900 seeds per kg (Eguiluz-Piedra 1985).

Information on the age at which *P. maximartinezii* trees produce cones at Cerro de los Piñones is not consistent. Local farmers maintain that trees start to produce cones around 10 years of age in the natural stand on the mesa. However, Granados and Silva (1994) suggest that *Pinus maximartinezii* begins producing cones at about 25 years of age on the Cerro de los Piñones. Trees planted at the Maximino Martínez arboretum, Chapingo (Mexico), and in the Coyoacán district of Mexico City produced cones at 15 and 18 years, respectively (T. Eguiluz-Piedra, personal communication). At Frankfort, Mpumalanga, South Africa

(lat. 25° 02', elev. 1005 m, ann. precip. 1616 mm), two trees produced their first cone crop at 18 years of age, but the seeds were not viable (W. Hinze, personal communication). The climate at Frankfort is mild and currently supports the production of subtropical crops such as avocado.

ECOLOGY AND ASSOCIATED SPECIES

Pinus maximartinezii occurs primarily in pure stands and in association with several oak species, including *Quercus macrocarpa* (Rzedowski 1964). The species is occasionally seen with other pines such as *P. lumholtzii*, and *P. leiophylla* var. *chihuahuana*, as well as with *Fraxinus uhdei*, *Ipomea intrapilosa*, *Pseudobombax palmeri* and *Lysiloma acapulcensis* (Lara 1997). Shrub vegetation dominates the landscape around the *P. maximartinezii* trees. These shrubs reach 3 to 5 m in size and are without leaves for seven to nine months each year (Arteaga et al. 2000). Lara (1997) lists approximately 20 shrub species on the Cerro de los Piñones.

Pinus maximartinezii appears to be easily damaged by fire. The bark of juvenile trees is only 8 to 10 mm thick (Reynoso 1976).

PLANTATIONS

NURSERY PRACTICES

Seed Handling

Seeds have been stored long term at 4 °C, but little quantifiable information is available on how long viability can be maintained under these conditions. A seed shipment of *Pinus maximartinezii* placed in and out of cold storage over a 12-month period resulted in germination rates less than 30% (CAMCORE unpublished data). Examination of failed germinants revealed moldy embryos that shrank as a consequence of dehydration. Seeds that were dried to moisture contents of 7 to 9% and placed in cold storage by a commercial nursery in Mexico have maintained their viability for years (T. Eguiluz-Piedra, personal communication). Improved guidelines on optimum seed storage conditions and the effects of international shipment of seeds need to be developed.

No cold stratification of seed before sowing is needed. In Mexico, nurserymen have found that gently rubbing seeds with sandpaper prior to sowing helps break the seed coat and improves germination (T. Eguiluz-Piedra, personal communication). Seeds germinate well when placed in moist sand. Recently collected seeds begin germinating within 10 days after planting, but seeds stored in cold

rooms for long periods may require up to 30 days. Fresh seeds have a germination capacity of approximately 80% (Eguiluz-Piedra et al. 1985).

Containers and Growth Media

Various nursery media can be used to grow *P. maximartinezii*. It is critical that the chosen medium drains well. Heavy media cause roots to become waterlogged and promote damping-off (*Fusarium* spp.). Composted *P. patula* pine bark has worked well as a medium in South Africa, as has crushed volcanic rock in Mexico. A mixture of two parts sand and one part pine bark was used at North Carolina State University without problems (Photo 7-6). For small planting programs, containers with volumes of 4 to 5 liters are recommended. Black plastic bags and large pots are both suitable.

Seedling Management

After seedling radicals appear, germinants can be pricked into larger containers. Occasionally, seed coats need to be manually removed from the top portion of the plant to free developing cotyledons. *Pinus maximartinezii* is unique in that it produces between 17 and 25 cotyledons (Eguiluz-Piedra 1985). Seedlings have been successfully



Photo 7-6. Large containers are used by CAMCORE to raise *Pinus maximartinezii* seedlings at North Carolina State University. The seedling at right is not *P. maximartinezii*.



Photo 7-7. *Pinus maximartinezii* growing on the Cerro de los Piñones. Its future *in situ* will depend on good control of fires.

grown under 30 to 50% shade. Germinants grow rapidly and reach approximately 8- to 10-cm shoot height in several weeks before entering a resting stage during which root systems develop. Once established, watering should be conducted sparingly: once or twice every two weeks depending on growing conditions and nursery medium. Application of a slow release fertilizer such as Osmocote® several weeks after germinants are transplanted into containers is recommended. The seedling taproot grows rapidly, and its development must be considered when choosing growth containers. It may take seedlings one year to reach the recommended field planting height of 30 cm. The recommended root collar diameter for seedlings for field planting is 10 to 20 mm.

Vegetative Propagation

Based on research conducted by CAMCORE at North Carolina State University, *P. maximartinezii* appears to be relatively easy to root from seedling cuttings. Rooting success was best when the cuttings were treated with the auxin Rhizopon #3®, a commercial rooting powder (0.8% indole-3-butryic acid), and placed in a substrate of 65% peat and 35% perlite. Cutting position on the seedling stool plant did not have a clear effect on rooting. Cuttings

can be harvested from seedlings when shoot height is approximately 20 cm and should then be placed in a misting house. Optimization of misting regimes in the greenhouse is necessary. Rooting success of 70% seems feasible.

STAND MANAGEMENT

There are no commercial plantations of *Pinus maximartinezii*, but trials and arboreta have been established in several countries. Poynton (1977) mentions that a small introduction of *P. maximartinezii* was made into South Africa in the 1970s. Some of these trees, like those at Frankfort (mentioned earlier), are still alive. Perhaps the largest contiguous planting of the species is the 2 ha CAMCORE conservation bank established by Sappi at Tweedie, South Africa (lat. 29° 28' S, elev. 1122 m, ann. precip. 998 mm). Tweedie averages 5.4 frost days per winter. The most severe frost recorded was one of -5 °C. Survival of the planting was 89% at 30 months of age. Average height of the trees was 1.1 m and mean family heights ranged from 0.7 m to 1.9 m. In Michoacán, Mexico, a small planting of *P. maximartinezii* was 0.8 m tall at 37 months of age with average survival of 76% (Lara-Rubio 1994).

CONSERVATION

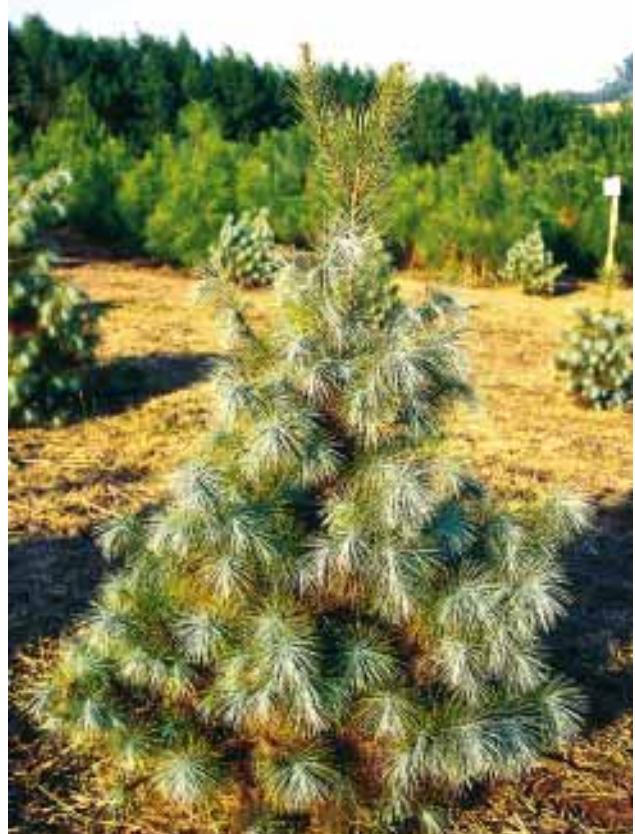


Photo 7-8a and b. Above, José Romero (CAMCORE) inspecting cone crops of *Pinus maximartinezii* on the Cerro de los Piñones for future *ex situ* conservation. Below, CAMCORE conservation bank of *P. maximartinezii* trees established by Sappi at Shaw Research Station, Tweedie, South Africa. The trees still have bluish-green juvenile foliage.

IN SITU GENE CONSERVATION

Genetic Diversity

There have been two genetic diversity studies of *Pinus maximartinezii* using chemical and molecular markers. In the first study, Ledig et al. (1998) used isozymes to examine variation patterns of *P. maximartinezii* on Cerro de los Piñones. Three of the study findings were of particular interest. First, results indicated that most of the alleles studied were present at intermediate frequencies, rather than very high or very low frequencies, as is more typical for pine species. Second, there were never more than two alleles at a locus. Third, trees with the highest selfing rates had more filled seeds per cone (50 vs. 40) and a higher percentage of filled seeds (90 vs. 73%) than trees with the highest outcrossing rate. One theory that partially explains these results is that *P. maximartinezii* recently survived a severe evolutionary bottleneck, and its ancestry may have been derived from a single seed (Ledig et al. 1998). The ability to produce sound seeds after selfing may suggest that the species carries few or no deleterious alleles. More work is needed to explain why outcrossed trees produce fewer filled seeds than do inbred trees.



The second study was conducted by CAMCORE and used Amplified Fragment Length Polymorphisms (AFLPs) to ascertain whether subpopulations within the *P. maximartinezii* range exhibited varying levels of genetic diversity. The subpopulations were grouped based on the spatial arrangement of trees and the position of natural boundaries of the collection sites, such as ridges and valleys. Seeds were collected from trees in each subpopulation. AFLP assessment did not demonstrate that genetic diversity was concentrated in any particular subpopulation.

Conservation Status

Pinus maximartinezii occurs on the Cerro de los Piñones on the property of at least seven different landowners. The owners understand that the species is very rare and needs to be protected. Because of its local economic value as an edible nut producer, each mature tree has been inspected by the caretaker of the property and is monitored for cone production. The annual seed collections conducted by landowners limit natural regeneration, as do the fires that occasionally enter the region, and both raise concern about the future conservation status of *P. maximartinezii*. Because of these man-made influences on the species and its limited geographic range, the conservation status of *P. maximartinezii* is considered **endangered** by the CAMCORE Cooperative. The pinyon pine is also

considered endangered by the Mexican government and is now protected by law.

EX SITU CONSERVATION

Urban forestry plantings serve as an important conservation tool for *Pinus maximartinezii*. In the early 1990s, a Mexican forest nursery company purchased 500 kg of seeds collected on Cerro de los Piñones and raised seedlings as ornamentals (T. Eguiluz-Piedra, personal communication). Seedlings were grown in Mexico City and sold to federal and state agencies, as well as to the public. As many as 20,000 plants have been distributed by this commercial nursery.

Fifty-nine families from CAMCORE collections were planted by Sappi at Tweedie, South Africa (coordinates given above), and family pedigrees have been maintained (Photo 7-8b). Mondi Forests and SAFCOL have also established small arboreta plantings of *P. maximartinezii* at several locations in South Africa. These have survived well. Two additional conservation plantings of the CAMCORE material were established at Makoholi ($19^{\circ} 47' S$, elev. 1204 m, ann. precip. 650 mm) and Nyamukwarara Valley ($18^{\circ} 42' S$, elev. 927 m, ann. precip. 1274 mm) in Zimbabwe by staff of the Zimbabwe Forest Research Centre. The conservation planting at Makoholi is doing better than the one in the Nyamukwarara Valley.

CONTRIBUTORS

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C h a p t e r 8



PINUS MAXIMINOI

W. S. Dvorak, E. A. Gutiérrez, W. J. Gapare, G. R. Hodge, L. F. Osorio, C. Bester and P. Kikuti

OVERVIEW

TREE DESCRIPTION

Pinus maximinoi H. E. Moore is a medium to large tree that ranges in height from 15 to 42 m with dbh (outside bark) from 40 to 100 cm at maturity. Stem form tends to be straight on good soils but is often crooked on degraded sites. Mature trees have a thick, rounded crown with large, horizontal to slightly ascending branches. Because of its rapid height growth, branch whorls can be as much as 3 m apart. The bark at the base of the tree is dark gray and is divided by deep horizontal and longitudinal fissures that form distinct plates (Perry 1991). On the upper stem the bark becomes smooth and grayish-brown. Young trees have smooth, grayish bark and a pyramidal crown. The needles are a light yellowish-green to glaucous-green (Farjon and Styles 1997), drooping to slightly pendent, 15 to 28 cm long, and usually occur in fascicles of five. Cones are 4.5 to 10.4 cm long (mean = 7.2 cm), dark reddish-brown, and are borne in groups of three or four. Cones ripen at the end of March from western Mexico (Guerrero) to northern Nicaragua. Seeds are dispersed by the end of the second to third week in April, just before the onset of the rainy season. In natural stands, the average seed potential per cone is approximately 145 seeds. There are between 55,000 and 115,000 seeds per kg (mean = 75,500), depending on the longitude of the collection site. The wood is white to whitish-yellow, of moderate density; low in extractives relative to most tropical pines, and can be used for construction and a number of other wood and paper products.

CONSERVATION STATUS

Based on CAMCORE assessments in Central America and Mexico, the conservation status of *P. maximinoi* in northwestern, central and southwestern Mexico is **low risk**. There are still populations of very large size (> 1000 ha) in these regions of the country. In Chiapas (Mexico), Guatemala, Honduras, El Salvador and Nicaragua, the conservation status of the species is classified as **vulnerable** to **critically endangered**. The population size of *P. maximinoi* ranges from 2 to 20 ha in central and eastern Guatemala and northern El Salvador and Nicaragua.

TEST STATUS

The CAMCORE Cooperative has sampled 26 provenances and 856 mother trees of *P. maximinoi* in southern Mexico (Guerrero, Oaxaca and Chiapas), Guatemala, Honduras and Nicaragua. Cooperative members in Brazil, Colombia, Honduras, Mexico, South Africa, Venezuela and Zimbabwe have established 47 provenance and progeny tests and conservation banks of *P. maximinoi*.

BEST PROVENANCES

Results from CAMCORE tests at 5 and 8 years indicate that the most productive provenances of *P. maximinoi* across sites in Brazil, Colombia and South Africa were La Cañada (Chiapas), Mexico and San Jerónimo, Guatemala. San Jerónimo (Chiapas), Mexico, Cobán, Guatemala and Dulce Nombre de Copán and Tatumbla, Honduras were also very good performers in at least one of the countries in which tests were established.

SUITABLE PLANTING SITES

Only small areas of *P. maximinoi* have been planted commercially primarily in the highlands of Colombia. However, the species appears well suited to a number of areas in the subtropics. Based on CAMCORE test results, *P. maximinoi* should perform well on fertile, well-drained soils in the Andes Mountains of Venezuela, Colombia and Ecuador at elevations from 1850 to 2300 m once seeds or cuttings selected for good growth, high wood density and a lack of foxtailing are available. *Pinus maximinoi* has also performed well in plateau regions of south-central Brazil in São Paulo and Paraná states (20° S to 24° S lat.) when planted at approximately 800 m elevation. It has shown great promise at mid-elevations in Zimbabwe and in the Mpumalanga region of South Africa. *Pinus maximinoi* lacks frost tolerance and should not be planted in areas prone to freezing temperatures. It has failed on sandy soils near the coast in Zululand, South Africa (lat. 30° S) and has grown poorly on clayey soils at 150 m elevation in western Venezuela (lat. 10° N). It also has failed on cold and dry sites in Lesotho (Leslie 1992). The species foxtails excessively when planted near the equator between 1400 and 1800 m elevation.

Photo 8-1. CAMCORE tree climber Mauro Gomez scales a *Pinus maximinoi* tree at San Jerónimo, Guatemala.

ADVANTAGES OF *PINUS MAXIMINOI*

- Easy to raise in the nursery.
- Grows rapidly in the field.
- Vegetative propagation using seedling cuttings is relatively easy.
- Provenance information now available.
- Reproductive cycle of 12 months in Colombia.
- Wood of excellent quality (between branch whorls).
- Suitable for pulp and a number of paper products.
- Moderately resistant to *Sphaeropsis sapinea* (*Diplodia*) in Brazil.
- Resistant to the *Pineus pini* (woolly aphid) in Swaziland.
- Recovers well after damage from light frost, windstorms and top dieback.

DISADVANTAGES OF *PINUS MAXIMINOI*

- Exhibits top dieback and mortality from droughts.
- Requires good weed control the first few years after field planting.
- Frost susceptible.
- Foxtails profusely near the equator.
- Has large branches that form an area of weak wood at the whorls.
- Top stem breakage is a problem at some locations.
- Graft incompatibility is a problem in clone banks and seed orchards.
- Potentially a poor seed producer in exotic environments at high latitudes ($> 24^{\circ}$ S)
- Seedlings moderately susceptible to *Fusarium subglutinans* f. sp. *pini* (pitch canker).
- Moderate susceptibility to *Cinara cronartii* (black aphid) in Lesotho.

NATURAL STANDS

DISTRIBUTION

Pinus maximinoi extends from Sinaloa, Mexico into Guatemala, Honduras, El Salvador and northern Nicaragua, a distance of about 2250 km. It occurs across a wide range of microclimates and environments, ranging from moist cloud forests to dry pine-oak ecosystems (see Ecology). After *P. oocarpa*, it is the most common pine in Central America.

The natural range of *P. maximinoi* in Mexico is disjunct but widespread, with populations occurring in all of the major mountain ranges in the southern half of the country. In northwestern Mexico (Jalisco to Sinaloa), *P. maximinoi*

often occurs from 1500 to 2800 m elevation (Farjon and Styles 1997), but individual trees can be found at elevations as low as 1000 m. In Guerrero and eastward through Central America, the elevational range is between 600 and 2400 m but the species is most common from 1100 to 1800 m (Dvorak and Donahue 1992).

Tree growth can be rapid at some locations. For trees in two natural stands in Oaxaca that were approximately 35 years old, the average annual height and diameter increments were found to be 0.70 m and 1.5 cm, respectively (Dvorak and Donahue 1988). In a natural stand at Cobán, Guatemala trees averaged 1.1 m/yr height

growth and 1.3 cm/yr diameter increment over approximately 25 years (Nuñez 1986). Bark content represented 24% of the total volume for trees that averaged 24 m in height and 32 cm in dbh. Height growth was most rapid between the ages of 10 and 15 years. Trees reach their largest size (40 m) on Alfisols in the cloud forests of San Jerónimo, Oaxaca, Mexico, San Jerónimo and San Lorenzo, Guatemala, and San José Bayuncún, Nicaragua. Populations in Guerrero, Jalisco and Oaxaca can be large, with some stands more than 1000 hectares in size. In Guatemala, Honduras, northern El Salvador and Nicaragua, populations of *P. maximinoi* are smaller and much more fragmented. Many stands in central and eastern Guatemala and northern Nicaragua range from 2 to 20 ha in size and are threatened by local agricultural enterprises.

The extent of the northern distribution of *P. maximinoi* in Mexico is still in question. We believe that some of what is being called *P. douglasiana* in northwestern and central Mexico is actually *P. maximinoi*. Stead (1983) suggests that *P. maximinoi* and *P. douglasiana* can be distinguished on the basis of external morphologic traits such as cone width, needle length and width, fascicle sheath length and number of stomatal lines. *Pinus maximinoi* and *P. pseudostrobus* can be separated using a combination of internal and external morphologic traits. Internal needle morphology, which shows hypodermal cells touching the endoderm in *P. maximinoi* but not in *P. pseudostrobus*, is the most diagnostic of these (Mittak and Perry 1979, Stead 1983). Species-specific molecular markers for *P. maximinoi*, *P. douglasiana* and *P. pseudostrobus* are needed to help foresters more accurately separate the three taxa in central and northwestern Mexico.

CAMCORE has sampled 26 provenances and 856 mother trees in southern Mexico, Guatemala, Honduras and Nicaragua (Table 8-1, Figure 8-1). CAMCORE collections of *P. maximinoi* are unique in two respects. They are the first to include populations from Guerrero, Oaxaca, and Chiapas, Mexico in international field trials and are also the first to maintain identity by individual mother trees.

CLIMATE

Pinus maximinoi occurs in areas that receive between 900 and 2200 mm of annual precipitation with a well-defined dry season from November through April (Table 8-2). However, the species is generally found on sites where annual rainfall amounts are above 1200 mm. When the species is found in areas that receive less than

1000 mm of precipitation, the sites are often characterized by clayey soils that hold moisture well (see Soils). In many mountainous areas, fog often provides trees with additional moisture.

Average monthly temperatures range between 14 and 20 °C in January and between 20 and 27 °C during the warmest months of May and June, depending on the elevation of the collection site. Because of the warmer influences of the Pacific Ocean, nighttime winter temperatures in northwestern Mexico (Jalisco, Nayarit and Sinaloa) where *P. maximinoi* occurs seldom fall below freezing. Nighttime winter temperatures at *P. maximinoi* sites in Michoacán may fall below freezing but only for a very short time (J. López-Upton, personal communication). Generally, populations of *P. maximinoi* should not be considered frost tolerant.



Photo 8-2. René Calderón (formerly with ESNACIFOR) inspects a *Pinus maximinoi* stand at Sierra de Omoa, Honduras.

Table 8-1. *Pinus maximinoi* provenance collections made by the CAMCORE Cooperative in Mexico and Central America.

Map Provenance Key	State or Department	Country	Latitude	Longitude	Elevation Range(m)	Rainfall (mm/yr)	No. of Trees
1 Cobán	Alta Verapaz	Guatemala	15° 28' N	90° 24' W	1330 - 1440	2109	31
2 San Jerónimo	Baja Verapaz	Guatemala	15° 04' N	90° 14' W	1280 - 1590	970	30
3 San Juan Sacatepéquez	Guatemala	Guatemala	14° 41' N	90° 38' W	1580 - 2000	1138	30
4 Dulce Nombre de Copán	Copán	Honduras	14° 50' N	88° 51' W	1100 - 1300	1386	50
5 Marcala	La Paz	Honduras	14° 10' N	88° 01' W	1600 - 1800	1670	40
6 Tapiquil	Yoro	Honduras	15° 10' N	86° 50' W	1500 - 1769	1069	49
7 Tatumbla	Fco. Morazán	Honduras	14° 01' N	87° 07' W	1400 - 1600	908	115
8 Altamirano	Chiapas	Mexico	16° 44' N	92° 03' W	1280 - 1350	1750	39
9 San Jerónimo	Chiapas	Mexico	17° 09' N	92° 08' W	940 - 1020	1750	24
10 Ciénaga de León	Chiapas	Mexico	16° 41' N	93° 52' W	1050 - 1240	1750	17
11 Coapilla	Chiapas	Mexico	17° 17' N	93° 09' W	1360 - 1510	1250	34
12 La Cañada	Chiapas	Mexico	16° 49' N	92° 17' W	1270 - 1360	1750	20
13 Monte Cristo	Chiapas	Mexico	15° 44' N	92° 33' W	750 - 900	2000	26
14 Valle de Angeles	Fco. Morazán	Honduras	14° 10' N	87° 02' W	1200 - 1600	908	50
15 San Juan Copala	Chiapas	Mexico	17° 10' N	97° 58' W	1370 - 1560	1027	25
16 San Jerónimo	Oaxaca	Mexico	16° 10' N	97° 00' W	1220 - 1480	1950	35
17 Candelaria	Oaxaca	Mexico	16° 00' N	96° 31' W	1370 - 1480	1350	25
18 Las Compuertas	Guerrero	Mexico	17° 10' N	99° 59' W	1050 - 1200	1400	29
19 El Portillo	Ocotepeque	Honduras	14° 28' N	89° 01' W	1400 - 1600	1325	30
20 Yuscarán	El Paraíso	Honduras	13° 50' N	86° 55' W	1500 - 1700	1300	30
21 Minas de Oro	Comayagua	Honduras	14° 47' N	87° 21' W	950 - 1300	1067	30
22 La Lagunilla	Jalapa	Guatemala	14° 42' N	89° 57' W	1540 - 1860	1017	20
23 San Lorenzo	Zacapa	Guatemala	15° 05' N	89° 40' W	1900 - 2100	1500	10
24 San Jose Bayuncún	Nueva Segovia	Nicaragua	13° 45' N	86° 20' W	980 - 1240	1184	30
25 San Francisco Murra	Nueva Segovia	Nicaragua	13° 45' N	86° 00' W	930 - 1130	1410	17
26 Datanlí	Jinotega	Nicaragua	13° 07' N	85° 54' W	980 - 1200	213	20
26 Provenances	17 State/Depts.	4 Countries	13 - 18° N	86 - 100° W	750 - 2100	1403	856

Figure 8-1. CAMCORE collections of *Pinus maximinoi* in Mexico and Central America.

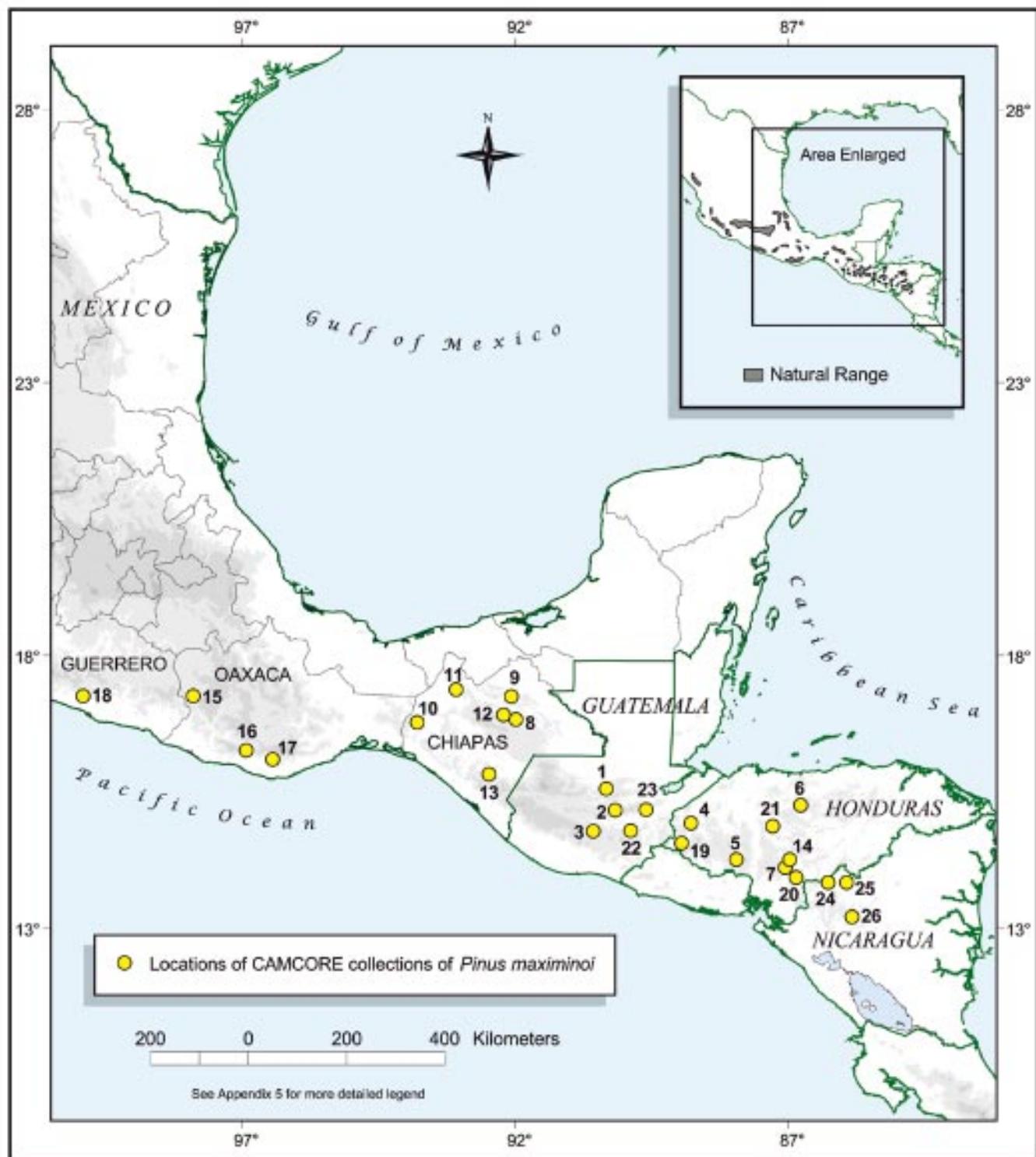


Table 8-2. Monthly mean temperature (°C) and rainfall (mm) recorded near CAMCORE collection sites of *Pinus maximinoi* at San Juan Copala, Oaxaca, Mexico (top) and San Francisco Murra, Nueva Segovia, Nicaragua (bottom).

San Juan Copala	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	16	17	18	19	21	21	20	19	19	18	17	17	18.6
Mean Rain mm	13	1	6	14	116	133	200	164	142	218	10	10	1027

Based on 9 years of data recorded at Juxtlahuaca, 1650 m elevation, 20 km from the collection site.

San Fco. Murra	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	21	21	22	23	24	23	23	23	23	23	22	21	22.5
Mean Rain mm	61	26	20	40	117	203	195	183	209	203	85	69	1410

Data recorded at San Francisco Murra, elevation 900 m, 4 km from the collection site (Donahue and Gutiérrez, 1992).

SOILS

As is the case for *P. caribaea* var. *hondurensis*, no single soil type defines the distribution of *P. maximinoi*. There are roughly two forest types where the species occurs, each of which has unique microclimatic and edaphic features: 1) moist subtropical forests and 2) semidry pine and pine-oak forests. Most *P. maximinoi* sites are characterized by well-drained soils.

Moist Subtropical Forests

The soils in a typical mesic subtropical forest that includes *P. maximinoi*, which occur from 600 to 2400 m elevation, are characterized by a 6- to 10-cm organic layer, a sandy clay loam to clay A horizon of 30 cm depth, and a clay loam to clay B horizon of 50 to 150 cm depth (Dvorak and Donahue 1988). These soils are very fertile. For example, soils at Cobán, Guatemala had 6% organic matter in the surface horizon (Nuñez 1986). Occasionally, an ash layer of several centimeters is seen in the soil profiles of Chiapas. The moist subtropical cloud forests of *P. maximinoi* at San Jerónimo and San Lorenzo, Guatemala, where mineral soils are 2 to 3 m deep, are typical of the high elevation populations of the species. The average soil pH value in these moist forests is approximately 5.7 but can be as high as 7.0 (e.g., as in Dulce Nombre de Copán, Honduras). These soils are predominantly Inceptisols and Alfisols and, because of their good drainage and high fertility, are often sought by coffee growers.

Transition Pine-Oak Forests

The pine-oak forests of Mesoamerica separate the moist subtropical forests from the dry scrub vegetation of the valley bottoms. *Pinus maximinoi* has occasionally migrated into these transition pine-oak ecosystems. Its abundance in these areas is determined by soil depth, elevation (nighttime temperatures), precipitation, and the frequency of fires (see Ecology). These transition forests are most common at the low and mid-elevations of the species range. In addition to a number of *Quercus* (oak) species, *P. oocarpa* and occasionally *P. devoniana* and *P. pseudostrobus* are found along with *P. maximinoi*. Soils in the transition

forests in which *P. maximinoi* occurs are generally clayey in Central America but become sandier in southern and northwestern Mexico (Donahue and Gutiérrez 1992). Specifically, the transition forests are characterized by relatively shallow, clayey soils that are often highly leached and eroded. As an example, at the San Juan Copala, Oaxaca site, where *P. maximinoi* and *P. oocarpa* occur in equal proportion, both the organic and A horizons have eroded and trees are growing on an exposed clay-mineral B horizon. Soils in transition forests are more acidic (average pH = 4.5) and less fertile than in the wet subtropical forests. On some of the poorer transition sites, soils can be more sandy than clayey. At Tatumbla, a well-known *P. maximinoi* site in central Honduras, sand, silt and clay percentages were 55, 32 and 13%, respectively, versus the more common values of 12, 28 and 60% in a subtropical forest like Yuscarán, Honduras (Dvorak and Donahue 1988). On pine-oak transition sites in northwestern Mexico, the soils are often very stony, deep sandy loams and sandy clays of marginal fertility. They have soil pH values between 4.5 and 5.0. Some of these transition sites receive less than 1000 mm of annual rainfall. Soils in the transition pine forests throughout Mesoamerica are mainly Ultisols and Inceptisols, are occasionally low in phosphorus (< 1.5 ppm), and are often critically low in boron (< 0.3 ppm).

REPRODUCTIVE BIOLOGY

In central Guatemala, *P. maximinoi* pollen dispersal begins at the end of February, reaches its peak in March and is complete by around the first week in April (Gutiérrez 1999). In northern Nicaragua, CAMCORE has observed heavy flowering in *P. maximinoi* stands on April 1st (Donahue and Gutiérrez 1992). The cone collection period from Guerrero, Mexico to northern Nicaragua is from the last week of March through the second to third week of April, just prior to the beginning of the rainy season. The time span for collection in any one stand is probably no more than 10 days. Little information is available on flowering and cone collection times for *P. maximinoi* in central and western Mexico, but it appears to differ from the more subtropical populations in the



Photo 8-3. Pollen dispersal in *Pinus maximinoi* peaks in mid-March at many localities in Central America and southern Mexico.

southern portion of the species range. It was initially thought that the length of the reproductive cycle (from pollination to cone collection) was 24 months for *P. maximinoi*. However, recent work in a Smurfit Cartón de Colombia seed orchard near Popayán, Colombia ($2^{\circ} 29' N$ lat., 2087 mm ann. precip., 1740 m elev.) clearly indicates that the reproductive cycle is 12 rather than 24 months (Isaza and Arce 1997, Isaza et al. 2000). Further studies are needed to determine the exact length of the breeding cycle in natural stands.

Pinus maximinoi cones occur at the end of long branches in clusters of three or four. Seeds are dispersed quickly in warm weather after the cones ripen. The average seed potential per cone for *P. maximinoi* is approximately 145 seeds. In natural stands in central Guatemala, CAMCORE obtained 29 viable seeds per cone in collections in 1996 (Gutiérrez 1996) and 22 viable seeds per cone in collections in 2000 (Gutiérrez 2000), resulting in seed efficiencies of 20 and 15%, respectively. A significant positive correlation ($r = 0.90$) was found between seed size and longitude of the collection site in 14 provenances. This variation was strongly clinal, and seed size increased from west to east. In Guerrero and Oaxaca, which are in the western part of the species range, approximately 100,000 seeds are obtained per kg versus approximately 55,000 per kg in central and southern Honduras. The average is 75,500 seeds per kg. There was no correlation between seed size and elevation of the collection site in this portion of the species range.

ECOLOGY AND ASSOCIATED SPECIES

Pinus maximinoi is an extremely aggressive pioneer species that quickly colonizes gaps in the forest. When studied in growth chambers at North Carolina State University, the lateral root initiation and root growth were more rapid for *P. maximinoi* than for *P. ayacahuite*, *P. chiapensis* or *P. tecunumanii* (Dvorak 1990). The early growth pattern in some moist cloud forests like Cobán and San Jerónimo, Guatemala is interesting. After initiating its first whorl of branches, the terminal shoot grows for 2 to 4 m without the development of lateral branches, i.e., the tree forms a foxtail. After this prolonged terminal leader growth, which gives the tree the appearance of having skipped production of a second whorl of branches in order to produce a third whorl, *P. maximinoi* often assumes a normal branching pattern. Even after the normal branching pattern resumes, branch internode lengths remain long. This rapid development pattern allows the species to outgrow competing broadleaf and pine species in mesic environments.

Pinus maximinoi occurs in both pure and mixed stands. Of 23 populations sampled by CAMCORE from Guerrero, Mexico to Honduras, 13% were pure *P. maximinoi* stands, 57% were predominantly *P. maximinoi* with some *P. oocarpa*, 26% were equal mixtures of *P. maximinoi* and *P. oocarpa*, and 4% were *P. maximinoi* with pines species other than *P. oocarpa* (Dvorak and Donahue 1988). Even when growing in association with other pine species, small

clusters of *P. maximinoi* trees are often seen. These "islands" within the forest are created as an opportunistic response to an opening in the canopy and quickly shade out competing trees and herbaceous vegetation and reduce the risk of intense fire in the stand. On fertile soils where fires are not common, *P. maximinoi* appears to outcompete all of the other pine species, with the possible exception of *P. chiapensis*. *Pinus maximinoi* is not resistant to fire when young, but rapid growth and the development of a thick bark offer trees some protection as they mature.

As mentioned previously (see Soils), *P. maximinoi* is found on two forest types: mesic subtropical forests and pine and pine-oak transition forests. In the mesic subtropical forests, *P. maximinoi* has been found with species such as *P. ayacahuite*, *P. chiapensis*, *P. patula* var. *longipedunculata*, *P. tecunumanii*, *Liquidambar styraciflua*, *Moraceae* spp., and *Quercus* spp. Other broadleaf species found in a typical moist subtropical forest, such as Cobán, included *Rhus striata*, *Myrica cerifera*, *Hedyosum mexicanum*, *Cedrela* spp., *Pimeineta dioica*, *Alnus* spp. and *Juglans guatemalensis* (Nuñez 1986). *Bromelia* spp. are often attached to the branches and stems of trees. On rare occasions, *P. maximinoi* is found with *Abies guatemalensis* and *A. religosa* in high elevation cloud forests. The species occurs with *P. caribaea* var. *hondurensis* at only one location, Lanquín, Guatemala, at an elevation of approximately 900 to 1000 m.

In the cooler cloud forest areas of Central America, *P. maximinoi* often occupies the most fertile areas near streambeds, *P. tecunumanii* the relatively fertile upper slopes, and *P. oocarpa* the drier exposed upper slopes. At La Lagunilla, Guatemala, *P. maximinoi* occupies the more fertile soils on the upper slopes, while *P. oocarpa* occurs on the more degraded soils of the lower slopes. The transition zone (approx. 1500 m elev.) between these two areas is very well defined. In areas of equal fertility and moisture in the high elevation subtropical cloud forests, *P. maximinoi* is often sympatric with *P. tecunumanii* (in Central America) and occasionally with *P. patula* var. *longipedunculata* (in Oaxaca), but it is seldom the predominant species in either of these forests. Because it has less resistance to fire than *P. tecunumanii*, the relative abundance of *P. maximinoi* in these areas may be directly related to the frequency of fires. In some of the more humid areas in the valleys and mountains of Chiapas, Oaxaca and Guerrero, Mexico and El Quiche, Guatemala, *P. maximinoi* grows in association with the white pine *P. chiapensis* but often occurs on the boundaries rather than intermixed within the stand (J. Donahue, personal communication).

Fires are more common and the sites more degraded in the transition pine forests than on the moist subtropical sites. *Pinus maximinoi* occurs with *P. oocarpa* in Central America and with *P. oocarpa*, *P. devoniana* and *P. pseudostrobus* in southern and central Mexico.

Depending on the amount of moisture and fertility at a given site, *Liquidambar styraciflua* may be present. *Quercus* (Oak) species are common, as is bracken fern (*Pteridium aquilinum*), especially after fires. *Byrsinima crassifolia* is common at some of the sites. In many transition forests of northwestern Mexico, *P. maximinoi* becomes the predominant species above 1500 m elevation. Below this elevation temperatures may be too tropical for *P. maximinoi* to colonize vigorously. In the transition boundary (around 1500 m elev.) *Pinus maximinoi* grows in association with *P. jaliscana*, *P. douglasiana*, *P. pseudostrobus* and *P. oocarpa*, as well as with a number of oak species.

Pinus maximinoi in natural stands appears to be as prone to disease and insect attack as the Mesoamerican closed-cone pines, with the possible exception of a greater susceptibility to damage by cone- and seed-boring insects. CAMCORE collections in several locations in Central America and Mexico have been aborted because of insect damage to cone crops. There is a wide host of insects in the Diptera, Hymenoptera and Coleoptera orders that damage cones throughout the natural distribution of the species (Carlin and Nuñez 1985, Cibrián-Tovar et al. 1995).

Like most middle and high elevation pines, *P. maximinoi* is especially susceptible to pest attacks after prolonged cyclic droughts during which annual precipitation can drop by as much as 50%, as was the case in many places in Mesoamerica in 1997. Trees weakened by drought and subsequent fires are often attacked by *Dendroctonus* spp. (pine bark beetles), and reports of infestations on *P. maximinoi* are abundant in the literature (e.g., Haack and Paiz-Schwartz 1997, Renwick et al. 1975, Coyne and Critchfield 1974, Clark 1973). Needle blights and branch galls also have been found on the species in Honduras (Booth and Evans 1984, Evan and Punithlingam 1985). On rare occasions, the species suffers from *Cronartium conigenum* (cone rust), a disease for which the alternate hosts are members of the Fagaceae family (Rayachhetry et al. 1995). *Arceuthobium aureum* (mistletoe) has recently been identified on *P. maximinoi* in Guatemala (Mathiasen et al. 1999).

WOOD QUALITY IN NATURAL STANDS

Local woodcutters in Guatemala consider *P. maximinoi* to be of average quality and comment that the wood is not as hard as *P. tecunumanii* and *P. oocarpa* but not as soft as *P. ayacahuite*. Wood samples taken and assessed by CAMCORE support this observation. Wood cores were extracted from 59 trees in the provenances of Las Compuertas, Guerrero, San Jerónimo, Oaxaca and Minas de Oro, Honduras using a 12-mm increment borer (Dvorak and Donahue 1988). Stand age averaged about 32 years. Wood density (unextracted) for the juvenile core (first 15 rings) was 430 kg/m³ and for the mature wood was 490 kg/m³ (mean = 460 kg/m³). Small differences were found among provenances, but there was large

within-tree variation. The wood density of *P. maximinoi* sampled from trees in Oaxaca was about 20% less than *P. tecunumanii* trees of a similar age sampled in Belize (Dvorak and Wright 1994). In a study by Zobel (1965), the average wood density (extracted) of five *P. maximinoi* trees in Michoacán was 440 kg/m³ at 48 years of age. The average wood density of *P. maximinoi* was found to be the same as *P. patula*, but *P. maximinoi* exhibited less of a density gradient from pith to bark than did *P. patula* (Zobel 1965). Average tracheid length was 3.6 mm for *P. maximinoi* versus 4.1 mm for *P. patula*.

In a study conducted on 15 logs of *P. maximinoi* sampled in Michoacán, Mexico by Schafer and Chidester (1961), the average density was found to be 439 kg/m³ on 26-year-old trees. *Pinus maximinoi* ranked in the upper third of the nine Mexican pine species tested for tear strength of groundwood pulp and in the middle third for bursting strength.

Much like *P. oocarpa*, the wood of *P. maximinoi* is used locally for construction, electric poles, small dimension supports, interior molding, vegetable crates, broomstick handles and firewood.

PLANTATIONS

Only a few hundred hectares of *P. maximinoi* have been established, primarily in the highlands of Colombia (Wright et al. 1993), and planting of the species in this country was curtailed because of the high incidence of foxtailing. But as more data are collected from CAMCORE tests, the potential of *P. maximinoi* is becoming apparent. When it is planted in places such as south-central Brazil, the highlands of Colombia or the highlands of South Africa and Zimbabwe, it often greatly outgrows improved commercial species (e.g., *P. elliottii*, *P. patula* and *P. taeda*). Wider acceptance of *P. maximinoi* in plantation forestry has been limited by an uncertainty about the species' wood quality and the final product it could best be used for; as well as by its propensity to foxtail near the equator. Current knowledge about *P. maximinoi* comes from information generated in genetic tests and arboreta.

NURSERY PRACTICES

Seed Handling

Like *P. caribaea* var. *hondurensis*, *P. oocarpa* and *P. tecunumanii*, the seed coat of *P. maximinoi* is rather thin and is easily damaged by rough handling. Seed size and weight vary greatly by provenance, which means cleaning methods (separating empty and filled seeds by a seed blower) established for one source may not be the best method for other sources. Seeds should be stored at 2.5 to 4.0 °C with moisture content between 6 and 9%. Good seed viability has been maintained under these conditions for about 5 years in Zimbabwe and 8 to 10 years at North Carolina State University. Seeds do not need to be stratified before sowing. Soaking seeds before sowing at 25 °C in water for 12 to 24 hours can improve germination uniformity. Seeds that float during the soak should not be discarded because they occasionally germinate (H. Mhongwe, personal communication). Fresh seeds begin germinating 7 to 10 days after sowing. Seed from a 1984 collection of San Jerónimo, Guatemala had

67% germination when sown in a mixture of vermiculite and sand.

Containers and Growth Media

At Klabin in Paraná, Brazil, *P. maximinoi* seedlings are grown in a 25% vermiculite, 75% composted pine bark medium with a pH value of 5.4. Seedlings are raised in tubes with a volumetric capacity of 56 cm³. The Forest Research Centre in Zimbabwe grows seedlings in 100% loamy topsoil collected from indigenous forests with pH values from 4.5 to 6.0 mixed with mycorrhizal soil from pine plantations (C. Musokonyi and N. Pindani, personal communication). They use a folding container that is 10 x 20 cm when pressed flat. At Smurfit Cartón de Colombia, 33% composted sawdust with 33% coal ash and 34% topsoil is used in trays (M. Arce and V. Betancur, personal communication). Jiffy® peat pellets with capacity of 34 cm³ also have been used successfully by the company.

Seedling Management

Pinus maximinoi seedlings are handled in the nursery in a manner similar to that for most other pine species. At Klabin, trees are grown under conditions like those used for commercial species such as *P. elliottii* and *P. taeda*. This regime includes a four-week period in the greenhouse, two weeks in 50% shade, and then a 14-week stay in an open nursery during which seedlings are allowed to harden off. Seedlings reach a plantable size of 20 to 25 cm in five months in Colombia and Brazil, and reach a shoot height of 10 to 20 cm in approximately nine months in Zimbabwe. Root collar diameter at time of planting varies from 2 to 4 mm. The species does not seem to be susceptible to any particular disease or insect in the nursery, although some problems with damping-off (*Fusarium* spp.) have been reported (Vásquez and Sanchez 1981). The species exhibits none of the root development problems that are characteristic of *P. tecunumanii* (see Chapter 12).

Vegetative Propagation

The most intensive research on vegetative propagation of *P. maximinoi* has been done by foresters at Smurfit Cartón de Colombia and is described in detail by Osorio (1993). The propagation system used for *P. maximinoi* is similar to that for *P. tecunumanii*. Seeds used for hedges are sown in trays and the seedlings are transplanted after six months to open field beds. Seedlings are planted 50 cm apart and are fertilized with 50 g of NPK (15-38-10) and 5 g of borax (48% B_2O_3) per seedling. The first pruning of the leader and lateral branches are made two months after transplanting. Five to eight sprouts are obtained per seedling. The hedges are pruned to 20 to 30 cm every two to three months.

Selected sprouts are 8 to 10 cm long and possess juvenile characteristics. The terminal portion of the shoot is trimmed to 6 cm and is immediately placed in 0.5% benlate fungicide. The cutting base is then soaked in a 50% ethanol solution with 1000 ppm Indolebutyric acid (IBA) for five seconds and is placed in the substrate to a depth of about 2.5 cm without removing the needles. The rooting substrate initially used at Smurfit Cartón de Colombia was a mixture of 50% subsoil and 50% coal ash, a byproduct of mineral coal burned in industrial boilers. The current operational substrate for pine cuttings is the Jiffy® peat pellet. Cuttings are established in a rooting facility that is covered with plastic and shade cloth (46%).

Fertilization begins in the rooting facility after eight weeks with an application of 0.05 g NPK (15-38-10) per cutting every two weeks. This regime continues until the cuttings are transferred to the open field beds to harden off. By the fourth month, the majority of the cuttings have rooted, and they are transferred to the shade area. Rooting is evaluated when the cuttings show vegetative growth. Cuttings are maintained in the shade for one month before they are taken to an open-air hardening-off area, where they remain for two more months or until they reach the desired planting size (Osorio 1993). Results at Smurfit Cartón de Colombia suggest that *P. maximinoi* roots better than *P. tecunumanii* (85 vs. 66%, respectively).

Studies of 8-year-old tests of *P. maximinoi* cuttings established in the highlands of Colombia were assessed by Osorio (2000). Results suggest that the development of cuttings differs little from normal seedling development. Average height and dbh for the cuttings at 8 years of age were 16.6 m and 20.8 cm, respectively.

STAND MANAGEMENT

Site Selection and Establishment

Based on CAMCORE experience, *P. maximinoi* prefers sandy loam to clay loam soils that are well drained and receive from 1000 to 2000 mm of annual rainfall that is evenly distributed throughout the year. The species is more sensitive to drought and equally sensitive to cold compared to *P. tecunumanii* (see Survival). Both of these climatic

factors have been responsible for low stocking rates in test plantings in southern Africa. In areas near the equator, plantings should be made above 1850 m elevation to reduce foxtailing problems, but growers should be aware that wood density often decreases with increasing elevation (see Wood Quality). The Forest Research Centre in Zimbabwe has found that optimal planting sites are around 1350 m (Nyoka 1994). A 900 to 1000 m elevational range appears to be appropriate in the Mpumalanga region in South Africa. Planting *P. maximinoi* between 780 to 900 m elevation in Paraná and southern São Paulo state in south-central Brazil has produced good results. The species has failed in South Africa when planted on coastal sands, and in Venezuela when established at 150 m elevation on heavy clays with long dry seasons of seven months. It has also failed on dry and cold sites in Lesotho (Leslie 1992).

Technicians in Zimbabwe also warn growers about planting *P. maximinoi* on exposed slopes because of crown stem breakage (H. Mhongwe and N. Pindani, personal communication). Even though the upper-stem breakage in *P. maximinoi* is not nearly as severe as in *P. tecunumanii* (see Chapter 12), it does occur. The breakage is most prevalent during the months of strong seasonal winds and often occurs at whorls with large, heavy branches. The problem is exacerbated if the terminal leader dies back during drought. Assessments in CAMCORE tests suggest that broken top damage averaged 1, 15, and 10% in Brazil, Colombia, and South Africa, respectively (Gapare et al. 2000).

Pinus maximinoi trees are planted at 2.5 x 3.0 m to 3.0 x 3.0 m spacing by CAMCORE members without problems. Fertilizer is generally not applied at time of planting, and baseline nutrient data is not available for this species. Weed control is essential during the first year after planting. Seedling mortality due to lack of weed control has been mentioned as one of the reasons for low stocking in test plantings in both Swaziland and South Africa (A. Kanzler, personal communication, L. van der Merwe, personal communication). In a separate series of tests planted in Swaziland, mortality continued for several years after field planting as a result of winter frosts (Kanzler 1995a).

Silviculture

Trees grow quickly if the proper seed source is used and if site selection and preparation have been properly performed. In CAMCORE tests, the average height of trees at 3 years of age in Brazil, Colombia and South Africa was 5.2, 6.3 and 5.2 m, respectively. By 5 years, the average height of *P. maximinoi* trees is 9 to 10 m and crown canopies have begun to close.

Since most *P. maximinoi* plantings currently use unimproved seeds, the initial quality of stands is sometimes very poor. There is tremendous tree-to-tree variability in both growth and stem form. Much like the study in natural stands in

Guatemala that suggested height growth reached its maximum between age 10 and 15 years (Nuñez 1986), there is some indication that trees grow faster in test plots once root systems have become firmly established. In studies in Swaziland, *P. maximinoi* was the tallest species at 68 months, despite having been ranked second, third and sixth relative to other species at earlier assessments (Kanzler 1995b).

