THE IMPROVEMENT AND BREEDING OF *PINUS PATULA*

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Abstract: --Pinus patula has a north to south geographic distribution in Mexico of approximately 900 km. It is the most commonly planted commercial softwood in southern and eastern Africa and Colombia and is characterized by its good growth, straight stem form, and excellent pulping and sawtimber properties. Nearly 1 million hectares of *P. patula* plantations are now established. The species exhibits great provenance variation. A 37% difference in volume was found between the best and worst sources at 5 to 8 years of age when grown in Brazil, Colombia, and South Africa. Provenance x site and genotype x site interaction appears to be more important in *P. patula* than in other tropical and subtropical pine species. The traits of height, volume, and stem straightness appear to be under moderate additive genetic control with individual tree h^2 of 0.27, 0.26, and 0.12, respectively, at age 8 years. Researchers have found significant juvenile-mature correlations in *P. patula* and conclude that early selection for good volume and high wood density is feasible in some environments.

Breeding programs began for *P. patula* in southern Africa in the 1950s and in Latin America in the 1970s. The most advanced programs are making crosses to begin their 3rd generation of breeding. Breeding initiatives most commonly used to develop *P. patula* are multiple breeding population strategies and an assortment of hierarchical population approaches. Estimated and realized gains for volume per generation for the first two breeding cycles are on the order of 18%. *P. patula* breeding programs should make great progress in the near future because of a) the infusion of 500 open-pollinated families from new collections in Mexico from CAMCORE, b) the use of more sophisticated statistical analytical tools for family and individual tree selection, and c) the development of vegetative propagation technology. Impediments to progress include poor seed production from controlled crosses, and low cone and seed set in seed orchards in some countries.

Keywords: pine hybrids, multiple breeding population strategy, heritability

INTRODUCTION

Pinus patula Schiede & Deppe in Schl. & Cham. is an important closed-cone pine that is native to Mexico and belongs to the same taxonomic group as *P. radiata* D. Don and *P. oocarpa* Schiede. It occurs in eastern and southern parts of the country in the Sierra Madre Oriental and the Sierra Madre del Sur between 24° N and 16° N latitude, a distance of approximately 900 km (Figure 1). Most provenances of *P. patula* are found in cloud forest environments on well drained soils between 1500 m and 3100 m altitude (Dvorak and Donahue 1992) but is most

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common at elevations of 2100 m to 2800 m (Perry 1991). *Pinus patula* occurs in regions that receive between 1000 mm and 2000 mm of precipitation annually with a distinct dry season of nearly four months. With the possible exception of provenances from southern Oaxaca, *P. patula* can withstand subfreezing weather and snow.

Pinus patula trees reach heights of 35 m and have a very distinct morphology that allows for easy identification in the field. The species is characterized by its very straight stem form, thick furrowed bark at the base of the tree, thin reddish flaky bark on most of the upper trunk, and pale-green pendent foliage. Locals refer to the species as "sad pine" or "weeping pine" because of the distinct droopiness of the needles. *Pinus patula* var. *longepedunculata,* a variety that occurs in southern Mexico (Guerrero and Oaxaca), differs morphologically from typical *P. patula* in that the cones have short peduncles and the color of the foliage may vary from pale to dark green with needles that droop less noticeably.

Pinus patula has been established in pilot plantings in as many as 20 different countries in the tropics and subtropics in the last 120 years (Wormald 1975). The first reported introduction of the species was into New Zealand in the late 1870s, South Africa in 1907, Australia in the 1920s, most other areas of southern and eastern Africa from the 1920s and 1940s, and in South America in the 1950s and 1960s (see Wormald 1975). The initial introductions into New Zealand and South Africa came from Mexico but several of the subsequent seed distributions to other countries came from existing plantations established primarily in South Africa. Interestingly, much of the genetic base for *Pinus patula* in South Africa during this period was thought to have come from only three small commercial collections in Hidalgo and northern Oaxaca (Burger 1975, Wormald 1975).

