

Future outlook for *Pinus patula* in South Africa in the presence of the pitch canker fungus (*Fusarium circinatum*)

R. G. Mitchell^{1,2}, T. A. Coutinho², E. Steenkamp², Martin Herbert³, M. J. Wingfield²

¹York Timbers, Sabie, South Africa

²Forests and Agricultural Biotechnology Institute, University of Pretoria, South Africa

³Fractal Forest, Constantia, Western Cape, South Africa

Corresponding author gmitchell@york.co.za

Abstract

Approximately 50% of the area planted to softwood trees in South Africa has been established with *Pinus patula* making it the most important pine species in the country. More effort has gone into developing this species for improved growth, tree form and wood properties than with any other species. This substantial investment has been threatened in the last 10 years by the pitch canker fungus, *Fusarium circinatum*. The fungus infects and contaminates nursery plants and, once transferred to the field, causes severe mortality of young trees in the first year after establishment. Although nurserymen have some control of the disease, it is recognized that the best long-term solution to mitigate damage due to *F. circinatum* infection is to identify tolerant species, clones and hybrids for deployment in plantations in the future. Research has shown that alternatives such as *P. tecunumanii*, *P. maximinoi* and *P. elliottii* are suitable for warm sites. Pine hybrids, particularly between *P. patula* and the high elevation sources of *P. tecunumanii*, appear to be a suitable replacement on sub-temperate and temperate sites. Although these alternative species and hybrids are more sensitive to sub-freezing temperatures than *P. patula*, their planting range can be increased by including cold tolerance as a selection criterion. Future breeding efforts will most certainly focus on improving the tolerance of pure *P. patula* to *F. circinatum*, which can be achieved by identifying specific family crosses and tolerant clones. The commercial deployment of disease tolerant control-pollinated *P. patula* and hybrid families will most likely be

established as rooted cuttings, which requires more advanced propagation technology. In the long term, new seed orchards comprised of *P. patula* clones tolerant to *F. circinatum* will be used to produce seed for seedling production.

Keywords; Camcore, *Pinus patula*, *Pinus patula* x *Pinus tecunumanii*, *Fusarium circinatum*, Site-species matching

The history of *Pinus patula* in South Africa

Pinus patula was originally introduced into South Africa in 1907 (Kotze 1926, Burgers 1975, Wormald 1975, Dvorak 1997). Further introductions were made in 1911 and 1928 (Burgers 1975) but it is not known exactly where this seed was collected in Mexico. One report is that the third introduction came from Guajmalpa in the State of Mexico (Burgers 1975, Butterfield 1990). Other possible locations include the states of Hidalgo and Veracruz because the original roads in these areas often followed old Aztec trails that were in close proximity to natural stands of *P. patula* making for easily accessible seed collections (Dvorak, pers. comm.). These early introductions formed the basis of the commercial deployment of the species in South Africa, and the initial *P. patula* breeding programs (Adlard 1981) that started in the late 1950s (Coetzee 1985). The species performed exceptionally well in the summer rainfall region and had superior growth, stem form and wood properties (Poynton 1979). The selections made in the early plantings responded well to tree improvement efforts (Darrow and Coetzee 1983) and by 1970 223,600 ha had been planted to *P. patula* (Nyoka 2003).

Several introductions of *P. patula* seed were made at a later stage. In 1969/70 Coetzee and Fisk, of the South African Department of Forestry, made collections again in Hidalgo and northern Oaxaca and also in Puebla from five provenances and 40 trees (Darrow and Coetzee 1983). Many families from these collections outperformed the yield from commercial plantations at the time (Darrow and Coetzee 1983). A comprehensive seed collection was also carried out by Barrett (1972) from Argentina,

who sent some seed to South Africa where a single trial was established. Several trials were also established in 1971 in Zimbabwe (then Rhodesia) from seed introduced in 1969 (Barnes and Mullin 1984). South Africa also received provenance material of *P. patula* from the Food and Agriculture Organization (FAO) in the 1980s. Although the majority of the selections in the South African orchards originate from the commercial plantings made in the 1920s (Coetzee 1985), selections from the provenance trials planted in South Africa and Zimbabwe have also been included in some breeding programs.