On several occasions, CAMCORE members expressed a desire to "write off" a particular *P. maximinoi* planting at an early age, only to be surprised by the improved quality at a later time. For example, material damaged by frost at a high elevation site in Zimbabwe showed poor form at 4 years of age, but by age 8 years the trees had recovered dramatically (Nyoka 1994). At a SAFCOL/CAMCORE planting near Sabie, Mpumalanga, South Africa, a windstorm severely damaged a cluster of tests at approximately age 5 years, but by age 8 the trials had recovered to the extent that individual tree selections could be made. In Colombia, a high incidence of foxtail trees at age 3 often discourages many foresters from planting the species again. However, by age 10 years, many trees have outgrown the foxtail stage and stands are of merchantable quality (Photos 8-5a and b).

As mentioned previously, frosts during the seedling stage often kill *P. maximinoi*. At a CAMCORE trial planted in southern Brazil, a one-in-20-year frost (-6 or -7 °C) at one year of age resulted in 67% mortality. Four-year-old trees in a different study in the same area suffered less than 10% mortality. When tree height is above 5 m, light frosts generally do not kill trees but can cause branch leaders to die, which has an adverse effect on tree form.

Foxtailing presents a major problem in *P. maximinoi* plantings near the equator and is discussed under Tree Improvement. Generally, foxtailed trees are most susceptible to top dieback. This problem is most pronounced on fertile sites like those in Colombia, but is found to some extent at most locations. The phenomenon may be both drought and nutrient related. *Pinus chiapensis* suffers the same type of problem, especially during the period of rapid terminal leader elongation.

Pinus maximinoi stands are correctively pruned at Klabin (Brazil) at 3 years and by the Zimbabwe Research Centre at 5 years. Trees respond well to pruning, but with improved seeds this silvicultural practice may not be as necessary.

Pests and Other Limiting Factors

Insects: Because relatively few *P. maximinoi* have been planted, there are not many reports of pest damage. Leaf-cutting ants in south-central Brazil have attacked *P. maximinoi* at various ages. Needle defoliation from *Mecostibus pinivorus* (wingless grasshopper) was reported on *P. maximinoi* trees in Zimbabwe (Mushongahande and Marunda 1995).

Pinus maximinoi appears to be resistant to *Pineus pini* (woolly aphid) in Swaziland (A. Kanzler, personal communication) and some provenances of the species were found to be more resistant than others to attacks in Zimbabwe (Nyoka 1994). Specifically, at Nyangui, Zimbabwe provenances such as San Juan Sacatepéquez and Dulce Nombre de Copán were relatively resistant to the woolly aphid, while sources from Nicaragua exhibited as much as 50% infestation. *Pinus maximinoi* has been found to be susceptible to *Cinara cronartii* (black aphid) on the Hleoheng Plateau (elev. 1740 m) at an off-site planting in Lesotho (Forest Research Section 1986). Low infestations of *Cinara atlantica* and *C. pinivora* (aphids) were also observed on a CAMCORE planting of *P. maximinoi* in southern Brazil (L. Duda, personal communication).

Disease: At Klabin, Brazil, *P. maximinoi* did not seem to be severely affected by the *Sphaeropsis sapinea* (Diplodia) that caused damage to *P. greggii* and *P. patula* test plots. Seedling screening trials indicated that *P. maximinoi* was moderately resistant (74%) to *Fusarium subglutinans* f. sp. *pini* (pitch canker) while species like *P. jaliscana* and *P. oocarpa* were very resistant (Hodge and Dvorak 1999).



Photo 8-4. Laercio Duda of INPACEL (right) and a research technician stand next to a 2.5-year-old CAMCORE planting of *Pinus maximinoi* established in southern Brazil. By age 5 years, crown canopies will have begun to close.



Photo 8-5a and b. Above, foxtailing is excessive in this 3-year-old planting of *Pinus maximinoi* in the highlands of Colombia. Below, *P. maximinoi* trees grow out of their foxtailing habit as they age and some excellent specimens exist. Bill Dvorak (left) of CAMCORE and Byron Urrego of Smurfit Cartón de Colombia stand next a 10-year-old *P. maximinoi* tree in Colombia.



WOOD QUALITY IN PLANTATIONS

Several wood quality assessments of *P. maximinoi* have been made in plantations. Wood density is moderate but is often as good as or better than commercial species such as *P. patula* when the two are planted together. It is low in extractives relative to tropical pines such as *P. caribaea* var. *hondurensis* and *P. oocarpa*, and is well suited to both kraft and thermomechanical pulping. The wood is whitish in color. Areas between internodes are of fine quality and provide an exceptional wood for finger-jointed products. The knotty wood generated at the whorls by the species' long, heavy branches poses concerns for sawmillers interested in long-dimension lumber.

Density

A number of researchers have evaluated the wood density of *P. maximinoi* at both the species and provenance level. In a study of seven tests in South Africa and Zimbabwe sponsored by the Oxford Forestry Institute (OFI), Crockford et al. (1990) found that there were significant density differences by provenance and that some of the slowest growing provenances of *P. maximinoi* had the highest densities. Results from the work of Crockford et al. (1990) in Zimbabwe and Wright and Osorio (1993) in Colombia indicate that wood density in *P. maximinoi* decreases with increasing elevation, a trend found for a number of other species, including *P. patula* (de Villiers 1965, Boden 1982, Ladrach and Lambeth 1991) and *P. tecunumanii* (see Dvorak and Kellison 1991). Interestingly, Wright and Baylis (1993) did not find this trend in studies in South Africa on two sites separated by approximately 600 m in elevation.

Wright and Malan (1991) examined 10 *P. maximinoi* trees and five *P. patula* trees for several traits at 10.5 years in trials grown at Helvetia, South Africa. The wood density of *P. maximinoi* and *P. patula* was 456 and 444 kg/m³, respectively. Individual-tree variation in wood density in *P. maximinoi* was significant, ranging from 399 to 505 kg/m³. There was more within-tree uniformity in density in *P. maximinoi* than in *P. patula*, primarily because of the lower percentage of latewood in the former. Average latewood percents in *P. maximinoi* and *P. patula* were 4.5 and 9.1%, respectively. Wright and Baylis (1993) found mean density of *P. maximinoi* trees assessed at 11.5 years of age to be approximately 496 kg/m³ at Tweefontein and Rhenosterhoek, South Africa. There were 35 trees assessed at each site. At Tweefontein, the *P. patula* control had a density of 460 kg/m³ and at Rhenosterhoek the *P. tecunumanii* (Yucul) control had a density of 500 kg/m³. Wright and Osorio (1993) studied the wood density of 14.5-year-old trees from eight provenances by sampling 27 trees per provenance of *P. maximinoi* grown at high elevation (2450 m) in Colombia. Average density was 394 kg/m³, and individual-tree density ranged from 321 to 477 kg/m³. Generally, the density of *P. oocarpa*

exceeds *P. maximinoi* in Colombia, but the density of *P. maximinoi* is greater than *P. tecunumanii* and *P. patula* where they were planted together.

In preliminary densitometer work on a small sample of 7.5-year-old *P. maximinoi* trees from a CAMCORE study in Colombia, wood density did not decrease with stem height in non-foxtailed trees. This may have been because the samples had all earlywood and no latewood. Extractives ranged from 1 to 2%. In a separate study in South Africa conducted on 21-year-old trees, Malan (1994a) found that extractives in five *P. maximinoi* provenances represented by a total of 20 trees ranged from approximately 2.4 to 4.3%. Percent extractives in the *P. patula* controls of the same age ranged from 1.8 to 2.1%.

Fiber Quality

In the previously mentioned study by Wright and Malan (1991), 10.5-year-old *P. maximinoi* trees differed from *P. patula* in cell wall thickness, tracheid lumen area and lumen diameters in the radial and tangential directions. Wood of *P. maximinoi* had tracheids larger in cross-sectional area than *P. patula* since both wall thickness (7.16 vs. 6.47 μm) and lumen area (717 vs. 548 μm^2) were larger. In the study of 21-year-old trees by Malan (1994a), tracheid length was 1.5 to 2.0 mm at the second ring and 2.5 to 3.0 mm at the sixteenth ring. The gradient of the increase differed significantly by provenance. Generally, tracheids of *P. maximinoi* were as long as those of *P. patula*.

Solid Wood

The only study conducted on the solid wood potential of *P. maximinoi* is by Malan (1994a). In a 20-tree sample of 21-year-old trees, Malan found radial shrinkage of the wood to be small (1.5 to 2.5%). Tangential shrinkage was 5 to 6%, with no difference among provenances. Spiral grain angle was within the limits set by local specifications for structural timber. However, the species performed poorly in terms of grading for long dimension lumber compared to *P. patula*, mainly due to the effect of regularly spaced knot clusters in the sawn board. Malan (1994a) suggests that the species should be very suitable for high quality, finger-jointed timber products because of its long, knot-free internode lengths.

Pulp Quality

There have been three laboratory-scale kraft pulping trials for *P. maximinoi*. In a study conducted by Wright and Wessels (1992), 10.5-year-old *P. maximinoi* trees sampled in South Africa had pulp yields similar to *P. patula*, with higher tear index values and lower burst values than *P. patula*. Wright and Baylis (1993) found that 11.5-year-old *P. maximinoi* trees grown in South Africa had pulp yields similar to *P. patula* (approx. 42% pulp yield at kappa number 28). Generally, overall pulping characteristics of *P. maximinoi* were more similar to the *P. tecunumanii* (Yucul sources) control lot than to *P. patula*. Wood density was negatively correlated to burst index and positively

correlated to tear index. Pulping characteristics differed among provenances, but no single provenance was superior to others across all traits. In the third study, Wright et al. (1996b) sampled 8-year-old *P. maximinoi* trees from CAMCORE trials in Colombia (lat. 2.5° N, elev. 1850 m) established by Smurfit Cartón de Colombia. These *P. maximinoi* trees showed screened pulp yields

intermediate between the best species (*P. patula*) and the poorest species (*P. chiapensis*). Because of its good growth, white wood color (requires less bleaching), relatively low extractive content, and good wood physical properties, *P. maximinoi* pulp quality is considered acceptable by international standards.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

CAMCORE has collected seeds from 26 provenances and 856 mother trees in Guerrero, Oaxaca, and Chiapas, Mexico, as well as Guatemala, Honduras, and Nicaragua (Table 8-1). The Cooperative has visited as many as 50 additional locations throughout Mesoamerica that have not been sampled, primarily because the stands contained only a few, widely scattered trees. Hundreds of such small stands exist throughout the region. Six of the 26 provenances sampled by CAMCORE were also sampled by the OFI, including San Juan Sacatepéquez and La Lagunilla, Guatemala (called Jalapa by OFI), Dulce Nombre de Copán, Tatumbla, and Minas de Oro, Honduras, and Datanlí, Nicaragua. Cooperative members in Brazil, Colombia, Honduras, Mexico, South Africa, Venezuela, and Zimbabwe have established 47 *Pinus maximinoi* provenance/progeny tests.

PROVENANCE VARIATION

Gapare (1999) conducted an across-site analysis on 3-, 5-, and 8-year data from CAMCORE provenance tests of *P. maximinoi*. Data from 22 provenances in 29 tests established in Brazil (six tests), Colombia (seven tests) and South Africa (16 tests) were used in the analysis. The

CAMCORE trials planted in Brazil were established in two distinct climates. One group of trials was planted on a deep Oxisol at Grão Mogol, Minas Gerais at latitude 16° S and the second group was established 860 km to the south on a deep Oxisol in Paraná state at approximately 24° S latitude (see Table 8-3). The Grão Mogul site is tropical but with a six-month dry season and 1000 mm of annual rainfall. The Paraná sites are subtropical with zero to six frosts per year and annual rainfall of approximately 1400 mm distributed evenly throughout the year. The trials planted in Colombia were all established in the tropical highlands of the country between 2° and 4° N latitude and 1400 to 1750 m elevation, with the exception of one test that was planted at 2450 m elevation. Annual rainfall amounts were generally above 2000 mm at the Colombian sites. The 16 tests in South Africa were all established in the highlands of Mpumalanga at approximately 25° S latitude between 980 and 1080 m elevation with 1200 to 1300 mm annual rainfall. The soils at the Mpumalanga planting sites are generally deep, well drained and predominantly Ultisols. The main differences between the southern Brazil (Paraná State) and the South African sites are that freezing is less severe and rainfall is slightly higher and more evenly distributed in Brazil.

Table 8-3. Productivity of *Pinus maximinoi* at 8 years of age in two distinct climates in Minas Gerais (MG) and Paraná (PR) States in Brazil. "Best 1/3" is the volume of the top one-third of the families.

ORGANIZATION	Florestas Rio Doce	Florestas Rio Doce	Florestas Rio Doce	PISA Florestal	PISA Florestal	KLABIN
Test Code	15-16-07D	15-16-15C	15-16-18A	15-06-07E	15-06-09A	15-26-02B1
State in Brazil	MG	MG	MG	PR	PR	PR
Planting Site	Grão Mogol	Grão Mogol	Grão Mogol	Moguem	17/T-13	Imbauzinho
Latitude	16° 30' S	16° 30' S	16° 30' S	24° 07' S	24° 07' S	24° 16' S
Elevation (m)	810	810	810	840	840	780
Rainfall (mm/yr)	1080	1080	1080	1339	1339	1473
Survival (%)	76	55	62	80	79	89
Volume (m ³ /ha/yr)	10	8	9	27	30	27
Best 1/3 (m ³ /ha/yr)	12	9	11	30	35	32
<i>P. taeda</i> (m ³ /ha/yr)	-	-	-	7	8	17

The only provenances listed in Table 8-1 that were excluded from the analyses are Minas de Oro, Honduras (because of poor germination) and Datanlí, San Francisco Murra, and San José Bayuncún, Nicaragua (because trials were less than 3 years old). There were 439 different open-pollinated families included in the analyses and a total of 74,000 trees. Results of this work are summarized below and can be found in their entirety in Gapare (1999).

Survival

Survival of *P. maximinoi* in CAMCORE tests at 8 years of age was approximately 70% in Brazil, 86% in Colombia, and 68% in South Africa (Gapare et al. 2000). Survival differences were great between test plantings in tropical and subtropical Brazil (Table 8-3). At Grão Mogol, the tropical site, average survival was only 64% after 8 years of age. Most of the mortality occurred the first several months after planting. Trees were planted in the rainy month of December, but in the following month only 26 mm of rain fell instead of the average 288 mm. The early drought extended into the "normal" dry season. No trend was observed in survival differences among provenances. Survival of low elevation *P. tecunumanii* planted at the same site but 10 months earlier than the *P. maximinoi* was 88% at 8 years of age. Mean survival of *P. maximinoi* at the subtropical sites in Paraná was 83 versus 92% for the *P. taeda* controls at 8 years of age.

The survival problems of CAMCORE *P. maximinoi* in South Africa are briefly mentioned in Stand Management and appear to be related to both the provenance source, as well as an assortment of climatic and silvicultural factors. Survival of provenances from Mexico, Guatemala, and Honduras in South Africa was 79, 64, and 58% respectively. The more southerly and easterly the collection site in Central America, the poorer the adaptability in South Africa. Kietzka (1988) also found that the Nicaraguan sources had poorer survival (60%) than the Guatemalan and Honduran sources did (67%) in the OFI studies planted 6 years earlier than the CAMCORE progeny trials in South Africa. The general conclusion is that survival can be maintained around 85% in areas with good soils and well-distributed rainfall, as in Colombia and southern Brazil. In areas that may be marginal due to rainfall, such as the tropical Cerrado region of Brazil, establishment at the beginning of the rainy season is essential to plantation success. In South Africa, where both cold and drought are problems, choice of provenance becomes more important. Interestingly, Gapare (1999) found that some provenances, such as Valle de Angeles and El Portillo, Honduras, survived poorly across all three countries.

Productivity

Mean productivity for *P. maximinoi* in CAMCORE tests (all provenances included) was 18, 25, and 11 m³/ha/yr, for Brazil, Colombia, and South Africa, respectively (Gapare et al. 2000). Average productivity values varied greatly between the tropical (9m³/ha/yr) and subtropical regions (28m³/ha/yr) of Brazil (Table 8-3). For comparison, the productivity of *P. tecunumanii* grown at the same two locations was 13 and 20 m³/ha/yr, respectively, at 8 years of age. Productivity values for *P. maximinoi* in South Africa are somewhat biased (downward) because of the low (68%) survival rates. The best trees on the Colombian sites had heights of 22 to 26 m with dbh (outside bark) of 41 to 44 cm at 8 years of age. If the best one-third of the families are selected in the CAMCORE tests and an average of 85% survival is assumed, mean annual increments become 11 m³/ha/yr in tropical Brazil, 32 m³/ha/yr in subtropical Brazil, 41 m³/ha/yr in Colombia, and 17 m³/ha/yr in South Africa (Gapare et al. 2000). The productivity values of unimproved *P. maximinoi* are approximately twice that of improved *P. taeda* in subtropical Brazil (Table 8-3) and *P. patula* in Colombia, and 17% better than improved *P. patula* in South Africa.



Photo 8-6. Ivone N. Fier of Klabin stands next to an outstanding CAMCORE selection in an 8-year-old *Pinus maximinoi* test in Brazil.

Table 8-4. Basal area performance (Gain) of 22 provenances of *Pinus maximinoi* assessed at 3, 5 and 8 years by CAMCORE members (after Gapare et al. 2000). Predicted gains were calculated using a BLUP approach and are expressed as a percentage below or above the mean. Provenances are listed in descending order of longitude from west to east.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests
Mexico	18	Las Compuertas	1.2	10	3	1.0	.	.	1.2	8	4
	15	San Juan Copala	-2.8	1	2	-1.1	.	.	0.0	1	2
	16	San Jerónimo, Oaxaca	-4.5	10	3	-2.0	.	.	-0.5	11	3
	17	Candelaria	-1.6	13	3	0.6	.	.	3.1	13	4
	10	Ciénaga de León	-4.1	.	.	-4.8	11	3	-5.5	6	2
	11	Coapilla	-2.6	5	1	-5.5	14	3	-4.3	14	2
	13	Monte Cristo	-1.3	.	.	-4.7	13	3	1.5	10	2
	12	La Cañada	7.4	11	3	6.2	16	2	7.0	16	4
	9	San Jerónimo, Chiapas	3.5	23	6	4.5	23	2	7.1	23	10
	8	Altamirano	3.6	6	1	2.5	13	3	1.6	13	2
Guatemala	3	San Juan Sacatepéquez	-2.2	9	7	-5.4	24	6	4.6	24	15
	1	Cobán	4.1	8	2	2.2	24	4	6.6	24	5
	2	San Jerónimo	4.8	18	6	5.3	19	6	4.8	19	15
	22	La Lagunilla	2.1	.	.	2.4	7	1	2.8	6	2
	23	San Lorenzo	0.3	.	.	0.0	3	1	0.8	6	2
Honduras	19	El Portillo	-3.3	17	3	-4.1	.	.	-6.8	13	4
	4	Dulce Nombre de Copán	5.4	22	5	4.9	32	2	0.8	32	10
	5	Marcala	-3.5	5	2	-1.9	15	4	-0.7	18	5
	7	Tatumbla	-1.3	10	2	4.6	21	4	-2.7	21	5
	14	Valle de Angeles	-3.6	16	3	-1.1	6	1	-8.4	6	2
	20	Yuscarán	1.7	23	3	-0.7	.	.	-3.3	9	2
	6	Tapiquil	-2.6	16	1	-2.2	13	1	-8.3	13	2

Basal Area

Best Linear Unbiased Prediction (BLUP) provenance effects for basal area of *P. maximinoi* in CAMCORE tests are shown in Table 8-4. There was as much as a 15% difference between the best and worst sources depending on the country where they were planted (Gapare et al. 2000). The best provenances across all sites were La Cañada, Chiapas, Mexico and San Jerónimo, Guatemala. San Jerónimo (Chiapas), Mexico, Cobán, Guatemala, and Dulce Nombre de Copán and Tatumbla, Honduras, were also very productive in at least one country.

There was no relationship between forest type (moist subtropical or pine-oak transition) and productivity; La Cañada, San Jerónimo (Chiapas) and Tatumbla all fall into the transition forest type and Cobán, San Jerónimo and Dulce Nombre de Copán represent the moist subtropical forest types. Nor was there any apparent relationship between elevation and annual precipitation and productivity. However, there was a relationship between productivity and longitude of the collection site. Sources in north-central Chiapas (San Jerónimo, La Cañada and Altamirano) and central and eastern Guatemala (Cobán, San Jerónimo, La Lagunilla, San Lorenzo), including far western Honduras (Dulce Nombre de Copán), were all

above average, while populations sampled by CAMCORE on the extremes of the natural distribution performed poorly. The only exception was Tatumbla, which performed relatively well in Colombia but relatively poorly elsewhere. The early (3-year) performance of the most southern Nicaraguan sources of *P. maximinoi* established in CAMCORE tests in Brazil and Zimbabwe has not been promising relative to Guatemalan and Mexican provenances (data not shown). The poor performance of the Nicaraguan provenances is consistent with the results of Crockford et al. (1990) in southern Africa. Two of the Nicaraguan sources were of average productivity in an OFI trial planted at high elevation (2450 m) in a more tropical setting in Colombia (Wright and Osorio 1993).

CAMCORE results suggest that the genetic material used in the development of *P. maximinoi* breeding programs should come from the central part of the range, which extends from north central Chiapas to Dulce Nombre de Copán, Honduras (excluding San Juan Sacatepéquez in Brazil and Colombia). More southerly sources like Tatumbla may perform well but appear to be very site specific. CAMCORE has returned several times to Tatumbla to make additional collections.

The importance of provenance variation for diameter growth decreased with age in the CAMCORE tests (Gapare et al. 2000). Significant provenance differences in dbh were observed in 60% of the CAMCORE trials at ages 3 and 5 years; at age 8 significant differences were observed in only 30% of the trials. The same trend was seen for volume in the *P. maximinoi* tests by OFI in Zimbabwe. At age 4.5 there were significant differences among sources for volume production at two sites (Crockford et al. 1990), but no differences were found when the tests were analyzed at 8 years (Nyoka 1994). This is in contrast to *P. caribaea* var. *hondurensis*, for which provenance variation remained high through 8 years of age (Hodge et al. 2001).

There appears to be a relatively poor correlation between the 22 provenances assessed for basal area in CAMCORE tests (shown in Table 8-4) in South Africa (Gapare et al. 2000) and the 15 provenances for volume obtained for *P. maximinoi* in the OFI tests in South Africa and Zimbabwe (Crockford et al. 1990). Some of the sites in South Africa were common to both the CAMCORE and OFI trials. Four provenances were also common to both of the analyses: San Juan Sacatepéquez and La Lagunilla, Guatemala, and Dulce Nombre de Copán and Tatumbla, Honduras. CAMCORE test results indicate that only the San Juan source was above average (approx. 5%) in productivity in South Africa (see Table 8-3), while the OFI test results indicate that Dulce Nombre de Copán, La Lagunilla, and Tatumbla were much better than average for volume in southern Africa. This discrepancy may be the result of a number of factors, including differences in the provenance subsets being tested, varying analysis techniques (combining provenance effects across country versus keeping them separate), etc. Another possible source of variation is year of planting, especially in areas that are marginal in terms of growth of tropical pines, such as South Africa. The Mpumalanga region sometimes experiences a series of consecutive frost-free and drought-free years, followed by a number of cold and dry years that together affect provenance ranking, particularly with respect to the conditions that prevailed during the year of test establishment. Year effects in South Africa need to be better studied for *P. maximinoi*.

Quality Traits

As anticipated, stem straightness and branch diameter were better overall in Brazil and South Africa than in the more tropical areas of Colombia in the CAMCORE trials (Gapare et al. 2000). San Juan Sacatepéquez, Guatemala had particularly poor stem and branch form in both the CAMCORE and the OFI trials (Crockford et al. 1990, Nyoka 1994). Even though there was variation in branch diameter for *P. maximinoi* in CAMCORE tests, large trees with fine thin branches, like those that occasionally occur in unimproved populations of *P. tecunumanii* and *P. caribaea* var. *hondurensis*, were never found.

Foxtailing in *P. maximinoi* decreases with an increase in the elevation and latitude of the planting site. At elevations of 1400 to 1800 m in Colombia, average foxtailing at 3 years in CAMCORE *P. maximinoi* tests averaged about 73% (Urrego and Lambeth 1988). A single test of *P. maximinoi* planted at 2450 m elevation in Colombia had less than 1% foxtailing (Gapare et al. 2000). Sister *P. maximinoi* studies planted in Brazil and South Africa at 800 to 1100 m elevation had less than 10% foxtailing. In Colombia, large provenance differences were found in foxtail percentages. Tatumbla had 51 versus 84 and 88% for San Juan Sacatepéquez and Coapilla, respectively (Urrego and Lambeth 1988).

Internode length is closely related to the propensity towards foxtailing (Crockford et al. 1990) and is an important trait when considering solid wood products and producing clear boards. This trait was not measured in the CAMCORE tests but was assessed in four OFI tests in South Africa (Crockford et al. 1990). There were noticeable differences in internode length between provenances. La Lagunilla, Guatemala and Dulce Nombre de Copán exhibited the longest node lengths.

In a different study of 21-year-old trees grown at Tweefontein and Wilgeboom, South Africa, Malan (1994a) found that San Juan Sacatepéquez (Guatemala) trees had more than twice the average internode length (1.8 m) than the provenance with the shortest internode length (0.8 m) from La Fortuna (Honduras). There was a positive correlation between mean internode length and branch diameter.

Provenance x Site Interactions

In paired within-country CAMCORE tests, the mean type B genetic correlation for dbh assessed at 5 and 8 years was 0.97. The value was 0.72 between pairs of tests in different countries (Gapare et al. 2000). These results suggest that very little provenance x site interaction occurred in CAMCORE tests for dbh within a country. Nyoka (1994) also found little meaningful provenance x site interaction for volume assessed across three sites at 8 years in Zimbabwe. The between-country Type B values found in CAMCORE tests suggest that some provenance x site interaction is occurring but that it is not excessive (Gapare et al. 2000). Most of the across-country interaction appears to be caused by changes in ranks of two sources, Tatumbla and San Juan Sacatepéquez.

Crockford et al. (1990) found significant provenance x site interaction for stem straightness but not for wood density. Wood density has proven to be quite stable across environments for most pine species.

Family x Site Interactions, Genetic Parameters for Growth and Quality Traits

There was very low family x site interaction within a country for dbh measured at 5 and 8 years in the



Photos 8-7a and 7b. Development of a normal graft (above) and an incompatible graft (below) being examined by Gildardo Montenegro in a Smurfit Cartón de Colombia seed orchard.



CAMCORE studies, with a type B genetic correlation of 0.94 (Gapare et al. 2000). The type B genetic correlation between pairs of tests in different countries was 0.68. These values are higher than for species such as *P. tecunumanii* and *P. caribaea* var. *hondurensis*, possibly because the test sites chosen by CAMCORE members did not represent extremes, as was sometimes the case for the other two species. Alternatively, *P. maximinoi* may be more stable across environments. Results suggest that exchanging genetic material based on growth traits will be beneficial to the parties involved.

Mean individual tree heritability assessed at 8 years of age in CAMCORE studies in Brazil, Colombia, and South Africa was 0.21 for dbh, 0.11 for branch diameter, 0.17 for stem straightness, and 0.19 for foxtailing (Gapare et al. 2000). The heritability values are comparable to those of other pine species. For example, Hodge et al. (2001) found the h^2 for foxtailing in *P. caribaea* var. *hondurensis* to be 0.17.

Genetic correlations between dbh and branch diameter at 5 and 8 years ranged from 0.28 to 0.39, which indicates a tendency for large trees to have large branches (Gapare et al. 2000). Genetic correlations for dbh and stem straightness at 5 and 8 years of age ranged from 0.23 to 0.41. This observation indicates that large diameter trees tend to be associated with straight stems. This relationship was also noted by Crockford et al. (1990), who found that some of the best provenances were also the ones that scored the highest for stem straightness.

FLOWERING AND SEED PRODUCTION

There is little information on flowering or cone and seed production for *P. maximinoi* when the species is planted as an exotic. However, some results are available from Colombia, Zimbabwe, and Brazil. Smurfit Cartón de Colombia performed a cone assessment in all of its plantations at ages 7 to 15 years. Cones matured at different times throughout the year. Researchers found between one and 32 filled seeds per cone (mean = 4) and suggested that the low seed yields were due to poor synchronization between female receptivity and pollen flight (Arce and Isaza 1996). Also noted were the insect (*Coleoptera*) attacks that had occurred on some of the collected cones. These attacks, which are common in natural stands, may have also contributed to the low seed yield.

Field observations in *P. maximinoi* tests in Zimbabwe indicate that the pollen collection period ranges from June to August (Gapare 1999). Information from these initial studies indicate that there are distinct differences in flowering times among trees; some flower early and others flower late in the season. Similar reproductive biology studies are needed in seed orchards and flowering times will need to be well monitored. The cone ripening period is longer than for most pine species in Zimbabwe; it extends from October/November to late February. Good cone crops are obtained on trees at mid-elevations (around 1350 m). At Arapoti, Brazil (lat. 24° S, elev. 850 m, ann. precip. 1450 mm), flowering in *P. maximinoi* occurs in early August, about 10 days after *P. taeda*, beginning at age 4 (L. Duda, personal communication).

Seed Orchards

Two replicates of a *P. maximinoi* seed orchard have been established with CAMCORE clones in the highlands of Colombia by Smurfit Cartón de Colombia. One orchard is near Popayán (elev. 1740 m, ann. precip. 2087 mm). The other is near Barragán (elev. 2400 m, ann. precip. 2000 mm). Flower production has been heavier at the low elevation site than at the high elevation site (N. Isaza, personal communication). A small *P. maximinoi* orchard has

also been grafted at John Meikle Research Station (lat. 18° 41' S, elev. approx. 1130 m, ann. precip. 1575 mm) in Zimbabwe by the Forest Research Centre. Genetic material for the orchard came from OFI provenance test selections.

Scion material grafted onto *P. maximinoi* rootstock in Colombia has shown nearly 40% grafting incompatibility. Grafting *P. maximinoi* onto *P. taeda* rootstock in Zimbabwe has resulted in grafting success as low as 42% (Zimbabwe Forestry Commission 1997). In Colombia, the incompatibility becomes prevalent a year or two after grafting as the scion material outgrows the rootstock (Photos 8-7a and b). Establishing ramets by air-layering may be the only way to overcome the problem. Because *P. maximinoi* grows so quickly, especially in the humid tropics, the crowns close rapidly. Care must be taken when initial orchard spacing is established. An orchard spacing of 10 × 10 m or 10 × 15 m may be needed. Some thought should also be given to cone collection methods and harvesting equipment when trees become large. Cones are usually borne at the tips of long branches and can only be reached with great care with the use of lightweight but long cone-shearing poles.

The orchard near Popayán began producing seeds 3 years after grafting. To maximize flower production, Smurfit Cartón de Colombia applies 400 kg of ammonium nitrate (30-6-0), 40 kg of triple superphosphate (P_2O_5) and 1.5 kg of boron per hectare of orchard after each of two rainy periods each year (Isaza et al. 2000). At 8 years of age, the orchard is producing between 15 and 24 filled seeds per cone. Flower and cone phylogeny studies in the orchard indicate that the reproductive cycle of the species is 12 months (Isaza et al. 2000). The reproductive cycle of *P. merkusii* on the island of Java, Indonesia has been found to be nine months. The importance of this shorter-than-average cycle length in *P. maximinoi* is that it effectively shortens the breeding cycle by one year. The majority of *P. maximinoi* cones ripen in April and May, which is similar to the collection dates for most of Central America and southern Mexico.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

Little information has been generated on between-population and within-population genetic diversity of *P. maximinoi* using either chemical or molecular markers. Matheson et al. (1989) included one population of *P. maximinoi* from Honduras in their allozyme study that also studied provenances of *P. caribaea* var. *hondurensis*, *P. tecunumanii* and *P. oocarpa*. The *P. maximinoi* population had 1.7 alleles per locus versus approximately 2.2 for the other species studied and expected heterozygosity

was 0.14. It had the lowest outcrossing rate (0.65) of any of four species studied. The authors concluded that the low outcrossing rate might be due to higher selfing rates, forms of inbreeding depression, crown structure or stand density (Matheson et al. 1989). Field visits to CAMCORE provenance/progeny trials give the impression that the within-family variation, or more specifically, the frequency of extremely large trees, is much higher in *P. maximinoi* than in other pine species. This may be related to a low outcrossing rate, low heterozygosity, and/or high levels of inbreeding. Additional studies of diversity in the species are very much needed.



Photos 8-8a and b. The conservation status of the *Pinus maximinoi* stand at Tatumbla, Honduras (left) is **vulnerable**. The status of the stand at San Jerónimo, Guatemala (right) is **endangered** due to the increased activities of woodcutters and shifting agricultural farmers in the region.

Conservation Status

There are still large areas of *P. maximinoi* in central and northwestern Mexico, as well as in Guerrero and to a lesser extent in Oaxaca. However, in Chiapas State, Mexico and Honduras, woodcutting, annual fires and intensive grazing are taking their toll. Stands in central and eastern Guatemala, northern El Salvador and Nicaragua are the most threatened. Populations average 2 to 20 ha in size, are extremely fragmented and are in danger of eradication.

Six provenances that demonstrated potential were identified in the CAMCORE testing program: La Cañada, and San Jerónimo (Chiapas), Mexico, Cobán and San Jerónimo, Guatemala, and Dulce Nombre de Copán and Tatumbla, Honduras. La Cañada is a transition forest of *P. maximinoi* interspersed with *P. oocarpa*, *P. devoniana* and *Quercus* spp. (M. Arizmendi, personal communication). The forest is 10 to 20 ha in size, and the local owner has been planting coffee among the trees (J. Donahue, personal communication). The conservation status of La Cañada is **vulnerable** to **endangered**. San Jerónimo (Chiapas) consists of small stands of pure *P. maximinoi* interspersed with *P. oocarpa* and broadleaf species. Like La Cañada, the area is small (approx. 15 to 20 ha) and is being exploited by woodcutters. Its conservation status is **vulnerable**.

The CAMCORE collections at Cobán have primarily been made at Finca Holanda. This area has been reduced from its original size of approximately 20 ha to 3 to 5 ha. Its status is **critically endangered**, but the local landowner has declared the property an ecological reserve. Farmers continue to clear the land in the region to plant coffee but no longer plant the high-value spice crop cardamom because the market price has dropped. There are other stands of *P. maximinoi* that are larger than Finca Holanda near Cobán, but these are also under severe pressure. The government now plans to reforest much of the area with *P. maximinoi* but using seeds obtained from the Tatumbla provenance in Honduras.

The status of the San Jerónimo, Guatemala stand is discussed in Chapter 12 (*P. tecunumanii*), since both *P. maximinoi* and *P. tecunumanii* occur sympatrically in this area. The large 40 m *P. maximinoi* trees have been removed and the area opened to shifting agriculture farmers. The original 40 ha area of *P. maximinoi* present in 1980 has been reduced to approximately 20 ha, and its status is **endangered** primarily by colonizers planting corn and tomatoes. Honduran sources of *P. maximinoi* have been planted in the region as part of a local reforestation project.

The Dulce Nombre de Copán site is still sufficiently large (approx. 400 ha) and, consequently, immediate concern is

unwarranted. Its status is **low risk to vulnerable**. The Tatumbla site, which also includes forests that extend into Cofradia (the provenance collected by OFI), is represented by small groups of phenotypically degraded trees that are being encroached upon by farms and intersected by stone fences. Its status is **vulnerable**, but because of the relatively large forest of *P. maximinoi* in the area it is not in immediate danger of eradication.

Based on CAMCORE's assessment in Central America and Mexico, the conservation status of *P. maximinoi* in western, central, and southwestern Mexico is **low risk**. In Chiapas, Guatemala, Honduras, El Salvador and Nicaragua, the conservation status of the species is classified as **vulnerable** to **critically endangered**.

In situ conservation of the six stands identified as promising in CAMCORE tests would be a good start to protecting genetic diversity in this species. A complete rangewide assessment of the genetic diversity in *P. maximinoi* using various molecular marker systems is needed. Marker results need to be combined with provenance results

generated by CAMCORE so that additional populations for *in situ* conservation can be selected. Taxonomic work would invariably need to be linked to both genetic diversity and provenance work in order to confirm the identity of populations in northwestern and central Mexico.

EX SITU CONSERVATION

The CAMCORE collections are the most complete ever made for this species and amply sample the species range from Oaxaca through Nicaragua. Still, additional collections need to be made in Guerrero, where there are many *P. maximinoi* stands, and throughout the species range in northwestern and central Mexico. Because of the commercial interest in the species, *ex situ* conservation will likely proceed without much reservation. However, growers need to take the introduced material to the second generation of improvement in order to quantify its potential. Better information on wood quality as it relates to the final product at the mill is needed. Markets for the wood of *P. maximinoi* need to be found.

CONTRIBUTORS

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C h a p t e r 9



PINUS OOCARPA

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OVERVIEW

TREE DESCRIPTION

Pinus oocarpa Schiede ex Schlectendal var. *oocarpa* is a small to large tree that ranges in height from 13 to 35 m with dbh from 25 to 80 cm at maturity. Juvenile trees usually have a pyramidal crown that becomes rounded and often irregular in shape as the tree matures. Stem form can be relatively straight, especially when on deeper soils in the eastern part of the species' natural distribution, but often is crooked and twisted when found on shallow soils. The bark of mature trees is thick, grayish to grayish-brown and is formed into rough, longitudinal, geometrically shaped plates by shallow vertical and horizontal fissures (Perry 1991). The needles are yellowish to medium green, stiff and erect to slightly drooping, and 19 to 25 cm long. Needles usually occur in fascicles of five; however, when growing in transition zones with species like *P. caribaea* var. *hondurensis* or *P. tecunumanii*, with which *P. oocarpa* can introgress, needle number varies from three to five. In eastern Mexico and Central America, cones generally are borne on long, thick peduncles in clusters of three and four, while in western Mexico they more often occur singly. Cone form is variable, ranging from almost round to ovoid conical. Cone size ranges from 5.5 to 10.0 cm. *Pinus oocarpa* has an average seed potential of 140 seeds per cone (Houkal 1983), with an average of 57,750 seeds per kg. The wood of *P. oocarpa* is yellowish-white, high in density and extractives, and can be used for a number of wood and paper products.

CONSERVATION STATUS

Pinus oocarpa is one of the most common pines in Mesoamerica. Even though it is harvested for timber and fuelwood as well as cleared for agricultural crops, the sheer magnitude of the species' current geographic range protects it from eradication in the near future. Consequently, the overall conservation status of the species is **low risk**. However, the conservation status of the most southern populations in Nicaragua, are **vulnerable**, and more intensive conservation efforts are needed in this area.

TEST STATUS

The CAMCORE Cooperative has established 29 tests in Brazil, Colombia, Honduras, Mexico and Venezuela. Most of the tests were measured through age 8, and some were assessed through age 15. Conservation banks were established for most populations using single-tree plot designs.

BEST PROVENANCES

Because provenance performance varies so greatly from one planting site to the next, no general recommendations on which sources are the best can be given. The most useful approach is to test a number of different sources and then develop a local landrace from the best trees of superior provenances.

SUITABLE PLANTING SITES

Pinus oocarpa is a very site-specific species, and therefore, does not demonstrate the plasticity of *P. caribaea* var. *hondurensis*. When planted as an exotic, it requires well-drained soils with depths of approximately 1.0 m. It performs best on fertile soils in areas that receive more than 1000 mm of annual precipitation. Ideal soils for this species are sandy clay loams, clay loams, or friable clays. In Colombia (2° N), *P. oocarpa* has been planted commercially on Ultisols and Andisols between 1500 and 1800 m altitude. In central Brazil (13° to 20° S), it has performed exceptionally well in the Cerrado region on deep but infertile Oxisols that occur between 550 and 1000 m altitude and receive 1300 to 1500 mm of annual rainfall. In coastal Brazil (18° S), the species has been competitive on deep, sandy clay Ultisols at 150 m elevation. In high rainfall areas near the equator at 100 m altitude, performance has been poor. Survival on sandy soils in eastern Venezuela at 100 m elevation has been inconsistent. The species has failed at 1000 m altitude in western Venezuela when planted directly on eroded mineral soils that were 30 cm deep.

Photo 9-1. Typical form of *Pinus oocarpa* in eastern Guatemala.

ADVANTAGES OF *PINUS OOCARPA*

- Easy to raise in the nursery.
- Easy to propagate as rooted cuttings.
- Moderately drought tolerant once established.
- Good cone and seed producer, except near the equator.
- Excellent wood quality.
- Provenance information is available.
- Resistant to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in the seedling stage.
- Relatively fire tolerant.
- Hybridizes with a number of species.

DISADVANTAGES OF *PINUS OOCARPA*

- Initial growth is slow relative to *P. caribaea* var. *hondurensis* and *P. tecunumanii*.
- Does not exhibit broad adaptability.
- Has a shallow root system and is subject to wind throw, especially on sandy soils.
- Has a thin crown that allows understory species to compete through mid-rotation and increase the risk of fire.
- Susceptible to attacks by *Cylindrocladium* spp. at low latitudes.
- Is preferentially attacked by some insects, diseases and animals over other tropical and subtropical pines.
- Lacks frost resistance.

NATURAL STANDS

EVOLUTION

Pinus oocarpa from eastern Mexico and Central America may represent one of the oldest lineages in the Mesoamerican closed-cone pine group. Presumably, a progenitor of *P. oocarpa* evolved somewhere in southwestern United States or northeastern Mexico more than 30 million years ago. The species migrated south along the Sierra Madre Oriental as far as present-day Nicaragua. *Pinus oocarpa* from western Mexico appears to be of much more recent origin and evolved directly from either the eastern race of the species or from *P. pringlei* (Dvorak et al. 2000). *Pinus oocarpa* from eastern Mexico and Central America appears to be the progenitor of *P. tecunumanii*.

DISTRIBUTION

Pinus oocarpa occurs from southern Sonora, Mexico ($28^{\circ} 10' N$) to northern Nicaragua ($12^{\circ} 40' N$), a distance of 3000 km. Its distribution is continuous across most of its range, broken occasionally by high mountains or deep valleys colonized by broadleaf species. It is the most common pine in southern Mexico and Central America constituting the major part of the pine forests in the area. It represents 45% of the pine forests of Chiapas State,

Mexico (Zamora-Serrano and Velasco-Fiscal 1978) and comprises a large portion of the pine forests in Central American countries: 50% in Guatemala (Dvorak 2000b), 66% in Honduras (Wolffsohn 1984), 90% in Nicaragua (Greaves 1979), and 60% in El Salvador (Dvorak 2000b). *Pinus oocarpa* also occurs sporadically near San Pastor Pine Ridge, Belize.

Although the species grows at altitudes ranging from 200 to 2500 m, development of *P. oocarpa* is best between 1200 and 1800 m elevation in Central America. Its lowest occurrence is at 200 m elevation on the Isthmus of Tehuantepec, Oaxaca, Mexico, where it is found in small patches in an area dominated by broadleaf species.

In the northern portion of its range, as well as on shallow soils on ridge tops throughout its distribution, *P. oocarpa* is usually a small, crooked tree of 10 to 15 m in height and 25 cm dbh. As precipitation increases from northwest to southeast throughout Mexico and Central America, tree height and stem diameters become greater, ranging from 20 to 35 m and 45 to 80 cm for height and dbh, respectively. Stem form also greatly improves in areas with deeper soils and more rainfall.

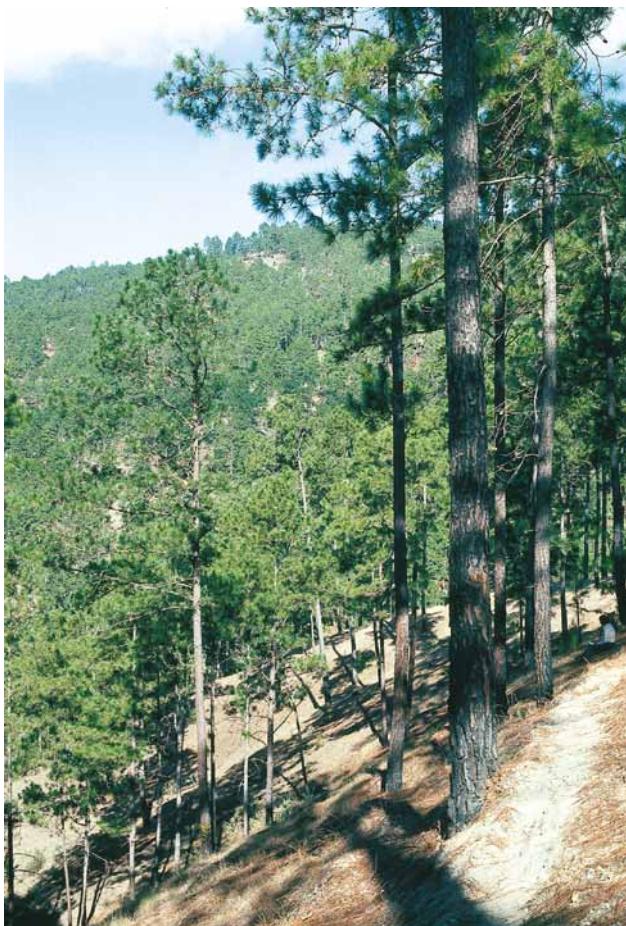


Photo 9-2a and b. Left, typical *Pinus oocarpa* stand at La Mina, Guatemala. Right, bark of mature *P. oocarpa* in Jalisco, Mexico.

CAMCORE sampled *P. oocarpa* sites in Guatemala and Honduras in the early to mid-1980s with the assistance of the national seed banks in both of these countries (Table 9-1). The Cooperative was especially interested in finding populations that occurred on very dry sites, with the hope of identifying trees that were well adapted to similar locations throughout the tropics and subtropics. One provenance was sampled in Ocotal Chico, Veracruz, Mexico, an area that receives high rainfall. A total of 515 mother trees from 17 provenances were included in the collections (Table 9-1).

CLIMATE

Because the natural distribution of the species extends across 3000 km, no single climatic type adequately describes the occurrence of all *P. oocarpa* populations. Annual rainfall in its natural distribution ranges from 800 to 2500 mm. In northwestern Mexico (Sonora, Durango, and Sinaloa), the species is found in regions that receive between 800 to 1000 mm of annual precipitation and have an extended dry season of six months. In eastern Mexico (Veracruz) and the higher elevations of Central America, where annual rainfall can be as much as 2500 mm, *P. oocarpa* exists in areas with a well-defined dry season that lasts from about December to May (Table 9-2). In these regions of abundant rainfall, the natural range of *P. oocarpa* occasionally crosses dry valleys where annual precipitation falls below 1000 mm. Throughout the majority of its natural range, *P. oocarpa* is not subjected to freezing

temperatures and consequently is not considered cold hardy. Even in the northern part of its distribution (Sinaloa and Durango), the species tends to occupy the protected warmer valleys in which temperatures seldom drop below freezing. Average annual temperatures at *P. oocarpa* collection sites in Central America range from 16 to 26 °C. Table 9-2 shows monthly mean temperature for one of these sites. In Mexico, the mean annual temperature ranges from 14 to 25 °C (Zamora-Serrano and Velasco-Fiscal 1978).

SOILS

Pinus oocarpa usually is found on yellow or reddish sandy clay to clay soils of average to below average fertility. Ultisols, Inceptisols and Entisols are the soil orders most common to *P. oocarpa* sites.

In most locations, soils are between 45 cm and 1.0 m deep, except on ridge tops and steep slopes, where soil depth falls to less than 30 cm. Even in these cases, *P. oocarpa* can grow to 20 m in height (Wolffsohn 1984). The clay content of soils at some locations is so high that local farmers use it to make adobe bricks. Soils are strongly to moderately acidic, with pH values ranging from 4.0 to 6.0. In a soil profile examined near Siguatepeque, Honduras, there was no organic material and the soil pH averaged 5.8. Most *P. oocarpa* sites are characterized by well-drained soils. The species cannot tolerate high pH, limestone-derived soils (Wolffsohn 1984).

Table 9-1. *Pinus oocarpa* collections made by the CAMCORE Cooperative in Mexico and Central America.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	La Lagunilla	Jalapa	Guatemala	14° 42' N	89° 57' W	1540 - 1730	1003	44
2	Selva Pinares	Jutiapa	Guatemala	14° 22' N	90° 04' W	1550 - 1600	1066	11
3	Tapalapa	Santa Rosa	Guatemala	14° 24' N	90° 09' W	1420 - 1555	1113	11
4	La Mina	Chiquimula	Guatemala	14° 48' N	89° 25' W	830 - 960	964	26
5	San José La Arada	Chiquimula	Guatemala	14° 40' N	89° 57' W	745 - 830	920	25
6	La Unión	Zacapa	Guatemala	14° 52' N	89° 16' W	1105 - 1280	1592	4
7	San Lorenzo	Zacapa	Guatemala	15° 05' N	89° 40' W	1570 - 1780	1700	25
8	San Jerónimo	Baja Verapaz	Guatemala	15° 03' N	90° 18' W	1425 - 1590	963	15
9	El Castaño (Bucaral)	El Progreso	Guatemala	15° 01' N	90° 09' W	930 - 1330	900	39
10	Ocotal Chico	Veracruz	Mexico	18° 15' N	94° 52' W	500 - 600	2305	30
11	Camotán	Chiquimula	Guatemala	14° 49' N	89° 22' W	740 - 960	964	26
12	San Luis Jilotepeque	Jalapa	Guatemala	14° 37' N	89° 46' W	950 - 1010	895	27
13	La Campa	Lempira	Honduras	14° 28' N	88° 35' W	1110 - 1405	1200	32
14	Las Crucitas	El Paraíso	Honduras	14° 07' N	86° 37' W	1010 - 1110	1170	50
15	Guaimaca	Fco. Morazán	Honduras	14° 32' N	86° 48' W	800 - 1040	1250	50
16	San Marcos de Colón	Choluteca	Honduras	13° 24' N	86° 51' W	1040 - 1200	877	50
17	Tablazón	Comayagua	Honduras	14° 09' N	87° 37' W	960 - 1120	1548	50
17	Provenances	13 State/Depts.	3 Countries	13 - 18° N	86 - 95° W	500 - 1730	1175	515

Table 9-2. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus oocarpa* site at San Luis Jilotepeque, Jalapa, Guatemala.

San Luis Jilotepeque	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	22.3	23.0	25.3	26.0	26.1	24.6	23.9	24.0	23.9	23.5	23.3	22.4	24.0
Mean Rain mm	3	1	4	30	103	216	138	142	165	73	16	4	895

Based on 9 years of data taken from 1970 to 1979 at Ipala, Guatemala (827 m elev.) approximately 10 km from the collection site.

Figure 9-1. CAMCORE collections of *Pinus oocarpa* in Mexico.