It is estimated that there are now nearly 1 million hectares of *P. patula* established in the tropics and subtropics for sawtimber and paper products (Wright 1994, Birks and Barnes 1991). The majority of the *P. patula* forests are located in southern and eastern Africa where it is the most important softwood plantation species. South Africa, Swaziland and Zimbabwe have nearly 400,000 hectares under operational management at the present time (SA Dept. of Envn. Affairs 1993, Kanzler 1997). In Colombia, 50,000 hectares of *P. patula* have been planted with lesser amounts in Argentina, Brazil, and Ecuador.

The wood of *Pinus patula* is white to yellowish-white and is moderately dense. Mature trees 30 to 50 years of age in natural stands in Mexico had wood densities that ranged from 440 to 600 kg/m^3 (Zobel 1965, Quiones 1974). Plantation trees 13 to 16 years of age in Brazil, Colombia, and South Africa had mean wood density of 389 kg/m^3, 410 kg/m^3 and 395 kg/m^3, respectively (Wright 1994, Ladrach 1984). *Pinus patula* had wood density slightly higher than loblolly pine at 14 years of age near Lages, Brazil, (Mendes 1989) but was no more dense that loblolly pine in Chile and South Africa (Dommise 1994, Rodriguez and Torres 1992). *Pinus patula* has longer fiber length than loblolly pine (Wright and Sluis-Cremer 1992, Dommise 1994, Rodriguez and Torres 1992) and the wood has only 1 to 3% extractives, much lower than either loblolly or slash pine *(Pinus elliottii* Engelm.). These beneficial features, plus the whiteness of the wood, makes *Pinus patula* especially well suited for a wide range of products (see Wright 1994).

This paper summarizes the improvement and breeding efforts underway for *P. patula* in the tropics and subtropics. The status of new introductions from Mexico, provenance testing, and *ex situ* gene conservation plantings are discussed. The breeding strategies being used by the organizations planting *P. patula* on a commercial scale are reviewed and both the opportunities and impediments for further improvement and developments are highlighted.

Figure 1. Geographic range of *Pinus patula* in Mexico. The dashed line shows the separation of provenances that are cold hardy to the north from those that are more susceptible to cold damage to the south and west.

PROVENANCE VARIATION

Provenance Collections 1959-1984

Following the original introductions of *P. patula* into southern and eastern Africa near the turn of the century, there have been several provenance collection made in Mexico by various organizations to enlarge the existing genetic base of the species. Seeds from four provenances of *P. patula* were collected in Mexico by New Zealand researchers between 1959 and 1962 as part of a larger introduction effort to determine if Mexican pine populations that were more productive than *P. radiata* could be identified. The four *P. patula* provenances in the collections were from the states of Hidalgo, (northern) Oaxaca, and Veracruz and therefore represented the central and southern distribution of the species' range. Provenance trials were established at four locations on the North Island with the seed collected. In 1969, the South African Forestry Department made seed collections in Hidalgo, (northern) Oaxaca, and Puebla and sampled four provenances and 22 mother trees (Darrow and Coetzee 1983). Trials were established at six locations in the Eastern Transvaal. Also, in 1969, the Zimbabwe Forestry Commission received seeds from 8 provenances of *P. patula* from Mexico and planted these on 6 sites in 1971(Barnes and Mullin 1984). All provenances were from the central part of the range of *P. patula*, with the exception of one source from northern Oaxaca. The Argentineans made one of the most comprehensive collections of *P. patula* in Mexico in 1972 that included 16 provenances and 110 mother trees (Barrett 1972). This collection was unique because it was the first to include a population from the northern range of the species in the state of Tamaulipas (El Cielo 23° 05'N). The seeds were established in trials mainly in Jujuy state in northern Argentina and one at Mac-Mac, South Africa. The populations represented central Mexico. In the early 1980s, the Food and Agriculture Organization (FAO) in collaboration with the Instituto Nacional de Investigación Forestal (INIF) Mexico, distributed bulk seed lots of *P. patula* from several provenances in Mexico to interested organizations in the tropics and subtropics.

