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

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PINUS PRINGLEI

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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 m^3/ha/yr at 8 years in south-central Brazil to 13 m^3/ha/yr at 9 years in the eastern highlands of South Africa. A mean annual increment of 20 m^3/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 Coetzee 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).

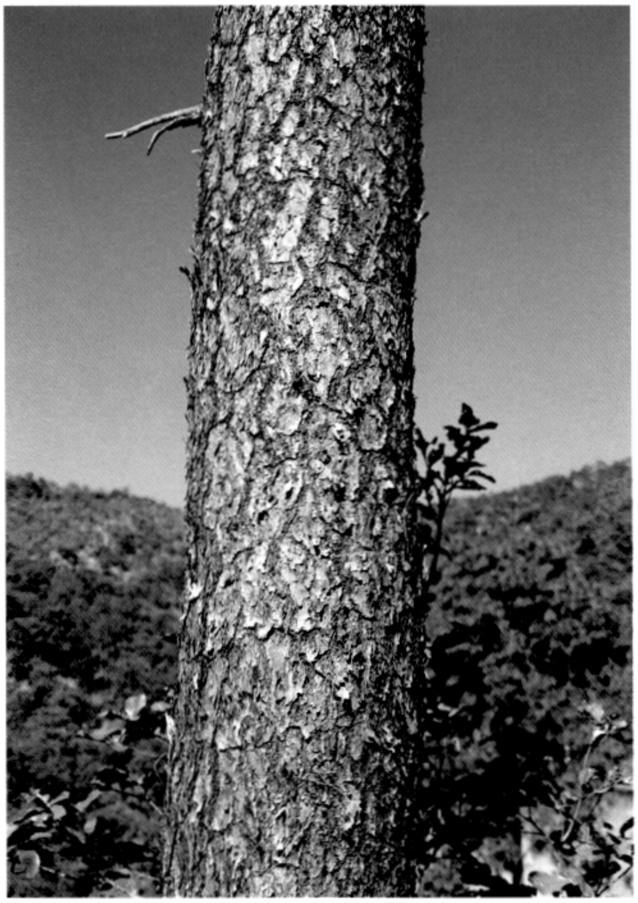

Photo 11-2. Bark of *Pinus pringlei.*

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 *Oocarpae* 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/m^3 and for mature wood was 734 kg/m^3. Individual-tree wood density (weighted) was 679 kg/m^3. 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 11-1. CAMCORE collections of *Pinus pringlei* in Mexico.