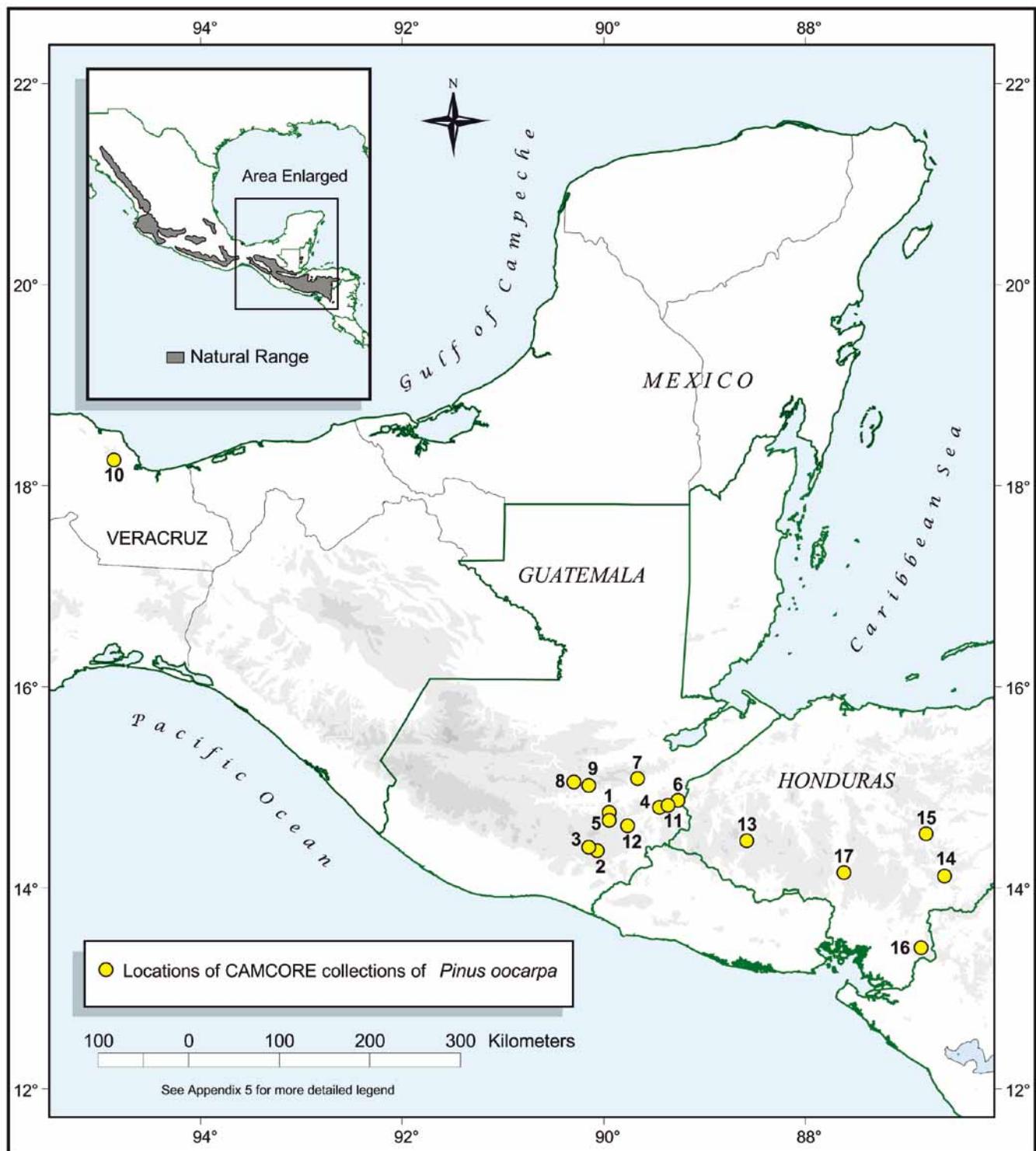




Photo 9-3. Soils where *Pinus oocarpa* occurs can be very shallow.

REPRODUCTIVE BIOLOGY

Based on observations made by CAMCORE staff, *Pinus oocarpa* begins flowering in November in most of Central America and southern Mexico, peaking in late December and early January (Dvorak 2000b). Critchfield (1966) and Robbins (1983) also noted the same period for *P. oocarpa* pollen shed in Central America. Flowering in Mexico is said to occur between January and February (Patiño 1973), beginning in Chiapas State in the driest areas or at the lowest elevations (Zamora-Serrano and Velasco-Fiscal 1978). Changes in yearly weather patterns, such as those brought about by El Niño-related events, have resulted in flowering as early as September in Central America (Houkal 1983).

Cones are borne in clusters of three to four on long thick peduncles. In western Mexico, it is more common to observe single cones. Several flushes of cones occur during each growing season, but in Guatemala and Honduras, the flush that matures in late February generally produces the most sound seed (Dvorak 2000b). Unlike *P. tecunumanii*, cone crops on *P. oocarpa* are often relatively abundant, although the number of cones does vary from year to year. In eastern Mexico and Central America, most cones appear to mature 22 to 29 months after pollination. However, Robbins (1982) reports that some cones may be ready to collect as early as 8 months after pollination. Short reproductive cycles in plantations have also been noted for *P. maximinoi* (see Chapter 8) in Colombia and *P. merkusii* in Indonesia. Robbins (1983) suggests that a circumvention of

the pollen tube's resting stage due to favorable climatic conditions may be responsible for the short ripening period for some *P. oocarpa*. Cones shed their seeds from March to May, just before the onset of the wet season (Wolffsohn 1984). Although production periods reach their peak in the early part of the year, it is possible to find a few flowers and maturing cones on trees throughout most of the year. The average seed potential per cone for *P. oocarpa* in natural stands in Honduras is 140 seeds (Houkal 1983), while the average number of filled seeds per cone in natural stands in Central America ranges from 15 to 35 seeds (Wilkinson 1983, Houkal 1983, Robbins 1983, Hudson et al. 1981), resulting in a seed efficiency ranging from 12 to 30% (Dvorak 2000b). Low filled seed percentage may be due to poor synchronization between male and female strobili or damage caused by cone and seed insects (see Carlin and Nuñez 1985). *Pinus oocarpa* produces between 43,000 and 77,450 seed per kg (mean = 57,750) depending on the collection site. In Guatemala, seed size decreased with increasing elevation (Dvorak 2000b).

ECOLOGY AND ASSOCIATED SPECIES

Like many of the pines in Mesoamerica, occurrence of *P. oocarpa* depends on altitude (nighttime temperatures), soil type, and the frequency and intensity of fires (Robbins and Hughes 1983). Fires play the greatest role in shaping the distribution patterns of *P. oocarpa* in natural stands. In fact, Denevan (1961) defines *P. oocarpa* as "fire subclimax" because its existence depends on the periodic fires that



Photo 9-4. An example of typical *Pinus oocarpa* growing at San Pastor Pine Ridge, Belize. Cone size of *P. oocarpa* can be quite variable.

suppress the majority of competition from broadleaf species (Denevan 1961, Robbins 1983). The advantage that *P. oocarpa* has over other tree species at mid-elevations in Mesoamerica is that young trees under 6-cm basal diameter will resprout from the base after fires (Houkal and Ponce 1985). From the mass of basal shoots that develop, a single, straight stem is ultimately produced that grows significantly faster than seedlings of the same age (Houkal and Ponce 1985). Sprouting may occur repeatedly over successive seasons until a series of favorable years allows the sprout to grow to a fire-tolerant size (Chable 1967). Mature trees possess a thick bark that protects them from fire. This adaptation makes the species an effective and competitive colonizer.

At elevations between 1000 and 1500 m in Central America, *P. oocarpa* is the predominant species in areas that are relatively dry and commonly experience fires, such as most of southeastern Guatemala, northwestern El Salvador, much of Honduras, and northern Nicaragua. In many situations, the species is found on the southern and eastern slopes of mountains where temperatures are higher and conditions more harsh than in protected moist valleys. At elevations above approximately 1700 m in Central America, rainfall increases, soils are more fertile, fires are less frequent and *P. oocarpa* gives way to other pines, such as *P. tecunumanii* and *P. maximinoi*. During century-long periods of droughts, *P. oocarpa* presumably invades these high elevation areas but then recedes when temperatures moderate. Below elevations of 600 m, *P. oocarpa* gives way

to scrubby vegetation in areas where annual rainfall drops below 700 mm; in the humid valleys of eastern Guatemala and Honduras, species like *P. caribaea* var. *hondurensis* become more common. The transition zone between *P. oocarpa* and *P. caribaea* var. *hondurensis* is between 500 and 700 m elevation (Robbins and Hughes 1983).

Pinus oocarpa is often found in pure stands in the proximity of *Quercus* spp. (oaks). These pine-oak transition forests extend through most of *P. oocarpa*'s natural distribution. Robbins (1983) accurately describes the *P. oocarpa* populations as uneven-aged, pure forests that are often a mosaic of even-aged stands. Fire produces the many even-aged stands within a single forest. The oak species in *P. oocarpa*/oak forests are numerous and include *Quercus acatenangensis*, *Q. corrugata*, *Q. crassifolia*, *Q. mexicana* and *Q. rugosa* in Chiapas (Breedlove 1973), *Quercus conspersa*, *Q. magnoliae*, and *Q. obtuse* in Michoacán (Madrigal-Sánchez 1973), and as many as 10 additional species in Central America. *Byrsonima crassifolia* and *Arbutus* spp. also are common at some sites. In Veracruz, Mexico, Gomez-Pompa (1973) lists 12 deciduous species that occur with *P. oocarpa*.

A number of different pine species have been identified growing with *P. oocarpa*. In northwestern Mexico, *P. douglasiana*, *P. engelmannii*, *P. herrerae*, *P. leiophylla* and *P. teocote* occur with *P. oocarpa*. In central-west Mexico, the species is found with *P. douglasiana*, *P. jaliscana* and *P. maximinoi* and rarely with *P. chiapensis*. In some of the



Photo 9-5. *Pinus oocarpa* harvested in a natural stand in Chiapas, Mexico.

drier regions of central and southern Mexico, *P. devoniana* and *P. pringlei* grow alongside *P. oocarpa*, while in Chiapas, it is found with *P. tecunumanii* and *P. oaxacana* (Zamora-Serrano and Velasco-Fiscal 1978). Throughout Central America, *P. oocarpa* intergrades with both *P. tecunumanii* and *P. maximinoi*. At the high elevations in Chiapas, Guatemala and Honduras, the species is generally found on the fringes of *P. tecunumanii* stands. For example, at San Jerónimo, Guatemala, *P. oocarpa* occurs from approximately 1200 to 1650 m elevation but then gives way to *P. tecunumanii* and *P. maximinoi* with the increase in altitude from 1650 to 1800 m. On the road from Tuxtla Gutiérrez to San Cristóbal de las Casas, Chiapas, relatively small, stunted, *P. oocarpa* grow from approximately 1200 to 1900 m and give way to *P. tecunumanii*, *P. ayacahuite* and *P. montezumae* on the plateau top. At San Pastor Pine Ridge in Belize, *P. oocarpa*, *P. tecunumanii* and *P. caribaea* var. *hondurensis* are intermixed. As already noted, throughout much of Honduras, *P. oocarpa* and *P. caribaea* occur sympatrically between 500 and 700 m altitude (Robbins and Hughes 1983). On dry sites in Nicaragua and Honduras at approximately 900 and 1200 m altitude, it is difficult to distinguish *P. oocarpa* and *P. tecunumanii* morphologically. *Pinus oocarpa* and *P. maximinoi* seldom occur together above 1800 m elevation in Central America but are quite often seen growing sympatrically at altitudes between 1000 and 1800 m (see Chapter 8, *Pinus maximinoi*).

In transition zones with other pine species, intermediate forms of *P. oocarpa* are often found. *Pinus oocarpa* has been

reported to hybridize with *P. caribaea* var. *hondurensis* in Honduras (Styles et al. 1982, Fernández de la Reguera et al. 1988), *P. tecunumanii* throughout most of Central America (Squillace and Perry 1992), and *P. pringlei* in central Mexico (J. López-Upton, personal communication).

The understory species in *P. oocarpa* forests vary depending on climate and the history of fires in the area. Madrigal-Sánchez (1973) lists as many as 20 herb and shrub species associated with *P. oocarpa* in a botanical exploration of Cerro de Condembara, Michoacán. In a 1.7-ha natural stand of *P. oocarpa* in west-central (Siguatepeque) Honduras, Clewell (1973) identified 124 species of vascular plants, many of which were similar to those described in Nicaragua by Taylor (1963).

A number of insects have been identified on *P. oocarpa* in natural stands. Tantalen (1986) reports 42 insect species on *P. oocarpa* and *P. caribaea* var. *hondurensis* in Honduras and Cibrián-Tovar et al. (1995) list 22 insect species found on *P. oocarpa* in Mexico. Most noteworthy of these are the *Dendroctonus* spp. (pine bark beetles). When at their cyclic high, these pests may infest millions of hectares of *P. oocarpa* forests in Mexico and Central America (Maes 1992, Lanier et al. 1988, Beal 1964). *Rhyacionia* spp. (pine shoot borers) are also common on *P. oocarpa* throughout Mesoamerica (Miller 1988, Rodas 1997). Cone and seed insects can greatly reduce seed crops during periods of high infestation (Carlin and Nuñez 1985, Becker 1973).

Cronartium conigenum (cone rust) is quite common on *P. oocarpa* throughout the tree's natural distribution. In

addition to the common symptom of enlarged cones on an infected tree, the disease occasionally manifests itself on nursery-grown seedlings. When infected at the seedling stage, *P. oocarpa* produces a large, spongy swelling resembling a carrot below the root collar.

Although not very common, several types of mistletoe have been identified on *P. oocarpa*. *Arceuthobium hondurensis* (dwarf mistletoe) has been observed in Honduras (Gibson 1979) and by CAMCORE researchers in northern Nicaragua. Mathiasen et al. (2000) reports *Psittacanthus angustifolius* (mistletoe) on trees in Honduras.

WOOD QUALITY IN NATURAL STANDS

Hundreds of thousands of hectares of *P. oocarpa* exist throughout Mesoamerica, and the species has become an important timber export commodity (especially in Honduras), as well as a minor plantation species outside of Central America and Mexico. Consequently, there is considerable interest in the wood quality of this species and a number of studies investigating the characteristics of *P. oocarpa* in natural stands have been conducted.

The wood of *P. oocarpa* is yellowish-white when young, but turns a reddish color over time with the accumulation of resins (CETEFOR 1972). The species has also been described as having brownish-yellow sapwood and light reddish-brown heartwood (Hess et al. 1950).

Wood density values for mature trees (age not given) sampled in Guatemala and Honduras ranged from 480 to 600 kg/m³ (Hess et al. 1950, Le Cacheux et al. 1959, Schafer and Chidester 1961, CETEFOR 1972). In a sample of 15 trees from the highlands of Honduras that were 28- to 31-years-old, Houkal et al. (1988) found the density of *P. oocarpa* to be 517 kg/m³. Wood density decreased from the pith to ring five and then began gradually to increase to ring 18, where it stabilized. The transition from earlywood to latewood was mild. Using a sample of 55 trees ranging from 35 to 51 years old from six southeastern Guatemalan provenances, CAMCORE found mean wood density to vary from 450 to 520 kg/m³ (Dvorak 1981). Differences among stands accounted for only 6% of the variation, while within-stand and unexplained environmental effects accounted for 45 and 49% of the variation, respectively. The transition between

juvenile and mature wood occurred at approximately 15 years. Density increased from the pith outward until about age 40 years and then leveled off. Examination of ring patterns on core samples suggest that the species has the capacity to rebound and grow normally after years of being suppressed by unfavorable climatic conditions or neighboring trees (Dvorak 1981).

Rosales et al. (1995) found that 2- x 4-inch boards cut from *P. oocarpa* in natural stands in Guatemala had slightly better quality in terms of specific gravity, modulus of rupture, and modulus of elasticity than pines from the southern United States when evaluated for equivalent grades of lumber. However, since trees from natural stands in Guatemala were tested against plantation-grown trees in the southern United States, direct comparisons between the two groups may not be appropriate.

Prats-Llaruado (1960) found wood of *P. oocarpa* to have a mean tracheid length of 5.7 mm, 51.2% α -cellulose content, and 27.2% lignin content. In mature trees in Honduras, Le Cacheux et al. (1959) found a tracheid length to be 4.8 mm with α -cellulose content of 50.2 to 52.3%. Percent extractives of *P. oocarpa* trees sampled at an average age 41 years in Honduras was 3.7% (Schafer and Chidester 1961). The only two of the nine Mexican species studied with higher extractive percents were *P. montezumae* and *P. devoniana*.

The general conclusions reached by researchers conducting these studies are that *Pinus oocarpa* has a high-density, straight-grained wood and produces timber that seasons easily. It has exceptionally high stiffness, above average toughness (Hess et al. 1950), and competes well with the best quality southern United States pines. The groundwood pulping characteristics of *P. oocarpa* are better than those of *P. caribaea* var. *hondurensis* (Schafer and Chidester 1961) and as good as those of the southern United States pines (Prats-Llaruado 1960). The species' high resin content is a negative characteristic for certain pulping processes but increases resistance to decay in wood. Local industries and farmers have used the wood for charcoal, fuelwood, plywood, construction lumber, packing boxes, palettes, soft drink boxes, broom stick handles, popsicle sticks, railroad sleepers, and posts (Zamora-Serrano and Velasco-Fiscal 1978, Robbins 1983).

PLANTATIONS

Pinus oocarpa from Central America was thoroughly tested in the 1970s and the early 1980s by the Oxford Forestry Institute (OFI), and by the CAMCORE Cooperative throughout the 1980s. Commercial plantation programs were initiated in several places around the world, particularly in tropical Brazil. Over time, foresters lost interest in the species because it did not grow as fast as

P. tecunumanii or *P. caribaea* var. *hondurensis*, was more prone to wind damage than *P. caribaea* var. *hondurensis*, seemed as prone to wind throw as *P. tecunumanii*, had poor form at some equatorial sites, and was more site demanding than *P. caribaea* var. *hondurensis* or *P. tecunumanii*. At the peak of the species popularity, possibly over 100,000 hectares of *P. oocarpa* had been planted in the tropics and



Photo 9-6. *Pinus oocarpa* hedges at Smurfit Cartón de Colombia.

subtropics. CAMCORE's experience suggests that *P. oocarpa* may have high potential in certain ecological niches. Its excellent wood quality, apparent resistance to pitch canker disease, ability to hybridize with other Mesoamerican pines, and the ease with which it can be vegetatively propagated offer foresters many advantages.

NURSERY PRACTICES

Seed Handling

The handling of *P. oocarpa* seed is no different than for the other tropical pines like *P. caribaea* var. *hondurensis* and *P. tecunumanii*. Seed can be stored for periods of more than 60 months at a moisture content of 6 to 9% without problems. Care is needed during the cleaning process because the seed coats of *P. oocarpa* are thin and can crack or chip easily. Cold stratification of the seed is not needed prior to germination, but some organizations soak the seeds in water at 25 °C for 24 hours prior to sowing to enhance germination uniformity.

Containers and Growth Media

Several different growing media and container sizes have been used to raise *P. oocarpa* seedlings. At Smurfit Cartón de Colombia, tubes with capacity of 125 cm³ have been used, as have Jiffy® pellets with capacity of 34-cm³. Black plastic bags of various dimensions have been used throughout Central America. *Pinus oocarpa* root systems do not seem to be as sensitive to container size as are *P. tecunumanii* roots.

Nurseries at Smurfit Cartón de Colombia use equal parts composted sawdust, carbonized ash from the mill, and yellow subsoil with some organic material as media for *P. oocarpa* seedlings (M. Arce an V. Betancur, personal communication). Substrate pH is 5.5 to 6.0. The main requirement of growth media used for *P. oocarpa* is that it be well drained.

Seedling Management

Germination begins 7 to 10 days after sowing. As long as the radicals do not become too large, germinants can be successfully pricked into containers. Some organizations keep seedlings under 40 to 50% shade the first four weeks after sowing. Seedlings take between 18 and 24 weeks to reach a plantable size of 15 to 20 cm. The growth rate of *P. oocarpa* can be slightly slower than for *P. caribaea* var. *hondurensis* in the nursery. Normal foliar application of fertilizer in the nursery seems to work well. Some seed lots of *P. oocarpa* have shown symptoms of phosphorous deficiencies (purple-colored foliage) in the nursery, but this can be easily corrected with supplemental applications of the nutrient.

Vegetative Propagation

As mentioned earlier, *P. oocarpa* often sprouts from the base when cut before 5 years of age. In an experiment conducted using stump sprouts from 5-year-old trees, Smurfit Cartón de Colombia researchers found that the best rooting (41%) was found for non-lignified terminal cuttings (Easley and Lambeth 1989). In tropical



Photo 9-7. Bushy appearance of *Pinus oocarpa* in a young CAMCORE trial in Brazil.

environments, some trees harvested as late as 15 years of age will produce basal sprouts, but rootability varies greatly by location of the plantation.

Smurfit Cartón de Colombia has propagated rooted cuttings from seedling stumps in the Colombian highlands according to the following protocol. Seeds used for the hedges are sown in polyethylene bags or in trays. The seedlings are transplanted after six months to open field beds, where they are placed 50 cm apart and are fertilized with 50 g of NPK (15-38-10) and 5 g of borax (48% B₂O₃) per seedling (Osorio 1993). The first pruning of the terminal and lateral branches are made two months after transplanting; five to eight sprouts per seedling are obtained. The hedges are pruned to a height of 20 to 30 cm every two to three months.

Sprouts selected for production of cuttings were 8 to 10 cm long and exhibited juvenile characteristics (Osorio 1993). The terminal portion of the shoot is used to make a 6 cm long cutting, which is placed immediately in 0.5% benlate fungicide and is then stuck approximately 2.5 cm deep in the substrate without removing the needles. After four months in the rooting facility, cuttings that show vegetative growth of the terminal bud are transferred to the shade house, where they remain for one month (Osorio 1993). Cuttings are then taken to an open-air nursery bed for two months to harden off.

Osorio (1993) compared the growth and development of rooted cuttings and seedlings grown in Colombia. At

3 years of age, there were no differences between the growth of seedlings and rooted cuttings, but the rooted cuttings did have significantly fewer forks. At 8 years of age, the cuttings had significantly higher volume and less forking than trees from seeds, but also had larger branches and 2% lower wood density (Osorio 2000).

STAND MANAGEMENT

Site Selection and Establishment

Growers of *P. oocarpa* need to realize that the species does not possess the adaptability exhibited by species like *P. caribaea* var. *hondurensis*. *Pinus oocarpa* needs deep, well-drained soils to survive and grow well. On shallow soils or in areas of high winds, the species is highly susceptible to wind throw. It can tolerate soils of low natural fertility, like Oxisols and Ultisols, but performs better on soils with a high base status. *Pinus oocarpa* should not be planted in areas that are subject to frosts or have poor drainage. In one case in northern Argentina, temperatures of -8 °C greatly damaged 5-year-old plants of *P. oocarpa* (Picchi and Barrett 1967). Afterwards, 25% of the trees resprouted from the base of the tree. In a different freeze event in southern Brazil, 1-year-old *P. oocarpa* trees did resprout after a heavy frost killed all the neighboring *P. caribaea* var. *hondurensis*. (The Caribbean pine did not resprout). Survival on sandy soils never seems to be as high as survival on clayey soils (see Productivity). As Table 9-3 indicates, the species seems well adapted to a number of locations in the tropics and subtropics between

100 and 2000 m altitude. An ideal planting site in the Colombian highlands (2° N) region would be characterized by an elevation of approximately 1800 m, sandy loam to clay loam soils that are at least 70 cm deep and a soil pH value of 4.6 to 5.2 (J. B. Urrego, personal communication). The species also seems well adapted to most regions of the Brazilian Cerrado between 550 and 1000 m altitude.

Silviculture

As explained earlier, *P. oocarpa* responds to fire in natural stands by producing a number of basal shoots, one of which ultimately becomes the main leader. In plantation environments devoid of fires, the species still may produce multiple shoots from the base in the first few years after planting, resulting in a tree that is very bushy in appearance. Eventually, a single leader takes over; but this may not occur until the second or third year after field planting. During this initial phase when the trees are bushy and growth is slow, good weed control is needed in *P. oocarpa* plantations.

A lack of understanding of the early developmental patterns of *P. oocarpa* has led to plantation failure in some cases. For example, in the eastern Llanos of Venezuela, *P. caribaea* is mechanically planted deep in the sands with only the top 5 to 7 cm of the terminal shoot above ground in order to protect the plant from desiccating winds. When *P. oocarpa* was planted in the same manner, most of the trees died. Deep planting prevented *P. oocarpa* from resprouting from the root collar area when the terminal leader died back from the heat and wind. A much better approach in such situations would be to plant *P. oocarpa* at a normal depth and allow it to resprout as it does in natural stands.

Cannon (1982) examined different site preparation methods for *P. oocarpa* in the highlands of Colombia. He found that ploughing and double disking, and ploughing, disking and bedding, gave better results than manually removing vegetation 70 to 100 cm around each tree. The finding suggests that *P. oocarpa* is better suited to more intensive rather than less intensive site preparation.

Pinus oocarpa has been planted from 2.5 x 3.0 m to 3.0 x 3.0 m spacing. Most CAMCORE organizations apply fertilizer at the time of planting. Smurfit Cartón de Colombia applies NPK (15-38-10) at a rate of 50 g per tree and 10 g of 68% borax per tree (Ladrach 1980). Borax application has a tendency to reduce forking in pines. PROFORCA researchers in eastern Venezuela applied triple phosphate, potassium chloride and borax at rates of 250, 60 and 12.4 kg/ha, respectively, to *P. oocarpa* and *P. caribaea* var. *hondurensis* eight weeks after field planting (González 1993). Results after 10 and 22 months indicate that *P. oocarpa* was approximately 25% taller than *P. caribaea* var. *hondurensis*. *Pinus oocarpa* responded to the fertilizer only on well-drained sites (González 1993). Ribas et al. (1985) also saw a response of *P. oocarpa* to the application of NPK fertilizer in plantings in São Paulo, Brazil.

Good baseline nutrient data is not available for *P. oocarpa* and is very much needed.

During the first year after outplanting, *P. oocarpa* from Central America seems very sensitive to drought. After the root system is established, it appears to be quite drought hardy. Timing outplanting to coincide with the onset of the rainy season is essential for good stocking in this species. Because of its apparent sensitivity to environmental conditions after outplanting and its habit of slow initial growth, foresters in some locations strongly prefer to plant the more hardy *P. caribaea* var. *hondurensis* over *P. oocarpa*.

Crown closure begins in *P. oocarpa* at approximately 8 years of age. Crowns of *P. oocarpa* are not dense and allow sunlight to reach the forest floor after crown closure at many locations. This allows for fuel buildup in the understory, increasing the risk of fire. The species seems well suited to both pruning and thinning.

Pests and Other Limiting Factors

Insects: *Pinus oocarpa* is often defoliated by *Atta laevigata* (leaf-cutting ants) in the tropics and subtropics when ant populations are not controlled. In the eastern Llanos of Venezuela, *P. oocarpa* seems more susceptible to attack than does *P. caribaea* var. *hondurensis*. This may be because *P. oocarpa* has softer needles with a terpene content that differs markedly from *P. caribaea* var. *hondurensis* (see Squillace and Perry 1992). Defoliating beetles (Bostrichidae) were found to show a preference for *P. oocarpa* over four other tropical pines in studies in São Paulo State, Brazil (Flechtmann et al. 1997). In Brazil, *P. oocarpa* logs also were found to be more attractive to Ambrosia beetles (species name not given) than were varieties of *P. caribaea* (Flechtmann et al. 1999). Infestations of *Pineus pini* (woolly aphids) in Kenya (Mailu et al. 1982) and *Hylastes angustatus* (Hylastes bark beetle) in Swaziland (Morris 1988) have been noted on *P. oocarpa*.

Disease: CAMCORE trials of *P. oocarpa* have been attacked by *Cylindrocladium* spp. in northern Brazil (Jari); the species seemed more susceptible to the disease than did *P. caribaea* var. *hondurensis*. *Pinus oocarpa* and several of its closed-cone pine relatives have shown excellent resistance to *Fusarium subglutinans* (pitch canker) in laboratory screening trials in the United States (Hodge and Dvorak 2000).

Other limiting factors: Bush pigs (*Potamochoerus porcus*) preferentially attacked *P. oocarpa* over *P. tecunumanii* and *P. patula* in Zimbabwe (Sniezko and Mullin 1987). Preferential browsing is likely the result of the different monoterpenes composition of *P. tecunumanii* and *P. oocarpa*.

Pinus oocarpa has a shallow root system and is highly susceptible to wind throw when planted in typhoon belts. In assessments after heavy rain and hurricane damage in Puerto Rico, Liegal (1984) found that total damage in *P. oocarpa* was 52% versus only 22% for *P. caribaea* var.

hondurensis. However, *P. oocarpa* is not nearly as susceptible to top-crown breakage as is *P. tecunumanii* (Dvorak et al. 1993a).

WOOD QUALITY IN PLANTATIONS

The wood properties of *P. oocarpa* in plantations are, for the most part, excellent. Some care is needed in reviewing the literature on the subject because much of what is called *P. oocarpa*, particularly in publications written before the late 1980s, may actually be *P. tecunumanii*. Generally, the density and extractive content of *P. oocarpa* is higher than for *P. tecunumanii*.

Density

Ladrach (1987) conducted a comprehensive study of wood density and tracheid length of *P. oocarpa* at eight locations in the highlands of Colombia, sampling 156 trees from age 4 to 11 years. *Pinus oocarpa* displayed a wood density of 420 kg/m³ at 8 years of age, versus 350 kg/m³ for *P. patula* and 340 kg/m³ for *P. kesiya* between 1500 and 2200 m altitude. In the highlands of Colombia, *P. oocarpa* always has a higher density than the three other commercial species: *P. maximinoi*, *P. tecunumanii* and *P. patula*. On similar sites, the density of *P. oocarpa* can be up to 10% higher than that of *P. tecunumanii*.

Moura et al. (1991) assessed the wood specific gravity of four *P. oocarpa* provenances planted at three locations in the Brazilian Cerrado that ranged in altitude from 480 to 1000 m. A slight decrease in density with increasing altitude (dropping from 440 to 420 kg/m³) was observed at 12 years of age, an environmental trend common in many pine species (Chapter 10, *Pinus patula*). One provenance of *P. oocarpa*, Dipilto, Nicaragua, had growth

equivalent to *P. tecunumanii* from Yucul, Nicaragua and slightly higher density.

In provenance trials planted around the world, Birks and Barnes (1990) found little difference in wood density between *P. oocarpa* (415 kg/m³) and *P. tecunumanii* (409 kg/m³). However, the density differences between the two species can be important locally.

Fiber Quality

In the study conducted in Colombia by Ladrach (1987), tracheid length increased with tree age, as was expected. At ages 8 and 12 years, mean tracheid length was 3.4 and 3.8 mm, respectively; tracheid length was 4.1 and 4.6 mm for *P. patula* at the same ages. The fact that *P. oocarpa* has higher wood density but much shorter tracheids than *P. patula* suggests that *P. oocarpa* has thicker cell walls than *P. patula* in Colombia.

Pulp Quality

In studies of *P. oocarpa* in Africa, 7-year-old trees were readily pulped in the kraft process to give a 44% yield (Tissot 1968). Normal bleaching was achieved in a four-stage process. The breaking length and burst factor of unbleached *P. oocarpa* pulp was inferior to *P. patula* in Swaziland but superior to *P. caribaea* and *P. kesiya* in Madagascar (Tissot 1968). *Pinus oocarpa* tracheids from Brazilian plantations were broad and extremely thick-walled (FAO 1980). In Brazil, the species produced an average yield of unscreened sulfate pulp, but the screening content of pulp was very high. The pulp possessed acceptable brightness. In Colombia, 10-year-old *P. oocarpa* produces acceptable kraft pulp with yields of 47 to 48% at kappa number 48 to 60 (J. Berrio, personal communication).

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

CAMCORE sampled 16 provenances from Guatemala and Honduras and one from Veracruz, Mexico from 1980 through the early 1990s. As stated previously, the initial objective was to collect material from the driest sites in Central America that were also in need of conservation, and to test these collections as exotics on marginal sites. As Table 9-1 shows, the majority of collection sites were in Guatemala and Honduras. Only four of the sites CAMCORE sampled were also collected by the Oxford Forestry Institute (OFI). These are La Lagunilla, San José la Arada and El Castaño, (called Bucaral by OFI) Guatemala, and San Marcos de Colón, Honduras. The seeds that were collected from the 515 *P. oocarpa* trees by CAMCORE were distributed to members in Brazil, Colombia and Venezuela in a series of 29 tests.

PROVENANCE VARIATION

Various *P. oocarpa* assessments have been conducted by CAMCORE and its members and have been reported on by Murillo (1988), Cesar et al. (1988) and Moura et al. (1998). CAMCORE recently conducted an analysis on 14 trials, most of which were 8 to 15 years old. The results from these assessments are summarized in Tables 9-3 and 9-4. These 14 trials can be grouped into six climatic/edaphic regions: dry llanos of eastern Venezuela, wet llanos of eastern Colombia, the highlands of Colombia, coastal Brazil, central (Cerrado) Brazil, and southern Brazil. Survival and productivity results from the analyses are summarized in Table 9-3 and best linear unbiased predictors (BLUP) for volume are presented in Table 9-4.

Table 9-3. Mean survival and productivity (over bark) of the best *Pinus oocarpa* provenance at 8 years in each of six geographical regions. (Results based on data from 14 CAMCORE trials).

Region	Lat.	Elev. (m)	Rainfall (mm)	Soil Order	Num. Tests	Surv. (%)	Best Provenance	Prod. (m ³ /ha/yr)
Eastern Venezuela	10° N	150	920	Ultisol	3	80	San Marcos	11.0
Eastern Colombia	11° N	150	2200	Ultisol	1	75	Las Crucitas	5.2
Colombian Highlands	2° N	1600	2000	Andisol	1	80	Lagunilla	26.0
Coastal Brazil	17° S	50	1500	Spodosol/ Ultisol	6	79	Guaimaca	14.6
Central Brazil	13° to 18° S	550 to 1000	1450	Oxisol	2	92	La Unión, San José	21.4
Southern Brazil	22° S	700	1400	Alfisol	1	87	Guaimaca	36.4

Survival

Average (weighted) survival of *P. oocarpa* across the six regions shown in Table 9-3 was 79%. The best survival (92%) was on deep, infertile Oxisols in the Cerrado region of central Brazil, and the poorest survival (75%) was on sandy soils in the wet llanos of eastern Colombia. Average survival in the tests fell by approximately 6.3% from age 3 to 8 across all locations. However, in the two tests established in coastal Brazil at Aracruz and San Mateus, for which 15 years of data was available, survival fell an additional 24% from 8 to 15 years of age (data not shown). In a third test in central Brazil, which was established at Planaltina on a deep Oxisol, survival remained high and constant through age 13 years. The sharp fall-off in survival at Aracruz and San Mateus may be a combination of normal mortality due to competition effects on sandy soils along with damage by leaf-cutting ants. Furthermore, some mortality at Aracruz was attributed to wind throw. Many who grow *P. oocarpa* find it difficult to maintain appropriate stocking when plantations are established on predominantly sandy soils. Within locations, there was no important provenance variation in survival.

Productivity

Productivity in *P. oocarpa* varied greatly depending on planting site (Table 9-3). Productivity (over bark) was best at Angatuba, Brazil, where MAI at 8 years was 34 m³/ha/yr. The *P. tecunumanii* control lot in the same test had a MAI of 39 m³/ha/yr. The Angatuba site has one of the most fertile soils of any of the more than 1000 CAMCORE tests sites established in the tropics and subtropics. The poorest productivity was in the wet llanos of eastern Colombia, where trees grew at a rate of approximately 5.2 m³/ha/yr. The soils are sandy and, during heavy rains, drainage can be slow and localized flooding is common. *Pinus caribaea* var. *hondurensis* grew only 6.5 m³/ha/yr in this area (Chapter 2, *Pinus caribaea*). The general trend with *P. oocarpa* is increased growth with greater soil depth and fertility. Soils that are clayey are better suited for *P. oocarpa* than are sandy ones. Productivity can be good on soils of poor

fertility, as long as they are deep (approximately 1.0 m or more). *Pinus oocarpa* should not be planted on shallow or poorly drained soils. There were no geographic trends in productivity by provenance for *P. oocarpa*, with the exception that at Angatuba, which is the best site, the Tablazón, Honduras source performed the poorest.

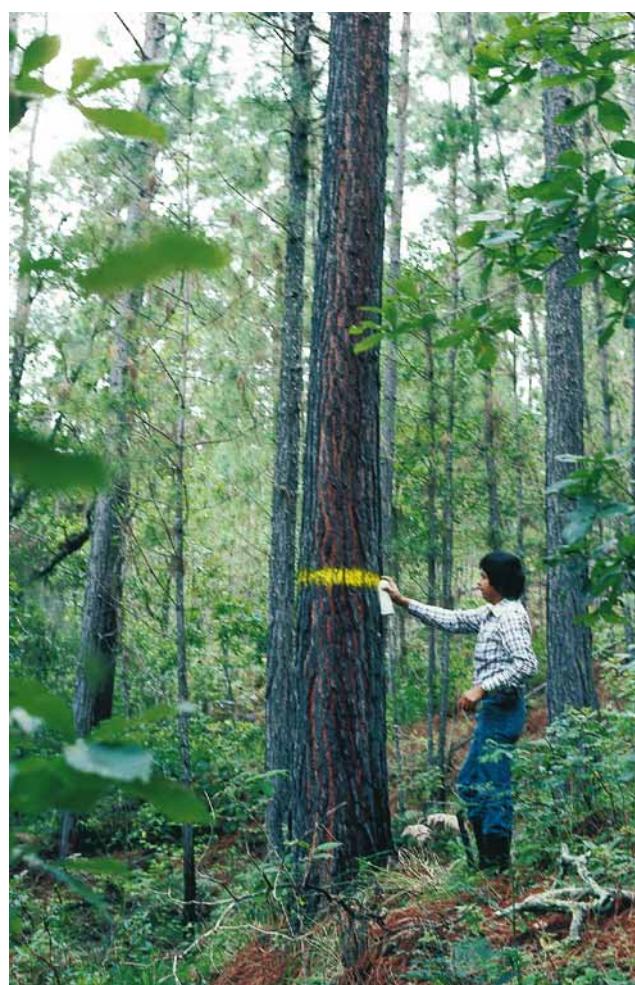
Volume Performance

Murillo (1988) analyzed 3-year-old CAMCORE *P. oocarpa* tests that were established on 10 sites in Brazil, Colombia and Venezuela and found no statistical differences among provenances on 8 of the 10 sites. A subsequent volume analysis made on the same series of CAMCORE tests between 8 and 15 years is summarized in Table 9-4. The difference between the best and worst sources was only 10 to 11%, a much smaller spread than that observed for *P. caribaea* var. *hondurensis* (Hodge et al. 2001) and for *P. tecunumanii* (Hodge and Dvorak 1999). These observations may be the result of the limited number of provenances (15) that were examined across a small geographical area or the marginal quality of most planting sites, which may have reduced differences in growth between the best and the worst sources. However, even on the most productive site at Angatuba, where differences among sources might be more pronounced, the provenances of El Castaño, Guaimaca, La Campa, Las Crucitas, San Luis Jilotepeque, and San Marcos all exhibited approximately the same productivity at 8 years of age, while Tablazón was inferior. It appears that the Guatemalan and Honduran provenances do not exhibit much variation in growth rate, although there are important tree-to-tree differences.

El Castaño and La Unión, Guatemala and Guaimaca, Honduras were the best sources for volume production in Brazil (Table 9-4). San Lorenzo, Guatemala, was the superior source in Colombia. San Marcos de Colón, Honduras was the top volume producer in Venezuela. There was no apparent relationship between geographic location of collection sites in Guatemala and Honduras and performance as an exotic. There may be a relationship

between altitude and precipitation at the collection site in Central America and performance in Colombia, but results from additional provenances are needed. The high elevation and high rainfall source, San Lorenzo, Guatemala, which occurs at 1700 m altitude with 1700 mm annual rainfall, outperformed sources from other areas in Central America when planted in the highlands of Colombia. Interestingly, San Lorenzo is the only *P. oocarpa* stand listed in Table 9-4 where *P. tecunumanii* is also present. The trees from San Lorenzo had extremely straight stem form and morphologic characteristics that suggested past introgression with *P. tecunumanii*.

Results from CAMCORE *P. oocarpa* testing program are in some ways very similar to those of the OFI program (reported on by Crockford et al. 1990 and Birks and Barnes 1990). Crockford et al. (1990) assessed six *P. oocarpa* provenances growing at 11 locations; Birks and Barnes (1990) assessed 19 provenances grown at 13 locations. No single provenance in the OFI series performed best across all sites (Crockford et al. 1990, Birks and Barnes 1990), which is similar to the CAMCORE findings. As an example, in the CAMCORE trials, the El Castaño (Bucaral) source was one of the most productive in Brazil, but was relatively unproductive elsewhere. Crockford et al. (1990) also found the source to be unproductive. Birks and Barnes (1990) suggested that sources from the Sierra de las Minas in (northeastern Guatemala) and Dipilto (northern Nicaragua) produced above average growth on most sites. Currently, the only provenance that CAMCORE has for comparison is San Lorenzo (also from the Sierra de las Minas), which, as mentioned previously, grew well only in Colombia. Again, it is intriguing that the sources from the northeastern range



Photos 9-8a and b. Above, William Ordoñez (formerly with BANSEFOR, Guatemala) marking a CAMCORE selection made in 1980 in a natural stand at La Lagunilla, Guatemala. Below, Edson Andrade (left), Aracruz Florestal, and José Luis Romero (right), CAMCORE, inspect a 15-year-old tree from the original Guatemalan collections in a CAMCORE provenance/progeny test in Brazil in 1999.

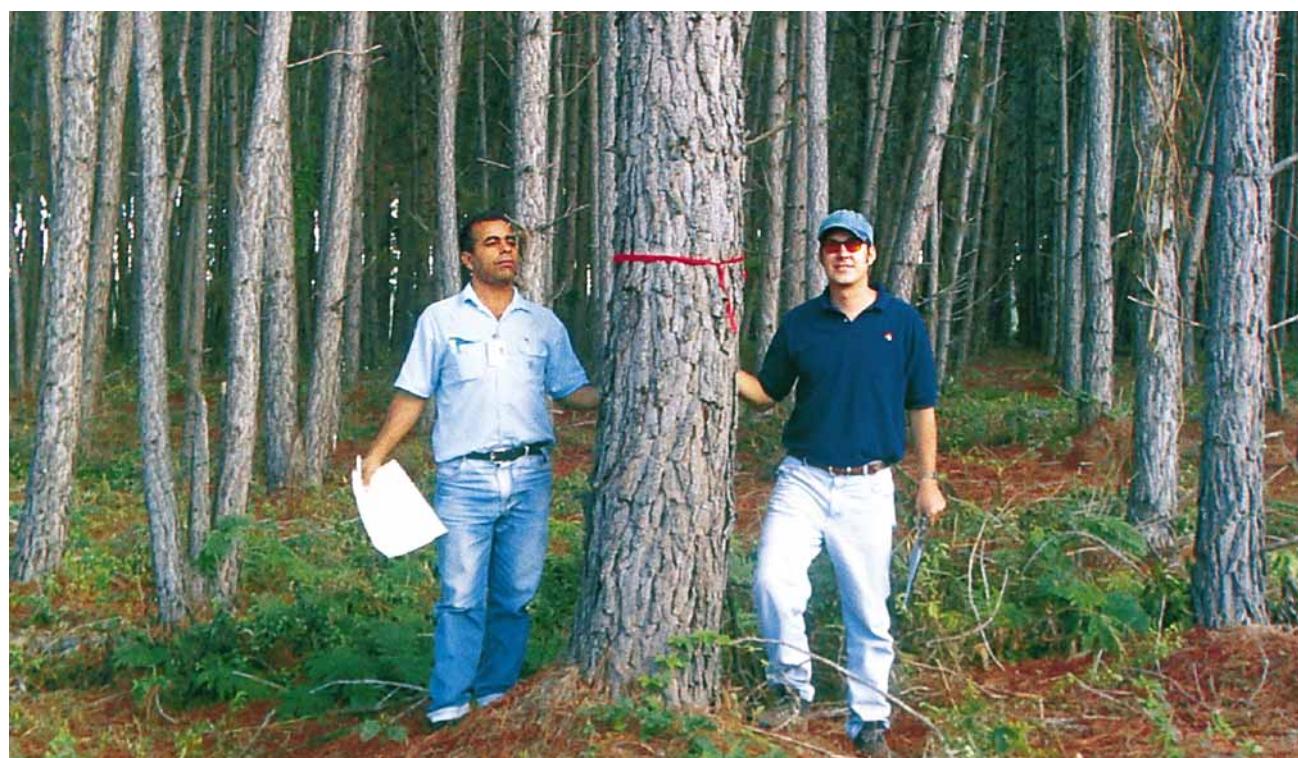


Table 9-4. Volume performance (Gain) from 8 to 15 years of age of 15 *Pinus oocarpa* provenances tested in Brazil, Colombia and Venezuela by the CAMCORE Cooperative. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			COLOMBIA	VENEZUELA	Gain	Fams	Tests
			Gain	Fams	Tests					
HONDURAS	14	Las Crucitas	-0.3	26	5	1.7	10	2	-0.9	18
	15	Guaimaca	5.1	22	6	-2.1	10	2	-1.2	16
	16	San Marcos de Colón	0.8	28	5	-0.2	13	2	6.4	22
	17	Tablazón	-3.7	29	7	0.7	11	2	-1.0	15
	13	La Campa	-6.3	18	5	3.0	10	1	-2.2	8
GUATEMALA	6	La Unión	5.3	5	3	-3.5	4	1	.	.
	11	Camotán	0.1	16	4	.	.	.	-3.5	8
	4	La Mina	2.0	6	3	-3.8	5	1	.	.
	7	San Lorenzo	-2.5	8	3	6.4	7	1	.	.
	12	San Luis Jilotepeque	2.4	19	7	-0.9	3	1	2.3	20
	1	La Lagunilla	-4.9	18	6	-0.3	10	2	-1.7	15
	5	San José La Arada	1.6	7	3	-3.9	5	1	.	.
	2	Selva Pinares	-1.4	1	3	0.3	1	1	.	.
	9	El Castaño (Bucaral)	4.8	21	7	1.5	7	1	1.9	14
	3	Tapalapa	-2.9	8	3	1.2	6	1	.	.

Map key does not correspond to CAMCORE provenance codes.

of Sierra de Las Minas and the upper altitudes of Dipilto occur with *P. tecunumanii*, while those from southeastern Guatemala do not. Birks and Barnes (1990) found that *P. oocarpa* from southeastern Guatemala tended to perform poorly. The CAMCORE results cannot be used to confirm this finding because many of our tests included only the southeastern Guatemalan sources and because great efforts were made to establish these tests on only the driest sites. Generally, the lack of consistency in volume performance across locations in both the OFI and CAMCORE tests emphasizes the site specificity of the species and the need to adequately test at both the population and family levels.

Some foresters have observed that the growth rate of *P. oocarpa* increases with time. CAMCORE results for two tests measured from 3 to 15 years of age indicate this may be partially correct. Average height for *P. oocarpa* grown in CAMCORE tests averaged 2.9 to 6.5 m at 3 years of age. When planted on a shallow soil (30 cm in depth), *P. oocarpa* reached its maximum height increment from age 3 to age 5 and diameter increment from age 8 to age 11. On deep sandy soils, height increment reached its maximum between 8 and 11 years and diameter increment between 3 and 5 years.

Quality Traits

Pinus oocarpa exhibits great natural variation at both the provenance and family level for some quality traits. Trees with very straight stem form and fine branches exist in most trials. Therefore, the possibility of making improvements through selection appears to be significant.

Moura et al. (1998) assessed stem form, branch diameter, forking, foxtails and multiple stems in a CAMCORE test planted at Planaltina, Brazil (site described previously) using measurements taken at 13 years of age. They found little provenance variation in stem form, branch diameter and foxtail percents. However, there were important differences in forking and multiple-stem percent, with El Castaño exhibiting the least defects. A multiple stem is formed when several competing sprouts emerge at or near the base, usually as a consequence of the main leader dying at an early age. The cause of main leader death is unknown but is thought to be related to burning by solar radiation reflected off the mineral soils (Chapter 2, *Pinus caribaea*). The degree of forking is thought to be partially related to environmental conditions at the planting site and to the degree of adaptability.

In their across-site analysis, Birks and Barnes (1990) found that La Lagunilla had the least stem lean and ranked high for straightness, but had the most multiple stems and forks.

As was mentioned before, *P. oocarpa* is generally a very shallow rooter. Lean and wind throw in the species is common on sandy soils in high wind areas and on shallow soils.

Provenance x Site Interactions

In Murillo's (1988) across-site analysis of 10 CAMCORE tests at 3 years for height, he found all provenances were unstable (interactive) across locations, with the exception of San Marcos de Colón and San Luis Jilotepeque. Changes in volume rankings across sites continued to persist from ages 8 to 15, as indicated in Table 9-4. No single environmental factor can be singled out as being the main cause for the interactions.

Family x Site Interactions, Genetic Parameters for Growth and Quality Traits

In most CAMCORE testing programs, there are higher type B genetic correlations for volume between pairs of tests in the same country than pairs of tests in different countries. To determine if the same trends exist for *P. oocarpa*, three CAMCORE tests were examined for similarities in family ranks for 8-year volume at Aracruz and San Mateus, Brazil and La Arcadia, Colombia. Each pair of tests had between 20 and 30 open-pollinated families in common. Although Aracruz and San Mateus are located only 90 km from each other, they occur on two distinct soil types. The Aracruz location is a shallow, compacted Spodosol, while San Mateus is a deep sandy Ultisol. La Arcadia is a deep Andisol (see Table 9-3). There were significant (positive) Spearman family rank correlations between Aracruz and San Mateus ($r = 0.49$), as was expected, and significant (positive) family rank correlations between the Aracruz site and La Arcadia ($r = 0.44$). However, there were no significant correlations between San Mateus and La Arcadia ($r = -0.09$). Moura et al. (1998) also conducted Spearman rank correlations on a different set of CAMCORE *P. oocarpa* tests for volume at 5 years of age. They found that there were important family x site interactions for some pairs of tests and not for others. The general conclusion reached is that there is less family x site interaction for pairs of tests in the same country than between countries, but that interactions at the family level can be important for the species.

Mean single-site heritability for *P. oocarpa* assessed in 14 tests at 8 years of age in CAMCORE tests for height, volume and stem straightness was 0.17, 0.20, and 0.18, respectively. Crockford et al. (1990) found individual tree heritabilities for height, volume and stem straightness to be 0.14, 0.21 and 0.21, respectively, in the OFI *P. oocarpa* tests established on nine sites and measured at 4.5, 6 and 8 years of age. Volume and height heritabilities were essentially constant at ages 5, 8, 11, and 15 in two of the CAMCORE tests in Brazil through age 15 years. On these two sites, genetic correlations of volume at age 5 with volume at ages 11 and 15 were 0.71 and 0.62, respectively.

The corresponding genetic correlations between volume at age 8 with volume at ages 11 and 15 were 0.93 and 0.67, respectively. These data suggest that selection for volume could be possible as early as age 5. In an assessment of *P. oocarpa* on a single site in Zimbabwe, Nyoka and Barnes (1995) found high positive genetic correlations between metric traits measured from age 2 to 8 years. The authors also concluded that early selections were feasible.

DEVELOPMENT OF IMPROVED MATERIAL

Flowering and Seed Production

Clonal banks and seed orchards of *P. oocarpa* have been established at only a few locations in the tropics and subtropics e.g., in the Colombian highlands by Smurfit Cartón de Colombia (Isaza et al. 2000), the eastern highlands of Zimbabwe by the Zimbabwe Forestry Commission (Nyoka et al. 2000) and near Agudos, SP, Brazil by Duratex S.A. (ex CAFMA) (Davide et al. 1996). Interestingly, after the establishment of the Duratex orchard, researchers determined that four clones thought to be *P. oocarpa* were actually *P. tecunumanii*, and 20 clones were variants between *P. oocarpa* and *P. tecunumanii* (Davide et al. 1996).

Flowering occurs throughout the year but appears to peak in July to August in a seed orchard that are located in the highlands of Colombia (lat. 2° N, elev. 1800m, ann. precip. 2344 mm). In the highlands of Zimbabwe, the onset of flowering and flower productivity varies greatly with the altitude of the planting site (Nyoka et al. 2000). The general flowering period is between June and October, with male flowers appearing a month to two months before female flowers.