CAMCORE Range-Wide Collections and Conservation Efforts 1986-till the present

From 1986 to 1994, the Central America and Mexico Coniferous Resources Cooperative (CAMCORE), North Carolina State University, sampled 23 populations and 510 mother trees throughout the entire known geographic range of *P. patula* in Mexico (Dvorak and Donahue 1992). The objectives for the collection were to develop *ex situ* conservation field plantings, establish genetic tests, and expand the relatively small gene base of the species being managed by forestry organizations. The collections re-sampled eight of the locations visited by the Argentineans in 1972 but also included a number of new populations like the most known northern provenance, Conrado Castillo, Tamaulipas (24° N) and sources in southern Oaxaca (16° N). Seeds for 50 conservation banks and provenance/progeny tests were distributed to Brazil, Colombia, Chile, Mexico, South Africa, and Zimbabwe. The conservation banks were established in several designs ranging from single tree plots to row plots at several different spacings (Dvorak et al. 1996). The CAMCORE genetic tests were planted in a compact family design, with open-pollinated families clustered together in a provenance block. Families were planted in six-tree row plots replicated 9 times at 3m x 3m spacing.

Provenance Trial Results

In New Zealand, the provenance La Venta (near Mexico City) was the best and the population from northern Oaxaca (Llano de Las Flores) was the worst when assessed at 22 years of age for productivity and stem form. Results from the studies in Argentina (24° to 25° S latitude) indicated that the northern population, El Cielo, Tamaulipas was the most productive and the sources from northern Oaxaca were the worst (Picchi 1988). There were also several good sources from the central part of the species range in Mexico that did well in the Argentinean highlands. Results showed a strong positive correlation between latitude of the collection site in Mexico and productivity in Argentina. The results from the international CAMCORE series (Hodge and Dvorak 1998, Dvorak et al. 1996) and the local South African and Zimbabwean provenance tests (Falkenhagen 1979, Barnes and Mullin 1984) showed that most sources from the central part of the range in Puebla, Hidalgo, and Veracruz grew reasonably well. One exception to this were the provenances from the highest elevations (2750-2950 m) in both the CAMCORE and Zimbabwean tests. These sources grew slowly across most locations relative to the other provenances from central Mexico. In the CAMCORE tests, the sources from Oaxaca did poorly when planted in the colder areas of Brazil and South Africa. However, some of the southern *P. panda* sources from Oaxaca appeared to have potential when established in the tropical highlands of Colombia (Dvorak et al. 1996), Swaziland (Kanzler 1994), Zimbabwe

(Barnes and Mullin 1984), and in the warmer areas of South Africa (Hodge and Dvorak 1998). Trees from the El Cielo, Tamaulipas source in northern Mexico performed well in the CAMCORE tests when planted on sites with temperate climates. However, it and the other northern source, Conrado Castillo, performed poorly for volume across locations when established on warmer sites in the subtropics (Dvorak and Hodge 1998).

The CAMCORE international series of provenance tests demonstrate the importance of continued explorations and seed collections in the natural range of the species for both the purposes of conservation and genetic testing. Several new populations from the state of Veracruz were found that were 14% to 18% better in volume than the average of all provenances across 50 test locations. The productivity of the sources from Veracruz were within 7% of the volume performance of second generation check lots (Hodge and Dvorak 1998). The best families from these excellent Mexican sources were competitive in volume with many first and some second generation *P. patula* controls. The difference in volume between the best and the worst provenances across all locations in the CAMCORE *P. patula* series was 37% (Hodge and Dvorak 1998).

Cold tolerance, drought tolerance and disease and insect susceptibility

As alluded to before, provenances of *P. patula* from southern Oaxaca (and presumably Guerrero) that comprise the variety *longepedunculata* are not nearly as cold hardy as sources to the north. The morphology of some of these populations indicate that they may carry *P. tecunumanii* genes but appear to group separately from either typical *P. patula* or *P. tecunumanii* (Dvorak and Raymond 1991) Three year results of a number of CAMCORE tests in South Africa, where freezes can sometimes be severe, showed that the average survival of the southern Oaxacan sources to be 26% and the rest of the provenances 70% (Dvorak et al. 1996).