The largest collection of *P. patula* seed was made by Camcore at North Carolina State University (formally known as Central American and Mexican Coniferous Resources Cooperative, now known as the “International Tree Breeding & Conservation Program”) between the years 1986 and 1994 where 22 populations/provenances and over 500 selected trees across Mexico were sampled (Dvorak et al. 1995, Dvorak 1997). The seeds from these trees were distributed to companies in Brazil, Colombia, Chile, South Africa and Zimbabwe where trials were established using the same field design (Dvorak 1997). Similar to the collection by Coetzee and Fisk (Darrow and Coetzee 1983) many of the selections outperformed commercial *P. patula* orchard material for volume which, by this stage, had undergone further improvement (Dvorak et al. 1995). To date, 289 F1 (1st generation) selections, from 18 provenances, have been identified in the South African Camcore trials (Camcore, unpublished) and are available to members. These selections have not been commercially deployed and local breeding programs have only just begun testing their progeny. Considering that many of the selections outperformed advanced generation orchard material, it can be expected that these selections would add much value to local breeding programs from the standpoint of productivity and genetic diversity.

Current status

Currently 340,000 ha are planted to *P. patula* in South Africa which is approximately 52% of the total area planted to pine (650,000 ha) (Department of Agriculture, Forestry

and Fisheries 2010). The tree performs exceptionally well in the afforested regions between Stutterheim in the Eastern Cape and Tzaneen in the Limpopo province where mean annual temperatures are less than or equal to 16.5 °C and rainfall is greater than 880 or 780 mm/annum at its warmest and coolest planted limits, respectively (Fig. 1 – derived from gridded data supplied by Schulze *et al*, 2007). Although *P. patula* has proven to be an excellent species on these sites, it is particularly susceptible to a number of biotic and abiotic stress factors. Due to its thin bark in the mid and upper section of the main stem (Dvorak *et al.* 2000c) *P. patula* dies easily after fire damage (de Ronde and du Plessis 2002) and it is very susceptible to drought and high temperatures during the first year of establishment (Allan and Higgs 2000). Commercial stands of *P. patula* are also frequently affected by pathogens. In the early years of the commercialization of the species, foresters learned that it was particularly susceptible to infection by the blue stain fungus, *Diplodia pinea* (Swart *et al.* 1985), which could result in the loss of both young and mature stands after hail damage.

Today, the susceptibility of *P. patula* to *F. circinatum* is the most significant reason for poor survival after planting and the cause of death of young trees (Crous 2005). One company has measured a constant annual decline in survival of *P. patula* seedlings from approximately 88% in the year 2000 to approximately 64% in 2007 (Morris 2011) and it is estimated that 25% of all seedlings die in the first year in those nurseries where the disease has reached epidemic proportions (Crous 2005). It is clear that seedling mortality in the field results from contaminated or infected nursery plants (Mitchell *et al.* 2011) and, therefore, it is crucial that the pathogen is controlled in the nursery. It has also been noted that the correct planting of seedlings, which may be carrying *F. circinatum* spores, reduces the risk of infection and seedling mortality (Crous 2005) highlighting the importance of good silvicultural practice.