Nyoka et al. (2000) also found that in Zimbabwe, male strobili are produced earlier at high altitudes than at lower ones, while the number of female strobili decrease with increasing altitudes. Furthermore, some trees produce few or no flowers, while others are predominantly male or female. The cause for these trends is unknown but is thought to be related more to environment than genetics (Nyoka et al. 2000).

Seed yields in *P. oocarpa* orchards and seed stands established near the equator are probably greater at higher altitudes. For example, in the highlands of Colombia (2° N), Arce and Isaza (1996) found only seven filled seeds per cone in stands 12 to 21 years of age when established between 1360 and 1800 m altitude. However, in a 29-year-old seed stand at 1800 m elevation, an average of 21 filled seeds per cone is obtained (Isaza et al. 2000). Seed yields average approximately 25 seeds per cone in Venezuela (10° to 11° N) in stands 10 to 12 years of age when established above 800 m altitude (Dvorak 2000b). The seed production of *P. oocarpa* is usually better than *P. caribaea* var. *hondurensis* at low latitudes and superior to *P. tecunumanii* at latitudes from 15° to 25° S.

Hybrids

Pinus oocarpa from eastern Mexico and Central America has been crossed with *P. caribaea* var. *hondurensis*, *P. tecunumanii* and *P. patula* (Dieters et al. 1997, Critchfield 1967). Observations in natural stands suggest that the species crosses with *P. pringlei* (J. López-Upton, personal communication). Phylogeny assessments suggest that *P. oocarpa* from western Mexico should also cross easily with *P. herrerae* and *P. jaliscana*.

Much of the recent interest in hybridization among tropical pines has centered on *P. caribaea* var. *hondurensis* × *P. tecunumanii* crosses. However, Smurfit Cartón de Venezuela finds that the more impressive hybrid is *P. caribaea* var. *hondurensis* × *P. oocarpa* (L. Rosales, personal communication). Both hybrids are being tried in west-

central Venezuela by the company, courtesy of the Queensland Forestry Research Institute, and are approximately 7 years old. Wood density assessments will be made soon.

Pinus caribaea var. *hondurensis* × *P. oocarpa* hybrids are also being tested at two locations in Zimbabwe. Results indicate that the *P. caribaea* var. *hondurensis* × *P. tecunumanii* hybrid is superior to the *Pinus caribaea* var. *hondurensis* × *P. oocarpa* hybrid for volume at 5 years of age (Nyoka 2000). It will be interesting to see if the trend of improved growth with increasing age observed with the *P. oocarpa* hybrid in Venezuela will also be observed in Zimbabwe. *Pinus oocarpa* brings to a hybrid cross the advantage of good wood quality and an improved capacity to be propagated vegetatively.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

Although the species is an important timber and fuelwood species in Mexico and Central America, there has never been a rangewide genetic diversity study conducted for *P. oocarpa* at the molecular level. There have been two isozyme studies that included *P. oocarpa* provenances.

Herrera et al. (1997) looked at variation in several Mexican populations and found that average values for polymorphic loci ranged from 53 to 67%, similar to levels of genetic variation for other North American pines. Matheson et al. (1989) examined genetic diversity in two Nicaraguan populations of *P. oocarpa*, Dipilto and Cusmapa. They found both populations had 77% polymorphic loci and expected heterozygosity of 0.17. Generally, *P. oocarpa* was found to have slightly lower levels of heterozygosity than *P. caribaea* var. *hondurensis*. Recent phylogeny studies indicate that *P. oocarpa* from western Mexico is genetically different than *P. oocarpa* from eastern Mexico and Central America (Dvorak et al. 2000); this emphasizes the importance of gaining a better understanding of how the species evolved and how genetic diversity is structured within populations. Complete rangewide genetic diversity studies would be helpful for developing *in situ* conservation strategies for the species.

Conservation Status

Abrams and Rue (1988) suggest that the Mayan Indians cut *P. oocarpa* for fuelwood and for structural components in rural house construction long before colonization by the Spaniards. Harvesting *P. oocarpa* trees to clear land for agriculture has probably been occurring for hundreds of years.



Photo 9-9. Damage to a *Pinus oocarpa* tree in Guatemala by woodcutters extracting resin and “ocote” (lighter wood). Although *P. oocarpa* is abundant in Mesoamerica, some populations are under severe pressure.

There is still an abundance of *P. oocarpa* throughout Mexico and Central America. However, many of the stands are being genetically high-graded. As an example, CAMCORE reassessed the conservation status of *P. oocarpa* at La Unión, La Lagunilla, La Mina, and San José la Arada, Guatemala in the late 1990s, nearly 20 years after the Cooperative's original collection. All stands had been reduced by 20 to 50% of their original area, and cutting to clear land for agricultural crops and to obtain firewood continues. Under current international guidelines (Farjon and Page 1999), the conservation status of *P. oocarpa* is still considered **low risk**, but the dynamics of individual populations are being greatly altered by man. The most southern populations of the species in Nicaragua are **vulnerable**.

EX SITU CONSERVATION

CAMCORE has sampled only a small portion of the species' geographic range. Based on CAMCORE estimates, collections in Guatemala and Honduras may represent only 54% of the total genetic diversity of the species (Dvorak 1996b). Further ex situ conservation efforts should be concentrated in Belize and central Nicaragua, where populations are small and sometimes endangered.

Delineation of true *P. oocarpa* from *P. tecunumanii* in the

southern part of their range based on morphology and molecular markers has proven unreliable. The difficulty of distinguishing these species at all locations hinders effective gene conservation efforts.

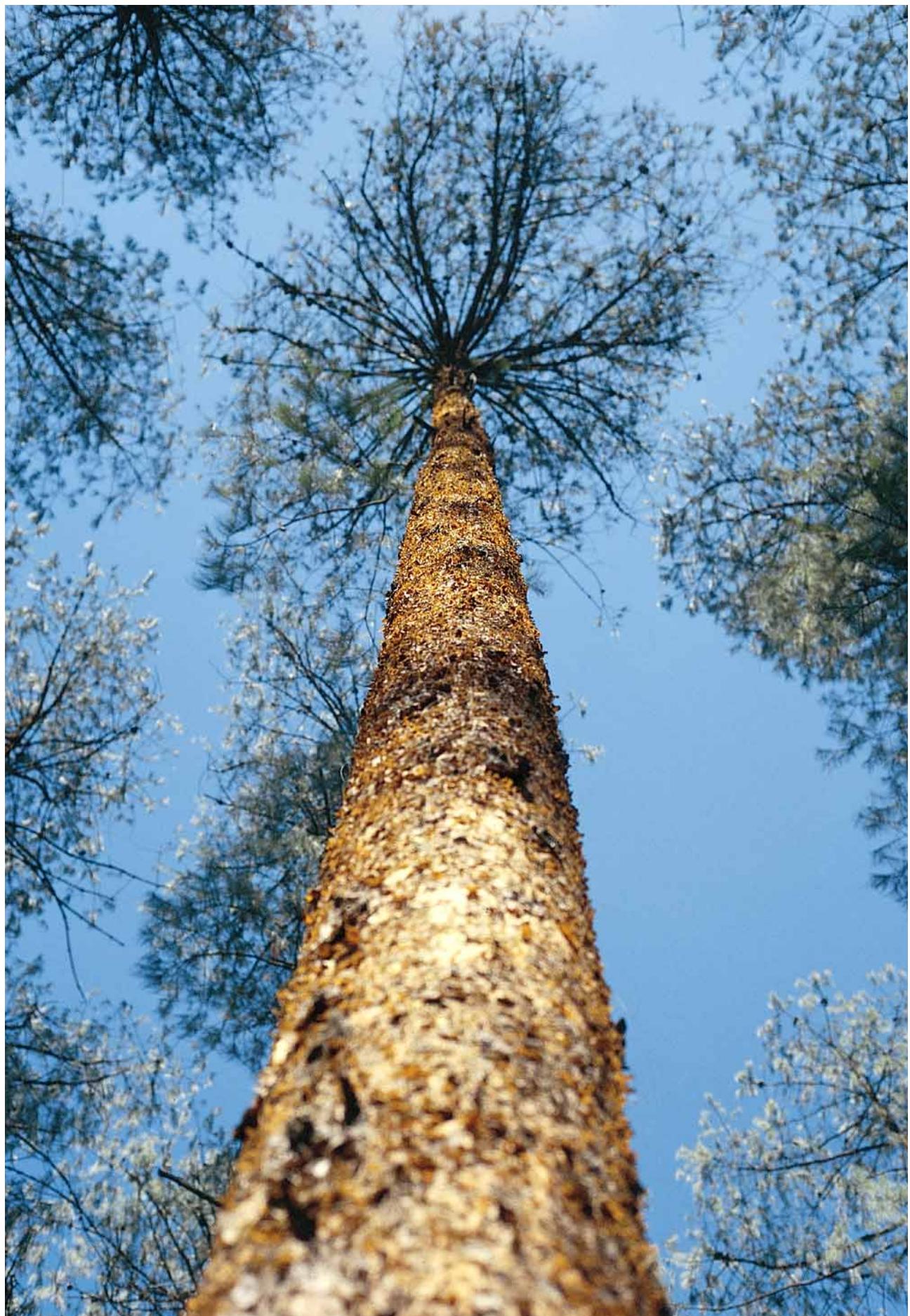
Re-evaluation of the Mexican provenances is needed. A 10-provenance sample was collected by the Instituto Nacional de Investigación Forestal (INIF)/Food and Agriculture Organization (FAO) in Mexico in 1972 and 1973 and was distributed to several countries (INIF 1973). The collections included populations from western, central and southern Mexico but not from the eastern part of the country. Little has been published on the results from this series of tests, but the information that is available suggests that the Mexican sources performed very poorly relative to the more tropical Central American provenances. Possibly a larger collection and better site matching would allow for the identification of several good provenances from the region.

Field conservation banks for *P. oocarpa* have been established for the fifteen provenances sampled by the Cooperative. Currently, CAMCORE's plans include selecting the best trees from each of the populations and breeding these in open-pollinated seed orchards.

CONTRIBUTORS

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C h a p t e r 1 0



PINUS PATULA

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OVERVIEW

TREE DESCRIPTION

Pinus patula Schiede ex Schlect. & Cham. var. *patula* occurs in the Sierra Madre Oriental from Tamaulipas to northeastern Oaxaca, Mexico. The natural distribution of *P. patula* Schiede ex Schlect. & Cham. var. *longipedunculata* Loock ex Martínez overlaps with var. *patula* in northeastern Oaxaca and extends along the Sierra Madre de Sur as far west as Guerrero.

Pinus patula var. *patula*

In natural stands, *P. patula* var. *patula* is a medium to large tree that can reach heights of 35 m with dbh (outside bark) of 80 cm. Young trees have a pyramidal-shaped crown that becomes rounded and sometimes irregular as the tree becomes older. Juvenile trees have a distinct smooth, reddish-brown to reddish-gray bark. Mature trees have rough, furrowed gray bark at the base that gradually becomes scaly to smooth, and reddish-gray midway up the main stem. Stem form varies from straight to crooked, depending on site quality and stand density. The needles of *P. patula* var. *patula* are often pale green to yellow-green, drooping to distinctly pendent and occur mostly in fascicles of three and occasionally four (mean = 3.2). Needle length ranges from 175 to 255 mm (mean = 216 mm). Needle resin canals are predominantly in the medial position (93%), with the remainder positioned internally. Cones are long and conical, sessile (Perry 1991), 55 mm to 100 mm in length (mean = 73 mm) and are usually borne in groups of two, with clusters containing up to 14 cones on the branches and the main stem. Cones ripen from October to December in Mexico. The average seed potential per cone is approximately 125 seeds in natural stands. There are from 97,000 to 157,000 seeds/kg (mean = 118,000). The wood is yellowish-white, of moderate density, low in extractives and has been used for a number of wood and paper products.

Pinus patula var. *longipedunculata* from northeastern Oaxaca

Pinus patula var. *longipedunculata* is a medium to large tree and at maturity is about the same size as var. *patula*. In northeastern Oaxaca, where the variety was first identified (Martínez 1948) and officially described (Loock 1950), taxonomists noticed that var. *longipedunculata* exhibited many of the same morphological characteristics as var. *patula*. The *longipedunculata* variety differed only in that its

cones were slightly smaller, ranging from 51 to 90 mm (mean = 73 mm), opened earlier and possessed scales that were weaker (softer) than the typical northern variety. Cones for the *longipedunculata* variety were borne on peduncles that ranged in size from 1 to 13 mm (mean = 6 mm).

Pinus patula var. *longipedunculata* from southwestern Oaxaca and Guerrero

In the Sierra Madre del Sur in southwestern Oaxaca and Guerrero, the populations of *P. patula* var. *longipedunculata* (i.e., Manzanal, San Mateo, Tlacuache, Yextla, and Carrizal de Bravo) are morphologically more distinct from var. *patula* than the *longipedunculata* specimens originally described in northeastern Oaxaca by Loock (1950). Based on our current interpretation of molecular marker results (CAMCORE, unpublished data), the more conspicuous differences in morphology may be partly caused by introgression of some populations (Yextla and Carrizal de Bravo and some trees in Tlacuache) with *P. herrerae*. The bark of mature var. *longipedunculata* trees in this region is sometimes gray along the entire length of the main stem and is scaly rather than smooth in appearance. Needle color on var. *longipedunculata* trees from southwestern Mexico ranges from dark green (like *P. herrerae* or *P. tecunumanii*) to pale green (like typical var. *patula*). Needle color is more uniform in var. *longipedunculata* trees from northeastern Oaxaca. Needles on trees from southwestern Mexico also tend to be shorter than those observed on their more northern relatives, ranging from 131 to 209 mm in length (mean = 170 mm). Needles occur in fascicles of three, four and five (mean = 4.3) and can be anywhere from erect to moderately pendent on the branches. Needle resin canal position of the southwestern populations of var. *longipedunculata* also differs from that of typical *P. patula*. Resin canals are predominantly (57%) in the internal position, with the remainder positioned medially. Cones are borne mainly in clusters of two, range in size from 34 to 88 mm (mean = 61 mm) and are attached to peduncles that are from 3 to 15 mm long (mean = 9 mm).

The cones of var. *longipedunculata* from both northeastern Oaxaca and southwestern Oaxaca and Guerrero ripen from January to March. The average seed potential per cone is 95 seeds. The wood quality of var. *longipedunculata* does not appear to differ much from that of var. *patula*.

Photo 10-1. *Pinus patula* growing in a natural stand in Veracruz, Mexico.

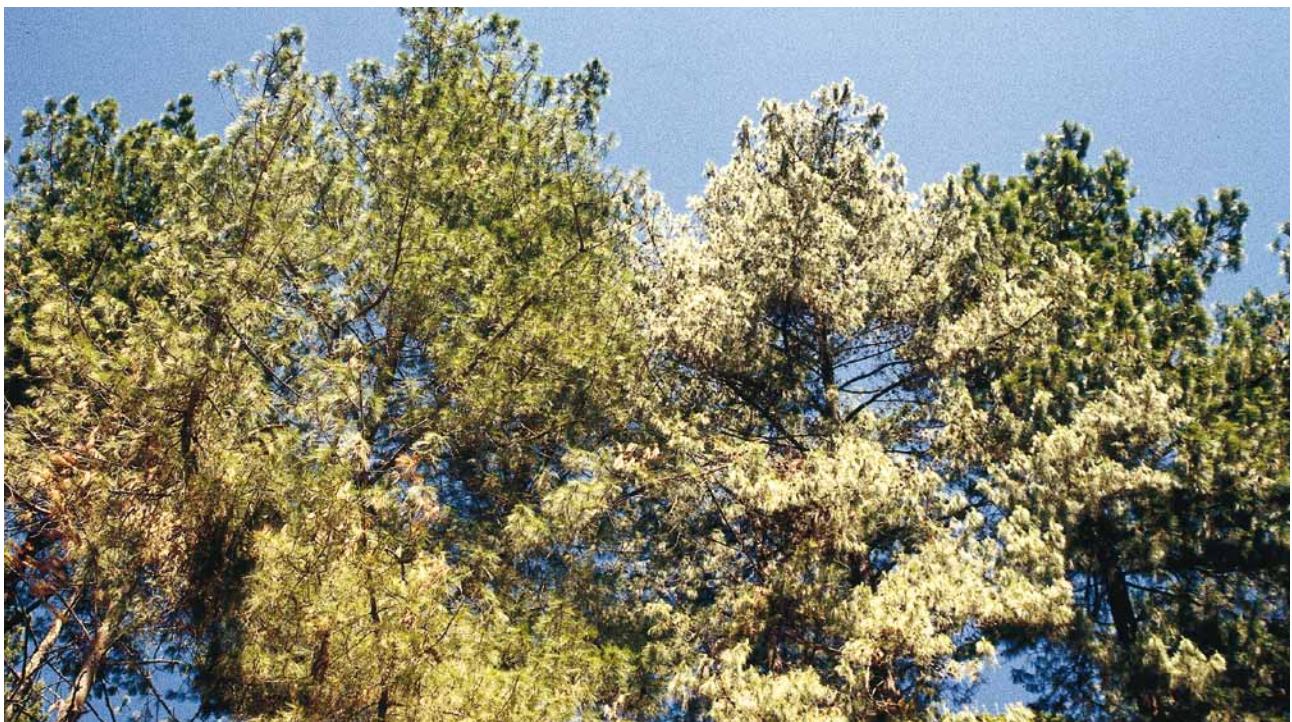


Photo 10-2. Morphological differences between trees of *Pinus patula* var. *longipedunculata* are quite distinct at Manzanal, Oaxaca. Trees with light foliage (like the tree right of center) are similar to populations of typical var. *patula* and var. *longipedunculata* that occur throughout the Sierra Madre Oriental. Trees with dark foliage are more similar to the var. *longipedunculata* that occurs throughout most of the Sierra Madre del Sur. Molecular markers have yet to distinguish between the two foliage types.

CONSERVATION STATUS

The conservation status of *P. patula* var. *patula* is **low risk** throughout most of its natural distribution, but there are several vulnerable populations. *Pinus patula* var. *longipedunculata* in both northeastern Oaxaca and southwestern Oaxaca and Guerrero are more threatened because of smaller stand sizes (10 to 20 ha) and the greater pressure being placed on the variety by agriculture and woodcutters in this area. The provenances of Manzanal and San Mateo, Oaxaca and San Lucas, Guerrero, are **vulnerable** to **endangered** as a consequence of logging. At Yextla and Carrizal de Bravo, Guerrero, the local communities (*ejidos*) do harvest some trees, but currently do so at a relatively low level. The conservation status of *P. patula* var. *longipedunculata* is **vulnerable** but needs to be reassessed in several years to determine the impact of both logging and agricultural activities.

TEST STATUS

Since 1986, CAMCORE has sampled 25 provenances and 624 mother trees of *P. patula* in Mexico. The CAMCORE collections represent the most complete coverage of the species' natural distribution to date. The Cooperative has established 93 provenance/progeny trials in Brazil, Chile, Colombia, Mexico, South Africa and Zimbabwe, as well as a number of *ex situ* conservation plantings.

BEST PROVENANCES

At the high latitudes in Brazil and South Africa (24° to 31° S), the Potrero de Monroy (Veracruz) source performed very well. At low latitudes in Colombia

(2° to 4° N), the most productive sources included all of the var. *longipedunculata* provenances (Ixtlán, Santa María Pápolo, Manzanal and Tlacuache, Oaxaca), along with Corralitla (Veracruz), a high rainfall source from the southern extreme of the range of *P. patula* var. *patula*. Other sources that performed well in individual countries, but were not consistently good performers across all countries included Zacualtipán, Hidalgo, and El Cielo, Tamaulipas in Brazil, and Cumbre de Muridores and La Encarnación, Hidalgo in South Africa.

SUITABLE PLANTING SITES

Approximately 1.0 million ha of *P. patula* has been planted worldwide, predominantly in southern and eastern Africa and to a lesser extent in the highlands of western South America. *Pinus patula* requires deep, well-drained soils and grows best in areas above 1000 m altitude at latitudes of 18° to 30° and above 2200 m near the equator. The species is moderately drought tolerant when mature and should be planted in areas that receive more than 850 mm of annual precipitation. *Pinus patula* var. *patula* and the northeastern Oaxaca sources of var. *longipedunculata* can withstand freezing temperatures to about -10 °C. The var. *longipedunculata* sources from southwestern Oaxaca and Guerrero are less frost tolerant. All varieties of *P. patula* have done poorly in areas below approximately 850 m elevation, which are probably too tropical. Freezing temperatures in the northeastern Cape of South Africa have damaged var. *longipedunculata* provenances from southwestern Oaxaca.

ADVANTAGES OF *PINUS PATULA*

- Grows rapidly and captures the site quickly.
- Good provenance information available.
- Improved seed available.
- Good wood quality that is suitable for a number of different products.
- Roots easily from seedling cuttings.
- Will hybridize with a number of other pine species.
- Variety *patula* exhibits moderate resistance to both drought and frost.
- Resistant to *Pineus pini* (woolly aphid) in southern Africa.

DISADVANTAGES OF *PINUS PATULA*

- Exhibits root instability in some nurseries.
- Aggressive colonizer that may negatively impact fragile ecosystems.
- When planted off site, will grow well for several years before stagnating.
- Lacks fire tolerance.
- Heavy slash residues and litter buildup on some sites.
- Very susceptible to *Sphaeropsis sapinea* (Diplodia), *Cinara cronartii* (black aphid), *Hylastes angustatus* (*Hylastes* beetle) and several defoliating insects.
- Moderately susceptible to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in the seedling stage.
- Variety *longipedunculata* from southwestern Oaxaca and Guerrero is susceptible to damage from heavy frosts.
- Exhibits dieback due to boron deficiencies at some locations.
- Not as tolerant to waterlogged soils as are *P. elliottii* and *P. taeda*.
- High female strobili abortion rate after bagging for controlled pollination in some environments.

NATURAL STANDS

EVOLUTION

Pinus patula apparently diverged from an *Oocarpace* cluster in northern Mexico or the southwestern United States during the mid-Tertiary (25 Million Years Ago) and migrated to the Sierra Madre Oriental of Mexico. The species moved south along this mountain range and served as a progenitor to *P. greggii*. *Pinus patula* is also closely related to *P. pringlei* (see Chapter 1, Evolution). *Pinus patula* var. *longipedunculata* is the southern extension of the typical *patula* and may have evolved more recently.

DISTRIBUTION

Pinus patula var. *patula*

The natural range of *Pinus patula* var. *patula* extends from 24° N latitude at Conrado Castillo, Tamaulipas to 17° 30' N in the mountains of northeastern Oaxaca, where it occurs sympatrically with var. *longipedunculata* (Figure 10-1). Although var. *patula* occurs from 1490 to 3100 m altitude, the majority of the stands are found between 2100 to 2800 m (Dvorak and Donahue 1992). The primary range of *P. patula* var. *patula* runs from northwest to southeast at

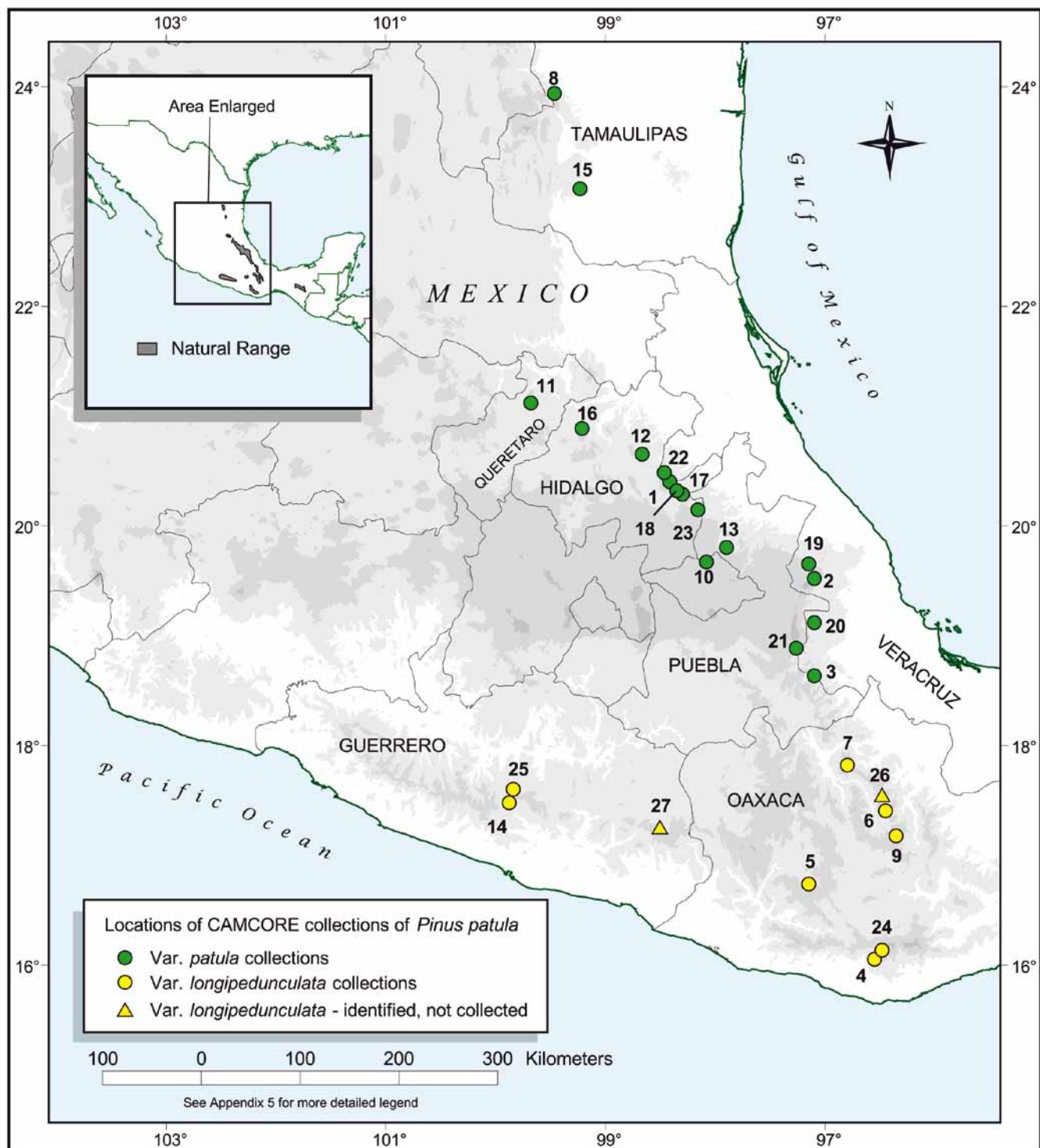
the high altitudes of the Sierra Madre Oriental from approximately Molango, Hidalgo to Las Vigas, Veracruz and then turns southward to Orizaba, Veracruz (Barrett 1972). For the most part, the distribution of the species is uninterrupted in this region of Mexico. The largest *P. patula* stands in this portion of the species range occur in the Sierra de Huayacocotla, which is on the border of Hidalgo and Veracruz and may represent the center of diversity for the species (J. Donahue, personal communication). After a 30-km break at Orizaba, Veracruz, the distribution continues in a north-south orientation across the eastern escarpment of the Eje Neo Volcánico Transversal through Veracruz, Puebla and northeastern Oaxaca. The Río Quiotepec Valley interrupts the distribution in northeastern Oaxaca and the variety reappears in the mountain ranges of Oaxaca, Sierras de Pájalo and the Etla de Juarez (Barrett 1972). Isolated outlier populations exist in Conrado Castillo, El Cielo, Pinal de Amoles, and La Encarnación, which are located at distances of 395, 295, 145 and 90 km, respectively, from the large stands in the Sierra de Huayacocotla.

Table 10-1. *Pinus patula* collections made by the CAMCORE Cooperative in Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	Potrero de Monroy	Veracruz	Mexico	20° 24' N	98° 25' W	2320 – 2480	1350	31
2	Ingenio del Rosario	Veracruz	Mexico	19° 31' N	97° 06' W	2770 – 2870	1346	22
3	Corralitla	Veracruz	Mexico	18° 38' N	97° 06' W	2000 – 2230	2500	23
8	Conrado Castillo	Tamaulipas	Mexico	23° 56' N	99° 28' W	1500 – 2060	1012	25
10	Tlacotla	Tlaxcala	Mexico	19° 40' N	98° 05' W	2750 – 2915	1097	21
11	Pinal de Amoles	Querétaro	Mexico	21° 07' N	99° 41' W	2380 – 2550	1350	24
12	Zacualtipán	Hidalgo	Mexico	20° 39' N	98° 40' W	1980 – 2200	2047	15
13	Llano de las Carmonas	Puebla	Mexico	19° 48' N	97° 54' W	2530 – 2880	1097	26
15	El Cielo	Tamaulipas	Mexico	23° 04' N	99° 14' W	1600 – 1730	1200	23
16	La Encarnación	Hidalgo	Mexico	20° 53' N	99° 13' W	2400 – 2650	1200	18
17	La Cruz	Hidalgo	Mexico	20° 17' N	98° 18' W	2300 – 2450	1869	24
18	Cumbre de Muridores	Hidalgo	Mexico	20° 19' N	98° 21' W	2380 – 2480	1869	30
19	Cruz Blanca	Veracruz	Mexico	19° 39' N	97° 09' W	2450 – 2550	1347	38
20	Calcahualco	Veracruz	Mexico	19° 07' N	97° 06' W	2350 – 2400	2020	30
21	Magueyes	Veracruz	Mexico	18° 53' N	97° 16' W	2250 – 2350	1200	30
22	Sierra Huayacocotla	Veracruz	Mexico	20° 29' N	98° 28' W	1840 – 2860	1405	70
23	Acaxochitlán	Hidalgo	Mexico	20° 09' N	98° 10' W	2460 – 2490	1857	10
4	El Manzanal	Oaxaca	Mexico	16° 06' N	96° 33' W	2350 – 2660	1348	28
5	El Tlacuache	Oaxaca	Mexico	16° 44' N	97° 09' W	2300 – 2620	2000	28
6	Ixtlán	Oaxaca	Mexico	17° 24' N	96° 27' W	2600 – 2870	1750	27
7	Santa María Pápaló	Oaxaca	Mexico	17° 49' N	96° 48' W	2270 – 2720	1100	24
9	Cuajimoloyas	Oaxaca	Mexico	17° 10' N	96° 21' W	2450 – 2770	1135	16
14	Carrizal de Bravo	Guerrero	Mexico	17° 34' N	99° 53' W	1980 – 2440	1209	10
24	San Mateo Río Hondo	Oaxaca	Mexico	16° 08' N	96° 29' W	2360 – 2520	1300	17
25	Yextla	Guerrero	Mexico	17° 36' N	99° 51' W	2180 – 2410	1700	14
26	Llano de las Flores	Oaxaca	Mexico	17° 27' N	96° 29' W	2850 – 2920	1400	0*
27	San Lucas	Guerrero	Mexico	17° 15' N	98° 30' W	2660 – 2700	1500	0*
25	Provenances	7 States	1 Country	16 - 24° N	96 - 100° W	1500-2920	1489	624

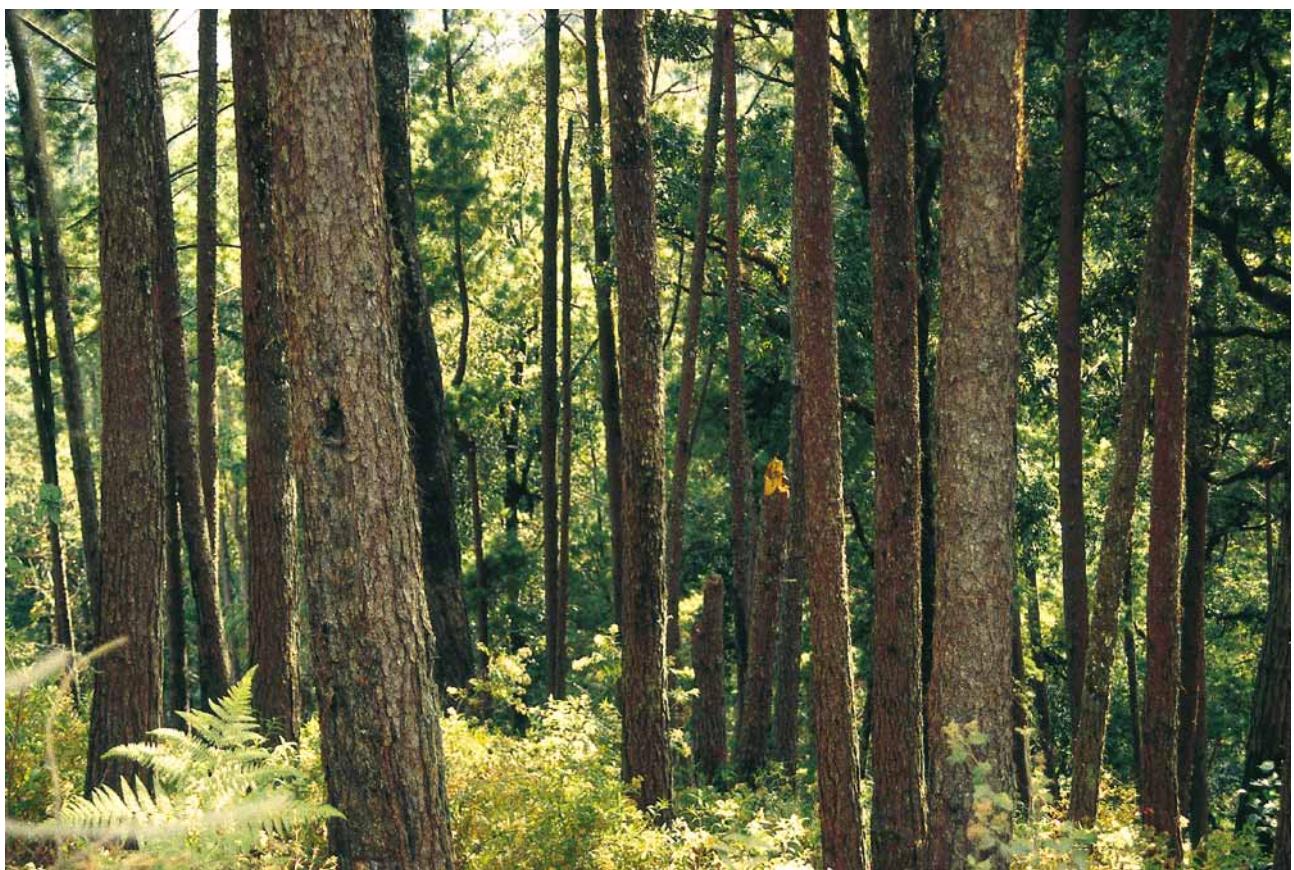
* Site visited, no collections made.

Figure 10-1. CAMCORE collections of *Pinus patula* in Mexico.





Photos 10-3a, b and c. Bark characteristics of typical *P. patula* var. *patula* (above left) at Zacualtipán, Hidalgo, var. *longipedunculata* (above right) from northeastern Oaxaca at Ixtlán, and var. *longipedunculata* (below) in the far western part of its natural distribution at Yextla, Guerrero.



Pinus patula var. *longipedunculata*

Pinus patula var. *longipedunculata* was first identified by Martínez (1948) in the Sierra de Oaxaca at San Andrés Pápolo and was officially described later by Loock (1950). The variety extends southward and westward into the Sierra Madre del Sur and has been identified in southwestern Oaxaca at Tlacuache (Perry 1985), and in Yextla and Carrizal de Bravo, Guerrero (Donahue 1986). The var. *longipedunculata* populations in the Sierra Madre del Sur are morphologically different from those originally described by Loock (1950) in the mountains of northeastern Oaxaca. Their needles and cones are shorter, and needles are darker green, less pendent, and have a higher percentage of resin canals in the internal position. In a study conducted by CAMCORE, most var. *longipedunculata* populations were not distinguishable from *P. patula* var. *patula* using RAPD or AFLP markers. However, trees from Yextla, Guerrero, as well as several trees from Tlacuache, Oaxaca, were atypical in that they lacked several markers that were present in var. *patula* and the other var. *longipedunculata* populations. These unusual trees are more closely related to *P. patula* than to *P. herrerae* or *P. pringlei* (CAMCORE, unpublished data).

Both Perry (1991) and Farjon and Styles (1997) suggest that var. *longipedunculata* also occurs east of the Isthmus of Tehuantepec near San Cristóbal de las Casas, Chiapas. Although some trees around San Cristóbal appear almost morphologically identical to those in the Sierra Madre del Sur around Manzanal, Oaxaca, the Chiapas populations examined by CAMCORE possess only *P. tecunumanii* species-specific markers and not *P. patula* ones (CAMCORE, unpublished data).

CLIMATE

Pinus patula occurs in moist temperate to subhumid temperate climates throughout most of its range (Vela 1980). Annual precipitation varies from 1000 mm to 2500 mm with most of the rain falling between June and October. The clouds and fog that often cover the forests increase the total moisture received by the trees over documented precipitation. Vela (1980) states that *P. patula* sites are under the influence of misty weather between

42 and 176 days per year. Dry seasons (i.e., periods with monthly precipitation less than 40 mm) are nonexistent at some sites but may be up to five months long at others, typically between the months of December and May (Tables 10-2a and b).

Average temperature at *P. patula* sites ranges from 10 to 18 °C. During the winter months, nighttime temperatures can fall as low as -9 °C in the mountain highlands and, depending on the site location, the number of frosts ranges from 5 to 101 (Vela 1980). The most frost-prone locations in the CAMCORE collections are probably Cruz Blanca, Cumbre de Muridores and Ejido Ingenio del Rosario. The average number of snow days averages from less than one to about two per year at locations north of the state of Oaxaca. Although probably at a low frequency, the var. *longipedunculata* populations of Manzanal, San Mateo and Tlacuache all experience frosts. The Guerrero populations at Yextla and Carrizal de Bravo may experience the most subtropical climate of any of the populations in the species range.

SOILS

The soils on which *P. patula* occurs tend to be deep and well drained. Of 14 *P. patula* soil profiles excavated by Vela (1980) across the species' natural distribution, the most shallow soil was 60 cm in depth, while others were as deep as 1.0 to 2.0 m. Surface soil horizons on *P. patula* sites are generally coffee-colored, with a tendency to become reddish or yellowish with increasing depth. Of the profiles that Vela examined, A horizons were pure loams at eight sites, while the others were sandy loams or clay loams. The B horizons had higher clay content than the A horizon and varied from sandy to clay loams to pure clay. Soil pH values in Vela's (1980) study ranged from 4.8 to 6.4 when soil samples were assessed from the A1 horizon (approx. 5 to 25 cm depth).

CAMCORE also collected soil information at a number of *P. patula* locations in Mexico. At Ejido Ingenio del Rosario, Donahue (1986) summarized the soil conditions as follows: "Soils formed on level to rolling terrain with slopes to 40% and are well drained with needle and organic layers of 4 to

Table 10-2a and b. Monthly mean temperature (°C) and rainfall (mm) recorded at the *P. patula* var. *patula* site in Zacualtipán, Hidalgo (top) and var. *longipedunculata* site at Manzanal, Oaxaca (bottom).

Zacualtipán	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	10.7	11.1	13.9	15.8	17.5	15.7	15.0	15.5	14.1	12.9	11.4	10.1	13.6
Mean Rain mm	49	41	44	69	87	215	278	206	577	312	114	56	2048

Based on 40 years of data collected at Zacualtipán (1800 m elev.), 2 km from the collection site (Donahue 1986).

Manzanal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	16	19	18	20	18	18	18	18	18	18	17	16	17.8
Mean Rain mm	25	5	13	21	116	216	249	261	257	146	29	10	1348

Based on 40 years of data collected at Pochutla (2842 m elev.), 11 km from the collection site (Donahue 1986).

10 cm that overlay a silt loam A horizon and a silt clay loam E (A2) horizon that reach a depth of 35 to 65 cm. The B horizon extends an additional 70 cm or more on the more level surfaces but is very thin on sloping sites. Soil pH increases with depth, ranging in values from 4.0 to 4.5 in the A horizon and 4.7 to 5.4 in the B horizon". *Pinus patula* usually occurs on Alfisols but is occasionally found on more degraded and shallow Ultisols and Inceptisols, especially in transition zones where it occurs with the more drought-tolerant *P. teocote*.

REPRODUCTIVE BIOLOGY

Pinus patula var. *patula*

Flowering of *P. patula* var. *patula* occurs from January to April in the states of Hidalgo, Puebla and Veracruz (Patiño and Kageyama 1991). Conelets start developing the year after pollination and reach their full size of 55 to 100 mm from September to November. On *P. patula* var. *patula* trees, cones are borne both on the branches and the main stem in clusters of 2 up to 14. Cone collections generally are conducted from December to March, approximately 24 months after pollination. However, local governmental organizations in Mexico have collected cones as early as October (Patiño and Kageyama 1991). Because the cones are serotinous, collections can sometimes be made much later than March. Patiño and Kageyama report that seeds may remain in the cone for as long as seven years with viability sustained at above 60%. However, the CAMCORE experience is that for both *P. patula* and *P. greggii*, most of the seeds are dispersed by the end of March, and mother tree collections should commence in late January and February. Cone crops are generally light for *P. patula* and do not usually occur with regular frequency in natural stands before trees are 10 to 15 years old (Vela 1980). The average seed potential for var. *patula* is 125 seeds (Dvorak 2000). In his rangewide botanical collections from natural stands, Barrett (1972) found an average of 22 filled seeds per cone, yielding a seed efficiency rate of 18%. The average number of seeds per kg is 118,000, but the exact number differs greatly by provenance.

Pinus patula var. *longipedunculata*

The flowering period for *P. patula* var. *longipedunculata* occurs in January and February in the states of Oaxaca and Guerrero. Cones ripen approximately 24 months later from January to March. Cones are usually borne in pairs. Unlike the cones of *P. patula* var. *patula*, which are serotinous, the cones on trees of var. *longipedunculata* located in southwestern Oaxaca and Guerrero are only semiserotinous and most begin to open by late March to late April, as monthly temperatures increase. The average seed potential for var. *longipedunculata* is 95 seeds. The serotinous nature of cones of var. *longipedunculata* from northeastern Oaxaca is intermediate between those of var. *patula* in the north and var. *patula* in southwestern Oaxaca and Guerrero.

ECOLOGY AND ASSOCIATED SPECIES

Pinus patula var. *patula* and var. *longipedunculata* occur in a moist cloud forest environment. Even though they have common ancestry with forests of western North America, *P. patula* vars. *patula* and *longipedunculata* (from northeastern Oaxaca) are often found in association with plant genera that presumably originated in the eastern United States (e.g., *Carpinus*, *Cercis*, *Cornus*, *Juglans*, *Liquidambar*, *Magnolia*, *Prunus* and *Rhus*) (Miranda and Sharp 1950, Barrett 1972). Furthermore, some of the herbaceous components of the forest are of tropical and subtropical origin (Vela 1980). The forests in which var. *longipedunculata* from southwestern Oaxaca and Guerrero occur, have stronger evolutionary ties with plant communities endemic to western North America.

The distribution of *P. patula* var. *patula* in the high Sierras of eastern Mexico mirrors the occurrence of the fog and cloud belt of the region. Above the cloud belt, at approximately 3100 m altitude and the upper limit of the species distribution, relative humidity drops and *P. patula* gives way to other conifers and broadleaf species (Vela 1980). Below 1490 m altitude at the lower limit of the species distribution, nighttime temperatures increase, fogs and rainfall become less frequent and *P. patula* is outcompeted by other pines (e.g., *P. greggii*, *P. oocarpa*), as well as by other conifer and hardwood species.

Within the fog belt region, the occurrence of *P. patula* var. *patula* is defined by soil depth (see Soils). *Pinus patula* is the dominant species in most areas where soils are well drained and at least 60 cm deep. In areas where soils are more shallow, *P. teocote* and *Quercus* (oak) species dominate. The change in species occurrence based on the location of cloud belts and soil depth can be abrupt. For example, as one drives north towards Zacualtipán, pure *P. teocote* stands predominate on the shallow soils on the southern and eastern slopes of the mountain. On the ridge in areas shrouded by clouds, soils become deeper and the dry zone transition forests give way to pure *P. patula* forests within a distance of 400 m.

Pinus patula is an aggressive pioneer species that regenerates rapidly when seeds fall on the exposed mineral soils in forest gaps. Fires play an important role in generating these gaps, and the evolution of serotinous cones allows *P. patula* to take advantage of these natural (and now man made) events. Except at the base of the tree, *P. patula* has thin bark and is therefore killed by most fires of moderate intensity. However, the species can survive low intensity fires, offering the opportunity for *P. patula* seeds to germinate and develop into pine thickets in situations where competing underbrush is removed. Seedling counts of 10,000 plants per ha have been made following the development of a forest opening at one location and 5000 5-m-tall saplings were reported at a different site in Mexico by Vela (1980). Their ability to grow at close spacing maintains a level of humidity within the



Photo 10-4. High mountain ridges of the Sierra Madre Oriental in the distance offer the perfect environment for the development of *Pinus patula* var. *patula*. The region shrouded in clouds is near Zacualtipán, Hidalgo, one of the CAMCORE collection sites.

stand and lessens the risk of destructive fires. The spacing also prevents early invasion by *Quercus* spp., thereby serving as an adaptive mechanism that allows *P. patula* to outcompete neighboring vegetation. For this reason, *Quercus* spp. are commonly observed on the fringes of mature *P. patula* stands but not in the interior. As competition increases and pine mortality occurs as a consequence of the close spacing, additional gaps are opened in the forest and *Quercus*, *Alnus* and other broadleaf and pine species become more common in the understory.

Height growth for *P. patula* in the natural stands of Mexico ranges from an average of 1.0 m/year at 25 years to 0.4 m/year at 72 years (Vela 1980). Diameter increments of 1.0 to 1.5 cm per year are common (Loock 1950, Zobel 1965, Aguirre-Bravo and Winter 1994).

Vela (1980) lists as many as 100 overstory and understory species found in association with *P. patula* and readers are referred to his complete ecological assessment. At approximately 50% of the CAMCORE sampling locations, *P. patula* was found with *P. ayacahuite*, *P. pseudostrobus*, *P. teocote* and *Quercus* spp. In several instances, *P. ayacahuite* occupied areas close to streams, *P. patula* the middle slopes and *Quercus* spp. the fringes of the stand. *Abies* spp. were found at about one-third of the sites. Occasionally, *P. patula* is found with *Liquidambar styraciflua*, *P. greggii* var. *australis*, *P. leiophylla*, *P. oaxacana* or *P. rudis*. On rare occasions, *P. patula* occurred with *Alnus* spp., *Cupressus* spp.,

P. chiapensis, *P. montezumae* or *Taxus* spp. In Guerrero, the var. *longipedunculata* at Yextla and Carrizal de Bravo occurs with both *P. herrerae* and *P. pringlei*.

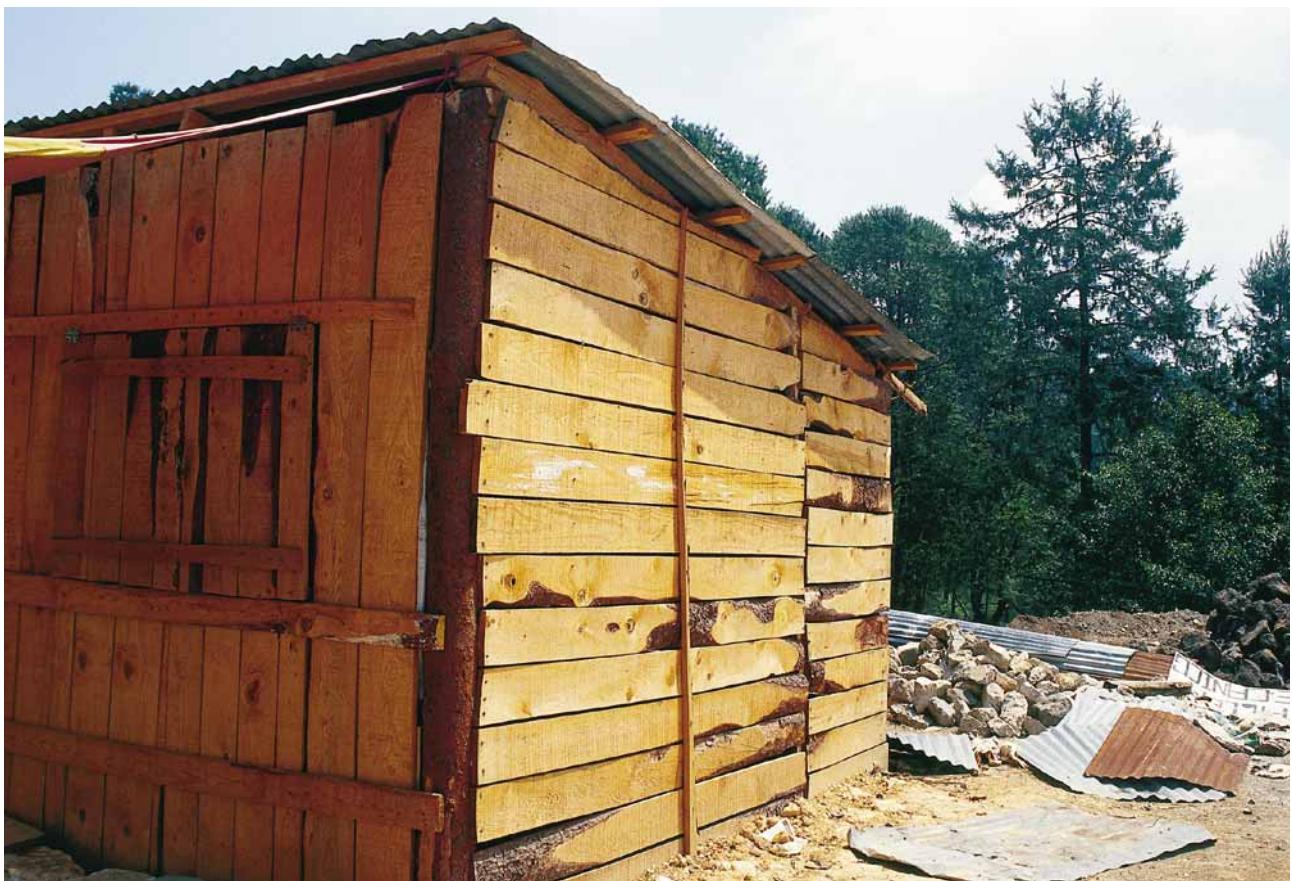
Pinus patula appears to be relatively disease-free in its natural environment, an intriguing observation given that the species is quite susceptible to pests as an exotic (see Pests and Disease). Cone and seed borers have been described on the species (Cibrián-Tovar et al. 1995). *Cronartium conigenum* (cone rust) occasionally affects the cone (Patiño and Kageyama 1991), but not as frequently as is the case for *P. oocarpa* in Central America.

WOOD QUALITY IN NATURAL STANDS

Pinus patula has pale brown heartwood, yellowish-white sapwood and displays well-defined annual rings when grown in native environments. Despite its importance as a timber species worldwide, there have been relatively few studies on the wood quality of *P. patula* in Mexico. Zobel (1965) sampled 10 trees from two provenances in Tlaxcala and Puebla and found the wood to be of moderate density: 430 kg/m³ (extracted) at approximately 40 years of age. These values were the same as those obtained from samples of *P. maximinoi* but 12% less than from *P. oocarpa* of the same age. Average tracheid length of *P. patula* was 4.0 mm. In Mexico, the wood is used as siding for sheds and houses, sawtimber, telephone poles, mining timber, containers for export products, fences, furniture, fruit crates, pallets and fuelwood (Patiño and Kageyama 1991, Romero 1991).