Pinus patula is generally found to be more drought tolerant than loblolly pine and in a recent severe drought in southern Africa was found to be as drought tolerant as slash pine (Morris and Molony 1993). The species is very wind firm as the needle architecture promotes the passage of wind through the upper crown instead of serving as a barrier to it. Wind throw is only a problem when poor nursery practices or silviculture management has promoted poor root system development or stand overstocking (Munishi and Chamshama 1994). *Pinus patula* does not perform well on sites that are often wet or have poor drainage. Furthermore, the species is very susceptible to *Sphaeropsis sapinea* (formerly called *Diplodia)* in both South Africa and Brazil. Hail is usually the casual agent that damages the trees that promotes *Sphaeropsis* infection in South Africa (Swart and Wingfield 1991) and it is hypothesized that late spring frosts that damage growing shoots may be the event that initiates the disease in Brazil (CAMCORE Annual Report 1996). *Pinus patula* susceptibility to aphid attacks in southern Africa has been well documented as is its tendency to be defoliated by *Glena* spp. in both Colombia and Brazil (Rodas 1996, Martin et al. 1994) and the tent caterpillar *(Lechriolepis nephopyropa tams)* in Zimbabwe (Mushongahande 1996). *Pinus patula* seedlings have also been screened for resistance to fusiform rust *(Cronatium quercuum* (Berk.) Miyabe ex Shirai f sp. fusiforme) in the US and in one study was found to have a 30% infection rate versus 64% for the slash pine control (Tainter and Anderson 1993). This is much lower infection rate than some of the other Mexican closed-cone pines like *P. caribaea* and *P. tecunumanii* (Lambeth et al. 1997). Oak species *(Quercus)*, the alternate host to fusiform rust, are common throughout the natural range of *P. patula* in Mexico.

REPRODUCTIVE BIOLOGY

Observations on Flowering

Poor seed or cone crops have often been given as the reason for the limited success in making *Pinus patula* seed collections in Mexico (Darrow and Coetzee 1983, FAO 1972). However, the fact is that *Pinus patula* is often a very shy seed producer in its native environment even during good seed years.

In natural stands in Mexico, male and female strobili of *P. patula* are produced from January to April and cones are produced 22 to 24 months later (Romero 1991, Patifio and Kageyama 1991). The first crop of cones on trees in natural stands may not be produced until approximately 15 years of age (Patin() and Kageyama 1991). The cones of *P. patula* range in size from 70 to 100 mm and may be borne in pairs or in clusters of up to 5 to 6. The cones of the southern variety *longepedunculata* are smaller and range in size from 50 to 80 mm. These are often borne singularly or in pairs. The seed potential of a cone of *Pinus patula* and its variety *longepedunculata* is 125 and 95, respectively (Dvorak 1997). An average of 22 filled seeds per cone were found in studies in natural populations of *P. patula* (Barrett 1972) for a seed efficiency rate of 18%. This value is the lowest of the Mexican closed-cone pines with the exception of the high elevation populations of *P. tecunumanii* where only 6 filled seeds were found per cone; a seed efficiency rate of 9% (Dvorak and Lambeth 1992). There are approximately 115,000 seeds per kg in *Pinus patula*.

Pinus patula begins to flower at 2 to 3 years of age in many locations in southern Africa but takes longer at high elevations near the equator in Latin America. As expected, flowering times vary considerably where *Pinus patula* is planted as an exotic. In southern Colombia (2° N latitude), *Pinus patula* flowers all during the year with a peak in July and August (Isaza 1997). In southern Brazil (27° S latitude), the flowering time appears to be in September but more study is needed (Mendes 1997). In southern Africa (18 to 28° S latitude), there are two flowering periods, a small peak from January to May and a more pronounced peak from September and October (Barnes and Mullin 1974, van der Sijde and Denison 1967). Most breeding work is done on the flowers in the second semester. A bi-annual flowering period has also been observed for *Pinus greggii* in several locations where it has been planted as an exotic species (Critchfield 1967, Kietzka 1997).