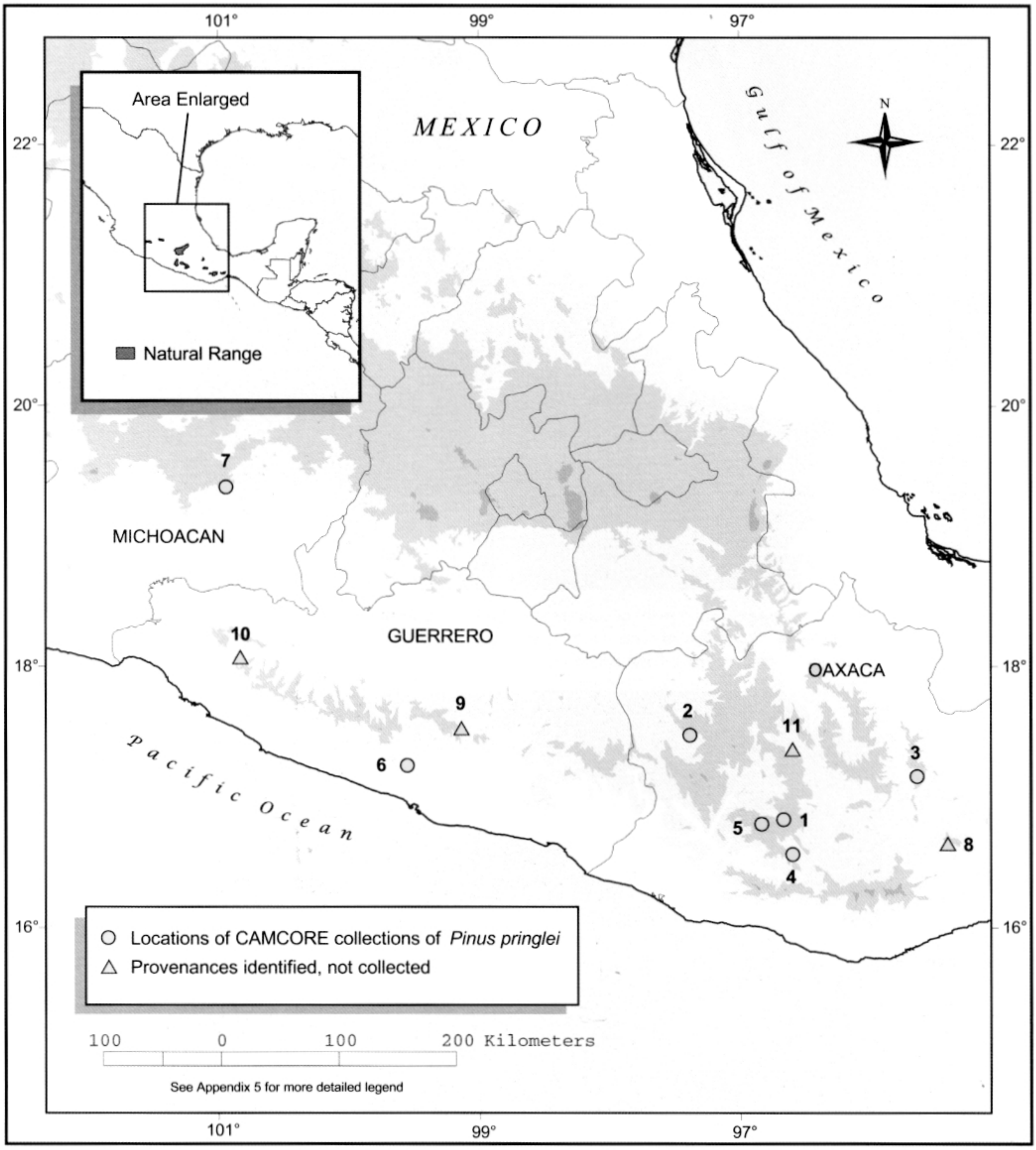

Photo 11-3. Branch of *Pinus pringlei* with 4 years of cone crops. The green conelet (partially hidden, far left) is in its first year of development, the ochre-brown cone (left of center) is in its second year of development and is ready to be harvested, the closed cone (right of center) is one year 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 cm^3. 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 Coetzee (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/m^3 and averaged 530 kg/m^3 (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	KLABIN	MONDI	SAPPI
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
Survival (%)	Age	1	95	97	71	79
		3	95	97	71	78
		5	94	96	68	-
		8	73	76	69	77
Height (m)	Age	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
DBH (cm)	Age	3	4.8	5.0	5.5	3.3
		5	11.4	10.9	11.8	-
		8	15.6	15.0	19.2	15.4
Volume (m^3)	Age	5	0.0277	0.026	0.0311	-
		8	0.0709	0.069	0.1522	0.0829
Forking (%)	Age	8	63	67	61	37
Foxtail (%)		8	11	13	3	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 m^3/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 m^3/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 m^3/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 m^3/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 m^3/ha/yr at 20 years of age (Darrow and Coetzee 1983). Productivity in an arboretum planting (297 trees/ha) at Tweefontein, South Africa, averaged about 17.4 m^3/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 Gain	Fams	Tests	S. AFRICA 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 Coetzee (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 ėt 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.

Photo 11-8. Male flowers on 3-year-old *Pinus pringlei* in Brazil shortly after shedding pollen.

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 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 1, 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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