Photos 10-5a and b. Above, pale brown heartwood and yellowish-white sapwood of recently cut *Pinus patula* at Huayacocota, Veracruz. Below, the wood of *P. patula* is used locally for siding on small houses and sheds and for a number of other products.



PLANTATIONS

Pinus patula is the most widely planted species in the Mesoamerican *Oocarpace* subsection. Approximately 1.0 million ha have been established worldwide, the majority of which is in southern and eastern Africa in the countries of Tanzania, Malawi, Kenya, Zimbabwe and South Africa. Commercial plantings of varying sizes have also been established in the highlands of Argentina (Jujuy State), Colombia, Ecuador, and Peru. Two small but successful *P. patula* operations exist in Brazil in Minas Gerais and Santa Catarina. Test plantings and arboreta exist near sea level as far south as Valdivia, Chile (40° S). After *P. radiata*, it is possibly the most widely tried species in the tropics and subtropics. Depending on site quality and the amount and distribution of precipitation, average productivity values in commercial plantations vary from 12 m³/ha/yr to approximately 25 m³/ha/yr at rotation ages of 15 to 25 years.

NURSERY PRACTICES

Seed Handling

CAMCORE members store *P. patula* seed at 2 to 8 °C with a moisture content ranging from 6 to 10%. Seeds can remain viable from five to ten years under these conditions. Most organizations do not stratify the seeds before sowing. However, Daniels and van der Sijde (1975) increased germination of *P. patula* seed by 5% by incorporating a cold stratification at 4 °C for seven weeks followed by storage at 25 °C for two weeks. INPACEL soaks *P. patula* seed in water for 24 hours, followed by a 30-day incubation at 5 °C prior to sowing (L. Duda, personal communication).

Some members use pregermination treatments before sowing seeds. Sappi soaks *P. patula* seed in 1.0% hydrogen peroxide (aerated) at 25 °C for 24 to 48 hours to promote consistently high germination (A. Bayley, personal communication). Smurfit Cartón de Colombia subjects seeds to a 24-hour water soak at 25 °C and then dries the seeds in the shade before sowing (M. Arce and V. Betancur, personal communication). Mondi Forests pregerminates seeds in a water bath for 24 hours at pH 5.6 and 28 °C with compressed air bubbling through the water. RIGESA and Klabin do not use any pregermination treatment for *P. patula*.

Containers and Growth Media

Pinus patula nurseries are predominantly containerized. Container size varies from one organization to another. Sappi uses a 340 × 340 mm tray with 49 cavities. Cavity depth is 80 mm, with a diameter of 40 mm and a volume of 80 cm³. Smurfit Cartón de Colombia uses a tray with 40 tubes as well as Jiffy® pellets. The capacity of tubes and pellets are 125 and 34 cm³ (height 55 mm and diameter 22 mm), respectively. Mondi, SAFCOL, INPACEL and

Klabin all use tubes with a capacity of approximately 60 cm³. RIGESA uses a slightly larger tube with capacity of 110 cm³ (H. Guimaraes, personal communication).

The planting media also differs among organizations. The South African organizations (Sappi, Mondi and SAFCOL) use 100% composted pine bark for *P. patula* seedlings. In Brazil, INPACEL uses 75% composted pine bark, 15% vermiculite and 10% rice husks. Klabin uses 75% composted pine bark and 25% vermiculite. RIGESA uses equal parts of composted pine bark, vermiculite and topsoil. Smurfit Cartón de Colombia uses equal parts composted sawdust, carbonized ash (from the boilers at the mill) and yellow subsoil with some organic material. The pH of the most media is between 4.5 and 5.9.

Seedling Management

The goal of CAMCORE organizations is to produce a *P. patula* seedling that is 10 to 25 cm tall with a root collar diameter from 2 to 8 mm. The South African and Colombian organizations have opted to outplant smaller seedlings with heights of 10 to 20 cm with 2 to 4 mm root collar diameters, while the Brazilian organizations, with their abundant and well-distributed rainfall, tend to outplant larger seedlings. Seedlings reach plantable height 20 to 30 weeks after sowing. The optimum planting window for *P. patula* at Sappi's Ngodwana nursery is from 20 to 28 weeks after sowing, after which seedlings become root bound (Bayley and Snell 1998).

Fertilization of seedlings in the nursery follows the normal protocol used for other commercial species. Several organizations begin fertilizing 10 weeks after sowing. INPACEL applies the slow-release fertilizer Osmocote (19-6-10) several weeks after seedlings begin to develop in the nursery. Nurserymen at Smurfit Cartón de Colombia suggest care in fertilization in an effort to avoid burning plant needles.

In South Africa, most nurseries use shade cloth to protect growing seedlings from the hot sun and damage from birds. The shade cloth also serves as a barrier to hail storms. At Klabin, Brazil, seedlings are kept for four weeks in the greenhouse, followed by two weeks under shade in an outdoor nursery and are then allowed to harden off for 18 weeks.

Pinus patula is quite sensitive to Glyphosate, and as a consequence, herbicide application in the nurseries and young plantations needs to be timed for periods without strong winds. The species was particularly susceptible to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in several nurseries in South Africa (Viljoen et al. 1994).

Seedling age, seedling size and postplanting climatic factors affect *P. patula* seedling survival rates (Morris 1990, 1991,



Photos 10-6a and b. Above, hedges of *P. patula* being grown in a Mondi Forest nursery in South Africa. Below, Dick Danks, Mondi Forests, walks through a field trial of 2.5-year-old cuttings of *P. patula*.



Bayley 1995, Bayley and Kietzka 1997, Bayley and Snell 1998). Seedlings with height to root collar diameter ratios greater than 100 and young seedlings (approx. four months old) where the root plug had not been properly bound are most susceptible to mortality (Bayley 1995). Mortality is higher when seedlings are outplanted just prior to the onset of either hot or freezing weather or the dry season.

Vegetative Propagation

Several organizations have propagated *P. patula* as a rooted cutting with operational success. Many organizations claim that hedge management is critical to rooting success in *P. patula*. However, there are many management options. Smurfit Cartón de Colombia attempted to propagate *P. patula* with the protocols developed for *P. tecunumanii* and *P. maximinoi* (see Osorio 1993). Their success rate was much lower with *P. patula* than with the other species. As was mentioned earlier, when *P. patula* is planted near the equator, it grows best at elevations above 2200 m. Because the Smurfit Cartón de Colombia nursery is located at 1450 m altitude, new hedges were established at 2100 m and cuttings were transported to the nursery for rooting. The rooting success for cuttings harvested from the "high elevation" hedges was much greater than rooting percentages from the hedges at 1450 m elevation (80% rooting for cuttings from high elevation hedges versus 39% rooting for cuttings from hedges at 1450 m elevation).

Hedges for the Smurfit Cartón de Colombia program are established at 1 x 1 m spacing and are fertilized with 50 g NPK (15-38-10) and 10 g borax at the time of planting. The operational life of these hedges is approximately four years. The first hedging is conducted when the seedlings are 40 to 50 cm tall; stock plants are hedged to a height of 20 cm. The first sprout harvest occurs six months after the first hedge cut and can be repeated every two months for the life of the hedge. If the hedges are harvested intensively, they are fertilized every six months with NPK and as well as with micronutrients. Even if the hedges are not being harvested, they are cut back to 20 cm twice a year to maintain the juvenility of the sprouts (V. Betancur, personal communication).

The Smurfit Cartón de Colombia nursery only harvests juvenile sprouts (no secondary needles) about 6 cm in length with minimum diameter of 2 mm (V. Betancur, personal communication). The sprouts (cuttings) are dipped in a fungicide solution for 10 minutes before being processed. Liquid Indolebutyric acid (IBA) at 1000 ppm is used as the rooting hormone. The base of the cutting (2 cm) is submerged in IBA for five seconds and then is allowed to dry for 10 minutes before setting. The cuttings are set in Jiffy® pellets and placed in a mist house for rooting. The mist house is kept at 15 to 32°C with 40 to 70% humidity. Cuttings remain in the mist house for approximately 10 weeks before they are moved to a shade house (46% shade) for another six weeks. After the shade house, the rooted cuttings are hardened off under direct

sunlight for four to seven weeks and then are sent to the field for plantation establishment. The total time required for *P. patula* rooted cutting production at the Smurfit nursery ranges from five to six months.

Fertilization begins seven or eight weeks after the cuttings are set and continues every two weeks until the cuttings are sent to the field. Smurfit Cartón de Colombia applies 0.025 g of fertilizer per cutting (V. Betancur, personal communication).

In South Africa, organizations are extremely cautious about large-scale commercial production of family rooted cuttings. First, the rooting percentages need to be improved some to maximize returns. Second, the high incidences of *Fusarium subglutinans* f. sp. *pini* (pitch canker) outbreaks in hedged plants has caused some concerns as well as the difficulty in achieving good stocking after field establishment (G. Mitchell personal communication). Rooted material is being used on a limited basis with each organization planting approximately 200,000 cuttings per year until techniques of hedge management and outplanting have been further refined.

Sappi keeps their *P. patula* hedges in 10-liter black plastic bags for a period of 3 years. Hedges are first cropped to a height of 15 cm above ground level to initiate shoot production and are kept at that height to help maintain juvenility. Cuttings harvested from these hedges are 8 to 10 cm in length and reduced to 6 to 8 cm upon setting. Such cuttings are referred to as macrocuttings. Mondi reports an improvement in root strike and cutting quality by producing microcuttings. Microcuttings are harvested from minihedges grown under intense management in Unigro® 98-way trays. The hedges remain in trays for 18 months before they are planted out into 10-liter black plastic bags for macrocutting production. This is done to best utilize small quantities of seed available from controlled crosses. In the current approach used by Sappi and Mondi, hedges are established from seed and replaced every 3 years with new seedlings.

In Sappi's Ngodwana nursery, hedges are fertilized on a monthly basis by manual application of soluble fertilizer (6.5, 2.7, 13% NPK) at a rate of 5 g per hedge; the hedge is irrigated following the fertilizer application. As hedge age increases there is a reduction in nutrients from the composted pine bark growing medium supporting the hedge plant in the bag, making the application of fertilizer increasingly important (G. Mitchell, personal communication). At their Klipkraal nursery, Mondi applies Follifert and Calmag fertilizers through the irrigation system plus a granular application of 2:3:4 NPK (10g/bag) to the potted hedges.

Juvenile shoots, which are identified by an actively growing bud and a high proportion of primary needles, are set on a monthly basis. Approximately 10 harvests are conducted each year, with hedges receiving a harvest once a month

during the summer growing period and every six weeks during the winter growing period. An average of five to eight shoots is set from each hedge during a harvest. Expected rooting percentage can exceed 80% during the summer period and 65% during the winter period. Rooting is increased, particularly during the winter months, by heating the root zone area, with optimum temperature between 25 and 28 °C. Failing to heat the growth medium can result in a loss in rooting of up to 50% and root mass of 166%. Cuttings are set either directly into well-composted pine bark or a 4:1:1 mixture of pine bark, vermiculite and perlite. No rooting hormones are applied. Misting the cuttings for approximately 20 seconds every 30 minutes is necessary during the day to reduce transpiration. Misting frequencies may be altered depending on the weather. *Pinus patula* cuttings are left to root in this environment for a period of 90 days in winter and 60 days in summer; after which they are maintained under a 17% shade cloth for 4 to 5 months before outplanting.

STAND MANAGEMENT

Site Selection and Establishment

Because a number of sites have been planted to *P. patula*, reliable information on where and where not to establish the species is now available. In Colombia (2° to 7° N), a typical site on which *P. patula* would exhibit good growth would range from 2200 to 2500 m in altitude and would receive from 1500 to 2000 mm annual precipitation. Average monthly temperature would range from 10 to 22 °C with no frosts and no months with less than 25 mm of precipitation. An Andisol (Oxic Humitropept, Typic Dystrandapt) soil order with a sandy loam A and B horizon and soil depth of approximately 1.0 m would produce trees with good growth rates. Soil pH should range from approximately 4.6 to 5.0. (J. B. Urrego, personal communication).

In South Africa (24° to 31° S), an average site for *P. patula* would be defined as one in the mist belts of the eastern highlands between 1200 and 1650 m altitude. The soils would be Oxisols (Hutton series) and have a sandy loam to sandy clay loam A horizon and a sandy clay loam to clay B horizon of at least 70 cm, but preferably more than 1.0 m depth. Soil pH should be about 4.5. Rainfall should be at least 850 to 1000 mm per year with no more than 4 months with less than 25 mm of precipitation. Average monthly temperatures should range from 5 to 23 °C with approximately 20 frost events.

Pinus patula has either failed or performed poorly on sites that are too tropical (too low in altitude). Planting of *P. patula* should be avoided on sites below 2000 m in Colombia and below 1000 m in South Africa. The species also performs poorly on shallow soils (less than 40 cm) and above 1800 m in South Africa where temperatures may be too cold for proper development. Its growth stagnates on

poorly drained or waterlogged sites. The species is highly susceptible to *Sphaeropsis sapinea* (Diplodia) in hail belt areas in South Africa and in humid areas of Brazil between 24° and 27° S and less than 1000 m altitude. Sites that are deficient in boron may result in poor development unless fertilizer containing the nutrient is applied (see Pests and Limiting Factors).

Silviculture

Plantations have been established at spacings between 2.5 × 2.5 m and 3.0 × 3.0 m, depending on the organization. Morris (1995a) found that when tree stocking fell below 1333 trees per ha (approx. 2.75 × 2.75 m spacing) on good sites in Swaziland pulpwood yields were not maximized. Planting density had no effect on the development of stand mean height (Morris 1995b) or on stem form (Morris 1995c). Stocking had minimal effects on wood density and pulp and paper properties (Malan et al. 1997).

The response of *Pinus patula* to fertilizer in South Africa, applied at planting appears to be very site specific. Currently the recommendation within South Africa is to fertilize all pines at planting with 20 g of phosphate per seedling (ICFR Annual Report 1999). However, as discussed in the ICFR Annual Report (1999), this recommendation is made with caution, as the duration and magnitude of the growth improvement is variable. Generally, the application of phosphorous improves growth in the short term after planting (Morris 1986). On some sites where there is an inherent nutrient deficiency, the correction of this can lead to large and sustained responses. For example, the addition of phosphorous and potassium at planting and again at 6 to 8 years increased growth on gabbro-derived soils (Morris 1986, 1987). However, on other sites, the early growth improvements are not large or are not sustained (Morris 1986, Carlson and Soko 1999). The application of fertilizer at planting, or soon thereafter, gives better responses than delayed applications (Carlson and Soko 1999). In addition, it is imperative that good weed control is practiced when fertilizer applications are made, otherwise poor and even negative responses to the nutrient additions can occur (Little et al. 1997). In southern Africa, nitrogen additions are also recommended for unthinned stands 10 years and older that are above 1400 m elevation (Morris 1994, Carlson et al. 2000). *Pinus patula* has also been found to respond to nutrient additions made at the time of first thinning (Carlson and Soko 2000). As with fertilizer applications made at planting, there is a strong geological influence on the elements that initiate the positive growth response when nutrients are added at the time of the rotation.

Replacement of dead trees (blanking) was much more effective at two months than 11 months after field planting (Morris 1995d). Trees replaced at 11 months remained small and adversely affected the utilizable yield of the stand. Crown closure occurs between 4 and 6 years.



Photo 10-7. Trees of *Pinus patula* were pruned at Smurfit Cartón de Colombia to improve access to the trial and to reduce the fuel load.

A number of pruning and thinning studies have been initiated in South Africa (Poynton 1977). If a large proportion of the crown is removed during pruning (> 25%), growth can be greatly reduced for as long as 4 years. When 25% of the crown was removed, diameter growth was minimally affected. Height growth was less sensitive than diameter growth to pruning (Poynton 1977). Precommercial thinning for sawtimber is conducted at 8 years of age in South Africa.

In Colombia, *P. patula* is pruned at approximately 5 years of age to reduce fuel load on the site and decrease fire hazard (Photo 10-7). Also the pruning allows more easy access to the stands.

Pests and Other Limiting Factors

Pinus patula is attacked by a number of insects and diseases and has been damaged by rodents, antelopes and baboons. Wingfield and Swart (1994) consider the two most serious diseases on pine plantations in South Africa to be dieback caused by *Sphaeropsis sapinea* (Diplodia) of hail-damaged pines and a root disease caused by *Rhizina undulata* that develops after slash burning of old pine sites. Aphid infestations on stressed pine trees have been reported in southern and eastern Africa for years (e.g., Katerere 1983, Madoffe and Austara 1990). In Colombia and Brazil, insect defoliators are a problem. The most serious and potentially most harmful pests seen in CAMCORE visits to members are summarized in this section.

Insects: *Hylastes angustatus* (Coleoptera) girdles the base of *P. patula* seedlings shortly after field planting in southern Africa. The insect appears to prefer plant parts with high nutrient and moisture contents (Erasmus and Chown 1994). In studies to control the beetle, Atkinson and Govender (1997) found that seedling mortality increased when large amounts of slash were left after harvesting. In one experiment, *H. angustatus* attacks were reduced when seedlings were watered at time of field planting. Treatment of seedlings with the insecticides Lindane and Deltamethrin also reduced the incidence of attack.

Glena spp. (Lepidoptera) are defoliators common throughout Latin America. When large areas of native vegetation are removed, *Glena* spp. move to both pines and eucalyptus, but the damage on *P. patula* has been particularly serious (Rodas 1996, Vila et al. 1975). More than 100 ha of 17-year-old *P. patula* was defoliated in southern Brazil during an outbreak in the 1980s (Martins et al. 1984). *Pinus taeda* and *P. elliottii* growing in the same region were not affected. In the highlands of Colombia, defoliation has occurred repeatedly when insect populations have reached their zenith. Possible remedies include leaving vegetation in the plantation as an alternative host for the insect, identifying and using well-adapted seed sources, and developing resistant family clones for commercial operations. Smurfit Cartón de Colombia researchers have also used natural biological controls such as *Siphonomyia melaena* and *Rogas* sp. to parasitize *Glena* larvae (Rodas 1997).

Sphaeropsis sapinea (Diplodia) has been a problem for years on *P. patula* in southern Africa, particularly in areas subjected to hail storms. For many years it was thought that the pathogen entered the trees only after wounding of the host tissue. Now it appears that the fungus also occurs endophytically in healthy tissue and after stress it initiates infection. Outbreaks can occur after wind damage or other stress events, not necessarily related to hail. Different strains of the fungus exist throughout the world (de Wet et al. 2000). The current thought is that this fungus has been introduced into South Africa on pine seeds imported from various parts of the world (Smith et al. 2000). Based on casual observations in CAMCORE tests, trees from the provenance of Pinal de Amoles seem more susceptible to the pathogen in South Africa than other sources. Damage due to *S. sapinea* dieback is often exacerbated by infestation of trees by the *Pissodes nemorensis* weevil and the *Orthotomicus erosus* bark beetle in southern Africa (Wingfield and Swart 1994).

Sphaeropsis sapinea is also a serious problem for *P. patula* in southern Brazil, where humidity is high and rainfall is well distributed throughout the year. *Pinus patula* is being planted at about 800 m altitude in most of the region, and the trees may also be under some stress. Usually, stands grow vigorously until about age 3 years and then are severely attacked. No wounding agent is present. The disease kills young trees, and although larger trees survive, they are often repeatedly attacked every two years or so resulting in relatively slow growing trees of very poor form. A technician working in the region stated that the disease is always worse when *P. patula* is established in areas that were once planted with *P. taeda* or *P. elliottii*, as opposed to being planting on abandoned agricultural lands. In Brazil, if trees are planted above 1000 m elevation, the *S. sapinea* problem becomes less serious.

There are a number of reports of aphid attacks on *P. patula* in southern Africa (Katerere 1983, Madoffe and Austara 1990). The aphid species most common on *P. patula* include *Eulachnus rileyi* (leaf aphid) and *Cinara cronartii* (black aphid). *Pinus patula* is relatively resistant to *Pineus pini* (woolly aphid). Aphid attack can reduce tree growth and increase stress during the dry season, thereby resulting in either mortality or higher susceptibility to damage by other pests. The CAMCORE *P. patula* provenance trials offer researchers a wonderful opportunity to determine whether some provenances from Mexico are more resistant to aphid attacks than others. Remedies to control high aphid populations include biological control. Infestations of aphids decrease during the rainy season.

Disease: *Fusarium subglutinans* f. sp. *pini* (pitch canker) has been identified on *P. patula* seedlings in nurseries in South Africa and can cause serious problems (Viljoen et al. 1994). The disease has yet to be identified on mature trees in the region. Seedling screening studies done by CAMCORE in the United States also suggest that *P. patula* is very

susceptible to the disease (Hodge and Dvorak 1999). Remedies include finding resistant *P. patula* trees in currently established plantations and crossing *P. patula* with resistant relatives such as *P. jaliscana*, *P. oocarpa* and *P. pringlei*.

Other limiting factors: Boron deficiency limits growth of *P. patula* in exotic plantations on volcanically derived soils. This problem has been most evident in the highlands of Colombia, possibly because Smurfit Cartón de Colombia researchers have done an excellent job of monitoring the status of their plantations. Symptoms of boron deficiency include dieback of the terminal leader and the branches in the upper crown, which gives the tree a bushy appearance. Ladrach (1978) found that applying borax at a rate of 5 g per tree at time of planting, accompanied by standard doses of nitrogen and phosphorus, produced very favorable growth responses. An unexpected outcome of boron application was a reduction in forking (Ladrach 1978).

WOOD QUALITY IN PLANTATIONS

As many as 500 articles have been written on the wood quality of *P. patula* and these have been summarized in annotated bibliographies written by Wormald (1975) and Wright (1994). The wood tends to be whitish with a yellowish tinge, moderately dense and very low in extractives relative to the southern United States pines. It also has long tracheids, high fiber coarseness, and low lignin content when compared to other species (Domisse 1994); these characteristics make *P. patula* superior to the southern pines in South Africa for mechanical pulping. Wood quality of *P. patula* is influenced by harvest age and by climatic and edaphic factors. When planted as an exotic, the wood of *P. patula* is used for charcoal, fuelwood, pallets, fruit crates, telephone poles, plywood, pulp, paper, medium density fiberboard, cement board, sawtimber and a number of other products. Limited amounts of sawtimber have been exported to the southern United States and have competed well with *P. taeda* and *P. elliottii* in those markets. The wood of *P. patula* is generally considered of good quality, but more work is needed in relating how density, tracheid length, microfibril angle, etc. influences the quality of the final product produced at the mill. Because of the wealth of data on wood quality, some of which is contradictory, only a general summary of wood quality is given below.

Density

A number of assessments have been made on the wood density and tracheid length of *P. patula*. Average wood density was estimated to be 400 kg/m³ at 14 years of age on trees planted at 2200 m in the highlands of Colombia (Ladrach 1984), 387 kg/m³ at 14 years of age at when planted at 900 m altitude in southern Brazil (C. Mendez, personal communication), 365 kg/m³ at 11 to 13 years of age when established at 200 m altitude in (Valdivia), Chile

(Rodriguez and Torres 1992), and 332, 412 and 419 kg/m³ at 10, 16 and 17 years of age, respectively, when planted at approximately 1100 m altitude in the Mpumalanga region of South Africa (du Plooy and Venter 1981, Malan and Hoon 1991, Robertson 1991). Generally, *P. patula* has a density that is equal to or slightly lower than the southern United States pines when it is planted as an exotic and a lower density than *P. tecunumanii* or *P. oocarpa*.

Wood density of *P. patula* decreases with increasing elevation in Colombia (Ladrach 1984), but the relationship was found to be much weaker over the range of 800 to 1450 m elevation in Swaziland (Morris et al. 1997). In Colombia, there are distinct differences in wood density between juvenile and mature wood around 1800 m elevation but very few differences at 3000 m. Despite the importance of environment on population mean density, there is likely to be little genotype x environment interaction of any importance. For example, Barnes and Mullin (1984) found no provenance x site interactions across sites for wood density in Zimbabwe, i.e., the provenance ranks remained the same across all sites.

Pinus patula differs from species like *P. maximinoi*, *P. pseudostrobus* and *P. tecunumanii* in that it has higher latewood percentages (Wright and Malan 1991, Malan 1994a). This observation explains to a large extent the more rapid increases in pith-to-bark density in *P. patula* than in species like *P. tecunumanii* (Malan and Hoon 1991, Malan 1994b). The transition between juvenile and mature wood occurred between 4 and 8 years in Colombia (Ladrach 1984) and from 6 to 10 years at locations in southern Africa.

The general conclusion is that there is no significant correlation between wood density and growth rates in *P. patula* (Wright 1994, Malan et al. 1997). Improvements in density can be achieved through selection and breeding, allowing trees to grow longer before harvesting and planting the species at lower (2200 m) rather than higher altitudes (2800 m) in places like Colombia.

Fiber Quality

Like most pine species, tracheid length in *P. patula* increases with tree age. However, tracheid length decreased with the altitude of the sampling site in Colombia (Ladrach 1984). Malan and Hoon (1991) found tracheid length to vary from 2.3 to 3.8 mm at rings from ages 2 and 14 years, respectively. Average tracheid length in a pulping study done on 10-year-old trees in South Africa was 3.2 mm. (du Ploy and Venter 1981). In a study of 16-year-old trees of 10 pine species, Domisse (1994) concluded that *P. patula* generally has longer than average tracheids compared to the other pine species examined.

Sawmilling Properties and Extractives

Pinus patula is used for solid wood products in South Africa, Zimbabwe and other African nations. Its timber quality is

very acceptable for structural uses. Spiral grain in *P. patula* averaged 3 to 3.5° and is not a limitation in the production of quality boards.

Pinus patula trees have 2.1% extractives at 18 years when grown at 1490 m in Swaziland (Morris et al. 1997), 2.8% at 11 to 13 years at 150 m altitude in Chile (Rodriguez and Torres 1992) and 3.1% for 17-year-old trees grown at 1100 m in Mpumalanga, South Africa (Robertson 1991). Generally, *P. patula* has lower extractive contents than the southern United States pines as well as many of the Mexican and Central American pines, including *P. caribaea*, *P. greggii*, *P. tecunumanii* and *P. oocarpa*. Morris et al. (1997) found that percent extractives decreased with increased age of the tree.

Pulp Quality

In laboratory kraft pulping of juvenile (8-year-old) pines conducted by CAMCORE and Smurfit Cartón de Colombia, *P. patula* wood required the lowest active alkali to achieve a given kappa number (Wright et al. 1996b). Percent lignin in *P. patula* was approximately 28% in both South Africa and Swaziland and 31% in Chile (Morris et al. 1997, Robertson 1991, Rodriguez and Torres 1992). Lignin content of *P. patula* was less than *P. elliottii* in Swaziland, and less than or equal to lignin content of *P. elliottii* in Chile and South Africa.

Morris et al. (1997) found strong correlations between pulp strength properties and both age and elevation in *P. patula*. Burst strength, tensile index and double folds decreased with increasing altitude. Tear strength increased with age, but there was no relationship between tear strength and site altitude. Yields of *P. patula* were greater than that for *P. elliottii*.

In a study on 17-year-old trees, Wright and Sluis-Cremer (1992) found *P. patula* to have statistically higher kraft pulp yields than *P. taeda*. In a kraft pulping study using 8-year-old trees from Smurfit Cartón de Colombia/CAMCORE trials grown in Colombia, *P. patula* had higher screened pulp yields than did *P. tecunumanii*, *P. maximinoi*, and *P. chiapensis* (Wright et al. 1996a). In TMP and CTMP tests, Domisse (1994) found that *P. patula* had one of the lowest energy requirements for both refining and beating, demonstrated excellent opacity values, good yields, and with the exception of *P. radiata*, had better strength properties than the other nine Mexican and United States pine species tested. In a different TMP and CTMP study conducted on 8-year-old CAMCORE material, *P. patula* demonstrated better tear and physical sheet brightness than *P. tecunumanii* (Wright et al. 1996b). Better brightness suggests the need to use less bleach to achieve a target brightness in the pulping process. In general, *P. patula* has excellent pulp qualities. However, in some regions, the wood's low density may affect the strength properties of the final product.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

Prior to the collections made by CAMCORE, four *P. patula* provenance collections were made over the last 45 years in Mexico. Between 1959 and 1962, New Zealand researchers collected seeds from four provenances as part of a larger introduction effort to determine if Mexican pines could outgrow *P. radiata*. The provenances were from the state of Hidalgo, northeastern Oaxaca, and Veracruz. In 1969, the South African Department of Forestry made collections in Hidalgo, northeastern Oaxaca, and Puebla, sampling four provenances and 22 mother trees (Darrow and Coetze 1983). Also in 1969, the Zimbabwe Forestry Commission received seeds from eight provenances from a limited area of Mexico (Hidalgo and Veracruz) and planted these on six sites in 1971 (Barnes and Mullin 1984). In 1972, Argentinean researchers conducted one of the most comprehensive collections of *P. patula* in Mexico, sampling from 16 provenances and 110 mother trees (Barrett 1972). Their collection was unique because it was the first to include populations from the northern part of the species range in the state of Tamaulipas (El Cielo). The seeds were established in trials in Jujuy state in northwestern Argentina and at Mac-Mac, South Africa. In the early 1980s, the Food and Agriculture Organization (FAO), Rome, Italy, in collaboration with the Instituto Nacional de Investigación Forestal (INIF), Mexico, distributed 12 bulk seed lots of *P. patula* to interested participants around the world. The collections came mainly from the central part of the species range in Veracruz, Puebla, Hidalgo, Querétaro and Tlaxcala. Some results are available from all of these studies, but the differences in composition of provenance trials make it difficult to make comparisons across environments. Generally, local *P. patula* improved controls were much better in stem form (Barnes and Mullin 1984) and grew more rapidly than the unimproved, introduced material (Kanzler 1994). On warm subtropical sites, the northeastern Oaxaca provenances demonstrated potential (Darrow and Coetze 1983) but when planted in moist temperate regions showed much less promise (Picchi 1988).

From 1986 to 1995, CAMCORE, in collaboration with host organizations in Mexico, made seed collections of both *P. patula* var. *patula* and var. *longipedunculata* in 25 provenances and sampled 624 mother trees throughout the entire natural distribution of the species in Mexico (Dvorak and Donahue 1992). The CAMCORE collections included the most northern population of the species, Conrado Castillo (24° N), as well as never before sampled provenances of the southern variety in southwestern Oaxaca and Guerrero. Seeds were distributed to Brazil, Chile, Colombia, Mexico, South Africa, Swaziland and Zimbabwe. Ninety-three provenance/progeny trials and 50 gene conservation banks were established.

GENETIC VARIATION

Provenance Assessment

There have been three assessments and analyses of the CAMCORE international provenance/progeny tests series. The assessments occurred when trees were 3 years (Dvorak et al. 1995), 5 years (Hodge 1997), and 8 years of age (CAMCORE, unpublished data). Results from all three assessments are presented below.

Survival

Average survival of 33 tests measured at 3 years of age in Brazil, Colombia and South Africa was 83%. At 8 years of age, survival values were approximately the same, indicating that once *P. patula* is well established, it is relatively hardy.

At 8 years of age, survival was 87% in southern Brazil, and 87% in the Colombian highlands. In South Africa, survival was 59% in Jessievale (Mpumalanga), 85% in Sabie (Mpumalanga), 92% in KwaZulu-Natal, and 88% in the northeastern Cape. Jessievale (lat. $26^{\circ} 14'$ S, elev. 1730 m, ann. precip. 921 mm), which had the lowest observed survival, can be cold and dry and has sandy soils. Most of the tests at this site suffered a long drought shortly after establishment, and consequently mortality was high.

Pinus pseudostrobus appears to be better adapted to the marginal conditions at Jessievale than *P. patula*.

Three provenances from southwestern Oaxaca and Guerrero (Manzanal, Tlacuache and Carrizal de Bravo) and one from northeastern Oaxaca (Cuajimoloyas) were susceptible to freezing temperatures and/or drier climates in South Africa. All four of these provenances are classified as var. *longipedunculata*. At Jessievale, the average survival of these four provenances was 17 versus 61% for the other remaining *P. patula* provenances when assessed at 8 years of age (Dvorak et al. 1995). At Commonage in the northeastern Cape (lat. $31^{\circ} 02'$ S, elev. 1480 m, ann. precip. 757 mm), the Cuajimoloyas source exhibited average survival (86%) and Manzanal and Tlacuache poor survival (60%). At climatically moderate sites near Sabie, Cuajimoloyas exhibited average survival (approx. 81%), Tlacuache and Manzanal had poor survival (63%) and Carrizal de Bravo very poor survival (27%). At Maxwell (KwaZulu-Natal), South Africa (lat. $30^{\circ} 02'$ S, elev. 1350 m, ann. precip 877 mm), where freezing temperatures are infrequent, all sources had approximately the same survival (90%). In general, frost resistance of the var. *longipedunculata* provenances decreases as one moves west in the Sierra Madre de Sur. Cuajimoloyas in northeastern Oaxaca occupies an intermediate position between the more temperate provenances to the north and the more subtropical ones to the south and west. Its survival in field tests reflects this intermediacy, sometimes exhibiting cold and drought hardiness, other times not.



Photo 10-8. Eric Kietzka, Mondi Forests, stands in a CAMCORE provenance/progeny test in the northeastern Cape region of South Africa. Trees from southwestern Oaxaca have been killed by frost (foreground) while those from other locations in Mexico have survived very well.

Productivity

Average productivity of unimproved *P. patula* provenances at 8 years of age (over bark) was 11 m³/ha/yr in southern Brazil, 21 m³/ha/yr in the Colombian highlands, 12 m³/ha/yr in Jessievale (Mpumalanga), 12 m³/ha/yr in Sabie (Mpumalanga), 21 m³/ha/yr in KwaZulu-Natal, and 17 m³/ha/yr in the northeastern Cape, South Africa. Productivity of the best unimproved source in each group was 15 m³/ha/yr in Brazil, 28 m³/ha/yr in Colombia, 15 m³/ha/yr in Jessievale, 15 m³/ha/yr in Sabie, 26 m³/ha/yr in KwaZulu-Natal, and 21 m³/ha/yr in the northeastern Cape.

Volume Performance

Provenance performance for *P. patula* is summarized in Table 10-3. The results presented are based on 5- and 8-year measurements of 19 provenances and 180,000 trees established in 70 tests. There was a 25 and 27% difference in volume between the best and the worst source tested in Brazil and South Africa, respectively. In Colombia, the difference between the best and worst provenances was 75%, due primarily to the extremely slow growth of Conrado Castillo (-51% in Colombia, Table 10-3). Excluding Conrado Castillo, the range between the best and worst sources in Colombia was 48%. The best provenances for volume in South Africa were Potrero de Monroy, Cumbre de Muridores, La Encarnación and Corralitla. In Colombia, the best sources

were Corralitla, Manzanal, Santa María Pápolo and El Tlacuache. In Brazil, Zacualtipán, El Cielo, Potrero de Monroy and Corralitla were the most productive. Picchi (1988) also found that Zacualtipán and El Cielo performed best in Argentina. Therefore, only the high rainfall site, Corralitla, from the southern portion of the *P. patula* var. *patula* range was among the best across all three countries. The best provenances from natural stands were only slightly less productive than the best improved sources of *P. patula* in Colombia and South Africa. In Brazil (24° to 27° S), *P. taeda* was more productive than any of the *P. patula* sources planted.

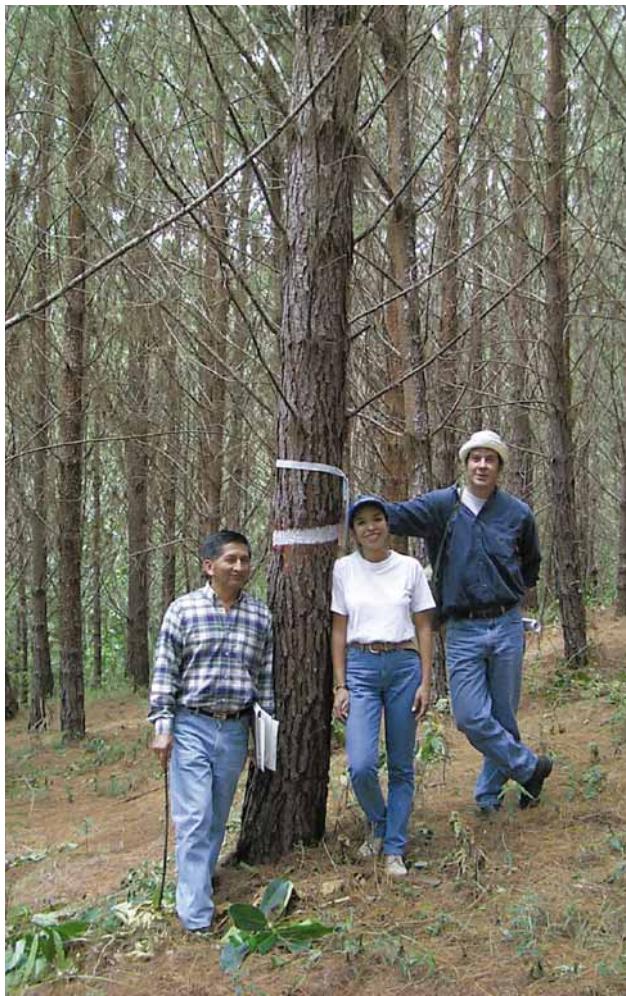
Latitude of the collection site in Mexico was significantly correlated with volume performance in both Colombia and South Africa. A negative correlation between latitude and volume was observed in Colombia ($r = -0.46, p = 0.05$); sources from the southern part of the species range in Oaxaca were superior. As mentioned above, the worst provenance in Colombia was Conrado Castillo (lat. 23° 56' N), the most northern source. In South Africa, there was a positive correlation between latitude of the collection site and volume growth ($r = 0.72, p = 0.001$). Sources from the northern part of range in Veracruz, Hidalgo, and southern Tamaulipas (El Cielo) performed best in South Africa.

Longitude of the collection site in Mexico was also correlated to volume performance in South Africa



Photos 10-9a, b, and c. Above, Enrique Caceres, Forestal Mininco, stands in a young CAMCORE planting of *Pinus patula* in Chile. Below, Heuzer Guimaraes of Rigesa (left) and Bill Hammond, now with Westvaco, inspect a young planting of *P. patula* in southern Brazil. Opposite page, Harold Campo and Norha Isaza, Smurfit Cartón de Colombia, and José Romero, CAMCORE, stand next to an 8-year-old selected tree in a CAMCORE trial of *P. patula* in Colombia.





($r = 0.65$, $p = 0.005$). As mentioned earlier, the natural distribution of *P. patula* is oriented in the northwest-southeast direction in the Sierra Madre Oriental and then goes southward near Las Vigas (see Figure 10-1). The best sources in South Africa are from areas in the northern Sierra Madre Oriental, which also happen to lie more westward than populations in Oaxaca. Falkenhagen (1979) also found the same trends when assessing four *P. patula* provenances planted at four different locations in the Mpumalanga region.

Elevation of the collection site in Mexico was negatively correlated with volume performance in tests in Brazil and South Africa. This probably reflects the fact that provenances from the highest locations in Mexico, like Tlacotla, simply did not grow well. Perhaps trees from high altitude populations set resting buds sooner than other sources and do not grow as tall. In contrast, no significant effect of elevation was observed on volume performance in Colombia. The Oaxacan sources that performed well in Colombia originated at elevations as high as 2300 to 2600 m in Mexico. However, the climatic effects where these sources occur, especially in the southwestern part of the state, are ameliorated somewhat by the effects of the Pacific Ocean.

Volume performance in Colombia was significantly positively correlated with annual rainfall at the collection

site in Mexico. This suggests that provenances in high rainfall areas in Mexico are well adapted to high rainfall areas in Colombia.

Quality Traits

Detailed assessments of branchiness and forking are still being made on 8-year-old tests and will be reported in future CAMCORE documents. Our observations are that branchiness and internodal swelling become more pronounced with increased elevation and rainfall of the planting sites in Colombia. Barnes and Mullin (1984) also found a negative correlation between annual rainfall and stem form ($r = -0.89$) for *P. patula* growing in Zimbabwe, that is, increasing rainfall led to decreases in stem quality. In South Africa branches become larger as one approaches the transition zone between planting *P. patula* and *P. radiata* near Hogsback (32° S) in the Eastern Cape province of the country.

Crown form of the two Tamaulipas provenances, and especially Conrado Castillo, is quite distinct from other sources of the species. The Conrado Castillo provenance has a more compact crown and thicker needles than do other provenances. Its possible coancestry with *P. greggii* needs to be elucidated.

There are distinct differences in stem breakage patterns between provenances of *P. patula* var. *patula* and var. *longipedunculata* from northeastern Oaxaca and *longipedunculata* provenances from the Sierra Madre del Sur. Trees from Manzanal and Tlacuache in southwestern Oaxaca exhibited significantly more stem breakage at both Sombreros, Colombia and Maxwell, South Africa than did trees from more northern sources of both varieties. For example at Sombreros, Colombia (lat. $2^{\circ} 15'$ N, elev. 2450 m, ann. precip. 2177 mm) mean stem breakage for Tlacuache and Manzanal was 56 versus 24% for northeastern Oaxaca var. *longipedunculata* and 11% for typical *patula* (CAMCORE, unpublished data). The stem breakage problem of trees from populations in the Sierra Madre de Sur was also noted during cone collection trips and not only affected var. *longipedunculata* but also *P. herrerae* at Palo Blanco.

Provenance x Site and Family x Site Interactions

Genotype x environment interactions in *Pinus patula* were examined at the provenance and family level in a total of 63 tests (21 in Brazil, 10 in Colombia, and 32 in South Africa) with 5- or 8-year measurements. As Table 10-3 suggests, there are quite important provenance x site interactions for growth traits across countries. On an across-country basis, the Type B provenance correlation for volume between Brazil and South Africa was moderately low ($r_{Bp} = 0.40$), but lower still were Type B provenance correlations with performance in Colombia, with $r_{Bp} = 0.29$ for Brazil-Colombia, and $r_{Bp} = 0.00$ for South Africa-Colombia (Hodge et al. 2001). Interestingly, although Type B provenance correlations across countries

were quite low, Type B genetic correlations for *P. patula* were moderate, with $r_{B_B} = 0.49$ for Brazil-Colombia, $r_{B_B} = 0.66$ for Brazil-South Africa, and $r_{B_B} = 0.56$ for South Africa-Colombia (CAMCORE, unpublished data). These values indicate that family rankings within provenances were moderately stable across countries, although the provenance rankings in various countries would be rather different. Because of variable provenance performance for volume, CAMCORE has adopted a regional approach to breeding in which the populations selected for improvement will differ somewhat in each country or region to maximize genetic gain (Hodge 1997). If selections made in one country are exchanged for selections made in another breeding program, they should always be tested prior to commercial deployment.

On a within-country basis, Type B provenance correlations were moderate to high, with $r_{B_B} = 0.71$ in Brazil and 0.60 in Colombia, but only 0.42 in South Africa due to the very different types of sites that were planted to *P. patula* (CAMCORE, unpublished data). Type B genetic correlations within country were generally equal to or greater than Type B provenance correlations, with $r_{B_B} = 0.69$ in Brazil, 0.65 in Colombia, and 0.75 in

South Africa. Family \times site interactions for growth traits have also been found to be significant within countries by Barnes et al. (1992a, 1992b) and Ladrach and Lambeth (1991).

Genetic Parameters for Growth and Quality Traits

Data from 70 CAMCORE trials in Brazil, Colombia, and South Africa, indicate that individual tree single-site heritability for volume increased steadily from age 3 to age 8 (CAMCORE, unpublished data). Depending on country, age 3 heritability ranged from 0.11 to 0.15, age 5 heritability from 0.14 to 0.17, and age 8 heritability from 0.20 to 0.25. In general, heritabilities were slightly higher in Colombia, perhaps due to the better growth rates observed there. The increase in heritability for volume in CAMCORE South African tests ($h^2_B = 0.11$, 0.17 and 0.20 at ages 3, 5, and 8, respectively) is very similar to that found by Barnes et al. (1992a, 1992b) and Barnes and Schweppenhauser (1979) in tests in Zimbabwe ($h^2_B = 0.12$, 0.18 and 0.19 at ages 1.5, 5 and 8, respectively). Other researchers have also reported similar or slightly higher values for heritability (Ladrach and Lambeth 1991, Kageyama et al. 1977, Nyoka et al. 1994).

Table 10-3. Volume performance (Gain) of 19 provenances of *Pinus patula* tested in Brazil, Colombia, and South Africa. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests
MEXICO	1	Potrero de Monroy	9.6	13	12	-3.2	16	5	14.8	27	9
	2	Ingenio del Rosario	-2.3	.	.	-6.7	10	1	-0.2	22	7
	3	Corralitla	8.3	.	.	24.2	10	1	8.6	21	9
	4	El Manzanal	1.8	.	.	19.3	24	2	-10.9	24	4
	5	El Tlacuache	0.5	.	.	15.9	16	2	-12.2	15	6
	6	Ixtlán	0.2	.	.	11.5	24	2	-8.9	23	6
	7	Santa María Pápolo	3.4	.	.	19.2	24	2	-4.9	24	6
	8	Conrado Castillo	-0.8	25	8	-51.5	25	3	-7.6	25	13
	9	Cuajimoloyas	1.8	4	3	0.4	.	.	-9.1	9	4
	10	Tlacotla	-15.4	21	8	-23.3	17	3	-13.2	19	13
	11	Pinal de Amoles	-12.4	23	8	-10.5	22	3	6.0	23	13
	12	Zacualtipán	10.1	15	8	-2.5	13	3	5.4	14	13
	13	Llano de las Carmonas	-5.6	25	8	-16.7	22	3	-1.3	25	13
	15	El Cielo	8.6	21	5	6.3	.	.	6.2	21	3
	16	La Encarnación	-8.8	17	4	2.5	.	.	9.3	14	3
	17	La Cruz	4.3	24	5	5.2	.	.	6.6	22	3
	18	Cumbre de Muridores	-3.6	28	4	4.0	.	.	9.9	27	3
	19	Cruz Blanca/Manz	4.9	23	5	8.0	13	1	1.2	8	2
	20	Calcahualco	-4.9	13	2	-1.8	12	1	0.9	.	.

Age-age genetic correlations were found to be high in CAMCORE *P. patula* tests. Correlation between volume growth at age 5 with that at age 8 was 0.87 (Hodge 1997). Nyoka et al. (1994) found genetic correlations between growth traits measured at ages 5 and 8 to be above 0.94 in Zimbabwe. In a different data set, Barnes et al. (1992b) found the age-age genetic correlations between volume at 5 years and volume at 8 years at Martin, Zimbabwe close to 1.0. Early selection at age 5 appears to be effective at most locations but a higher heritability for volume at age 8 years than 5 years may better maximize genetic gains (see above).

Individual tree heritability for stem straightness in the CAMCORE tests at 5 years was 0.09 and increased to 0.12 at 8 years (Hodge 1997) and from 0.06 and 0.08 in the Zimbabwean tests reported by Barnes et al. (1992a, 1992b) for the same age period. The heritability for forking in the CAMCORE series was 0.07 at 5 years.

The CAMCORE results are consistent with those found by others who have assessed genetic tests of *P. patula*. The species exhibits appreciable levels of additive variance for metric traits and potential gains from selection and breeding are good. Age-age genetic correlations are high and early selections may be possible for some metric traits. Moderately intense selection of the best families and best trees within families in CAMCORE *P. patula* tests would give gains of 22 and 15%, respectively, for a total estimated gain of approximately 37% (CACMCORE, unpublished data). Realized gains should be on the order of approximately 25%. Interactions are important in *P. patula* for growth traits and provenance and family ranking may change drastically across diverse sites.

DEVELOPMENT OF IMPROVED MATERIAL

Flowering and Seed Production

Pinus patula begins to flower at 2 to 3 years of age in many locations in southern Africa but it takes longer at high elevations near the equator in Latin America (Dvorak 1997). Flowering times vary considerably depending on where the species is planted as an exotic. In the highlands of southern Colombia (2° to 7° N), *P. patula* flowers all during the year with a peak in July and August (Isaza and Arce 1997, Lambeth and Vallejo 1988). In a study in 13 plantations located between 2000 and 3000 m altitude in Colombia, Lambeth and Vallejo (1988) found flower and cone production increased with elevation up to 3000 m. They also found that flowers and cones were produced earlier at the high elevations than at the lower altitudes.

In southern Brazil (27° S) the flowering time appears to be in September but more study is needed (C. Mendez, personal communication). In southern Africa, (18° to 30° latitude) there are two flowering periods, a small peak from January to May and a more pronounced peak in September and October (Barnes and Mullin 1984, van der Sijde and Denison 1967). Results in Zimbabwe paralleled

those in Colombia; flowering began earlier and more flowers were produced at high than at low elevations (Nyoka et al. 2000). Most breeding work is done on the flowers in the second semester.

In both Colombia (Lambeth and Vallejo 1988) and South Africa (Denison 1973), initial attempts to establish seed orchards resulted in limited success because the orchards were placed at elevations too low for good seed production and had to be moved to higher altitudes. Studies now show that in Colombia altitudes between 2500 to 3000 m are best for the establishment of a *P. patula* orchard. Because in Colombia total seed production increases with elevation but percent filled seed decreases with elevation (Lambeth and Vallejo 1988), supplemental mass pollination is used. Supplemental mass pollination has not only increased the number of filled seeds per cone from approximately 6 to 30 but has increased by five-fold the number of cones per tree that reach maturity (J. A. Wright, personal communication). In southern Africa studies now show that the optimum altitude for a *P. patula* seed orchard appears to be 1900 m in the eastern highlands of Zimbabwe (approx. 19° S), 1600 m in Mpumalanga, South Africa (approx. 25° S) and 1450 m in KwaZulu-Natal, South Africa (approx. 30° S). A mean annual temperature between 13 and 16 °C was considered best for cone and seed production (Barnes and Mullin 1984). When seed orchards are properly located in southern Africa, 50 to 70 filled seeds per cone can be obtained.

Pinus patula flowers are much more sensitive to heat buildup in pollination bags than are most other tropical and subtropical pines species, and female strobili can be easily destroyed in spring when temperatures rise rapidly during the day (van der Sijde and Denison 1967). Studies now have shown that brown paper bags and microfibre (tightly woven cloth) are best for controlled crosses in the South African environment because they provide good heat exchange (Hagedorn 2000).

Hybrids

Pinus patula has been successfully crossed with *P. greggii*, *P. oocarpa* and *P. radiata* (Fielding 1960, Critchfield 1967). CAMCORE members have retried these crosses, as well as the cross between *P. tecunumanii* × *P. patula*, which produces many sound seeds. Observations in both natural stands in Mexico and pilot planting in South Africa near Entabeni suggest that *P. patula* will cross with *P. pringlei* (see Chapter 11 *P. pringlei*).

Genetic distance information obtained from assessments of phylogenies generated by CAMCORE (Dvorak et al. 2000) and others (e.g., Liston et al. 1999) suggest that *P. patula* may also successfully cross with a number of other species such as *P. leiophylla*, *P. lumholtzii*, *P. herrerae*, *P. jaliscana* and *P. teocote*. Progeny with morphological characteristics intermediate to *P. leiophylla* and *P. patula* were observed in



Photo 10-10. Terry Stanger, Sappi, stands between a row of *Pinus patula* seedlings (right) and a row of *P. patula* × *P. tecunumanii* hybrid cuttings (left) planted in South Africa.

a SAFCOL planting at Jessievale. The seeds for the planting were collected from *P. leiophylla* mother trees surrounded by commercial *P. patula* plantations (L. van der Merwe, personal communication). Observations of putative hybrids between *P. patula* var. *longipedunculata* and *P. herrerae* in natural stands in Guerrero (Donahue 1986, Dvorak et al. 2000) and *P. patula* var. *longipedunculata* × *P. teocote* in natural stands in Oaxaca (CAMCORE, unpublished data) also support the phylogeny results.