Environmental Factors and Seed Production

Environmental influences have affected the reproductive biology cycle of *P. patula* when planted as an exotic and have caused delays in seed production and breeding efforts in several countries.

In both Colombia and South Africa (Denison 1973), initial attempts to establish seed orchards met with limited success because they were located at elevations too low for good seed production and had to be moved to higher altitudes. Studies now show that in Colombia an altitude of 2500 m is acceptable for a *P. patula* orchard if 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 (Wright 1997). In southern Africa studies now show that the optimum altitude for a *Pinus patula* seed orchard appears to be 1900 m in the eastern highlands of Zimbabwe (19°S), 1500 m in the Transvaal, South Africa (25°), and 1450 m in Natal, South Africa (29°S). A mean annual temperature between 13° and 16° C was considered best for cone and seed production by Barnes and Mullin (1974). When seed orchards are properly located in southern Africa, 50 to 70 filled seeds per cone can be obtained.

A second factor that has affected not only breeding efforts for *P. patula* but also has influenced the type of breeding strategy adopted (discussed later) by several organizations in South Africa is the poor seed yields being obtained from artificial crosses. Results from one orchard indicated that 60 filled seeds per cone were obtained from open-pollination and 10 filled seeds per cone from controlled crosses (Kietzka 1997). *Pinus patula* flowers are much more sensitive to heat build-up in pollination bags than either loblolly or slash pine and can be easily destroyed in spring when the temperature rises rapidly during the day (van der Sijde and Denison 1967). Studies are underway to find a pollination bag that provides better heat exchange. The flower abortion problem during controlled crosses appears to be less in Zimbabwe, which has a more tropical climate but generally has less daily temperature fluctuations.

BREEDING STRATEGY

Breeding Programs

The first breeding programs for *Pinus patula* in South Africa and Zimbabwe began in the late 1950s (Barnes 1995, Denison 1973). Tree improvement activities were facilitated in the region in the 1960s and early 1970s in Kenya, Tanzania and Uganda through participation in the East African Agriculture and Forestry Research (EAAFRO) that allowed for an interchange of *P. panda* scion material across country (Dyson 1977). Today, most countries in southern Africa involved in plantation forestry have at least a first generation *P. patula* seed orchards made up of clones selected throughout the region. In Latin America, only Smurfit Carton de Colombia in Cali has an active breeding program for *Pinus patula* and this began in the early 1970s.

Some of the *P. patula* programs are well into their second generation of breeding and now have third generation material. Five of these organizations have been highlighted for the purposes of discussing breeding strategies: Mondi Paper Co., the South African Forestry Company (SAFCOL), South Africa, SAPPI (Pty) Ltd., South Africa, Smurfit Carton de Colombia, and the Forestry Research Centre, Zimbabwe. All are participating in the CAMCORE program in efforts to broaden their genetic base of *P. patula.* The number and origin of families in their breeding programs are summarized in Tables 1 & 2.

Table 1. Number of families in genetic tests of *Pinus patula* by generation for selected programs in South America and Africa (from Bester 1997, Gapare 1997, Kietzka 1997, Stanger 1997, Wright 1997).

Organization	Country	CAMCORE	1st Gen.	2nd Gen.	3rd Gen.
Cartón de Colombia	Colombia	435	91	37	
Mondi	South Africa	405	652	299	37
SAPPI	South Africa	468	882	136	---
SAFCOL	South Africa	366	1495	671	---
Research Centre	Zimbabwe	122	463	393	---

Table 2. Origin of plus tree selections represented in genetic tests of *Pinus patula* for breeding programs in South America and Africa.