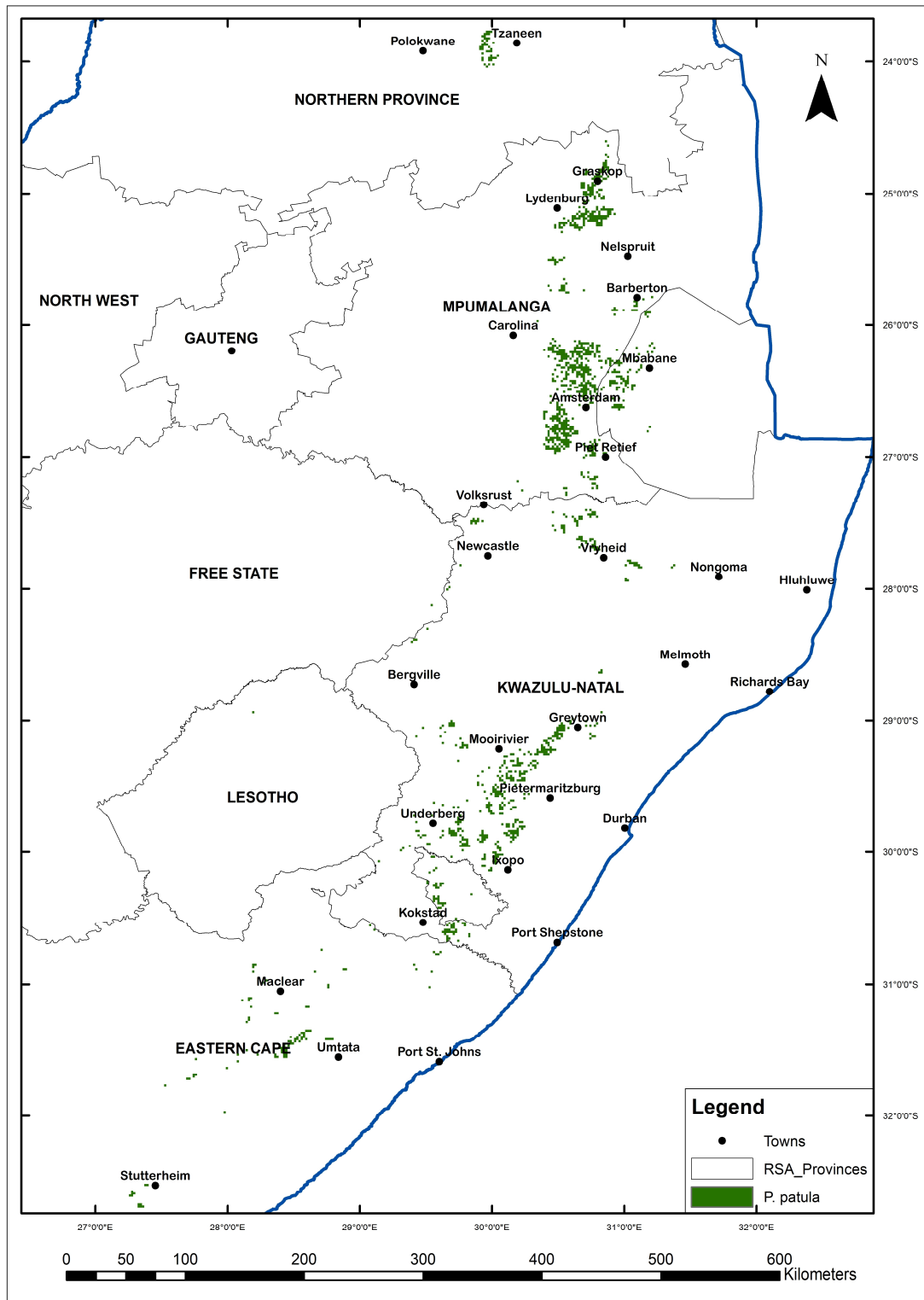


Figure 1. The optimal climatic distribution of *Pinus patula* within the current afforested regions along the eastern escarpment of South Africa.