The ability for *P. patula* to successfully cross with a number of other pine species combined with the development of technology to vegetatively propagate hybrid families from seedling cuttings, gives growers a tremendous opportunity to maximize productivity, especially on marginal sites. Tests with *P. patula* hybrids need to be established across a number of sites to determine their true potential.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

Several studies using allozymes have examined the genetic diversity of *P. patula*. In a study of 14 populations and 256 trees, Ramírez-Herrera et al. (1998) found an average of 2.3 alleles per locus; 67% of the loci studied were polymorphic and mean expected heterozygosity was 0.19. In a second allozyme study of five populations of *P. patula* conducted by Butterfield (1990), average expected heterozygosity was only 0.06. Hamrick et al. (1992) found average heterozygosity (within species) for all pines was 0.16. The results of Ramírez-Herrera et al. (1998) would suggest that *P. patula* has above average levels of genetic diversity and the results of Butterfield (1990) would

indicate that the species has below average levels of genetic diversity.

Furman (1997) attempted to calculate measures of genetic diversity for *P. patula* using the branch length of a phylogenetic tree generated by RAPD analysis. However, she found that there were so few (phylogenetic) differences among the 8 populations of *P. patula* in her study, that further genetic diversity calculations were not warranted.

Conservation Status

The conservation status of most populations of *P. patula* var. *patula* is **low risk**, with several like Corralitla in the **vulnerable** category because of intensive logging. Many of

the stands are large, especially in areas around Huayacocotla on the border of Hidalgo and Veracruz. Even though there are a number of sawmills in the region, there is also quite good stand management. Seed trees are left at time of harvest that produce a carpet of natural regeneration. After several years, foresters thin out the regeneration to a reasonable stocking and maintain the stand. Some outlier populations like Conrado Castillo are included in protected areas.

The populations of *P. patula* var. *longipedunculata* in northeastern and southwestern Oaxaca and Guerrero are often small (10 to 20 ha), and are under much more severe pressure from harvesting and agriculture that are provenances further north. Most threatened are the provenances of Manzanal and San Mateo, Oaxaca and San Lucas, Guerrero that are currently being harvested and are **vulnerable** to **endangered**. Cutting in the ejidos of Yextla, Guerrero (that includes Carrizal de Bravo) is not severe at

the present time, but its close proximity to a main road puts the genetic material from this area in doubt. CAMCORE's present classification of the conservation status of *P. patula* var. *longipedunculata* is **vulnerable**. However, the damage done by harvesting will need to be monitored and the conservation status reassessed in the near future.

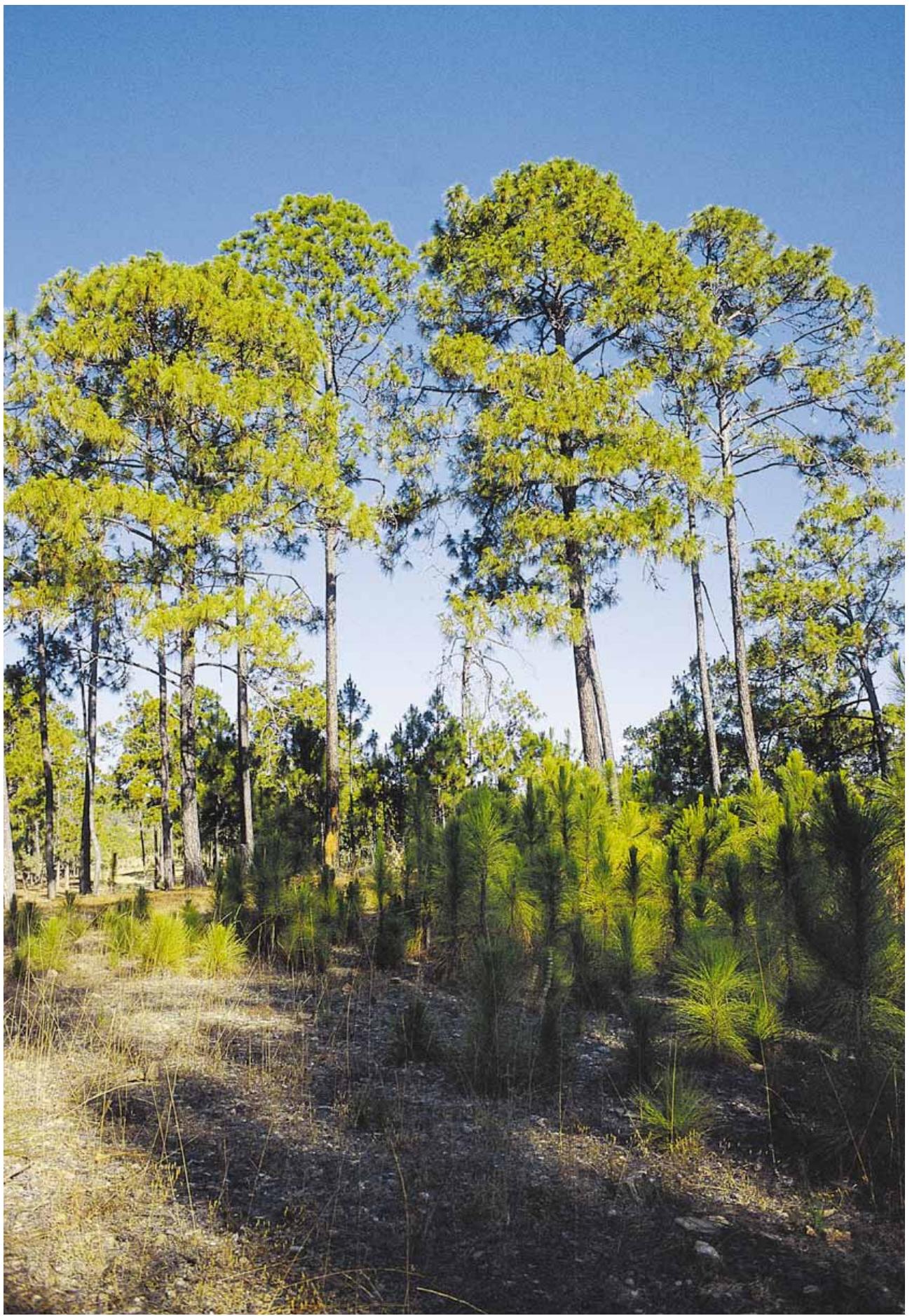
EX SITU CONSERVATION

The CAMCORE collections of *P. patula* in Mexico are the most comprehensive yet made. The international series of genetic tests and conservation banks have been well established and maintained. Explorations need to continue, especially in southern Mexico to determine if additional populations of *P. patula* var. *longipedunculata* exist. Much thought needs to be given about how to maintain conservation base populations for *P. patula*, through several generations, especially for those provenances that currently show little potential.

CONTRIBUTORS

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C h a p t e r I I



PINUS PRINGLEI

W. S. Dvorak, P. Kikuti and I. Fier

OVERVIEW

TREE DESCRIPTION

Pinus pringlei G. R. Shaw is a small to medium-sized tree that ranges in height from 9 to 28 m with dbh (outside bark) of 25 to 55 cm at maturity. The crown is thick, rounded and often irregular in shape on degraded sites. The branches are long and mostly horizontal. The bark of mature trees is thick, scaly and grayish-brown for most of the tree with a tendency towards a reddish color on the upper stem (Perry 1991). The needles are yellowish-green, 195 to 290 mm long, stiff and erect, and usually occur in fascicles of three. New needle growth is produced in small tufts at the ends of branches. The fascicle sheaths are yellowish-brown when young and grayish-brown to black when old (Loock 1950); they range in length from 20 to 25 mm. Cones are 50 to 85 mm in length, long ovate to conical in shape, and are borne singly or in clusters of two, three or four and may carry a small prickle on the scales. Cones mature from late November to March in Mexico. In natural stands, the average seed potential per cone is approximately 120 seeds. There are approximately 55,000 seeds per kg. The wood is pale brown, has a high density and extractive content, and is well suited for construction purposes.

CONSERVATION STATUS

Based on our observations, the conservation status of *Pinus pringlei* is **vulnerable**. Its geographic range is confined to a relatively small area in southwestern Mexico. Many populations are degraded and are being heavily exploited by woodcutters. Population size has been reduced by 25% in many localities over the last decade.

TEST STATUS

CAMCORE members have collected seeds from seven provenances and 174 mother trees of *P. pringlei* in Mexico, mainly in Oaxaca. This work represents the largest mother tree collection ever made of the species. Twenty-one

P. pringlei tests were established in Brazil, Colombia, South Africa and Venezuela. Only eight of these tests have survived through age 5 years; most were lost due to frost in Brazil and drought in South Africa.

BEST PROVENANCES

CAMCORE results from a limited sample size indicate that Tlahuitoltepec and Santa María Lachixio, Oaxaca, Mexico are the best sources for volume production in south-central Brazil, while Santa María Lachixio and El Tlacuache, Oaxaca are preferred for plantings in South Africa. Trees from the El Tlacuache population have significantly better stem form than other sources when planted in South Africa.

SUITABLE PLANTING SITES

Pinus pringlei test plots have been established in tropical and subtropical areas of South America, Australia and eastern and southern Africa. The species has performed best at latitudes between 18° and 25° S on well-drained soils above 800 m elevation. It has been successfully grown in regions where mean annual rainfall ranges from 1000 to 2500 mm. Average productivity rates vary from 8 m³/ha/yr at 8 years in south-central Brazil to 13 m³/ha/yr at 9 years in the eastern highlands of South Africa. A mean annual increment of 20 m³/ha/yr at 20 years in the highlands of South Africa was predicted by Darrow and Coetzee (1983) for *P. pringlei* using models based on data from 10-year-old trees. *Pinus pringlei* does not possess great frost hardiness. Plantings have failed in South Africa, Zimbabwe and southern Brazil (see Poynton 1977), with frost damage being the primary cause. High seedling mortality due to drought has been exacerbated by planting at the end rather than the beginning of the rainy season at some locations. *Pinus pringlei* foxtails excessively when planted near the equator at mid-elevations (1550 to 1750 m) in areas that receive high rainfall.

Photo 11-1. *Pinus pringlei* in Oaxaca, Mexico.

ADVANTAGES OF *PINUS PRINGLEI*

- Excellent wood quality for solid wood products.
- Hybridizes easily with species such as *P. oocarpa*, *P. patula* and, presumably, *P. herrerae*.
- Some tolerance to fire.
- Appears to be a good cone and seed producer.
- Provenance information is available.
- Moderate drought tolerance once established.
- Resistant to *Sphaeropsis sapinea* (Diplodia) after hail storms.
- Resistant to *Fusarium subglutinans* f. sp. *pini* (pitch canker) at the seedling stage.

DISADVANTAGES OF *PINUS PRINGLEI*

- Grows slowly at early ages relative to other tropical and subtropical pines.
- Plantations need long periods of weed maintenance after initial establishment.
- Easily killed by heavy frosts.
- Foxtails excessively near the equator at elevations between 1550 and 1750 m.
- No improved seed available.

NATURAL STANDS

EVOLUTION

Morphologic studies suggest that *Pinus pringlei* is closely related to *P. oocarpa*. This finding is further supported by molecular marker-based RAPD studies, which indicate *P. pringlei* evolved from *P. oocarpa* from eastern Mexico and Central America (see Chapter 1, Evolution). *Pinus pringlei* in turn may be the progenitor of *P. herrerae* and is closely linked to the evolution of *P. oocarpa* and *P. jaliscana* from western Mexico. *Pinus pringlei* also appears to be closely related to *P. lawsonii*, but further research on this relationship is needed.

DISTRIBUTION

Pinus pringlei is found in the Mexican states of Michoacán, México, Morelos, Guerrero, Oaxaca and western Puebla in a series of small, disjunct populations between latitudes of 16° 28' N and 19° 30' N. One reference indicates that the species also occurs in the state of Tlaxcala (Olvera-Coronel 1985). It has been reported to occur at elevations from 1600 to 2600 m but is most common in tropical and subtropical environments between 1650 and 2000 m. The species often occurs on exposed slopes and rolling hills. It is found in pure stands up to 40 ha in size but usually occurs in smaller clumps of trees that are intermixed with other pines and with oaks (see Ecology and Associated Species). Stands in Michoacán at the northern part of the species range appear to be

phenotypically superior to populations in other locations. Many stands in Oaxaca tend to occur on poor sites and have been subjected to selective harvesting; as a result they often appear phenotypically inferior. Most trees have been scarred at the base by recent fires and in some areas trees have been excessively tapped for resin. The CAMCORE collections of *P. pringlei* sampled mainly Oaxacan populations but also included a Guerrero and a Michoacán source (Table 11-1, Figure 11-1).

CLIMATE

Pinus pringlei grows in warm tropical to subtropical climates throughout its geographic range in south-central Mexico. Average temperatures at CAMCORE collection sites range from 15 to 18 °C. At the highest elevations, the species may be subjected to light nighttime frosts from -1.0 to -2.0 °C during the winter months. Nonetheless, *P. pringlei* should not be considered frost hardy. Annual rainfall at CAMCORE collection sites averages 1000 to 1600 mm with a well-defined dry season of approximately five months (Table 11-2). One provenance sampled by South African collectors at El Capulín, Michoacán in 1969-70 is reported to receive 760 to 980 mm of annual rainfall (Darrow and Coetze 1983). During periods of drought, some populations of *P. pringlei* probably receive as little as 700 mm of precipitation annually.

SOILS

Pinus pringlei usually occurs on deep, eroded sandy clays. Soil pH values range from 4.0 to 6.5. Soil samples taken to a depth of 1.5 m in a *P. pringlei* stand near Uruapán, Michoacán revealed mineral horizons that were primarily sandy loams with pH values ranging from 5.8 to 6.1 (Bello-González 1983). The texture of the A horizon at the Santo Domingo Yosoñama, Oaxaca site was sandy with pH values from 4.0 to 5.0; subsoils were sandy clays to clays with pH values from 4.3 to 4.5 (Donahue 1987). The drier sites occupied by *P. pringlei* in Oaxaca are predominately Ultisols and Inceptisols. At higher elevations in areas of transition with *P. herrerae* and *P. patula* var. *longipedunculata*, *P. pringlei* occupies more fertile soils with pH values near 6.0.

REPRODUCTIVE BIOLOGY

Production of male and female strobili occurs from November to December in Michoacán (Bello-González 1983) and from January to February in Oaxaca and Guerrero. It is common to find recently formed conelets, first-year green cones, and second-year mature cones on the same branch, a trait that distinguishes *P. pringlei* from *P. lawsonii* (Photo 11-3). Cones turn yellowish-brown when mature, approximately 24 months after pollination, from the end of November through March. Cones can hold seeds for many months before they are dispersed, but seed fall occurs primarily in the warm months of March and April. Cone and seed production is generally good in *P. pringlei* if populations of cone-boring insects are not high (Cibrián-Tovar et al. 1995). In a cone and seed phenology study conducted in a natural stand in Michoacán, about 9% of the seeds collected were damaged by insects (Bello-González 1983). The average seed potential of *P. pringlei* is 120 seeds per cone. There are approximately 55,000 seeds per kg.

ECOLOGY AND ASSOCIATED SPECIES

Pinus pringlei occurs in both pure and mixed pine stands and in association with broadleaf species (predominantly *Quercus* spp.). Like most pines in southwestern Mexico, the natural distribution of *P. pringlei* is defined by fire and by elevation (nighttime temperatures). After germination, seedlings grow to a height of 10 to 20 cm and then enter a relatively brief grass stage during which shoot elongation ceases and root development occurs (Photo 11-4). The modified grass stage appears to last only one year in natural environments, possibly two years on very dry sites, but this needs more thorough study. If seedlings have received proper care in the nursery, the grass stage begins to break in less than one year in plantations (see Nursery Practices). In field studies conducted in the natural stands of Michoacán, mature *P. pringlei* trees exhibited less resistance to fire than did other grass-stage pines, such as *P. devoniana* and *P. montezumae* (Pérez-Chaves 1981).

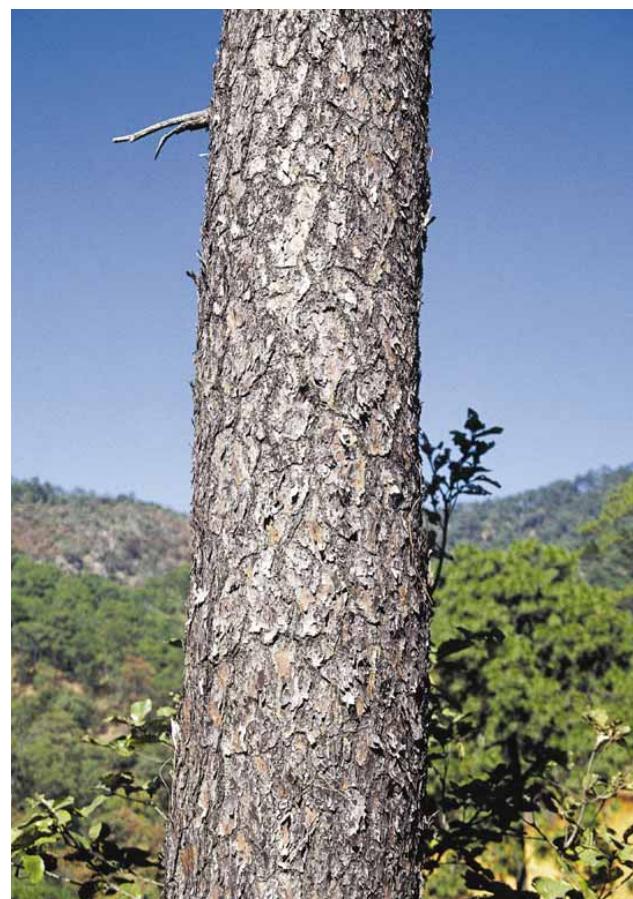


Photo 11-2. Bark of *Pinus pringlei*.

However, the species is presumed much more fire tolerant than other tropical pines, such as *P. tecunumanii* and *P. maximinoi*. *Pinus pringlei* is one of the few species that occasionally foxtails in its native environment (Donahue 1995).

Elevation greatly affects the species associated with *P. pringlei* and its position on the slopes and hillsides (see Donahue 1987). At El Guajolote (1630 to 2000 m elev.), *P. pringlei* occupies the middle to upper slopes, *P. maximinoi* the lower to middle slopes and *P. oocarpa* the lower hillside. At Santa María Lachixio (2110 to 2350 m elev.), *P. pringlei* occupies the middle to upper slopes, *P. patula* var. *longipedunculata* dominates the upper areas and *P. leiophylla*, *P. pseudostrobus* and *P. oaxacana* are more common on the lower slopes. At Sola de Vega (1710 to 1930 m elev.), *P. pringlei* occupies the middle to upper slopes and *P. lawsonii* and *P. devoniana* the lower slopes (Donahue 1987).

In drier locations, *P. pringlei* occurs with *P. lawsonii*, *P. devoniana* and *P. oocarpa*, as well as with oak species (*Quercus* spp.). On more humid sites it can be seen with *P. leiophylla*, *P. maximinoi*, *P. montezumae*, *P. oaxacana*, *P. pseudostrobus*, *P. patula* var. *longipedunculata* and *P. teocote*. At El Guajolote, Guerrero, *P. chiapensis* was also found scattered throughout the stands (Donahue 1987). At Tejocotes and Palo Blanco, Guerrero, *P. pringlei* was found adjacent to *P. herrerae* and occurred in transition with this species at 2200 m elevation.

Table 11-1. *Pinus pringlei* collections made by the CAMCORE Cooperative in Mexico.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
1	Santa María Lachixio	Oaxaca	Mexico	16° 44' N	97° 03' W	2110 - 2350	1350	23
2	Sto. Domingo Yosoñama	Oaxaca	Mexico	17° 23' N	97° 46' W	2280 - 2400	1100	28
3	Tlahuitoltepec	Oaxaca	Mexico	17° 04' N	96° 02' W	1760 - 2020	1565	21
4	Sola de Vega	Oaxaca	Mexico	16° 28' N	96° 59' W	1710 - 1930	1000	26
5	El Tlacuache	Oaxaca	Mexico	16° 42' N	97° 13' W	2000 - 2230	1500	20
6	El Guajolote	Guerrero	Mexico	17° 09' N	99° 56' W	1630 - 2000	1300	28
7	Acatén	Michoacán	Mexico	19° 17' N	101° 19' W	1820 - 2400	1254	28
8	El Español	Oaxaca	Mexico	16° 33' N	95° 48' W	1900 - 2100	1300	0*
9	Tejocotes	Guerrero	Mexico	17° 26' N	99° 31' W	2000 - 2250	1600	0*
10	Cerro el Billete	Guerrero	Mexico	17° 59' N	101° 13' W	1700 - 1900	1200	0*
11	Telixthahuaca	Oaxaca	Mexico	17° 16' N	96° 59' W	2090 - 2210	1100	0*
7	Provenances	3 States	1 Country	16 - 19° N	96 - 101° W	1630 - 2400	1297	174

* Site visited, no collections made.

In areas where *P. pringlei* and *P. lawsonii* occur sympatrically, intermediate forms often occur, suggesting that the two species intermate. Preliminary RAPD-marker results indicate that the two species are very closely related (CAMCORE, unpublished data). A similar situation has been observed with *P. pringlei* and *P. herrerae* at Tejocotes and Palo Blanco, Guerrero. Intermediate forms are common, making it difficult to distinguish the two species. Assessments of AFLP and RAPD species-specific markers can not separate the two, which suggests that either *P. pringlei* and *P. herrerae* have a common evolutionary heritage or that they naturally introgress (CAMCORE, unpublished data).

WOOD QUALITY IN NATURAL STANDS

The wood of *P. pringlei* is one of the densest of any species in the *Oocarpa* subsection. Wood cores 11 mm in diameter were taken from 34 mature trees (average age of 57 years) in two provenances in Oaxaca and Guerrero by CAMCORE and were analyzed by Murillo (1988). Average

wood density (unextracted) for juvenile wood (first nine rings) was 604 kg/m³ and for mature wood was 734 kg/m³. Individual-tree wood density (weighted) was 679 kg/m³. The transition between juvenile and mature wood began at age 9 and continued through age 25. Large differences in wood density were found among trees within provenances but no significant differences were found between provenances. In a single mature tree in a natural stand, Olvera-Coronel (1985) found average tracheid length to be 5.1 mm.

Pinus pringlei wood is used locally in sawmills, but is usually not preferred over other species. The species exhibits a high extractive content, and trees are often tapped for resin. Some sawmillers in Mexico do not like the wood because of its high resin content (T. Eguiluz-Piedra, personal communication). Wood pieces are often used as "ocote" (lighter wood) for starting cooking fires. Other uses for the species in Mexico include railroad ties, mining timbers, fence posts, small construction and furniture (Olvera-Coronel 1985).

Table 11-2. Monthly mean temperature (°C) and rainfall (mm) recorded near a typical *Pinus pringlei* site in Tlahuitoltepec, Oaxaca.

Tlahuitoltepec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	14.5	15.5	18.0	18.5	18.5	17.3	16.0	16.2	16.1	15.1	14.8	13.3	16.2
Mean Rain mm	11	5	15	52	113	318	317	215	299	160	40	21	1566

Based on 40 years of data (1921 to 1960) recorded at Ayutla, elevation 2100m, 6 km from the collection site (Donahue 1987).

Figure II-1. CAMCORE collections of *Pinus pringlei* in Mexico.

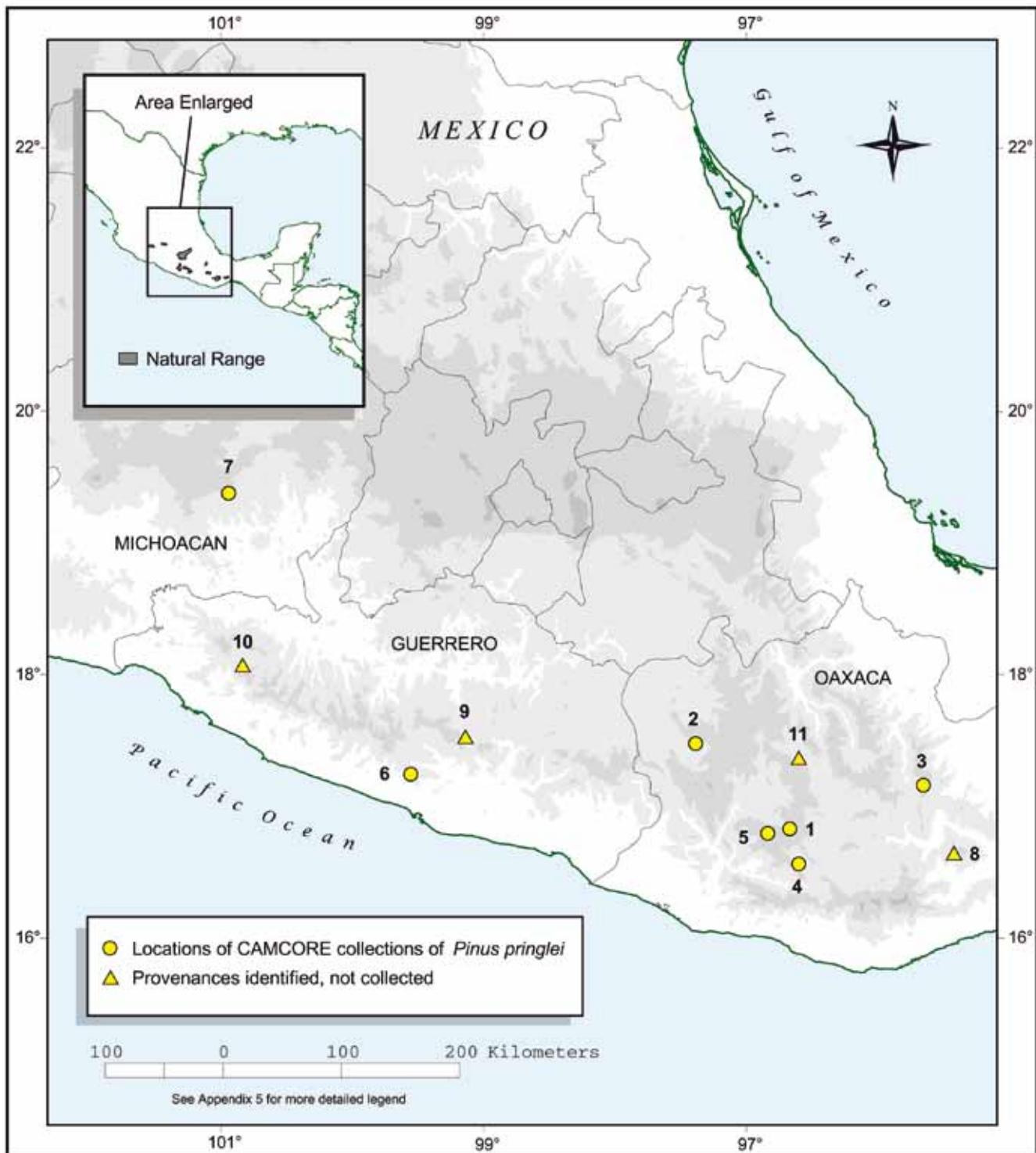




Photo 11-3. Branch of *Pinus pringlei* with 4 years of cone crops. The green conelet (partially hidden, far left) is in its first year of development, the ochre-brown cone (left of center) is in its second year of development and is ready to be harvested, the closed cone (right of center) is one year past maturity but still holds seeds, and the open cone (far right) is 2 years past maturity.



Photo 11-4. Grass stage of *Pinus pringlei*.

PLANTATIONS

No commercial *Pinus pringlei* plantations have been established. Information about the species is limited to observations in arboreta or measurements in genetic tests.

NURSERY PRACTICES

Seed Handling

Seeds of *P. pringlei* require no special treatment. Seeds can be stored for years in cold rooms at 4 °C without problems, provided moisture content of the seeds is maintained between 6 and 9%. Relative humidity of the storage facility should be maintained at approximately 60%. No cold stratification of the seeds is necessary. Seeds begin germinating 7 to 14 days after sowing. Average germination for seeds collected by CAMCORE in natural stands ranged from 75 to 85%.

Containers and Growth Media

Pinus pringlei has been grown successfully in black plastic bags in Mexico. At Klabin (Brazil), seedlings have been grown in plastic tubes with a cavity volume of 56 cm³. Various soil media have been used successfully. Seedlings of *P. pringlei* have been grown without problems in 25% vermiculite and 75% composted bark (pH 5.4), as well as in 100% composted (*P. patula*) pine bark.

Seedling Management

Seedlings exhibit rapid initial growth before entering the modified grass stage. In subtropical Brazil, their development in the nursery differs little from *P. taeda* and *P. elliottii*. At Klabin, plants are grown in the greenhouse for four weeks and are subsequently maintained in the shade house (50% shade) for two weeks. Seedlings are then moved to the main nursery bed, where they are allowed to grow for 18 weeks and eventually hardened-off for field planting. Nursery plants can reach 25 cm height and 5 mm root collar diameter in six to seven months.

Vegetative Propagation

CAMCORE members have not conducted any studies on the propagation of *P. pringlei* from seedling cuttings. Neither does there appear to be any ongoing research by other agencies on the vegetative multiplication of *P. pringlei*.

STAND MANAGEMENT

Site Selection and Establishment

Current data suggests that *P. pringlei* should be planted on well-drained sites in tropical and subtropical environments between latitudes of 18° and 25° N or S, and above 800 m elevation, but not in frost belts. It appears sensitive to drought as it enters the mild grass stage during the first postplanting year but seems more resistant to dry conditions thereafter. Because total plant height is only 40 to 50 cm at the end of the first year in the field, good weed control is critical for adequate survival. Most trees

emerge from the grass stage by an age of 1.5 years. The length of the grass stage is very dependent on seed source (see Dvorak and Donahue 1992).

Successful site preparation for *P. pringlei* has included burning or chopping vegetation, followed by disking, ripping to a depth of 0.7 m, and manual pitting. As with most species, proper site preparation improves seedling survival.

Planting should coincide with the start of the rainy season and/or when the danger of frost has passed. In CAMCORE trials, Sappi applied 100 g of 21-11-17 NPK fertilizer at time of planting. There is no good data on the baseline nutrient requirements of the species.

Silviculture

Trees in CAMCORE tests have performed well at both 2.7 × 2.7 m and 3.0 × 3.0 m spacings. Due to problems with heavy lower branches, foresters at Klabin (Brazil) correctively pruned at 3 years of age; tree height and dbh were approximately 3 m and 5 cm, respectively, and the trees responded well. Access to improved seed sources with smaller-branched trees should reduce the need for corrective pruning in the future. *Pinus pringlei* generally produces a clear bole up to 12 m in height (Poynton 1977). In a study of 22-year-old trees in eastern South Africa, Malan (1994c) found that *P. pringlei* averaged one branch whorl per meter of stem, as did the *P. patula* controls, while *P. greggii* had twice the number of branch whorls per unit length of stem.

Pests and Other Limiting Factors

As with most exotic pines in the tropics and subtropics, leaf-cutting ants will attack and damage the foliage of *P. pringlei*. In the CAMCORE trials at Klabin, *P. pringlei* was susceptible to attacks by a shoot moth (unidentified species), while other exotics, such as *P. tecunumanii*, *P. maximinoi*, *P. taeda* and *P. elliottii*, were relatively untouched. Poynton (1977) reports that *P. pringlei* was mostly resistant to *Pineus pini* (woolly aphid) attacks in southern Africa. In greenhouse seedling trials, *P. pringlei* demonstrated substantial resistance to pitch canker caused by *Fusarium subglutinans* f. sp. *pini* (Hodge and Dvorak 2000).

WOOD QUALITY IN PLANTATIONS

Density and Other Properties

Twenty-eight 22-year-old *P. pringlei* trees were destructively sampled at Hebron (lat. 24° 36' S, elev. 808 m, 1298 mm ann. precip.), and Tweefontein (lat. 25° 03' S, elev. 1152 m, 1298 mm ann. precip.), South Africa, to determine wood properties (Malan 1994c). This was part of the same trial that Darrow and Coetze (1983) reported on for growth traits at age 10 years (discussed later).

Malan's (1994c) results show that the earlywood zones of *P. pringlei* are characterized by a large number of false

latewood rings, which indicate that the species is very sensitive to weather changes during periods of active growth. The lack of distinct contrast between earlywood and latewood results in wood with a uniformly pale brown color, uniform texture and good finishing properties. There was much variability in wood density from tree to tree in the South African trials, which is similar to the pattern found in natural stands in Mexico (Murillo 1988). Wood density (unextracted) assessed on disks taken from the tree at breast height ranged from 490 to 730 kg/m³ and averaged 530 kg/m³ (Malan 1994c). Tracheid lengths average 2.5, 3.7 and 4.4 mm at the second, tenth and last ring of the tree, respectively. Tracheid length was similar to *P. patula* and longer than *P. greggii*. Extractive content averaged 3%, and overall the species was more resinous than *P. elliottii*. Variation between and within families for percent extractives was relatively high. Only 3% of the boards were rejected for problems associated with spiral grain (Malan 1994c). Malan concluded that *P. pringlei* possesses excellent properties for solid wood products.

Pulp Quality

No pulping tests have been documented for *P. pringlei*. Wood properties and percent extractives of the species are in some ways similar to those of *P. elliottii*. In order to develop baseline data for *P. pringlei*, micropulping tests are needed.

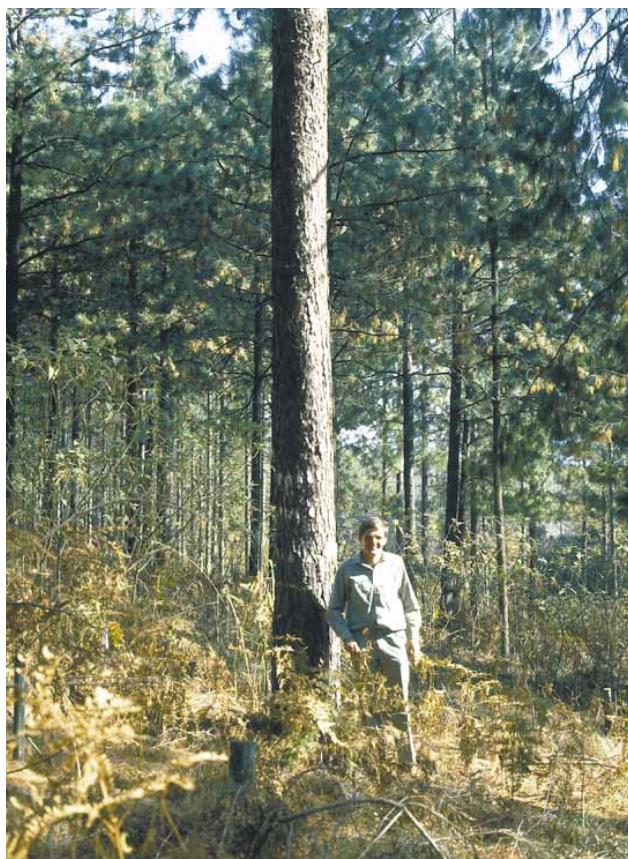


Photo 11-5. Twenty-year-old *Pinus pringlei* tree near Sabie, South Africa.

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

The CAMCORE Cooperative sampled seven provenances and 166 mother trees of *Pinus pringlei* in Oaxaca, Guerrero, and Michoacán during 1986 and 1987.

PROVENANCE VARIATION

Eight *P. pringlei* provenance/progeny tests established by Klabin, Smurfit Cartón de Colombia, Sappi and Mondi were assessed between the ages of 5 and 10 years in Brazil, Colombia and South Africa. Best linear unbiased predictions (BLUP) of provenance effects were calculated across six of the tests. The Colombian trials were excluded from the BLUP analysis because they had 80% foxtailing that would have biased results (discussed later). Results from four of the oldest tests are summarized in Table 11-3.

Survival

The average survival across all test sites between ages 5 and 10 years was 71%. At Klabin (Imbauzinho), trees were planted on a well-drained Oxisol with a soil pH of 4.2. The site receives up to 11 frosts per year but can go several consecutive years without any subfreezing winter temperatures. Initial survival was approximately 95% through age 5, but 20% of the trees died from a late freeze that occurred in 1994 when the tests were 3 years of age (Photos 11-6a and b). In South Africa, survival was approximately 68% due to a combination of factors.

Plantings at Sappi and Mondi were established during extended droughts that were common throughout southern Africa in early 1990s, and trees suffered mortality as a consequence. At Nooitgedacht, the survival of *P. pringlei* was vastly superior to the control, *P. tecunumanii*, and was 11% less than *P. elliottii*. At Ramanas, the survival of *P. pringlei* was about the same as for the controls, *P. patula* and *P. tecunumanii*, but significantly poorer than *P. elliottii*. Like the Imbauzinho site, the Nooitgedacht and Ramanas plantings were established on Oxisols. Nooitgedacht experiences only an occasional frost, while freezing temperatures are very uncommon at Ramanas (which was planted to *P. caribaea* prior to the establishment of *P. pringlei*). Trees were lost due to hail damage in the SAFCOL planting at Wilgeboom, South Africa (lat. 24° S, elev. 960 m, ann. precip. 1316 mm).

There were significant provenance differences in survival at individual sites but no consistent pattern existed across sites, with the exception that the Santa María Lachixio source most often exhibited the poorest survival. In the Sappi test, the survival of this seed source at 10 years of age was 59 versus 79% for the other populations.

In one of the Klabin tests, the survival of the Tlahuitoltepec source was significantly better than other sources (85 vs. 68%). The Tlahuitoltepec source produced slightly

Table 11-3. Results from four CAMCORE *Pinus pringlei* provenance/progeny tests established at three locations in Brazil and South Africa. Final measurements (labeled Age 8) were taken at 8 years of age at Klabin, 9 years at Mondi, and 10 years at Sappi.

ORGANIZATION		KLABIN 21-26-01A1	KLABIN 21-26-02A1	MONDI 21-18-02E	SAPPI 21-07-02D4
Test Code		21-26-01A1	21-26-02A1	21-18-02E	21-07-02D4
Country		Brazil	Brazil	S.Africa	S.Africa
Planting Site		Imbauzinho	Imbauzinho	Ramanas	Nooitgedacht
Latitude		24° 16' S	24° 16' S	24° 51' S	25° 40' S
Elevation (m)		780	780	820	1150
Rainfall (mm/yr)		1473	1473	1039	1017
<i>Survival (%)</i>		1	95	71	79
3		95	97	71	78
5		94	96	68	-
8		73	76	69	77
<i>Height (m)</i>		1	0.4	0.5	-
3		2.9	3.0	3.5	2.1
5		6.3	6.2	6.7	-
8		8.6	8.7	12.5	10.6
<i>DBH (cm)</i>		3	4.8	5.0	3.3
5		11.4	10.9	11.8	-
8		15.6	15.0	19.2	15.4
<i>Volume (m³)</i>		5	0.0277	0.026	0.0311
8		0.0709	0.069	0.1522	0.0829
<i>Forking (%)</i>		8	63	67	37
<i>Foxtail (%)</i>		8	11	13	17

taller trees than other provenances in the test and possibly escaped damage from frosts more effectively.

Results suggest that in some environments, *P. pringlei* is more drought-hardy at an early age than *P. tecunumanii* and *P. maximinoi* (L. van der Merwe, personal communication), but is less drought-resistant than *P. elliottii*. *Pinus pringlei* is as frost-susceptible as other tropical pines, such as *P. caribaea* var. *hondurensis*, *P. maximinoi* and *P. tecunumanii*, when planted as an exotic. Its recovery rate from frosts actually seems lower than other tropical pines. Trees of *P. tecunumanii* and *P. maximinoi* 5 to 8 m in height can recover from the occasional moderate nighttime freezes of -3 to -5 °C, but *P. pringlei* often succumbs.

Productivity

Pinus pringlei grows slowly during the first year while it is emerging from its mild grass stage. Average tree height at the end of one year ranges from 0.4 to 0.5 m. Height growth increases thereafter and averages 1.2 to 1.5 m/yr through age 10. Trees in the Tweefontein, South Africa arboretum had an average height growth of 0.9 m/year at 33 years (Poynton 1977). At early ages, the species has a much larger diameter to height ratio than other tropical species, such as *P. tecunumanii* and *P. maximinoi*.

Productivity of *P. pringlei* in a CAMCORE/Smurfit Cartón de Colombia trial at La Cecilia (lat. 03° 54' N, elev. 1550m, ann. precip. 1489 mm), Colombia, was approximately 5.7 m³/ha/yr at 5 years of age. In Colombia, *P. pringlei* was inferior to both *P. kesiya* and *P. tecunumanii* in terms of

volume production. At Klabin in south-central Brazil, productivity was approximately 8 m³/ha/yr at 8 years, which was less than half the volume of *P. taeda* and also significantly less volume than *P. elliottii*. At the Sappi Nooitgedacht site in the eastern highlands of South Africa, *P. pringlei* produced approximately 13 m³/ha/yr at 9 years of age, only about one-half the volume of the *P. tecunumanii* and *P. patula* controls. At the Mondi Ramanas site, *P. pringlei* produced around 8 m³/ha/yr at age 8 years, which was about 14% more volume than *P. tecunumanii*, but inferior to *P. elliottii*.

Models developed by the South African Forest Research Institute (SAFRI) from 10-year-old *P. pringlei* trees at Hebron, South Africa, predicted mean annual increment to be 20 m³/ha/yr at 20 years of age (Darrow and Coetze 1983). Productivity in an arboretum planting (297 trees/ha) at Tweefontein, South Africa, averaged about 17.4 m³/ha/yr at 33 years of age (Poynton 1977).

Volume Performance

BLUPs for volume production of provenances in Brazil and South Africa are shown in Table 11-4. Great variation was found among provenances in volume production, with differences of 19% between the best and the worst source in Brazil, and 9% in South Africa. Some of the Oaxacan sources were better than the provenances from Guerrero and Michoacán. Tlahuitoltepec and Santa María Lachixio were the best sources in Brazil, while Santa María Lachixio and El Tlacuache were superior in South Africa.

Table 11-4. Volume performance (Gain) of seven provenances of *Pinus pringlei* tested in Brazil and South Africa. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean.

Country	Map Key	Provenance	BRAZIL			S.AFRICA		
			Gain	Fams	Tests	Gain	Fams	Tests
Mexico	1	Santa María Lachixio	7.8	12	2	3.3	13	3
	2	Santo Domingo Yosoñama	-7.3	13	2	-0.7	18	3
	3	Tlahuitoltepec	11.3	18	3	1.2	18	3
	4	Sola de Vega	-6.4	15	2	-2.8	16	3
	5	El Tlacuache	-1.0	7	2	3.8	12	3
	6	El Guajolote	-6.2	15	2	-5.7	17	3
	7	Acatén	1.9	12	1	0.9	-	-



Photo 11-6a. Mike Butterfield, Sappi, walks through a 3-year-old CAMCORE *Pinus pringlei* trial in South Africa. **11-6b.** Below, 3-year-old *P. pringlei* trial in Brazil destroyed by a heavy freeze.



In the series of previously referenced *P. pringlei* provenance trials established in South Africa by SAFRI, Darrow and Coetze (1983) found that the sources from Oaxaca grew better than those from Michoacán when assessed at 10 years of age.

Quality Traits

Results from CAMCORE tests suggest that large provenance differences exist in stem straightness and forking percentages for this species. In South Africa, which has well-defined dry and wet seasons, the Tlahuitoltepec source is most crooked and the El Tlacuache source is the straightest. Results from the Sappi and Mondi tests, which are shown in Table 11-3, indicate that about 40% of the Tlahuitoltepec trees were classified as very crooked, while only 6% of the trees in the El Tlacuache source were crooked. No difference in stem straightness was observed for trees from these sources when planted in Brazil, where rainfall is more evenly distributed throughout the year.

Forking percentages averaged 57% across the four tests listed in Table 11-3. Some of the forking is due to cold damage and leader dieback. However, as mentioned previously, the Mondi planting at Ramanas does not experience frost, yet still averaged 61% forking. Average percent forking can vary as much as 20% by provenance within a single test site, but no trends that favor selection of one provenance over another for this trait were observed.

Percent foxtailing is high at planting sites near the equator and decreases with increasing latitude. Average foxtail percent in the Colombian tests established at 2° and 3° N latitude (elev. between 1550 and 1750 m) was 78% at 5 years of age; the worst provenances had 97% foxtails (Photo 11-7). The majority of trees possessed no lateral branches and represented the worst incidence of foxtails seen in the CAMCORE testing program. In the Brazil and South African plantings established at 24° and 25° S latitude, the foxtail percentage was only 10 to 12%, which is a manageable level.

Provenance x Site Interactions

Meaningful provenance x site interactions with respect to volume and forking exist for *P. pringlei* in CAMCORE tests. Interactions may have been amplified somewhat due to the frost damage suffered in the tests at Klabin between 5 and 8 years of age. Tests with greater provenance representation across more sites need to be established so that the magnitude of the interactions can be more accurately assessed. El Tlacuache appears to be the most interactive source for volume; it performs well in South Africa but is only average in Brazil.

Family x Site Interactions, Genetic Parameters for Growth and Quality Traits

Moderate family x site interactions in *P. pringlei* have been observed in CAMCORE tests. Selection of the best

15 families in terms of volume production at Sappi (test 21-07-02D4) at 9 years of age also would have included 12 of the best 15 families at Mondi (test 21-18-02E) at 10 years of age, and 11 of the best 15 families at Klabin (test 21-26-02A1) at 8 years of age. Spearman family rank correlations across test sites for 35 open-pollinated families were $r = 0.51$ (Sappi-Klabin), $r = 0.63$ (Sappi-Mondi), and $r = 0.80$ (Mondi-Klabin). The results suggest the species is site-sensitive, as changes in rank within country can be larger than between countries. Exchange of genetic material between organizations appears promising for the species, but all exchanged seedlots need to be tested before being included in breeding populations. Because samples come primarily from Oaxaca, it is difficult to determine if these interactions are of the same magnitude as for species with larger geographic ranges, such as *P. tecunumanii* (Hodge and Dvorak 1999) and *P. caribaea* (Hodge et al. 2001).

Mean individual tree heritability for volume at a single site at ages 8 to 10 years was 0.25 and is similar to values obtained for other pine species assessed at the same age. Heritability for volume increased from age 3 to 5 and remained approximately the same from 5 to 8 years of age. Mean genetic correlation between height at 3 years and



Photo 11-7. Severe foxtailing in *Pinus pringlei* trials in Colombia.

volume at 5 years was 0.86, for height at 3 years and volume at 8 years was 0.70, and for height at 5 years and volume at 8 years was 0.62. Lower genetic correlation between height at 5 years and volume at 8 years than that found for earlier ages could perhaps be partially explained by the freeze damage in tests at Klabin between 5 and 8 years. However, the same trend in genetic correlations between height and volume was also observed at the Mondi Ramanas site where there was no frost damage. Selection of candidate trees at 8 years of age after the modified grass-stage effects have been minimized and crown closure has taken place is recommended.

DEVELOPMENT OF IMPROVED MATERIAL

Flowering and Seed Production

In Brazil, male flowers are produced as early as 3 years of age (Photo 11-8) but no information is available when cone and seed production begins. In Zimbabwe, Nyoka et al. (2000) studied the flowering patterns of four clones of *Pinus pringlei* planted at elevations of 950, 1268 and 1850 m and assessed approximately 4 to 6 years after grafting. The flowering period ranged from early July to November with trees planted at the highest elevation usually flowering ahead of trees planted at the lowest. At 1850 m, male flowers appeared in early July to

mid-September with a peak in August. Female flowers appeared at the beginning of August till the end of October with a peak from mid-August to the end of September. At the lowest elevation site of 950 m, male and female flowers appeared in August but with female flowering persisting to the end of October and male flowering to November (Nyoka et al. 2000). The highest numbers of flowers were found at the mid-elevation site, while the synchronization of female and male flowering was better at low elevations.

In South Africa, attempts have been made to collect cones from *P. pringlei* trees planted in 1971. The few cones that have been collected did not have any viable seeds (L. van der Merwe, personal communication).

Hybrids

Observations by CAMCORE staff in natural stands suggest that *P. pringlei* may cross with *P. lawsonii*, *P. herrerae* and possibly *P. patula* var. *longipedunculata*. Research in natural stands in Michoacán suggests that areas of *P. pringlei* × *P. oocarpa* exist (J. López-Upton, personal communication), and genetic distances generated from RAPD marker data for these species suggest that successful crosses are a possibility (Dvorak et al. 2000).

An apparently successful *P. patula* × *P. pringlei* cross was made by researchers of the US Forest Experiment Station at Placerville, California. Critchfield (1967) makes reference to attempting the cross, and morphological assessments of the progeny years later indicate the hybrid cross was probably successful (J. Duffield, personal communication). The possibility of a successful *P. patula* × *P. pringlei* cross at Placerville is supported by observations in South Africa. At Entabeni, South Africa, SAFCOL planted seeds collected from a *P. pringlei* stand surrounded by *P. patula* (L. van der Merwe, personal communication). The stand contains all types of forms intermediate between *P. patula* var. *patula* and *P. pringlei*.

The morphology of the *pringlei* × *patula* hybrids at Entabeni is very different from the "rough-bark *patula*" planted around the D. R. de Wet Forestry Research Station at Frankfort, South Africa (see Poynton 1977). The latter has rough bark like *P. pringlei* but pendant foliage and a straight stem form like *P. patula*. The origin of the seed was Mexico, but the exact location is unknown. One explanation was that the rough-bark *patula* could have resulted from natural crosses between *P. patula* var. *patula* and *P. pringlei* (Poynton 1977). However, typical *P. patula* var. *patula* and *P. pringlei* do not occur sympatrically in Mexico. The only places where the authors have seen *P. patula* var. *longipedunculata* and *P. pringlei* come in contact in Mexico is at El Tlacuache and Santa María Lachixio, Oaxaca and Yextla, Guerrero (Donahue 1995, Dvorak et al. 2001). The origin



Photo 11-8. Male flowers on 3-year-old *Pinus pringlei* in Brazil shortly after shedding pollen.

of "rough-bark *patula*" needs to be evaluated more thoroughly using species-specific molecular markers.

Well-designed hybrid studies are still needed to determine the crossing ability of *P. pringlei* with other species. The Zimbabwe Forestry Commission has started such studies

in Zimbabwe (I. Nyoka, personal communication). Molecular marker assessments would be helpful in confirming the parentage of these interesting species combinations. An objective of interspecific hybrids with *P. pringlei* would be to produce progeny that possess some of its desirable wood properties.

CONSERVATION

Pinus pringlei is best described as a relatively unimpressive pine species in natural stands. It is of average height and volume, however; it possesses high wood density and extractive content. As an exotic species, it shows some potential in South Africa, but it is not as competitive as other species in terms of adaptability and productivity. Given this situation, it is uncertain as to whether or not enough interest can be generated for the successful conservation of *P. pringlei*.

IN SITU GENE CONSERVATION

Genetic Diversity

There have been several genetic diversity studies conducted in natural *P. pringlei* stands. Using seeds donated by CAMCORE and gel electrophoresis techniques, Ramírez-Herrera et al. (1998) found that *P. pringlei* has an average of 2.1 alleles per locus with 47% polymorphic loci. For comparison, several populations of *P. tecunumanii* from Guatemala averaged approximately 75% polymorphic loci (Dvorak et al. 1999). The low levels of genetic diversity for *P. pringlei* found in the Ramírez-Herrera study are contrary to the large provenance variation found for metric traits in the CAMCORE trials; both tests used the same seed sources. Lockhart (1990) found two distinct terpene groups in *P. pringlei*, which may support the theory that a close evolutionary relationship exists between *P. pringlei* and other pines like *P. herrerae* (see Chapter I, Evolution). Furman (1997) found distinct differences in levels of genetic diversity between groups of *P. pringlei* populations using RAPD markers. The discrepancy between marker and provenance results creates difficulties in making decisions about a gene conservation strategy. Further studies on genetic diversity patterns are obviously needed.