Origin	Carton Colombia	Mondi S. Africa	SAPPI S. Africa	SAFCOL S. Africa	Res.Centre Zimbabwe
CAMCORE	435	405	468	366	122
Colombia	41	---	---	---	---
ICFR[2]	---	154	391	146	---
Malawi	---	7	---	---	---
Mexico	---	83	---	51	---
South Africa	87	643	611	1185	70
Zimbabwe	---	101	16	42	438

Genetic Parameters

Heritability and Genetic Correlations

There have been a number of studies using both open and controlled pollinated test material to assess the magnitude of additive variance, degree of genetic correlation and importance of genotype x site interactions in *Pinus patula.* Individual tree heritability for height for *P. patula* ranged between 0.14 and 0.22 at 5 to 8 years of age in open-pollinated studies in Brazil and full-sib experiments in Zimbabwe (Kageyama et al. 1977, Barnes et al. 1992). Heritability values for diameter were lower than for height and ranged from 0.13 to 0.18 (Kageyama et al. 1977, Nyoka et al. 1994). Individual tree heritability values for height and diameter for open-pollinated trees assessed at between 5 and 8 years of age in the highlands of Colombia were as much as two times higher than those reported in Brazil and Zimbabwe (Ladrach and Lambeth 1991, Wright et al. 1996). Possibly this was due to the fact that trees in Colombia measured at 8 years of age are

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as tall as trees in other countries measured at 10 to 11 years of age and direct comparisons of additive genetic variance across country are biased somewhat by differences in ontogeny (Vasquez and Dvorak 1996). In individual sites analyses of 50 tests in Brazil, Colombia, and South Africa using CAMCORE material, individual tree heritability at ages 5 and 8 years for volume were 0.16 and 0.26 respectively (Hodge and Dvorak 1998). The age 8 heritability value for volume was approximately the same as that found for *Pinus caribaea* var. *hondurensis* but was 0.05 higher for *Pinus tecunumanii* in similar continent-wide plantings. Heritability for stem straightness in *P. patula* at 5 to 8 years of age ranged from 0.04 to 0.32 in studies in Brazil and Zimbabwe (Kageyama et al. 1977, Barnes et al. 1992, Nyoka et al. 1994) and from 0.09 to 0.12 in the individual site analyses done on 50 locations in the CAMCORE tests (Hodge and Dvorak 1998).

In a series of controlled cross experiments in Zimbabwe, Barnes et al. (1992), found strong juvenile-mature correlations between traits measured in the nursery and characteristics measured in the field at 8 years of age. Large seedlings with few cotyledons in the nursery grew into large trees with high wood density in the field and families with few branches and superior height in the second year developed into trees with high wood density and large volume the eighth year. Type B genetic correlations among open-pollinated families in CAMCORE tests in Brazil, Colombia and South Africa were sufficiently high to be useful in best linear prediction (Hodge and Dvorak 1998). Genetic information from families grown in one country could be used to improve prediction of performance in another country.

Provenance x Site and Genotype x Site Interaction

Because trees from the southern Oaxacan provenances suffered freeze damage on the more temperate sites but survived well on the more tropical sites, provenance performance for height and volume was generally unstable across wide locations in the CAMCORE tests. In addition, there appears to be more provenance x site interaction for populations from the central part of the *P. patula* range when grown across exotic environments than for either *P. caribaea* or *P. tecunumanii* (Hodge and Dvorak 1998). Height/diameter ratios were found to change noticeably across environments (Denison 1973, Dvorak et al. 1996). Important genotype x site interaction for volume at the family level was found across location in the international series of CAMCORE tests as well as those trials established on several sites in separate studies in both South Africa and Zimbabwe (Barnes et al. 1992; Falkenhagen 1979). Hodge and Dvorak (1998) suggest that genotype x site interaction may be greater in *P. patula* than in *P. caribaea* var. *hondurensis* or *P. tecunumanii.* Genotype x year interaction does not appear to be important in *P. patula* (Barnes et al. 1992).