Because the species is not commercially important locally or internationally, along with the lack of complete provenance and molecular marker information across the range, it might be prudent to protect at least one population from each of the six Mexican states in which the species occurs. Provenance information and electrophoresis results could help guide the selection of the one or two populations chosen in Oaxaca.

Conservation Status

The conservation status of *Pinus pringlei* is **vulnerable** in south-central Mexico. The species has a relatively restricted geographic range, tends to be uncommon, and population sizes are usually less than 40 ha. Woodcutters have reduced stand size in some areas (Dvorak and Donahue 1992), and annual fires have decreased the size of other populations. The Sola de Vega population has been reduced by about 25% since the original collection in the late 1980s. Fires continue to destroy much of the natural regeneration.

EX SITU CONSERVATION

CAMCORE collections of *P. pringlei* and subsequent establishment of trials in Brazil and South Africa have probably conserved a sufficient portion the genes of the populations in Oaxaca. Additional sampling is needed from other Mexican sources, particularly in the states of México, Morelos, and Puebla. Perhaps the best hope for the long-term conservation of *P. pringlei* is to develop a commercial interest in the species. This would require finding new provenances that are more productive than those currently being studied, or the development of *P. pringlei* hybrids in order to take advantage of the its high wood density and possible resistance to pitch canker.

CONTRIBUTORS

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C h a p t e r 1 2



PINUS TECUNUMANII

W. S. Dvorak, G. R. Hodge, E. A. Gutiérrez, L. F. Osorio, F. S. Malan, and T. K. Stanger

OVERVIEW

TREE DESCRIPTION

Pinus tecunumanii Eguiluz & J. P. Perry is a medium to very large tree that occurs from the highlands of central Chiapas, Mexico to central Nicaragua. The species was first identified in the montane cloud forests of western and central Guatemala in the early 1950s by German forester Fritz Schwertdfeger (1953). Eguiluz-Piedra and Perry (1983) officially described the species in the early 1980s. It was named after the famous Mayan Indian chief "Tecún Umán," who lost his life fighting Spanish conquistadors in Guatemala in the 16th century. Taxonomically, *P. tecunumanii* belongs to the commercially important *Oocarpa* subsection. Two groups of *P. tecunumanii* are recognized: 1) trees from high elevation (HE) populations that occur from approximately 1500 to 2900 m altitude and 2) low elevation (LE) populations that occur from approximately 450 to 1500 m altitude.

Trees from the HE populations can range in height from 40 to 55 m and can have dbh (outside bark) greater than 100 cm. The bark is gray and deeply furrowed at the base of the tree but abruptly becomes smooth and flaky at approximately 2 m stem height. Straight stem form, self-pruning ability and small crowns also are characteristics of this group. Needles usually occur in fascicles of four. Cones range in size from 30 to 93 mm (mean = 60 mm), are borne singly or in pairs, and ripen from January to the end of March in most areas of Chiapas and Central America. Average seed potential per cone is 90 seeds. There are approximately 88,000 seeds per kg.

Trees from LE populations are usually 20 to 30 m tall with dbh (outside bark) of 60 cm at maturity. Tree stem form is not as straight as in the HE trees and the crown form tends to be more irregular. The bark of the tree is often furrowed, as in *P. oocarpa*, for most of the stem but often becomes smooth and flaky near the crown. The number of needles per fascicle is usually four and occasionally three or five. Needles for both HE and LE populations are erect to slightly drooping and average 180 mm in length. Cones on trees from LE provenances are approximately 40 to 75 mm long (mean = 51 mm), are usually more ovoid than those found in HE populations, and are borne primarily in clusters of two to four. As in HE trees, cones ripen from January to the end of March. Trees in LE provenances tend to produce more cones and more filled seeds per cone than trees in HE provenances. The average seed potential per cone is 95 seeds. There are approximately 76,000 seeds per kg. The wood of both HE and LE *P. tecunumanii* trees is

of moderate density, has a yellowish hue and can be used for sawtimber and a number of wood and paper products.

CONSERVATION STATUS

Based on CAMCORE's observations in Central America and Mexico, *Pinus tecunumanii* is **vulnerable** in its natural range because of the small geographic size (5 to 15 ha) of most provenances and the ever-increasing pressure from human populations on the stands. Of the 54 HE and LE provenances inspected from Chiapas to Nicaragua by the CAMCORE Cooperative, 30% can be classified as either **critically endangered** or **endangered**, 60% as **vulnerable** and 10% as **low risk**.

TEST STATUS

CAMCORE has sampled 1473 mother trees and established 153 provenance/progeny tests and conservation banks of *P. tecunumanii* in 10 countries since 1980. This species was the most widely tested of any Mesoamerican pine in the 1980s.

BEST PROVENANCES

Results from CAMCORE data at 5 and 8 years of age show that Montebello, Chiapas, Mexico, and San Jerónimo, Guatemala are the best sources for planting on high elevation planting sites in Latin America and southern Africa based on productivity. San Miguel, Guatemala and La Esperanza, Honduras also show promise on some sites. Villa Santa, Honduras, and San Rafael del Norte and Yucul, Nicaragua were the most productive of the low elevation sources. Although trials are still young, Apante and Camelias, Nicaragua also appear to be very good sources.

SUITABLE PLANTING SITES

There are an estimated 10,000 ha of *P. tecunumanii* established worldwide. Most of the plantations occur in central Brazil, the highlands of Colombia and the east coast of South Africa. The species should be established on well-drained (deep) soils with considerable initial weed control in areas that are not subjected to strong seasonal winds. It survives well in regions where annual rainfall ranges from 900 to 2400 mm and the dry season varies from zero to five months. Once established, trees from several LE populations have shown excellent drought resistance on coastal sands in South Africa and sandy clays in Venezuela. The species does not have the edaphic plasticity that characterizes *P. caribaea* var. *hondurensis*. It is not frost tolerant, does not withstand heavy weed competition and does not do well on heavy, wet clays.

Photo 12-1. Natural stand of *Pinus tecunumanii* at Las Piedrecitas, Chiapas, Mexico.

ADVANTAGES OF *PINUS TECUNUMANII*

- Excellent information available on provenance variation for growth and form.
- Grows quickly in the nursery.
- Captures sites rapidly when weeds are controlled.
- Shows better drought resistance than *P. patula* in South Africa in the years following establishment.
- Better productivity than *P. oocarpa* and sometimes *P. caribaea* var. *hondurensis* on most sites in the tropics where rotation age is \leq 16 years.
- Higher productivity than *P. patula* in areas of infrequent frost.
- Higher productivity than *P. elliottii* at lower latitude, warmer and drier sites in the highlands of southern Africa.
- Lower bark content per unit volume than *P. taeda*.
- Low foxtail percent (approx. 5 to 15%, except Mountain Pine Ridge, Belize source).
- Lower extractive percent (approx. 4%) than some United States southern pines.
- Higher wood density than *P. patula* in Colombia and South Africa.
- Wood density more uniform within and between annual rings than *P. elliottii*, *P. patula*, and *P. taeda* in South Africa.
- Acceptable wood properties for pulp, paper and lumber.
- More resistant to *Sphaeropsis sapinea* (Diplodia) than *P. patula* and *P. greggii* in southern Brazil.
- Moderate to high tolerance to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in seedling screenings.
- Hybridizes easily with several pine species.

DISADVANTAGES OF *PINUS TECUNUMANII*

- Nursery container size greatly influences root architecture.
- Shallow rooted and prone to wind throw.
- Performs poorly on wet sites and when weed competition is severe.
- Frost tender.
- Upper-stem breakage common after 3 years of age at most locations.
- Light crown fails to completely block out understory weed competition after crown closure in some locations, resulting in a build up of fuel and an increase in the risk of fire.
- Does not resprout well after fire.
- Moderately susceptible to the *Pineus pini* (woolly aphid) in South Africa.
- Susceptible to *Cinara cronartii* (black aphid) attacks in southern Africa.
- Moderately susceptible to *Cylindrocladium* spp. in the lowland tropics.
- Very susceptible to the *Hylastes* sp. beetle in the seedling stage in southern Africa.
- Very susceptible to *Cronartium quercuum* f. sp. *fusiforme* (fusiform rust) in seedling screening trials.
- Preferentially browsed by livestock and antelope in South Africa.
- Wood has lower tear and burst strength than *P. patula*.
- Trees from HE populations do not usually produce large amounts of seed.

NATURAL STANDS

EVOLUTION

There has been much debate over the origin of *Pinus tecunumanii*. Phylogeny work using RAPD molecular markers at CAMCORE indicates that *P. tecunumanii* evolved from Central American *P. oocarpa* (Dvorak et al. 2000, Furman et al. 1997, Grattapaglia et al. 1993). Because the genetic distance between the two species is quite small, it is assumed that *P. tecunumanii* has evolved very recently (see Chapter 1, Evolution).

DISTRIBUTION

Pinus tecunumanii occurs over a distance of 900 km from the Chiapas, Mexico highlands ($17^{\circ} 02' N$) through central Nicaragua ($12^{\circ} 42' N$) in a series of small and often fragmented populations (Figure 12-1). Outlier populations have been reported to exist in the Mexican states of Oaxaca and Guerrero in the Sierra Madre del Sur (Farjon and Styles 1997, Perry 1991). Examination of extracted DNA from trees in these locations indicates that they are not *P. tecunumanii* but instead possess *P. patula* or a combination of *P. herreriae*/*P. pringlei* species-specific markers (CAMCORE, unpublished data).

Pinus tecunumanii has one of the largest altitudinal ranges of any of the Mexican closed-cone pines and is found from 450 to 2900 m. The geographic range of the species can be divided into two large groups on the basis of altitude, and are referred to as high and low elevation populations (Figure 12-1). Low elevation (LE) populations are found from approximately 450 to 1500 m elevation in the lowlands of Belize, Honduras and Nicaragua (Table 12-1a). High elevation (HE) populations occur from approximately 1500 to 2900 m altitude, primarily in Chiapas, Mexico, Guatemala, and Honduras with several isolated populations in northern El Salvador and Nicaragua (Table 12-1b, Figure 12-1). Trees in each group can be distinguished based on subtle morphological and monoterpenoid differences as well as by unique RAPD markers (Dvorak et al. 2000, Furman et al. 1997, Grattapaglia et al. 1993). Introgression between *P. tecunumanii* and *P. oocarpa* at high altitudes and between *P. tecunumanii*, *P. oocarpa* and *P. caribaea* var. *hondurensis* at low elevations has long been suspected in natural stands and is a factor that also may contribute to morphological differences between the groups (Squillace and Perry 1992). Over the last 20 years, CAMCORE has

Table 12-1a. Low elevation (LE) provenances of *Pinus tecunumanii* identified and collected by CAMCORE in Central America.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/year)	No. of Trees
1	Mountain Pine Ridge	Cayo	Belize	$16^{\circ} 53' N$	$88^{\circ} 54' W$	560 - 790	1558	125
2	San Pastor Pine Ridge	Cayo	Belize	$16^{\circ} 40' N$	$88^{\circ} 57' W$	600 - 800	1558	21
3	Campamento	Olancho	Honduras	$14^{\circ} 39' N$	$86^{\circ} 43' W$	900 - 1100	1484	35
4	Culmí	Olancho	Honduras	$15^{\circ} 08' N$	$85^{\circ} 36' W$	400 - 950	1491	40
5	Esquipulas del Norte	Olancho	Honduras	$15^{\circ} 15' N$	$86^{\circ} 30' W$	980 - 1020	1067	45
6	Gualaco	Olancho	Honduras	$15^{\circ} 03' N$	$86^{\circ} 08' W$	600 - 800	1491	40
7	Jocón	Yoro	Honduras	$15^{\circ} 16' N$	$86^{\circ} 53' W$	775 - 1000	1166	35
8	Locomapa	Yoro	Honduras	$15^{\circ} 30' N$	$87^{\circ} 20' W$	1200 - 1500	1167	36
9	Los Planes	Comayagua	Honduras	$14^{\circ} 48' N$	$87^{\circ} 53' W$	1100 - 1650	2287	40
10	San Esteban	Olancho	Honduras	$15^{\circ} 15' N$	$85^{\circ} 38' W$	600 - 1200	1071	50
11	San Francisco	Olancho	Honduras	$14^{\circ} 57' N$	$86^{\circ} 07' W$	900 - 1590	1491	35
12	Villa Santa	El Paraíso	Honduras	$14^{\circ} 12' N$	$86^{\circ} 17' W$	800 - 1000	1302	50
13	Apante	Matagalpa	Nicaragua	$12^{\circ} 54' N$	$85^{\circ} 56' W$	920 - 1040	1394	16
14	Cerro la Joya	Matagalpa	Nicaragua	$12^{\circ} 25' N$	$85^{\circ} 59' W$	940 - 1160	1394	32
15	La Rinconada	Matagalpa	Nicaragua	$12^{\circ} 42' N$	$86^{\circ} 11' W$	920 - 980	900	10
16	Las Camelias	Nueva Segovia	Nicaragua	$13^{\circ} 46' N$	$86^{\circ} 18' W$	950 - 1060	1500	18
17	San Rafael del Norte	Jinotega	Nicaragua	$13^{\circ} 14' N$	$86^{\circ} 07' W$	1080 - 1330	1362	26
18	Yucul	Matagalpa	Nicaragua	$12^{\circ} 56' N$	$85^{\circ} 46' W$	910 - 1170	1394	32
18 Provenances		8 State/Depts.	3 Countries	12 - 17° N	85 - 89° W	400 - 1650	1393	686

Map key does not correspond to CAMCORE provenance codes.

Table 12-1b. High elevation (HE) provenances of *Pinus tecunumanii* identified and collected by CAMCORE in Mexico and Central America.

Map Key	Provenance	State or Department	Country	Latitude	Longitude	Elevation Range (m)	Rainfall (mm/yr)	No. of Trees
19	Montecristo	Santa Ana	El Salvador	14° 25' N	89° 24' W	1700 - 1850	1997	2
20	Rio Chiquito	Chalatenango	El Salvador	14° 22' N	89° 08' W	1950 - 2280	1629	17
21	Cabricán	Quetzaltenango	Guatemala	15° 35' N	91° 38' W	2510 - 2670	1010	45
22	Chiul	El Quiché	Guatemala	15° 20' N	91° 04' W	2440 - 2680	1999	27
23	El Ingenio	Jalapa	Guatemala	14° 43' N	90° 02' W	1850 - 1920	1400	13
24	El Pinalón	El Progreso	Guatemala	15° 04' N	89° 54' W	2100 - 2770	2592	15
25	Km 33	Guatemala	Guatemala	14° 35' N	90° 22' W	2000 - 2200	1543	7
26	Km 47	Guatemala	Guatemala	14° 35' N	90° 25' W	2000 - 2200	1543	10
27	La Piedad	El Progreso	Guatemala	15° 02' N	90° 02' W	2080 - 2230	2592	30
28	La Soledad	Jalapa	Guatemala	14° 30' N	90° 24' W	2390 - 2465	1543	46
29	Pachoc	Totonicapán	Guatemala	14° 52' N	91° 16' W	2000 - 2500	1350	20
30	San Jerónimo	Baja Verapaz	Guatemala	15° 03' N	90° 18' W	1620 - 1850	1200	43
31	San Lorenzo	Zacapa	Guatemala	15° 05' N	89° 40' W	1900 - 2100	1700	28
32	San Mateo Ixtatán	Huehuetenango	Guatemala	15° 49' N	91° 26' W	2660 - 2900	1400	9
33	San Miguel	San Marcos	Guatemala	15° 16' N	91° 45' W	2280 - 2370	2127	16
34	San Vicente	Baja Verapaz	Guatemala	15° 05' N	90° 07' W	1690 - 2200	1700	45
35	Tacaná	San Marcos	Guatemala	15° 14' N	92° 03' W	2500 - 2830	1410	2
36	Celaque	Lempira	Honduras	14° 33' N	88° 40' W	1540 - 2030	1273	26
37	Cerro Cusuco	Cortés	Honduras	15° 30' N	88° 12' W	1450 - 1630	2287	40
38	La Esperanza	Intibucá	Honduras	14° 16' N	88° 13' W	1720 - 1850	1363	35
39	Las Trancas	La Paz	Honduras	14° 07' N	87° 49' W	2075 - 2185	1579	51
40	Chanal	Chiapas	Mexico	16° 42' N	92° 23' W	2010 - 2350	1238	29
41	Chempil	Chiapas	Mexico	16° 45' N	92° 25' W	2020 - 2220	1146	26
42	El Carrizal	Chiapas	Mexico	15° 24' N	92° 18' W	2130 - 2280	2000	19
43	Jitotol	Chiapas	Mexico	17° 02' N	92° 51' W	1660 - 1750	1701	27
44	Las Piedrecitas	Chiapas	Mexico	16° 42' N	92° 35' W	2360 - 2500	1252	27
45	Montebello	Chiapas	Mexico	16° 06' N	91° 45' W	1660 - 1750	1909	32
46	Napite	Chiapas	Mexico	16° 34' N	92° 19' W	2070 - 2350	1350	36
47	Rancho Nuevo	Chiapas	Mexico	16° 41' N	92° 35' W	2280 - 2340	1238	25
48	San José	Chiapas	Mexico	16° 42' N	92° 41' W	2245 - 2400	1252	21
49	Buena Vista	San Marcos	Guatemala	15° 15' N	92° 03' W	2300 - 2400	1800	0*
50	Chichicastenango	El Quiché	Guatemala	14° 54' N	91° 06' W	2100 - 2300	1996	0*
51	La Libertad	Huehuetenango	Guatemala	15° 29' N	91° 51' W	2380 - 2450	1400	0*
52	Unión Barrios	Baja Verapaz	Guatemala	15° 11' N	90° 11' W	1700 - 2100	1200	0*
53	Opatoro	La Paz	Honduras	14° 15' N	87° 51' W	2000 - 2150	1560	0*
54	Murra	Nueva Segovia	Nicaragua	13° 44' N	86° 03' W	1170 - 1350	1410	0*
30	Provenances	18 State/Depts.	5 Countries	14 - 17° N	86 - 93° W	1170 - 2900	1602	787

* Site visited, no collections made.

Map key does not correspond to CAMCORE provenance codes.

Figure 12-1. CAMCORE collections of *Pinus tecunumanii* in Mexico and Central America.

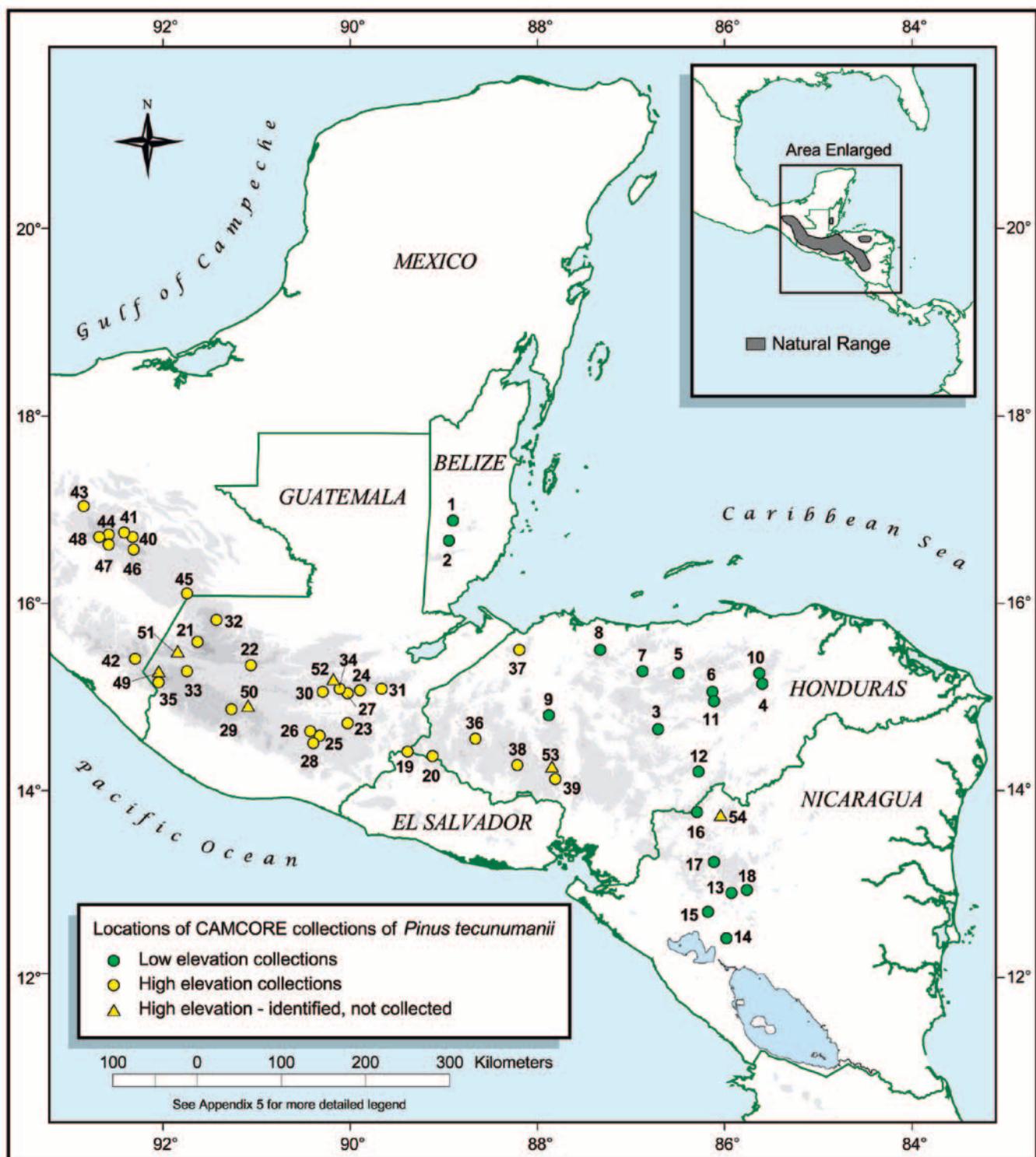


Table 12-2. Monthly mean temperature (°C) and rainfall (mm) recorded at a typical LE *Pinus tecunumanii* site, Villa Santa, Honduras (top) and HE site, Chiul, Guatemala (bottom).

Villa Santa, LE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	22.3	22.9	24.0	24.5	24.0	22.9	23.4	22.9	22.3	22.3	21.7	21.7	22.9
Mean Rain mm	32	22	11	25	148	210	244	124	252	144	50	42	1302

Based on 7 years of data recorded at Danlí, Honduras, 45 km from the collection site. Data provided by ESNACIFOR.

Chiul, HE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp. °C	13.9	14.4	16.7	17.8	18.3	17.5	16.7	16.7	17.1	15.2	15.2	14.2	16.1
Mean Rain mm	34	29	30	49	128	317	390	331	323	245	70	53	1999

Based on 15 years of data recorded Chiul, Guatemala, 28 to 30 km from the collection site. Data provided by Elmer Gutiérrez.

visited 54 populations and has made seed collections from 1473 *P. tecunumanii* trees throughout Mexico and Central America (Tables 12-1a and b). Many of the sampled stands are less than 15 ha in size and are most often between 3 to 5 ha. Styles and McCarter (1988) report 58 sightings

of *P. tecunumanii* in Honduras. Undoubtedly, many more small stands exist in cloud forest belts and humid valleys throughout Chiapas and Central America (Photos 12-2a and b).



Photos 12-2a and b. The morphology of trees of high elevation populations like San Lorenzo, Guatemala (left) is slightly different from that of low elevation provenances like Yucul, Nicaragua (right).

CLIMATE

Pinus tecunumanii occurs in areas that receive between 1000 and 2500 mm of annual precipitation. Many of the HE populations are situated in montane cloud forests that receive additional moisture from the fogs that often develop. Exceptions are provenances such as Cabricán in northwestern Guatemala that are located in rain shadow areas. Trees of HE populations are subjected to mild short duration frosts (-1 to -4 °C) during the winter months in the mountains of western Guatemala and on the San Cristóbal de las Casas plateau, Chiapas. Both HE and LE sources occur in areas with well-defined dry seasons from November to April. During years of extreme drought (El Niño events), annual rainfall can be as low as 700 to 800 mm. Typical temperature and rainfall patterns for HE and LE populations are shown in Table 12-2.

SOILS

Trees from HE populations generally occur on the same kinds of soil throughout the mountains of Central America and southern Mexico. A typical site composite for HE *P. tecunumanii* would possess a needle litter layer of 3 to 8 cm, an organic layer of 2 to 4 cm and mineral horizons that are 1 to 3 m deep. At sites from western Guatemala to Chiapas, 1 to 3 cm of volcanic ash from a geologically recent eruption may be interspersed in the mineral horizons. Normally, these mountain soils are well-drained, sandy or clay loams with high base status and fertility; they include Alfisols, Inceptisols and occasional Andisols. Soil pH is 5.0 to 6.0. At the lower altitudes of its natural distribution (1500 to 1700 m), HE *P. tecunumanii* is sometimes found on slightly more acidic eroded red clays (Ultisols) along with *P. oocarpa* and *P. maximinoi*.

Soil patterns at LE *P. tecunumanii* sites differ slightly from HE sites. The litter and organic layers are sometimes missing as a consequence of more frequent fires. The soils of LE sites are generally less than 1 m in depth, are more leached and sometimes less fertile, and occasionally have a higher proportion of clay in their mineral horizons than HE locations. Soil pH ranges from 4.2 to 5.8. The poorest soil types are found in transition zones where *P. tecunumanii* occurs sympatrically with *P. oocarpa*. Ultisols, Inceptisols and Alfisols are the soil orders that are generally represented.

REPRODUCTIVE BIOLOGY

Female strobili receptivity and pollen dispersal occur from December through March throughout Central America and southern Mexico depending on the altitude of the population. At San Jerónimo, Guatemala, pollen collections

have been made successfully the third week in February. Cones on trees in HE populations occur singly or in pairs, on long peduncles, and mature from January through March, 22 to 24 months after pollination. An early collection was made in the highlands of Guatemala (1700 m elev.) during October 1984 but percent germination was only 5% because cones had not fully matured (CAMCORE, unpublished data). Cone crops in HE trees usually are extremely light with fewer than 50 cones on trees as tall as 45 m. In a 1983 cone collection from 115 trees on the San Cristóbal de las Casas plateau, 20 grams of seeds were obtained per 100 cones collected (CAMCORE, unpublished data). The average seed potential per cone is 90 seeds (Dvorak 2000). An average of six filled seeds per cone was found for trees in HE populations, yielding a seed efficiency rate of 7% (Dvorak and Lambeth 1993). The average number of seeds per kg in HE Populations is 88,250.

Cones on trees in LE populations occur in clusters of two to four, and mature from January through March. Multiple flushes of cones are common. The average seed potential per cone is 95 seeds. An average of 30 filled seeds per cone was found for trees of LE provenances for a seed efficiency rate of 32%. The average number of seeds per kg for LE *P. tecunumanii* is 76,215.

ECOLOGY AND ASSOCIATED SPECIES

Pinus tecunumanii often occupies the mesic environments on the northern and eastern slopes of mountains and moist draws and valleys between hills. Fires are infrequent in these moist environments but are important for defining the species distribution. *Pinus tecunumanii* regenerates well on bare mineral soils after fire and grows very rapidly in dense stands (Hunt 1962). The species' rapid initial growth allows it to outcompete *P. oocarpa* and associated hardwood vegetation. The high relative humidity in the dense stands deters the spread of intense fires. As the tree becomes older, a thick bark forms around its base, offering additional protection from fire. In a typical Mesoamerican setting, *P. tecunumanii* is found on fertile soils along the lower slopes of the valley bottom, while *P. maximinoi* occupies moister areas along riverbeds and *P. oocarpa* inhabits the drier, exposed upper slopes. During periods of prolonged cyclic droughts, or in cases of human intervention in which fire becomes an annual event, *P. oocarpa* is likely to replace *P. tecunumanii* as the predominant species at altitudes between 1000 and 2200 m.

Trees of HE sources of *P. tecunumanii* in Central America are often found in pure stands or in association with *P. maximinoi*, less frequently with *P. ayacahuite*, *P. oocarpa*, *P. pseudostrobus* and *Cupressus lusitanica*, and rarely with *Abies guatemalensis* and *P. hartwegii* (at Pinalón, Guatemala) at the upper limits of its altitudinal range (Photo 12-3). In Chiapas, *P. ayacahuite*, *P. teocote*, *P. devoniana*, *P. montezumae*, and *P. oaxacana* also occasionally grow with *P. tecunumanii*. *Bromelia* spp. often cling to the stem and the branches of trees in these cloud forest environments. *Liquidambar styraciflua* and *Moraceae* spp., which are indicators of fertile, moist soils, are common at most provenance locations along with an abundance of *Quercus* spp., especially in the western part of the *P. tecunumanii* range. At the San José, Chiapas site on the San Cristóbal plateau, *P. tecunumanii* occurs with *Q. acatenangensis*, *Q. brachistagus*, and *Q. regiosa*. Understory vegetation, particularly at middle and high elevations, is quite dense and luxuriant, reflecting the increased fertility and moist soil conditions (Styles and McCarter 1988).



Photo 12-3. Trees of high elevation *Pinus tecunumanii* (left tree with reddish bark) often grow in association with *P. maximinoi* (grayish bark) in Central America. This photo was taken in the critically endangered population of Murra, Nicaragua.

Trees of LE *P. tecunumanii* occupy moist valleys or watersheds surrounded by drier slopes of *P. oocarpa* and *Quercus* spp. Unlike *P. oocarpa*, *P. tecunumanii* generally does not intergrade through transition forests dominated by *Quercus* spp. (Styles and McCarter 1988). In addition to *P. oocarpa*, *P. maximinoi* and *L. styraciflua* are found growing in association with LE *P. tecunumanii*. *Pteridium aquilinum* (bracken ferns) are common in the understory, especially after fires. At the lowest altitudinal range in Belize and along the northern coast of Honduras, *P. tecunumanii* sometimes occurs in disturbed landscape environments in association with *P. caribaea* var. *hondurensis* and tropical broadleaf species. With the possible exception of San Pastor Pine Ridge, Belize, the species grows along side, but rarely intermixed with *P. caribaea* var. *hondurensis* (Styles and McCarter 1988).

Pinus tecunumanii is relatively free of diseases in natural stands. Cones are occasionally infected with *Cronartium conigenum* (cone rust) and at one site in Guatemala stem cankers likely caused by the same pathogen were found on young saplings. *Arceuthobium vaginatum* (Mistletoe) is found on some trees at Mountain Pine Ridge, Belize (Hunt 1962). *Dendroctonus* spp. (pine bark beetles) attack *P. tecunumanii*, as well as other pines (see Eguiluz-Piedra and Zobel 1986), during the insect's cyclic population explosions which occur approximately every 7 to 10 years in Mesoamerica.

WOOD QUALITY IN NATURAL STANDS

Results from studies conducted in natural stands suggest that *P. tecunumanii* produces wood of moderate to high density, with tracheid lengths similar to many other pine species. The average wood density (extracted) of 108 trees sampled in HE populations in Guatemala between 30 and 60 years of age was 525 kg/m³ (Eguiluz-Piedra and Zobel 1986). Percent extractives averaged 5.4 and 1.2% for juvenile and mature wood, respectively. Tracheid length was 4.1 mm in juvenile wood (10th ring) and 4.8 mm for mature wood (30th ring). The average wood density (extracted) of 97 trees from the LE population in Mountain Pine Ridge, Belize (average age = 28 years) was 542 kg/m³ (Dvorak and Wright 1994). Tracheid length was 4.6 mm in mature wood sampled at the 15th ring. Percent extractives averaged 3.0 and 2.2% for the juvenile and mature core segments, respectively. The quality of pulp at yields 38 and 44% were similar to southern pines in the United States, with low tensile and bursting strength (Palmer and Gibbs 1976). The wood has a yellowish color and is used as lumber for construction, broomstick handles, pallets, fuelwood and fire kindling in its native range (Dvorak 2000).

PLANTATIONS

There are approximately 10,000 hectares of *Pinus tecunumanii* plantations established in Brazil, Colombia and South Africa. Within the CAMCORE program, SAFCOL and Smurfit Cartón de Colombia have the largest areas established. Results from 78 CAMCORE trials show that the average productivity of unimproved *P. tecunumanii* (outside bark) at 5 to 8 years is 14 m³/ha/yr in Brazil and Venezuela, 15m³/ha/yr in South Africa, and 25m³/ha/yr in Colombia (Hodge and Dvorak 1999).

NURSERY PRACTICES

Seed Handling

Seeds stored at 4 °C with 6 to 9% moisture content should remain viable for up to 15 years. *Pinus tecunumanii* has a thin seed coat that can crack, chip or split if handled roughly, so seeds must be handled carefully during processing (Dvorak 2000). No pretreatment or cold stratification is necessary. However, Smurfit Cartón de Colombia (in Colombia) and Mondi and Sappi in South Africa subject seeds to a 24 to 48 hour soak in aerated water at 25 °C as a presowing treatment to promote even germination. Seeds will germinate on moist filter paper in petri dishes or in moist sand without problems.

Germination usually begins 7 to 10 days after sowing. Normal germination capacity for cleaned seeds from natural stands is approximately 75%.

Containers and Growth Media

Growing seedlings of *P. tecunumanii* is sometimes more difficult than for *P. caribaea*, *P. oocarpa* and *P. patula*. The root system appears to be relatively delicate. In a rhizotron study where roots were allowed to grow unrestricted, *P. tecunumanii* exhibited the smallest tap root and the lowest ratio of lateral root area to shoot height when compared to *P. maximinoi* and two white pines, *P. chiapensis* and *P. ayacahuite* (Dvorak 1990). When grown in containers in the nursery, the species is very susceptible to J-rooting and root spiraling. Nursery managers must be careful when choosing container size and when deciding the length of production times in the nursery before outplanting.

A number of container sizes and nursery media have been used to grow *P. tecunumanii*. Media such as: a) 50% top soil and 50% fumigated river sand (Dvorak 1985), b) 100% composted pine bark (A. Bayley, personal communication), and c) 33% composted sawdust with 33% coal ash, and 34% topsoil (M. Arce and V. Betancur; personal communication) have been used successfully. The ideal soil pH for nursery media is 5.0 to 6.0. Fertile soils high

in organic matter stunted seedlings of HE *P. tecunumanii* in Guatemala, presumably as a consequence of poor drainage (Dvorak 1985). Trays with dimensions of 340 x 340 mm and 49 (7 x 7) cavities have been used by Sappi. Cavities were 80 mm deep x 40 mm wide for a soil volume of 80 cm³. Jiffy® peat pellets with a capacity of 34 cm³ also have been used successfully by Smurfit Cartón de Colombia.

Seedling Management

It usually takes four to six months to produce a *P. tecunumanii* seedling with a 20-cm shoot height. In locations where infrequent frosts are a concern, sowing should be timed in the nursery so that plants are ready for field planting after the danger of the last freeze, which is usually in September for the southern hemisphere. In Smurfit Cartón de Colombia, seedlings are fertilized after two months in the nursery with 0.1g of NPK per plant every two weeks until the plants harden off (M. Arce and V. Betancur; personal communication). Irrigation after fertilization is recommended to prevent needles from being burned. In climates with warm nighttime temperatures, LE trees may develop more rapidly than HE trees. The preferred seedling height for field planting is 10 to 20 cm. Root systems should be inspected on a regular basis in the nursery to ensure that spiral or J-rooting is not occurring. Seedlings greater than 25 cm in height should not be field planted. Plants left in the nursery too long in South Africa developed a large nodal swelling at the root collar.

Vegetative Propagation

Pinus tecunumanii is easily propagated from seedling hedges (stool plants). The following system is used in Colombia (Osorio 1991, Osorio 1993). Seeds are sown in trays (root trainers) and after six months are outplanted to beds (hedges) at 0.5 x 0.5 m to 0.5 x 1.0 m spacing. Hedges are fertilized with 50 g NPK (15-38-10) and 5 g of 48% borax. At two months, hedges are pruned and 5 to 10 sprouts are obtained. The hedges are pruned to an approximate height of 20 cm every two to three months.

Harvested cuttings are 8 to 10 cm long and have mainly juvenile foliage. The cutting is placed in a substrate of 50% coal ash and 50% subsoil after an IBA hormone is applied to its base. No needles are removed from the cutting. The cuttings are then placed in a mist house with 50% shade, where they are maintained for three to four months. While in the mist house, cuttings receive a weekly fungicide treatment and are fertilized at six to eight weeks.

Sprouting and rooting success is variable among provenances and families and less variable within families (V. Betancur, personal communication). The average rooting percent is around 80%.

After roots have developed, cuttings are transferred from a mist house to a shade house, where they are kept for four to five weeks. When the terminal buds show growth, the shade cloth is removed and cuttings are allowed to harden off in full sunlight for another five to eight weeks. The total production time for this method is seven to nine months but can be reduced by several months with the use of peat pellet containers.

The first rooted cutting tests of *P. tecunumanii* established by Smurfit Cartón de Colombia are now 8 years old. Vegetatively propagated material has 25% less forking than trees produced from seed (Osorio 2000). There were little differences between seedlings and cuttings in wood density and broken top percent.

STAND MANAGEMENT

Site Selection and Establishment

Pinus tecunumanii seems to perform best on well-drained sandy clay loam to clay loam topsoil of at least 40-cm depth and with subsoils of clay loams to clay of 60-cm depth (pH 4.5 to 6.0). Annual rainfall should be at least 900 to 1000 mm. The best growth rates ($> 25 \text{ m}^3/\text{ha/yr}$) for LE and HE *P. tecunumanii* have been recorded in Colombia (1750 to 2000 m elev.), where trees have been established on deep Andisols (Typic Dystrandpt, Entic Dystrandpt, Ustic Dystropept) in areas that receive 1200 to 2200 mm of annual precipitation and lack a pronounced dry season (J. B. Urrego, personal communication). In central Brazil, the species survives well on deep, well-drained Oxisols of low natural fertility at 1190 m altitude, with annual rainfall of 1546 mm and a dry season of five months (Moura and Dvorak 1998). In the Mpumalanga region of South Africa, it has done well at 1000 m altitude and with 1200 mm of annual rainfall on deep Alfisols and Ultisols. At Melmoth, South Africa, it has also shown promise at 1000 m altitude with 900 mm annual rainfall on Ultisols. In both coastal South Africa and eastern Venezuela LE *P. tecunumanii* has grown reasonably well when established on predominantly sandy soils at 50 to 150 m altitude in areas where strong seasonal winds are not prevalent. However, in Venezuela top dieback is common during prolonged periods of drought (see Survival).

Frost is one of the most common causes of mortality in *P. tecunumanii* plantings in Brazil, Chile and South Africa (see Falkenhagen 1990). Low lying areas in which frost pockets develop should be avoided. Survival has been poor on wet clayey Ultisols and Inceptisols but has been acceptable on well-drained Alfisols in East Kalimantan, Indonesia.

A number of site preparation methods have been employed for *P. tecunumanii*, including burning, disking and bedding. Young seedlings do not survive well when in competition with weeds and grasses. Removal of competing vegetation before planting and the use of herbicides during the year after planting are essential to species establishment. It appears that on most soils, *P. tecunumanii* will respond to fertilizer. In South Africa, 100 g of superphosphate per tree are added at time of planting (A. Bayley, personal communication). In Colombia, 50 g of 15-38-10 NPK and 10 g of 68% borax per tree are added at time of planting (N. Isaza and C. Rodas, personal communication). In Venezuela a 71% increase in volume was obtained on sandy clay soils at 4 years of age when triple superphosphate, potassium, and borax were applied at the rate of 250, 60 and 12.4 kg/ha, respectively, eight weeks after planting (González and Longart 1995). Baseline data on the nutritional needs of *P. tecunumanii* are urgently needed and are being developed in some countries.

Because of its shallow root system and propensity for wind throw, *P. tecunumanii* should not be planted near the coast on sandy soils where strong winds from tropical storms are common. Establishment of trees on beds without checking for sufficient root system development in the nursery has exacerbated the high incidence of windthrow. Because of its tendency towards stem breakage in the upper crown (discussed later), *P. tecunumanii* should not be planted on exposed slopes in areas where strong seasonal winds occur (Photos 12-4a and b). Like other Mesoamerican closed-cone pines, *P. tecunumanii* does not grow well when planted on soils that are constantly wet.

Silviculture

Spacing in most plantation programs ranges from 2.0 x 3.0 m to 3.0 x 3.0 m. A spacing study of *P. tecunumanii* in Karnataka, India indicated that 2.5 x 2.5 m spacing was best for a pulpwood rotation of 12 years (Torvi et al. 1998).

The species generally produces a single stem and does not need to be correctively pruned at an early age like *P. chiapensis*. However, trees respond well to silvicultural pruning for sawtimber. Initial shoot growth rates are from 1 to 2 m per year, depending on location. When planted at low elevations near the equator, *P. tecunumanii* has a tendency for rapid height growth, but diameters are smaller than *P. caribaea* var. *hondurensis*. When planted on sandy soils at low elevations, forking often occurs. *Pinus tecunumanii* does foxtail, but only at the rate of 5 to 15%, with the exception of the Mountain Pine Ridge, Belize source, which at some locations has 40% foxtails. Dieback of foxtails during dry periods is common at most sites.

Crown closure begins at about 5 years of age on most planting sites. The crown of *P. tecunumanii* is not as dense



Photo 12-4a. Top, Clem Lambeth (now with Weyerhaeuser) and members of the Smurfit Cartón de Colombia Forestry staff look at a *Pinus tecunumanii* tree that has fallen over during heavy rains. Root instability can be a problem with the species. **12-4b.** Bottom, Gary Hodge (CAMCORE) stands next to a *P. tecunumanii* tree that has lost its top, and competing lateral branches have taken over.

as that of *P. caribaea* var. *hondurensis* nor is it as sparse as that of *P. oocarpa*. Light can reach the forest floor several years after crown closure and weed growth may be sufficient to pose fire risks for the first 7 years. Unlike *P. oocarpa*, seedlings and saplings of *P. tecunumanii* seldom resprout from the base after intense fires.

Pests and Other Limiting Factors

Animal damage: Antelope in South Africa preferentially browse young *Pinus tecunumanii* seedlings. Research by South African organizations indicates that applying a raw egg mixture over the seedlings is the most effective way to limit browsing. Baboons occasionally have eaten the bark off trees at Wilgeboom, South Africa, causing moderate damage in some progeny trials. In Zimbabwe, bush pigs (*Potamochoerus porcus*) occasionally damage LE *P. tecunumanii*, but seem to prefer eating the roots of *P. oocarpa* (Sniezko and Mullin 1987). Preferential browsing is likely the result of different monoterpenes composition of *P. tecunumanii* and *P. oocarpa*.

Diseases: On sandy soils in coastal South Africa near Kwambonombi, *P. tecunumanii* is much more susceptible to *Phytophthora* root rot than is *P. caribaea*. In southern Brazil, *P. tecunumanii* is affected by *Sphaeropsis sapinea* (Diplodia), but damage has been restricted to the branch tips and the disease did not affect the growth or form of the tree. The disease kills small trees of *P. patula* and *P. greggii* grown in the same area. *Pinus tecunumanii* appears to be highly susceptible to *Cronartium quercuum* f. sp. *fusiforme* (fusiform rust) based on laboratory screening tests in North Carolina (Lambeth et al. 1997). LE populations were extremely resistant and HE populations moderately resistant to *Fusarium subglutinans* f. sp. *pini* (pitch canker) in screening tests conducted by CAMCORE in North Carolina (Hodge and Dvorak 2000). Fusiform rust and pitch canker have not been identified in exotic plantations to date.

Insects: Young seedlings of *P. tecunumanii* are very susceptible to the *Hylastes* sp. beetle in South Africa. Leaf-cutting ants (*Atta laevigata*) have damaged trees in CAMCORE trials in Brazil and Venezuela that were not properly protected from the insect. *Oiketicus* sp. (bagworms) show a preference for trees of LE *P. tecunumanii* from the Mountain Pine Ridge, Belize source over both *P. caribaea* var. *hondurensis* and *P. oocarpa* in eastern Venezuela (Vale et al. 1991). A chrysomelid (*Costalimaita ferruginea*) has been identified as a needle defoliator on *P. tecunumanii* in eastern Venezuela (Rosales and Savini 1995) but the insect did not harm CAMCORE trials in the area. Black pine aphids (*Cinara cronartii*) have shown a preference towards LE *P. tecunumanii* in southern Africa but not for *P. oocarpa* (Barnes and Styles 1983). *Pinus tecunumanii* appears to be moderately resistant to *Pineus pini* (woolly aphid) in southern Africa. Termite

damage has also been noted on *P. tecunumanii* in Thailand (Crockford et al. 1990).

Stem Breakage: The greatest limitation to planting *P. tecunumanii* is its propensity to break at the intersection of the main stem and branch whorls near the tops of trees (Dvorak et al. 1993). Upper-stem breakage normally occurs after age 3 years. Once the upper stem breaks, a competing lateral becomes the dominant leader and the tree continues to grow, but the usable volume of the tree is greatly reduced (Parfitt 1996).

The amount of breakage appears to be related to both environmental and genetic effects that vary across geographic regions (see discussion under "Quality Traits"). Trees assessed in sister CAMCORE studies of HE *P. tecunumanii* at 8 years of age indicate stem breakage to be 41 and 20% in Colombia and South Africa, respectively (Parfitt 1996). A more comprehensive analysis of *P. tecunumanii* trials in both countries shows stem breakage to be 32 and 12% for the two countries (Hodge and Dvorak 1999). Stem breakage percents were lower in LE than HE trees in both Colombia (14 vs. 32%) and South Africa (12 vs. 14%). Stem breakage of *P. tecunumanii* trees established on infertile Oxisols in the cerrado region of central Brazil at Planaltina was very low (< 3%) when assessed at 12 years of age (Moura and Dvorak 1998) and was also low in Venezuela on well-drained Inceptisols and Ultisols. Similar trends were observed in 16 and 20-year-old tests and pilot plantings on Oxisols in Minas Gerais and Ultisols in Amapa, Brazil. However, in Paraná State in southern Brazil, where rainfall is higher and the soils more fertile, stem breakage at 5 years of age was 35% in one test. Stem breakage percent in central Brazil and in places such as Venezuela and Malawi is thought to be low (<10% breakage) because the latitude and altitude of the planting sites are very similar to collection sites in the natural stands of Central America and Mexico (i.e., there appears to be an excellent environmental match between donor and receptor countries). Other edaphic factors also may be involved.

Currently, genetic selection against stem breakage accompanied by proper silvicultural practices appears to be the best, if not the only, way to manage the problem. Thinning a LE stand of *P. tecunumanii* to 100 trees per hectare at age 10 years in Colombia in an area where stem breakage was high seemed silviculturally feasible. Eight years after the removal of the trees, the re-occurrence of stem breakage was 10% (J. B. Urrego, personal communication). Additional work is needed to explain how environmental factors such as climate, soil and photoperiod influence the degree of stem breakage in a stand. Crossing the best selections of *P. tecunumanii* with other pine species that do not exhibit this phenomenon also may reduce stem breakage.

WOOD QUALITY IN PLANTATIONS

A number of wood quality assessments have been made in plantations of *Pinus tecunumanii* in the tropics and subtropics (see Dvorak and Kellison 1991). The species' wood density in plantations is considered moderate and its physical attributes and kraft and TMP properties make it acceptable for timber, pulp and paper products.

Density

The average wood density (unextracted) of *P. tecunumanii* at 8 years of age in Colombia was approximately 344 kg/m³ for HE and 361 kg/m³ for LE populations (Osorio and Dvorak 1993), 423 kg/m³ for HE populations at 8 years in the highlands of South Africa (Malan 1992b), 402 kg/m³ for LE populations in Queensland, Australia at 9 years of age (Harding 1990) and 412 kg/m³ for LE populations in Barinas, Venezuela at 10 years of age (Gimenez 1982). Trees from LE sources generally have higher densities than those from HE sources. Trees from HE populations in Guatemala and Honduras were found to have higher density than those from Chiapas (358 vs. 330 kg/m³) when grown in Colombia and assessed at 8 years of age (Osorio and Dvorak 1993). At Tweefontein, South Africa (lat. 25° 03' S, elev. 1152 m, ann. precip. 1298 mm) the densities of *P. tecunumanii* varied from about 450 to 470 kg/m³ at ground level to about 400 kg/m³ at 75% tree height. At lower elevation at Wilgeboom (lat. 24° 56' S, elev. 945 m, ann. precip. 1348 mm) the density values were considerably higher, varying from 530 to 560 kg/m³ at ground level to about 490 kg/m³ at 75% tree height. Both trials were sampled at 17 years of age (Malan 1992a).

In a wood study on 16-year-old trees in South Africa by Dommissie (1994), *P. tecunumanii* was found to have 10 and 13% higher density than *P. patula* and *P. taeda*, respectively. In a study of 17-year-old trees by Malan (1994b), earlywood of *P. tecunumanii* had a higher density than *P. patula* and *P. taeda*. Furthermore, *P. tecunumanii* had a mean latewood percentage of only 10 to 12% compared with 20% in *P. patula* and 31% in *P. taeda* and *P. elliottii* (Photo 12-5). The wood of *P. tecunumanii* was markedly less variable in density in both the radial and axial stem directions than *P. patula* and *P. taeda*. In Paraná State, Brazil, a preliminary study showed HE *P. tecunumanii* with 12% lower density than *P. taeda* assessed at 9 years of age (P. Kikuti, personal communication). In a separate study in Paraná State, LE *P. tecunumanii* had 12% less bark content per unit volume than did *P. taeda* at 12 years of age (A. Villela, personal communication). With respect to the Mesoamerican pines, the wood density of *P. tecunumanii* is generally equal to or greater than that of *P. patula*, is equal to or less than *P. oocarpa*, and is greater than *P. caribaea* var.

hondurensis when planted at mid-elevations. When planted near sea level at low latitudes, the density of *P. tecunumanii* is sometimes equal, but most often less than that of *P. caribaea* var. *hondurensis* (see Dvorak and Kellison 1991). The wood quality of *P. tecunumanii* relative to *P. taeda* in southern Brazil is still undetermined.

Fiber Quality

In a study of 17-year-old trees in South Africa by Malan (1994b), *P. tecunumanii* was found to have tracheid cells with much larger cross-sectional diameter than either *P. patula* or *P. taeda*. In an assessment of 16-year-old trees in South Africa, Dommissie (1994) reports average tracheid length from the lower section of the tree to be about 3.0 versus 2.7 mm for *P. patula*. In a different study in South Africa at 20 years of age, average tracheid length of *P. tecunumanii* was approximately 4.0 mm and slightly longer than *P. elliottii* (Malan 1992a). Generally the tracheids of *P. tecunumanii* appear to be longer and wider than either *P. patula* or *P. elliottii* when trees are planted in South Africa.

Spiral Grain

One of the most complete studies of spiral grain in HE populations sampled 46 families and approximately five trees per family in SAFCOL/CAMCORE tests at Tweefontein and Wilgeboom, South Africa (Malan 1992b). The results indicated that grain spirality among families varied significantly from 2.4° to 4.8°, but were not excessively out of line with values for other major pine species in South Africa.

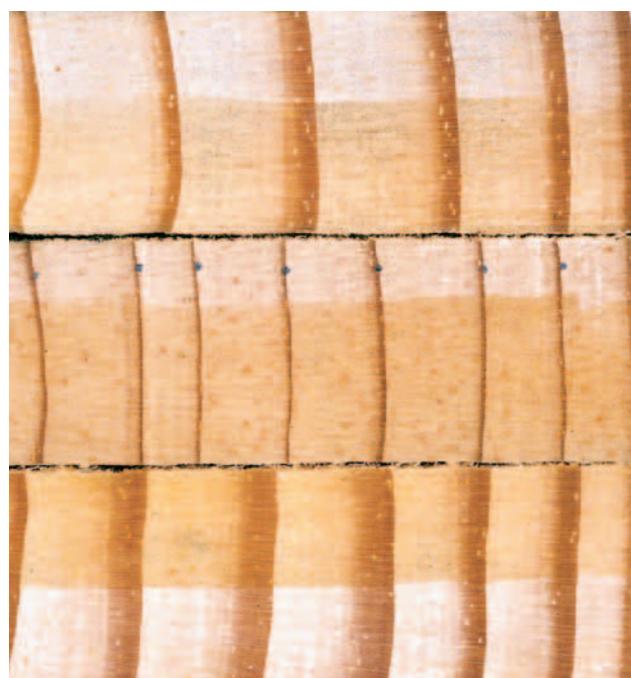


Photo 12-5. Annual ring structure of *Pinus tecunumanii* (middle) compared to those of *P. elliottii* (top) and *P. taeda* (bottom).

Sawmilling and Dry Processing

Sweep studies on the logs from the Tweefontein, South Africa trial showed a higher degree of butt sweep compared to the *P. patula* and *P. taeda* controls. Logs originating from higher up in the trees did not show any differences in average sweep among species or between provenances (Marais 1991).

On average, the branch diameters (above the pruning height) of the three *P. tecunumanii* provenances studied at Tweefontein varied from 23 mm to 31 mm, which is considerably less than the average values found for *P. patula* (43 mm) and *P. taeda* (47 mm). In *P. tecunumanii*, however, the size of the branch diameters was more variable. Knot frequency was markedly higher in the control species compared to *P. tecunumanii* provenances but the latter exhibited a higher incidence of knots with bark inclusions.

No detailed information is available on the green sawing properties of the species but it has been successfully sawn in a sawmilling trial carried out by Marais (1991) on sawlogs cut from 17-year-old trees from the Tweefontein trial. No species-related difficulties were experienced. It seasoned well without any difficulty. No problems with resin flow were experienced due to *P. tecunumanii*'s relatively low resin content. It tended to twist less than *P. patula* and *P. taeda* but no significant differences in bow, cup and spring could be found. In fact, the warp recorded for all species and provenances studied were well within the limits set by the South African Standard Specification for Stress-graded Softwood Structural Timber (SABS 563-1978).

Although studies have not been done, it is expected that in South Africa the wood of *P. tecunumanii* will be nondurable and require protection against biological degradation, like other commercial pines. Since the species has relatively low resin content and tracheids with larger lumens than other pines, it is likely that its permeability characteristics will be similar to those of other pines, or even better. Inmunisa, a wood treatment plant owned by Smurfit Cartón de Colombia, reports good penetration and retention when treating *P. tecunumanii* with CCA preservatives.

Since *P. tecunumanii* is relatively uniform and straight-grained with low resin content, good machining properties can be expected. The low latewood percentage will be conducive to good planing and sanding finishes, and the formation of crisp edges. Nailing and screw holding can be expected to be good as there will be a lower tendency of splitting along the weaker earlywood planes. The uniformity of the wood and its relatively low resin content will also be conducive to good paint finishes.

Pulp Quality

Robertson (1991) pulped 30 LE *P. tecunumanii* tree samples (age = 17 years) that were collected in the highlands of Mpumalanga, South Africa. The mechanical pulping test was run to yield a pulp at kappa number 38. *Pinus patula* and *P. taeda* were included as controls in the study. Little difference was found in lignin content among the three species. Extractive contents of the LE *P. tecunumanii* samples ranged from 1.7 to 7.7% and were generally higher than in the other two species. There were no significant differences in pulping characteristics or pulp strength among the three species. Kraft pulp yields of 40 to 45% at kappa number 40 to 60 were found in studies of *P. tecunumanii* grown in Colombia and South Africa (Wright et al. 1996b, Wright 1987). Burst strength for *P. tecunumanii* was low but maximum values for burst and tear indices are achieved quickly at low levels of refining. In a separate study in Brazil on a small sample of trees, kraft pulp yields were 54% at kappa number 68 (Francides 1992). Holocellulose, lignin and extractive percents were 60, 36, and 4%, respectively.

Thermomechanical tests on 8-year-old trees from Colombia and South Africa and 16-year-old trees from South Africa indicate that *P. tecunumanii* requires the least amount of energy to refine to a given level of freeness of several species studied (Domisse 1994). This was due to the ease of beating and therefore fiber fibrillation. Strength properties of *P. tecunumanii* were inferior to *P. patula* in South Africa. *Pinus tecunumanii* had above average opacity but lower brightness (due the yellowish-white color of the wood) than *P. patula*. The pulp produced from trees 8 to 16 years of age met quality criteria for industrial application (Wright et al. 1995).

GENETICS AND TREE IMPROVEMENT

PROVENANCE COLLECTIONS

CAMCORE has visited 54 *Pinus tecunumanii* sites in Belize, (Chiapas), Mexico, Guatemala, El Salvador, Honduras and Nicaragua since 1980. Seeds from 1473 trees in 48 locations have been collected (Figure 12-1, Tables 12-1a and 12-1b). Of these, 30 are HE provenances and 18 are LE ones. Two additional HE *P. tecunumanii* sources currently are being sampled in the mountains of western Honduras.

GENETIC VARIATION

Provenance Assessment

CAMCORE members have established 153 provenance and progeny trials across Argentina, Brazil, Colombia, Costa Rica, Chile, Guatemala, South Africa, Venezuela, and Zimbabwe. Seed exchanges also have been made with the Oxford Forestry Institute (OFI), UK. Results of productivity and quality traits from CAMCORE tests have been



Photos 12-6a and b. Top left, Louis van der Merwe (SAFCOL) stands by a 12-year-old tree of *Pinus tecunumanii* from a high elevation provenance, and above, by a 13-year-old tree from a low elevation population selected in CAMCORE tests in South Africa. **12-6c and d.** Left center, Paulo Kikuti (Klabin) stands in an 8-year-old CAMCORE *P. tecunumanii* test in southern Brazil, and bottom left, a researcher from Smurfit Cartón de Colombia inspects a selected *P. tecunumanii* tree in the highlands of Colombia.

reported by Dvorak and Shaw (1992), Moura and Dvorak (1998), Osorio and Dvorak (1993), Parfitt (1996) and Hodge and Dvorak (1999). Dvorak and Shaw (1992) summarized 5 years results for 12 HE provenances grown in 18 trials in Brazil, Colombia and South Africa. Hodge and Dvorak (1999) summarized 3- to 8-year results from 48 HE and 30 LE tests grown in the same regions.

Survival

In the majority of tests, survival of most provenances was greater than 80% across all sites grown in frost-free areas. Generally, no single provenance seemed superior to others in adaptability. One exception was at the PROFORCA planting at El Merey, Venezuela (lat. 8° N, elev. 60 m, ann. precip. 1065 mm) on a sandy Ultisol. Here, the Villa Santa source was the only population of the LE *P. tecunumanii* tested that did not suffer top dieback during drought periods. Average survival at 5 years of age of the Villa Santa source was 96 versus 73% for the HE population Cerro Cusuco. In most tests, the mortality that did occur was most often a consequence of tree fall resulting from poor root system development in the nursery. In areas of occasional frost, entire tests were sometimes lost. The Rancho Nuevo provenance from the San Cristóbal de las Casas highlands, Chiapas, showed some cold resistance when established near Lages, Santa Catarina, Brazil (27° S lat.). However, even this source slowly died out over the years due to repeated exposure to cold temperatures in the -7 °C range during winter.

A high elevation trial looked weak and under stress when planted at Morada Nova de Minas, Brazil (lat. 19° S,

elev. 570 m, ann. precip. 1400 mm) because it was established at too low of an altitude. Low elevation *P. tecunumanii* trees planted at the same location grew well and were healthy in appearance.

Productivity

Results from the Hodge and Dvorak (1999) assessment indicate that productivity of unimproved *P. tecunumanii* was 14 m³/ha/yr in Venezuela and Brazil, 15m³/ha/yr in South Africa, and 25m³/ha/yr in Colombia (Photos 12-6a to d). These volume estimates were based on outside bark diameter measurements. High elevation sources performed better than LE ones in Colombia; however, these results are biased somewhat in that the LE control came from Mountain Pine Ridge, Belize, which is a poor source. In South Africa, productivity of HE and LE sources were about the same. In Brazil, where the planting areas are generally better suited for the more tropical sources, LE sources performed slightly better than HE sources. Within the HE group, material from the highlands of Chiapas performed slightly better than provenances from Central America in Colombia and South Africa. In Brazil, the Central American HE *P. tecunumanii* provenances were superior.

Provenance Performance

Provenance variation for volume production is important in *P. tecunumanii*. Results for volume production from the 78 CAMCORE trials assessed at 5 and 8 years of age are presented in Tables 12-3a and b. Also presented are overall broken top percentages.

Table 12-3a. Volume performance (Gain) of 14 LE provenances and two HE provenances (La Esperanza and Cerro Cusuco) of *Pinus tecunumanii*. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean. “Btop33” expresses the amount of stem breakage expected when the average provenance has 33% stem breakage. Provenances are ordered from top to bottom based on latitude of the collection site (amended from Hodge and Dvorak 1999).

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA			Btop 33
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests	
Belize	1	Mountain Pine Ridge	-5.6	63	4	-9.6	89	3	-2.5	.	.	55.6
Honduras	8	Locomapa	-16.3	.	.	-18.6	9	1	-16.3	.	.	.
	37	Cerro Cusuco	2.1	.	.	2.4	7	1	2.1	.	.	.
	7	Jocón	-4.6	24	6	-0.6	29	2	-11.8	20	6	20.4
	10	San Esteban	2.7	48	8	3.8	25	4	1.6	31	7	31.0
	5	Esquipulas d. Norte	-3.2	.	.	-3.7	10	1	-3.2	.	.	.
	4	Culmí	5.8	.	.	5.7	29	2	6.8	.	.	46.2
	6	Gualaco	-1.0	.	.	-1.2	9	1	-1.0	.	.	.
	11	San Francisco	1.9	34	8	4.1	27	4	3.5	24	7	29.4
	9	Los Planes	1.3	.	.	1.5	30	2	1.3	.	.	.
	3	Campamento	0.3	.	.	0.3	11	2	0.3	.	.	.
	38	La Esperanza	5.9	.	.	6.7	11	1	5.9	.	.	.
	12	Villa Santa	5.7	35	7	3.4	27	6	8.4	27	7	33.4
Nicaragua	17	San Rafael d. Norte	13.0	.	.	14.9	16	1	13.0	.	.	.
	14	Cerro La Joya	-26.5	.	.	-30.3	16	1	-26.5	.	.	.
	18	Yucul	18.6	.	.	21.2	16	1	18.6	.	.	.

Map key does not correspond to CAMCORE provenance codes.

Table 12-3b. Volume performance (Gain) of 21 HE provenances of *Pinus tecunumanii*. Predicted gains were calculated using a BLUP approach and are expressed as a percentage above or below the mean. “Btop33” expresses the amount of stem breakage expected when the average provenance has 33% stem breakage. Provenances are ordered from top to bottom based on longitude of the collection site (amended from Hodge and Dvorak 1999).

Country	Map Key	Provenance	BRAZIL			COLOMBIA			S.AFRICA			Btop 33
			Gain	Fams	Tests	Gain	Fams	Tests	Gain	Fams	Tests	
Mexico	43	Jitotol	5.2	10	3	1.1	10	2	0.2	19	4	32.3
	48	San José	-10.2	8	2	-12.1	7	1	-4.2	17	4	32.1
	47	Rancho Nuevo	-1.4	13	2	2.9	23	2	-2.9	23	7	28.7
	41	Chempil	4.1	12	3	3.8	11	2	6.8	18	4	30.4
	40	Chanal	1.5	18	3	-8.7	26	3	0.3	26	7	34.6
	46	Napite	7.8	15	1	-3.5	16	1	1.7	32	2	37.8
	44	Las Piedrecitas	-22.8	13	3	-4.7	11	2	-11.1	19	4	26.1
	45	Montebello	20.0	12	3	10.1	10	2	6.4	20	4	43.6
	42	El Carrizal	-1.2	.	.	-5.1	17	2	1.5	17	7	39.8
	33	San Miguel	6.7	7	2	3.4	.	.	3.4	.	.	.
Guatemala	21	Cabricán	-7.7	19	2	-3.9	.	.	-3.9	.	.	.
	29	Pachoc	-0.7	.	.	-1.2	15	1	-0.9	18	2	29.0
	22	Chiul	2.0	.	.	2.7	12	1	3.2	10	1	29.2
	25	Km33	-9.3	3	2	-4.7	1	1	-4.6	1	1	31.6
	26	Km47	-9.1	3	2	-1.0	6	1	-4.2	6	2	26.2
	30	San Jerónimo	13.7	26	7	12.2	22	3	11.2	17	4	31.3
	28	La Soledad	2.2	6	3	1.4	6	1	5.5	10	3	37.0
	34	San Vicente	-5.8	16	4	-1.3	15	2	-1.5	23	4	32.9
	31	San Lorenzo	-3.5	18	5	1.1	18	3	-2.4	14	4	27.8
	36	Celaque	3.1	8	4	-1.9	15	2	-1.1	13	3	41.2
Honduras	39	Las Trancas	5.7	10	2	-7.4	9	2	-4.4	22	4	31.0

Map key does not correspond to CAMCORE provenance codes.

Provenance effects presented in Tables 12-3a and b are slightly different than those presented by Hodge and Dvorak (1999). Here, BLUPs of provenance effects in each country have been calculated versus the ordinary least squares (OLS) estimates of an overall provenance effect in the Hodge and Dvorak (1999) manuscript.

Quality Traits

There was significant provenance variation with respect to stem breakage among sources planted in CAMCORE tests at most locations (see Tables 12-3a and b). Montebello, Culmí and Mountain Pine Ridge had extremely high values for stem breakage. There also appears to be significant between-family variation in stem breakage. Results from assessments in several trials indicate that there are not strong correlations between tree growth rate and percent stem breakage (Dvorak et al. 1993a, Parfitt 1996, Hodge and Dvorak 1999). For example, the San Jerónimo source, which grew rapidly, and the Km 33 source, which grew slowly, had approximately the same stem breakage percents (approx. 31%). At age 8, the mean correlation between family means for volume and broken tops was -0.15 ± 0.03 for tests with a high incidence of broken tops and -0.04 ± 0.04 for tests with low incidence of broken tops (Hodge and Dvorak 1999). Dvorak et al. (1993a) found phenotypic correlations that ranged from 0.22 to 0.62 between family mean branch diameter and stem

breakage at age 8 years in several tests in Colombia. A subsequent and more complete analysis by Hodge and Dvorak (1999) showed a correlation between family means for broken tops and branch diameter at age 5 years of 0.48 ± 0.09 in tests with high incidence of stem breakage and 0.29 ± 0.04 in those with low incidence (Hodge and Dvorak 1999). Parfitt (1996) found that the number of branches per whorl was not significantly related to the breakage percent, and that trees with fewer heavy branches had less of a tendency towards breakage than trees with many fine branches. Furthermore, he noted that branches perpendicular to the main stem tended to break more often than branches that formed angles of less than 90°. After the main leader breaks, the competing lateral that becomes dominant also shows a high tendency for breakage.

Chempil had better stem form than most other Mexican seed sources of HE *P. tecunumanii* (Dvorak and Shaw 1992, Moura and Dvorak 1998). San José exhibited high levels of forking in the Brazilian cerrado (Moura and Dvorak 1998). Generally, forking followed the same country patterns as stem breakage, with values of 28% in Colombia, 21% in South Africa, 19% in Brazil and 5% in Venezuela. Forking and stem breakage could both be manifestations of the same trait.

Provenance x Site Interactions

Provenance performance for volume across locations was relatively stable. Average Type B genetic correlations for provenance effects for pairs of tests within the same country was estimated as 0.60 to 0.81, and for pairs of tests in different countries as 0.54 to 0.58 depending on the method of calculation (see Hodge and Dvorak 1999 for full details). Provenance performance was more stable for LE sources than for HE ones, probably because the HE populations were established over a wider range of sites with altitudes ranging from near sea level to 2400 m.

Family x Site Interactions, Genetic Parameters for Growth and Quality Traits

The levels of additive variance in *P. tecunumanii* are of the same magnitude as for many other tropical pines such as *P. patula*, *P. greggii* and *P. caribaea* var. *hondurensis* (CAMCORE, unpublished data). Mean individual tree heritability estimated from 78 provenance/progeny tests at age 5 and 8 years was 0.16 for volume, 0.13 for stem straightness and 0.09 for branch diameter. Heritability estimates derived from several OFI studies by Crockford et al. (1990) were similar. Individual tree heritability for stem breakage and forking in the CAMCORE tests was approximately 0.06 at 8 years of age in tests with a minimum of 15% stem breakage (Hodge and Dvorak 1999). Individual tree heritability in wood density at 8 years of age in four HE studies in Colombia ranged from 0.21 to 0.47 (Osorio and Dvorak 1993) and was 0.48 in one LE test (Dvorak and Wright 1994).

Family x site interactions for growth traits are important in *P. tecunumanii* (Jurado-Blanco 1989, Dvorak and Shaw 1992, Hodge and Dvorak 1999). Type B genetic correlations for volume growth within countries were 0.81 and between countries was 0.46. For stem straightness, genetic correlations between and within countries were 0.64 and 0.54, respectively. Family x site interactions for wood density were minimal when assessed at 4.5 years in three locations in Brazil and Colombia (Lima et al. 1990). In summary, for most traits, data from within a country (or breeding region) will be more valuable than data from another country (or breeding region) when selecting to improve performance. However, both types of data can be used for breeding value prediction and selection to improve growth and other characteristics. It is important that selections made in one environment be tested before being deployed commercially in another environment.

Zamudio (1992), who studied genotype x time interactions for volume in *P. tecunumanii*, suggests that most changes in rank occur within the first 3 years after field planting; families are then relatively stable with respect to environmental interactions. Age-age correlation for volume between 3 and 5 years was 0.86, between 3 and 8 years

was 0.74, and between 5 and 8 years was 0.89 (Hodge and Dvorak 1999). Results suggest that preselection of the best trees in field trials at age 5 is a good predictor of volume at age 8.

Provenance variance becomes less important with age compared to family variance. Provenance variance expressed as a percent of additive variance was 42% at age 3, 25% at age 5, and 13% at age 8 in trials analyzed by Hodge and Dvorak (1999). Hodge and Dvorak (1999) calculated potential gain in volume from breeding *P. tecunumanii* to be about 35.5%. Selection against stem breakage would result in the reduction of the defect by approximately 16%. On a smaller set of trials in South Africa, Parfitt (1996), estimated gains from between-family and within-family selection for trees with no stem breakage to be 8%.

Variation by Population Group

High Elevation Sources: Compilations of results from CAMCORE tests show that provenances from the San Cristóbal plateau in central Chiapas exhibited average to poor productivity. The exceptions were Chempil, which grew 4 to 7% above average in all three countries and Napite, which was average to poor in Colombia and South Africa, but did grow well in Brazil. Phenotypically, the *P. tecunumanii* stands on the San Cristóbal plateau are the best throughout Mesoamerica.

San Miguel and Chiul from the Sierra de los Cuchumatanes of western Guatemala showed some promise but other sources, such as Cabricán and Pachoc, were average to poor. The best two sources were Montebello from the Chiapas/Guatemalan frontier (but not on the San Cristóbal plateau) and San Jerónimo, which is situated on the boundary between the Sierra del los Cuchumatanes and the Sierra de las Minas in central Guatemala (Figure 12-1). Both sources are located between 1600 and 1900 m altitude at the lower elevation limit of the HE group. San Jerónimo had less stem breakage than did Montebello. East of San Jerónimo in the Sierra de las Minas (San Vicente and San Lorenzo) and in the mountain ranges 40 km to the south (La Soledad, KM 37, KM 44) productivity fell considerably. The possible exception was La Soledad, which showed good potential in South Africa and on sites near 1190 m in central Brazil (Moura and Dvorak 1998). Of the four high elevation sources tested in eastern and southern Honduras, La Esperanza and Cerro Cusuco were above average across all three countries, but Celaque and Las Trancas performed only slightly better than average only in Brazil.

Additional results are becoming available for the provenances of La Piedad, Pinalón and El Ingenio in eastern and southern Guatemala (results not shown in Table 12-3a). Preliminary assessments indicate that in Colombia and

South Africa, trees from Pinalón produce slightly above average volume, while La Piedad yields average volume, and El Ingenio yields slightly below average volume.

Low Elevation Sources: Villa Santa, Honduras and San Rafael del Norte and Yucul, Nicaragua were the best performing of the LE provenances (Table 12-3b). Camelias, Nicaragua also is a very good provenance (Crockford et al. 1990, Birks and Barnes 1990) and its early growth results are exceptional in CAMCORE tests. Other provenances, such as Apante, Nicaragua, also look promising in CAMCORE trials (data not shown). Culmí, San Esteban and San Francisco were above average in volume production but ranked slightly below the first tier provenances in terms of performance.

The Mountain Pine Ridge source, which has been intensively tested for a number of years, proved inferior in productivity when compared to other LE sources (Table 12-3b). Interestingly, the two sources that morphologically appear to be most introgressed with *P. caribaea* var. *hondurensis*, Mountain Pine Ridge, Belize and Esquipulas del Norte, Honduras, performed far below average. Sources from northern Honduras, with the exception of Culmí and San Esteban, were average at best. Some of the poorest sources, such as Jocón, Honduras and Cerro La Joya, Nicaragua could be introgressed with *P. oocarpa*. Jocón has monoterpenes more similar to *P. oocarpa* than to *P. tecunumanii* (Squillace and Perry 1992) and Cerro la Joya exhibited a number of *P. oocarpa* characteristics in the field (e.g., bushy development, sprouts from the base) that suggest recent ancestry with *P. oocarpa*.

Preliminary information is available for the most southern provenance of *P. tecunumanii*, La Rinconada, Nicaragua (data not shown). In a test at La Samaria, Colombia (lat. 4° N, elev. 1700 m, ann. precip. 2700 mm) established by Smurfit Cartón de Colombia, La Rinconada showed approximately 6% lower volume than the best source, Camelias, Nicaragua at 5 years of age. In a sister test planted at Pinhal Bonito (lat. 24° S, elev. 760, ann. precip. 1760 mm) by Klabin in Paraná State, Brazil, La Rinconada was 20% less productive than the best *P. tecunumanii* source from Yucul, Nicaragua.

Volume differences of over 30% exist between the best and the worst sources in both LE and HE populations. Using the best rather than the poorest seed sources could reduce harvest age in most plantation programs by as much as 2 years. The best HE seed sources for productivity across all regions are San Jerónimo and Montebello (although the latter has high stem breakage). Among LE sources the best are Villa Santa, Honduras and Yucul, San Rafael del Norte, Camelias (based on Oxford results) and possibly Apante. Good sources within the HE group appear to be randomly situated throughout

the group's natural range, while good performers in the LE group are regionalized in two locations: a) southern Honduras and northern Nicaragua and b) in northern Honduras around Culmí and San Esteban.

DEVELOPMENT OF IMPROVED MATERIAL

Seed Production

Cones of *P. tecunumanii* mature from late June to August in eastern Australia, southern Brazil, Malawi, South Africa and Zimbabwe, and throughout the entire year in Colombia. Flowering begins in most seed orchards at 3 to 4 years of age. Little information on when orchards come into full production is available.

Seed production of *P. tecunumanii* is best on the east coasts of Australia, Brazil, and South Africa between the latitudes of 18° and 28° S and in the highlands of Zimbabwe. At Stapleford, Zimbabwe (lat. 18° S, elev. 1760 m) 54 filled seeds per cone were being obtained at 8 years (Dvorak and Lambeth 1993). Seed production falls off drastically at low altitudes near the equator. Presumably, seed production in trees of HE *P. tecunumanii* will be much less than LE sources.

Seed Orchards

Clonal seed orchards of *P. tecunumanii* have been established in several locations, including Brazil, Colombia, South Africa and Zimbabwe (Photo 12-7). *Pinus tecunumanii* has been grafted successfully on *P. elliottii*, *P. patula* and *P. oocarpa* rootstock (in addition to *P. tecunumanii* rootstock). In South Africa, female flowers are produced on trees from LE sources in June and July and from HE sources in July and August. Placing clones of HE and LE *P. tecunumanii* together in a seed orchard may not be the best strategy because of poor synchronization between female strobili receptivity and pollen dispersal. At high elevations in Colombia, flowering occurs all during the year and seed production is stable and continuous once the orchards are old enough (> 18 years). Supplemental mass pollination is used to obtain good seed set in a young seed orchard of LE provenances located at mid-elevation, approximately 1750 m altitude (Isaza et al. 2000).

Hybrids

Pinus tecunumanii has been artificially crossed with *P. caribaea* vars. *hondurensis*, *bahamensis* and *caribaea*, *P. patula*, *P. greggii*, *P. elliottii*, *P. taeda*, *P. oocarpa* and *P. radiata*. The advantages of using *P. tecunumanii* in a hybrid cross include its fast growth, relatively low bark content (and thus increased wood production) as well as the relative ease of vegetatively propagating the species from seedling stool sprouts. Of the hybrid crosses made, the *P. caribaea* × *P. tecunumanii* cross has been the most widely studied. Crosses are more successful when *P. caribaea* var. *hondurensis* is the female parent (Nikles 1989).



Photo 12-7. *Pinus tecunumanii* clonal seed orchard established by Smurfit Cartón de Colombia on La Suiza farm near Restrepo.

CONSERVATION

IN SITU GENE CONSERVATION

Genetic Diversity

Several studies have been initiated to better define how genetic diversity is structured within *Pinus tecunumanii*. Assessments of allozyme patterns in several natural stands of LE and HE populations in Central America suggest that *P. tecunumanii* has average to above average genetic diversity compared to other pine species (Dvorak et al. 1999, Matheson et al. 1989). In separate studies, 3.0 and 2.2 alleles per polymorphic locus were found in HE and LE populations, respectively. Alleles that occurred at high frequencies in a large *P. tecunumanii* population in Guatemala also occurred at high frequencies in a small population 65 km away (Dvorak et al. 1999). This allele frequency trend may be useful for determining the importance of protecting small, degraded populations in natural stands relative to large ones that might be easier to monitor and conserve. Examination of phylogeny information generated by RAPD markers suggested that the genetic diversity among HE populations was greater than LE populations and that some HE provenances had more genetic diversity than others (Furman 1997).

Conversely, allozyme studies suggest that genetic diversity among LE populations was slightly greater than HE provenances with among population genetic diversity (G_{st}) values of 0.023 versus 0.014, respectively (Dvorak et al. 1999, Matheson et al. 1989). Results from assessment of adaptability and metric traits in provenance tests suggest that both LE and HE populations exhibit great natural variation.

CONSERVATION STATUS

Pinus tecunumanii is relatively abundant throughout southern Mexico and Central America and is not in immediate danger of being eradicated. However, the continual encroachment on natural stands by woodcutters and agriculture has caused severe fragmentation and degradation of some populations. Most of the large, old-growth trees greater than 50 m in height have been cut in Guatemala and Chiapas, Mexico (Photos 12-8a and b). San Jerónimo, Guatemala, once one of the largest contiguous stands of *P. tecunumanii* in the country and one of the most productive provenances in international field tests, has been reduced from 200 ha to approximately 30 ha in size in the last 20 years by local sawmilling and



Photo 12-8a. Left, an old-growth *Pinus tecunumanii* tree more than 1.0 m in diameter in the highlands of Guatemala has been lost through local harvesting. However, its genes have been conserved through CAMCORE seed collections. **12 - 8b.** Right, the critically endangered population at Ashigua, Guatemala is 4 hectares in size. Many provenances of *P. tecunumanii* in Mesoamerica are under severe pressure from wood cutting and agricultural activities.

agricultural activities. The average size of most HE populations of *P. tecunumanii* in Chiapas and Guatemala is between 5 and 15 hectares. Larger stands exist on isolated and inaccessible mountains of Celaque and Santa Bárbara, Honduras. Of the 54 HE and LE provenances inspected from Chiapas to Nicaragua by the CAMCORE Cooperative, 30% can be classified as either **critically endangered** or **endangered**, 60% as **vulnerable**, and 10% as **low risk**. Provenances that are critically endangered include Chempil, Chiapas, El Ingenio, Km 33, and KM 47, Guatemala, and Murra, Nicaragua. Overall, the species conservation status is **vulnerable**.

Using results from 78 CAMCORE international provenance trials as a guide, priorities for establishment and further development of *in situ* conservation areas should include Yucul and San Rafael del Norte Nicaragua, and Villa Santa, Honduras. These performed the best of the LE populations for volume production in the CAMCORE tests. The Las Camelias source should be included in this group based on early CAMCORE results and older OFI assessments. Montebello, Mexico and San Jerónimo, Guatemala showed promise for the HE provenances. These five provenances should all be given priority for *in situ* conservation work. Of these, Yucul and Montebello are the most protected due to efforts by local or international agencies. The more threatened provenances

are Las Camelias, San Rafael del Norte, Nicaragua and San Jerónimo, Guatemala, and there is an immediate need for their protection.

EX SITU CONSERVATION

More than 50 provenances of *P. tecunumanii* have been sampled by international organizations over the last 20 years for field trials, making it one of the most intensively tested of the Mexican and Central American closed-cone pines. In the CAMCORE program, the 1473 families grown in trials are also in field conservation banks in Argentina, Brazil, Colombia, and South Africa. The conservation banks have been planted in row or single-tree plots with their family identity maintained. The future *ex situ* conservation of *P. tecunumanii* will depend on whether the species generates sufficient interest to be used in commercial plantations, which in turn will depend on the success researchers achieve in reducing stem breakage through breeding or silviculture. Secondly, its future gene conservation will depend on how organizations manage aging conservation plantings and provenance trials. Without proper management and a practical, long-term *ex situ* conservation strategy, genes from some of these populations will be lost. In many instances, foresters will not have a "second opportunity" to return to Mesoamerica to obtain more genetic material.

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 Jorge Kondo, INIFAP, Mexico
 Felix Alfaro González, MAGFOR, Nicaragua

THE 2000 EXECUTIVE COMMITTEE

Chair: Juan Jurado-Blanco, Smurfit Cartón de Venezuela
 Djalma Chaves, IGARAS, Brazil
 José Pontones, Smurfit Cartón y Papel de México
 Andrew Morris, SAPPi Forests, South Africa
 David Darling, Fletcher Challenge Forests, New Zealand

THE 2000 TECHNICAL COMMITTEE

Chair: Claudio Balocchi, Arauco, Chile
 Bill Dvorak, CAMCORE, USA
 Gary Hodge, CAMCORE, USA
 José Luis Romero, CAMCORE, USA
 Heuzer Guimaraes, Rigesa, Brazil
 Luis Fernando Osorio, Smurfit Cartón de Colombia
 Eric Kietzka, MONDI Forests, South Africa
 David Darling, Fletcher Challenge Forests, New Zealand

COLLEGE OF NATURAL RESOURCES, NORTH CAROLINA STATE UNIVERSITY

Larry Tombaugh, Dean
 J.B. Jett, Associate Dean of Research
 Fred Cubbage, Head, Department of Forestry

APPENDIX 2:

LIST OF PAST CAMCORE MEMBERS

Australia

Queensland Forestry Research Institute

Chile

Universidad Austral

Brazil

Aracruz
 Cenibra
 Copinus
 EMBRAPA
 Florestas Rio Doce
 Jari Florestal
 PISA

Costa Rica

CATIE

Venezuela

Deforsa
 Forestal Orinoco

Zimbabwe

Zimbabwe Forestry Commission

APPENDIX 3:

SUMMARY OF CAMCORE SEED COLLECTIONS

Summary of CAMCORE collections	Number of:			
	Species	Countries	Provenances	Trees
Total of Pine species included in book	11	6	205	6284
Total of Softwood species not included in book	12	4	67	1660
Total of Hardwood species not included in book	13	11	105	1851
TOTAL CAMCORE COLLECTIONS	36	14	377	9795

Description of CAMCORE collections of *Pinus* species included in the book.

Geographic, elevation, and rainfall data apply to CAMCORE collection sites, not to the entire species distribution.

Species	Number of			Geographic Range Lat. N Long. W	Elevation Range (m)	Rain (mm/yr)	Tolerance to *			
	Countr.	Prov.	Trees				Dr	Fr	Fi	We
<i>Pinus caribaea</i>	6	29	1414	12 - 18° 83 - 90°	5 - 800	2115	M	N	M	H
<i>P. chiapensis</i>	2	16	380	15 - 20° 91 - 100°	470 - 2030	2013	L	L	L	M
<i>P. greggii</i> var. <i>greggii</i>	1	8	183	20 - 25° 100 - 101°	1960 - 2590	681	H	H	M	N
<i>P. greggii</i> var. <i>australis</i>	1	7	180	20 - 21° 98 - 99°	1150 - 2350	1367	M	M	M	M
<i>P. herrerae</i>	1	12	317	16 - 23° 97 - 106°	1600 - 2450	1047	M	L	M	M
<i>P. jaliscana</i>	1	9	88	19 - 21° 104 - 105°	700 - 2050	1886	M	N	M	N
<i>P. maximartinezii</i>	1	1	80	21 - 21° 103 - 103°	1600 - 2550	775	M	L	L	L
<i>P. maximinoi</i>	4	26	856	13 - 18° 86 - 100°	750 - 2100	1403	L	N	L	M
<i>P. oocarpa</i>	3	17	515	13 - 18° 86 - 95°	500 - 1730	1149	M	N	H	L
<i>P. patula</i> var. <i>patula</i>	1	17	460	18 - 24° 96 - 100°	1500 - 2880	1452	M	M	L	L
<i>P. patula</i> var. <i>longiped.</i>	1	8	164	16 - 18° 96 - 100°	1980 - 2870	1443	M	L	L	L
<i>P. pringlei</i>	1	7	174	16 - 19° 96 - 101°	1630 - 2400	1297	M	N	M	L
<i>P. tecunumanii</i> LE	3	18	686	12 - 17° 85 - 89°	400 - 1650	1393	M	N	L	L
<i>P. tecunumanii</i> HE	5	30	787	14 - 17° 86 - 93°	1170 - 2900	1602	M	N	L	L
TOTAL	6	205	6284							

* Dr (Drought), Fr (Freeze), Fi (Fire), We (Wet Soil): N = None, L = Low, M = Medium, H = High

Description of CAMCORE collections of species not included in the book.

Geographic, elevation, and rainfall data apply to CAMCORE collection sites, not to the entire species distribution.

Species	Number of Countr.	Prov.	Trees	Geographic Range Lat. N	Long. W	Elevation Range (m)	Rain (mm/yr)
<i>Abies guatemalensis</i>	2	3	120	15 - 16°	91 - 92°	2780 - 3890	1794
<i>Cupressus lusitanica</i>	1	1	25	15 - 15°	90 - 90°	1600 - 2110	1043
<i>Pinus arizonica</i>	1	3	68	25 - 28°	106 - 108°	2300 - 2375	700
<i>P. ayacahuite</i>	3	16	413	14 - 20°	88 - 98°	2000 - 2940	1361
<i>P. cooperi</i>	1	3	87	24 - 24°	105 - 105°	2500 - 2680	1100
<i>P. engelmannii</i>	1	3	71	24 - 29°	105 - 108°	2190 - 2500	800
<i>P. lawsonii</i>	1	3	41	17 - 19°	96 - 102°	1750 - 2450	1097
<i>P. leiophylla</i>	1	11	309	17 - 24°	97 - 106°	2000 - 2590	1197
<i>P. muricata</i>	1	3	85	38 - 39°	123 - 123°	5 - 170	975
<i>P. pseudostrobus</i>	2	14	261	16 - 21°	96 - 102°	2000 - 2880	1350
<i>P. radiata</i>	1	4	90	35 - 37°	121 - 122°	10 - 280	569
<i>P. teocote</i>	1	3	90	19 - 20°	97 - 98°	2215 - 2500	899
TOTAL SOFTWOODS	4	67	1660				
<i>Albizia caribaea</i>	2	5	69	13 - 14°	87 - 91°	20 - 700	1783
<i>Albizia guachepele</i>	2	3	55	10 - 14°	85 - 87°	10 - 650	1667
<i>Albizia saman</i>	1	1	20	14 - 14°	87 - 87°	600 - 650	1035
<i>Alnus acuminata</i>	2	5	71	9 - 15°	84 - 91°	1560 - 2840	2334
<i>Bombacopsis quinata</i>	5	9	274	9 - 13°	70 - 87°	10 - 740	1449
<i>Cordia alliodora</i>	4	13	184	9 - 18°	83 - 95°	20 - 1100	2183
<i>Enterolobium cyclocarpum</i>	2	3	60	14 - 15°	88 - 91°	100 - 650	1994
<i>Eucalyptus urophylla</i>	1	23	437	8 - 10° S	122 - 125° E	225 - 2000	906
<i>Gmelina arborea</i>	3	30	369	12 - 27°	72 - 102° E	50 - 1000	1892
<i>Schizolobium parahybum</i>	2	3	57	14 - 15°	88 - 91°	80 - 250	2029
<i>Sterculia apetala</i>	3	4	112	11 - 16°	75 - 91°	10 - 90	1443
<i>Tabebuia rosea</i>	2	3	86	14 - 20°	90 - 97°	50 - 950	1565
<i>Vochysia guatemalensis</i>	3	3	57	10 - 16°	83 - 88°	10 - 100	2536
TOTAL HARDWOODS	11	105	1851				

APPENDIX 4: CAMCORE DESIGN FOR PROVENANCE/PROGENY TESTS AND CONSERVATION BANKS

PROVENANCE/PROGENY TEST DESIGN

Through 1999, CAMCORE planted trials using a standard nine-replication randomized complete block design. Provenances were randomized within each replication, and families randomized within provenance subblocks. Families were planted in six-tree row-plots. Spacing between trees was usually 3 m x 3 m. Each test contained various genetic and commercial controls, which were occasionally different species. Within each replication, all control lots were planted together as a "provenance". Tests were typically measured at age 1 for survival, then at ages 3, 5, and 8 for growth and quality characteristics. A volume index (VOL) was calculated as:

$$\text{VOL} = 0.00003 \times \text{HT} \times \text{DBH}^2$$

where HT = height, DBH = diameter at breast height.

PROVENANCE EFFECTS

Volume

Provenance effects for volume presented in this document are Best Linear Unbiased Predictions (BLUPs), which were calculated using one of two methodologies described briefly below. Method A was utilized for *P. cariba* var. *hondurensis*, *P. tecunumanii*, *P. greggii*, and *P. maximinoi* (for basal area). Method B was utilized for *P. pringlei*, *P. chiapensis*, *P. leiophylla*, *P. oocarpa*, and *P. patula*.

Method A: A number of genetic parameters including genetic and phenotypic variances, heritabilities and age-age correlations were estimated from single-site analyses. Data were then standardized using the single-site within family error variances, and all possible pairs of tests with 15 or more common families were analyzed to provide estimates of G x E (specifically Type B genetic correlations, see Burdon 1977) at the provenance and family within provenance level. Standard genetic parameters were developed from these data. Genetic parameters, including Type B correlations within and between countries, could vary by country. Genetic parameter estimates were then incorporated into a SAS® PROC IML routine specifically written to predict provenance and parental breeding values (see White and Hodge 1989 for an example of a similar BLP program). Data were single-site family means from 3-, 5- and 8-year measurements.

Method B: Age 5 and age 8 volume data from all tests were standardized to have a mean of 100 and CV (coefficient of variation) of 50. (This CV is typical for many CAMCORE species). Standardized data were then used to calculate family means in each test, which were used as units of observations to predict the provenance effects. SAS® PROC MIXED was used to calculate the BLUPs, with the following MODEL and RANDOM statements:

```
model volume = testid / solution;
random prov country*prov family(prov) country*family(prov) / solution;
```

This approach allows one to calculate country specific BLUPs, with an assumption of homogeneous genetic parameters (including Type B genetic correlations) across countries and ages.

Quality Traits

A single across-country provenance effect for broken tops in *P. tecunumanii* was calculated using least squares means. A single across-country provenance effect for forking in *P. cariba* var. *hondurensis* was calculated using Method A described above. In both cases, only data from tests with a minimum incidence of 15% were used in the analysis. Units of observation were family means.

CONSERVATION BANK DESIGN

The conservation bank design has evolved over the years as our understanding of the species has improved and workloads have increased. Initially, all families from a particular collection were established in a single-tree plot design in the field in addition to the planting of the main provenance/progeny trial. Each conservation bank had from 10 to 20 replications and contained as many as 70 open-pollinated families. The pedigree of each family member was maintained. Some of these conservation banks are now 18 years old.

To reduce the complexity of conservation banks, the design was changed in the mid-1980s to accommodate each family in a row plot of 10 trees. Spacing was increased from 3×3 m to 5×3 m. The increased space between trees was recommended to promote flowering in the conservation banks. Increases in the testing and measurement workload have recently led to a modification where some provenance/progeny trials will be maintained as conservation banks after final measurements are completed.

As the original gene conservation banks and progeny tests become older, plans must be made to maintain these gene pools for another generation. Specific methods used for each species will depend to some extent on the commercial use of the species. Tree improvement programs will be developed for those species with substantial commercial potential, and our goal will be to ensure that the combined breeding populations of our member companies include selections from every provenance. For species with little or no commercial potential, we plan to maintain a large conservation population with selections from every provenance and every family. Each member organization will be assigned responsibility for the ex situ conservation of a group of species which grow reasonably well and, more importantly, reproduce on specific site types in the member's land base.

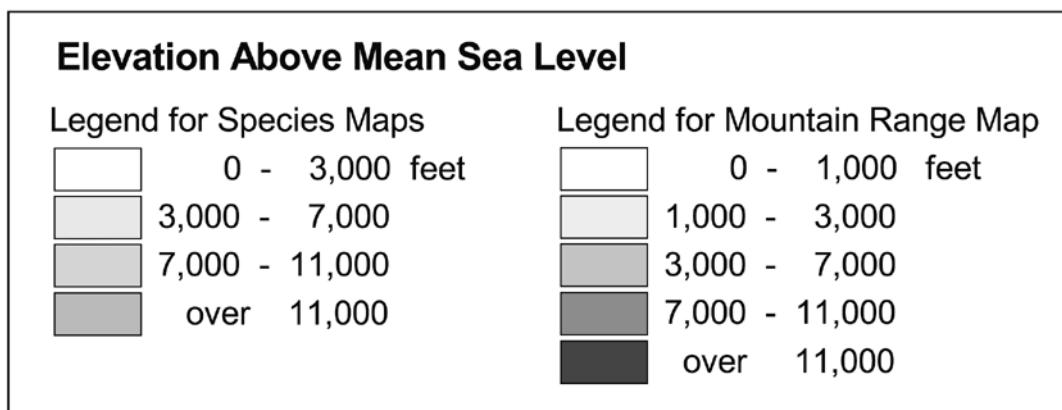
APPENDIX 5: MAP ANNOTATIONS

Maps for this book were created by CAMCORE using ESRI GIS software and data from several sources. Locations of collection sites have been recorded using both map-derived analog coordinates and GPS-recorded digital coordinates. In some cases, coordinates have been adjusted slightly to improve the display on the map of sites located very close to each other. Country and within-country geographical boundaries for Latin America were obtained from Jones (1996) and electronically retrieved from website: www.grida.no/cgari/htmls/latam.htm. Other country boundaries, lake boundaries, and hypsography data come from ESRI (1993), available at website: gis.esri.com.

Only lakes of very large size are included on some maps where their presence is meaningful at the scale of the map. These include Lago de Nicaragua in Nicaragua and Lago de Chapala (and surrounding lakes) in Jalisco, Mexico.

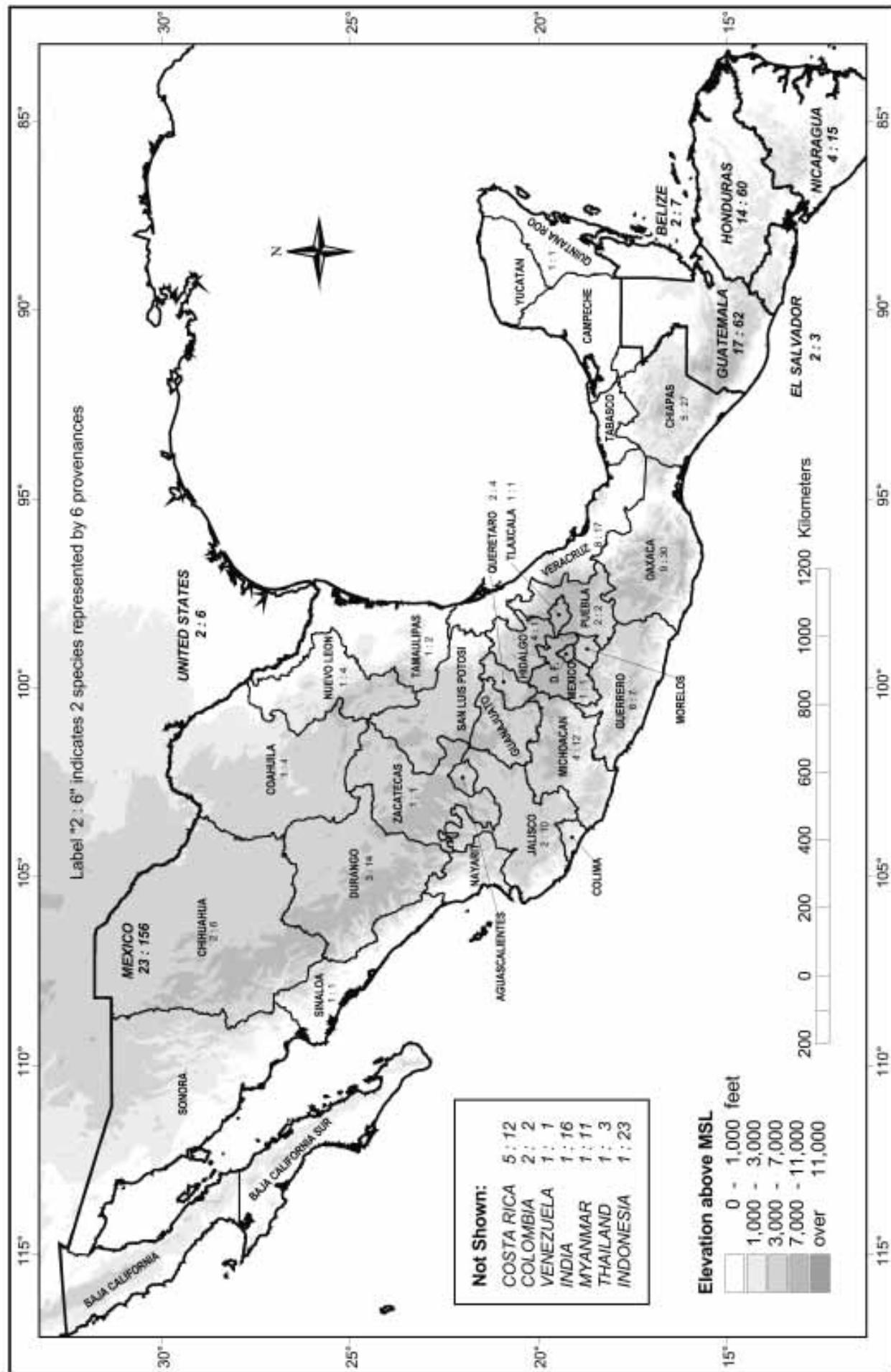
Information on species ranges comes from Perry (1991), Farjon and Styles (1997), and CAMCORE's field observations. These ranges are generalized and may not include every natural occurrence of the species.

Hypsography has been shaded in two different ways for two map types. For the species maps (Chapters 2 to 12) a more subtle shading has been used than for the back cover map and the mountain range map (Chapter 1). Below are legends for elevation using the two shading schemes.

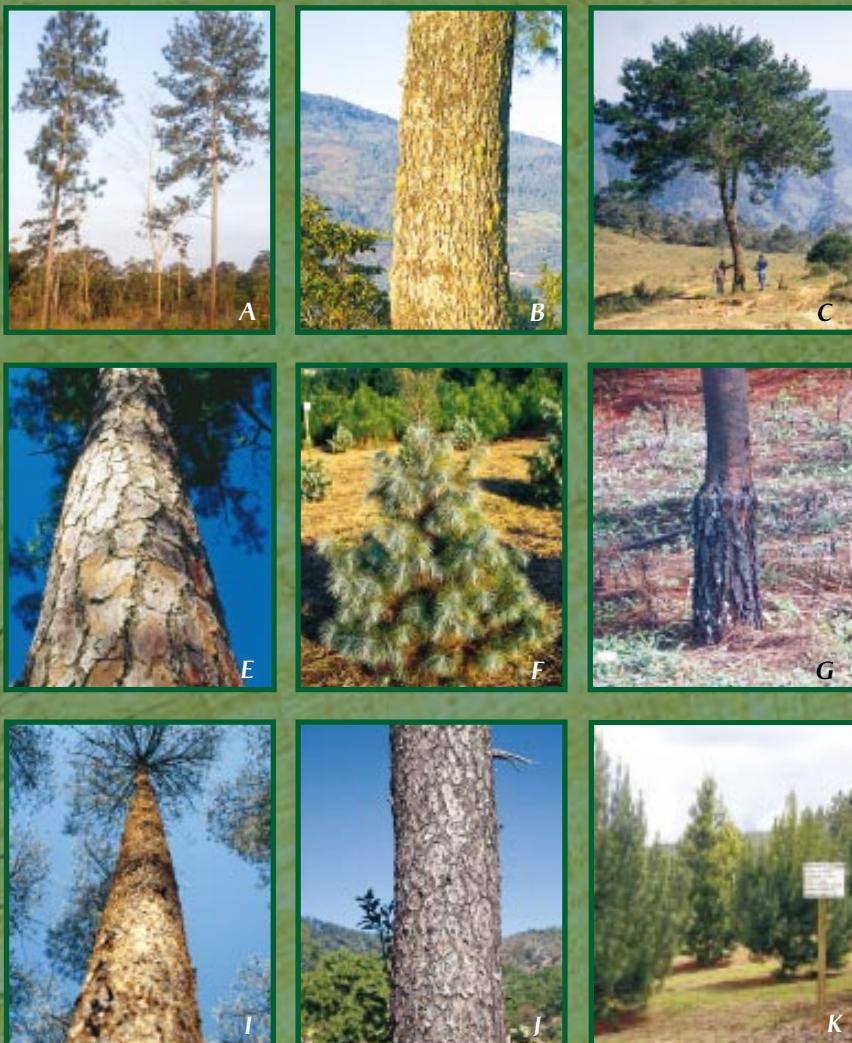


APPENDIX 6

MAP OF THE GEOGRAPHIC DISTRIBUTION OF CAMCORE SEED COLLECTIONS



- A *Pinus caribaea*
- B *Pinus chiapensis*
- C *Pinus greggii*
- D *Pinus herrerae*
- E *Pinus jaliscana*
- F *Pinus maximartinezii*
- G *Pinus maximinoi*
- H *Pinus oocarpa*
- I *Pinus patula*
- J *Pinus pringlei*
- K *Pinus tecunumanii*



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