Breeding strategies and mating designs

A number of breeding strategies and mating designs have been used to improve *Pinus patula* in the last 40 years. Several organizations in southern Africa are now using a multiple breeding population strategy (MBPS) that was first proposed by Namkoong et al. (1980) and later refined by Barnes (1994). The strategy allows one to work with a number of populations at different level of intensity with the goal to turn over generations as quickly as possible. The MPBS was developed for those organizations or countries in the tropics and subtropics that were working with many species and provenances, were not part of a cooperative breeding program, and had limited research staff or funds. The mechanism by which the MBPS is carried out in South Africa and Zimbawe is the breeding seed orchard (BSO), which, for all practical purposes, can be considered a combination seedling seed orchard/ progeny test (Barnes 1995).

As a practical example, the development of the MBPS by SAPPI (Pty) Ltd. (South Africa) has been described as follows by Stanger (1997). SAPPI has identified five different combinations of land types and/or elevation gradients in its plantations at Mpumalanga that it has separated into different breeding populations. In addition, it has identified selections from geographically different areas like Zimbabwe and Mexico as unique to the Mpumalanga material and these have also been placed into separate breeding populations. The arrangement of the 384 open-pollinated families in the 8 MBP are shown in Table 3. The breeding populations have been established in BSO's with five standard checks. All families have been established in 12 tree row plots with 10 replications at a spacing of 3.0 m x 1.5 m. The reason for the close initial spacing is to increase the selection intensity. The family plots will receive successive 50% thinnings at the onset of competition, the first thinning usually occurs at approximately 30 months. Before the first thinning the BSO will be assessed and the data analyzed to obtain family and within family information. After the first thinning no further measurements are usually made until the final tree per plot remains. A BSO may receive as many as five thinnings before reaching a final stocking of approximately 185 stems per hectare without family roguing. Open-pollinated seeds will be collected from the best trees in the best families using a selection index and the 45 to 50 trees selected will be used to establish the next generation of BSO's. A family culling of approximately 50% will also be done to remove the worst families and to convert the BSO into a seedling seed orchard for commercial production. At the same time that seed is collected from the best 45 to 50 trees, scion material is collected and grafted into a clone bank/orchard that will be culled when results from the next generation of tests become available. If the flowering and cone production is acceptable, a new generation can be established with open-pollinated seed every eight years. No estimates of gains have been made with the MBPS approach since the BSO's at SAPPI are still young.

Table 3. Composition of SAPPI (South Africa) Eight Breeding Populations (from Stanger 1997)

Population Origin	Type	No. of Families	Year Established
Mpumalanga	Land Type 601	42	1992
Mpumalanga	Land Type 507	41	1993
Mpumalanga	Land Type 405-1	46	1994
Mpumalanga	Land Type 405-2	47	1995
Mpumalanga	Land Type 312	60	1996
Mexico	Veracruz	35	1995
Mexico	Non-Veracruz	53	1993
Zimbabwe		60	1992

Other organizations that are breeding *P. patula* are using either the MBPS approach or a combination of hierarchical strategies that incorporate sublines, main and elite populations etc. to further improve the species. These programs are briefly summarized below.

a) Mondi, South Africa has structured its sublines based on origin of the material. The main population is generated by open pollinations and the elite population by controlled crosses. The present testing design is a randomized complete block with five replications and 6 tree row plots. This will be amended to single tree plots in the near future. Current selections are being made using BLP analysis. Realized gains for volume in the 1st generation was 20% and it is estimated that 2nd generation material will be 15% better than 1st generation planting stock (Kietzka 1997).

b) SAFCOL, South Africa has established one main breeding population for *P. patula* in its most important planting area for the species in the Transvaal. An open-pollinated approach was primarily used between first and second generation and currently second generation selections are being mated in a half diallel scheme. The controlled crossing program should be finished in 1997. The field tests were initially established using a RCB design, nine replications and six tree row plots but more recently lattice and single tree plots are being used. The selections in the tests are being made using BLP analysis. (Bester 1997).

c) The Forest Research Centre, Zimbabwe began its first generation *P. patula* program in 1958 based on the concept of hierarchy of populations and included using polycross, factorial and diallel mating designs (Barnes et al 1992). In 1981, the MBPS was adopted and 10 active populations developed. An intensive breeding program was implemented for *P. patula,* which included complete pedigree control through controlled pollination and full-sib families. To create full-sibs, a circular mating design is used where every parent is crossed with two other parents. Most recently, the MBPS has been amended. Multiple breeding populations in the future will be combined into one population called a composite breeding seed orchard (CBSO) to increase genetic gain and reduce costs (Nyoka et al. 1996). The best selections in the *P. patula* CBSO will make up the elite population for the next generation. Future selections will be made with a combined index generated by BLUP (Nyoka et al. 1996). Estimated genetic gains in volume production were 17% and 18% for the first and second generation, respectively (Wanyancha 1990).

d) Smurfit Carton de Colombia initial selections in Colombia came from seeds of both South African and Zimbabwean origin. It has a first generation breeding orchard made up of plantation selections from this material and will probably use a complementary mating approach (polymix and partial diallel) to generate breeding material for the next generation. Open-pollinated progeny from the first generation orchard is being tested on two sites. The CAMCORE infusion material will form the majority of its genetic base and will be controlled crossed to produce superior progeny for the next cycle of breeding. Selections for the breeding population are currently based on BLP analysis (Wright 1997).

PROPAGATION AND DEPLOYMENT

Most organizations growing *Pinus patula* are planting seedlings rather than cuttings from seedling stools. However, this will change greatly in the next 10 years as propagation systems become more wide spread. Organizations in both Colombia and South Africa have developed the technology to mass produce cuttings from seedlings. Furthermore, *P. patula* was easily propagated and multiplied in Chile using the Arauco systems originally designed for *P. radiata* D. Don. (Balocchi 1996).

Smurfit Carton de Colombia and Mondi now deploy 5-10% of all their *P. patula* as cuttings and the rest as seedlings (Wright 1997; Kietzka 1997). Furthermore about 5% of the seedlings that are established by Mondi are planted in family blocks but this will increase as enough seed becomes available by clone in the seed orchard. Mondi is using 70 clones operationally for its seedling program and 25 clones for cuttings.

DISCUSSION AND CONCLUSIONS

There have been a number of changes in *Pinus patula* breeding in the last 5 to 8 years that will greatly improve the productivity of the species. First, a large group of open-pollinated families from Mexico has been introduced by CAMCORE to enlarge the existing genetic base of most of the major *P. patula* programs in the world. Some of the best families from these collections of unimproved material compete very well in terms of volume with improved first generation families and some second generation families in existing *P. patula* programs. Second, vegetative propagation technology has been developed for the species and it will be possible to capture additional productivity and uniformity gains from the best controlled crosses. Third, more sophisticated statistical analysis are being used such as BLP or BLUP by *P. patula* growers to better identify good families and individuals. Genetic correlations in growth are sufficiently high between countries to improve breeding value estimates across breeding regions and provide the benefits of exchange of genetic material in the future. Fourth, because it can be hybridized easily with several of the other closed-cone pines like *P. greggii, P. oocarpa, P. tecunumanii,* and *P. radiata,* tremendous opportunities exist for the development of more productive forests in areas that are now marginal for *P. patula* (Lambeth at al. 1997, Dvorak et al. 1996). Fifth, a new area of *P. patula* var. *longepedunculata* has been recently identified in Guerrero, Mexico several hundred km from known populations in the eastern part of the country (Donahue 1990) Genetic material from this region may be especially promising in the more tropical and humid areas where typical *P. patula* is currently being planted.

Several challenges do remain in *Pinus panda* breeding. First, now that better knowledge exists on placement of breeding orchards everything possible must be done to reduce the generation time. The breeding cycle was as long as 15 to 20 years for some programs in the first generation for reasons described in the paper. Second, exchange of genetic material between organizations of the best *P. patula* material must become common place. Such exchanges are planned through the CAMCORE program, but benefits could also be derived from strategic exchanges of more genetically advanced non-CAMCORE material between the most active breeding organizations.

Third, disease, insect, and nutrient problems in *Pinus patula* need to be more intensively studied in some countries, particularly those in southern Latin America.

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