Opportunities to improve tolerance

Operational experience indicates that the most effective method to manage *F. circinatum* infections is to plant tolerant stock. This is best done by planting alternative pines such as *P. elliottii* and *P. taeda* that are more tolerant to infection (Hodge and Dvorak 2000, Mitchell et al. 2012c). Although the most popular alternative, *P. elliottii*, is known to be susceptible to *F. circinatum* as seedlings (Barnard and Blakeslee 1980), poor ranking families are still significantly more tolerant than the general tolerance of *P. patula* in South Africa (Mitchell et al. 2012c). Due to the good availability of *P. elliottii* and *P. taeda* seed, many forest companies have increased the planting of these two species in areas which were previously planted predominantly to *P. patula*. An analysis of the area planted by York Timbers for the past 6 years clearly shows this trend (Fig. 2).

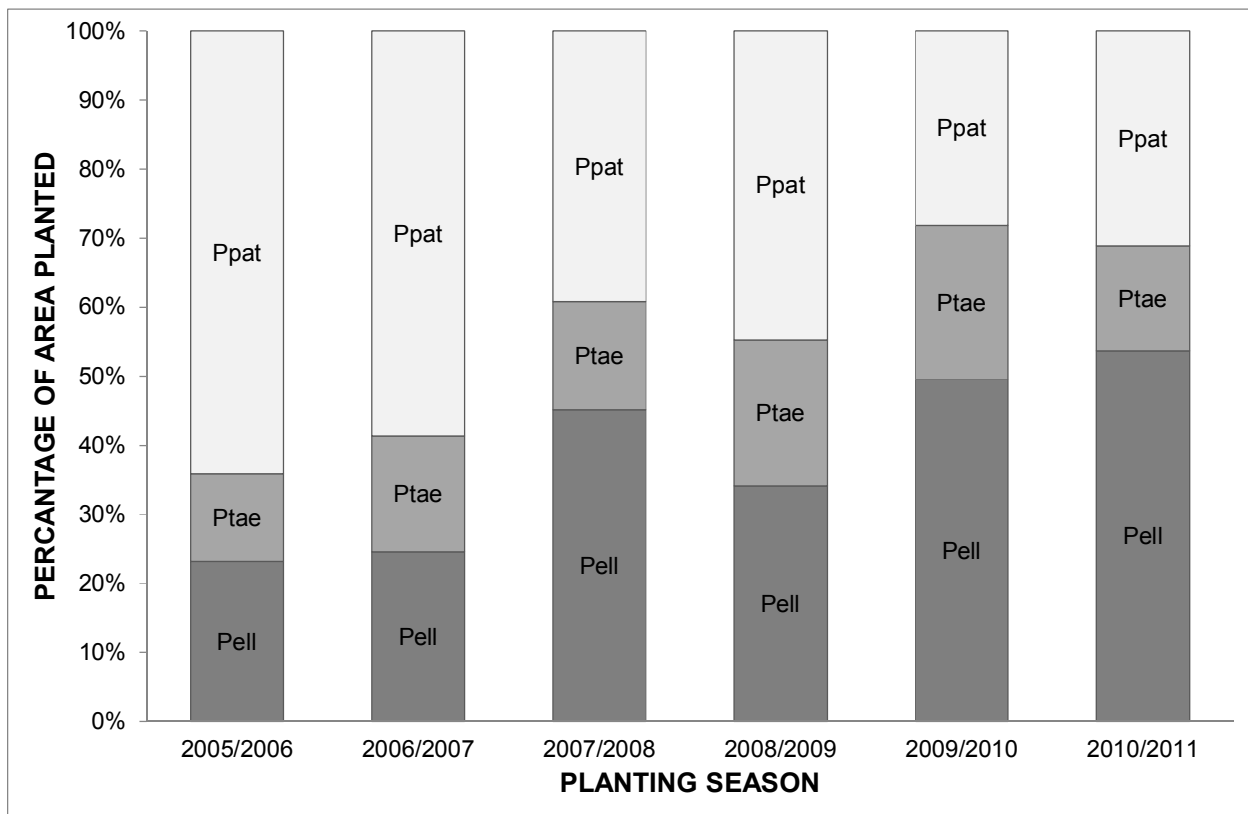


Figure 2. The proportion of *P. elliottii* (Pell), *P. taeda* (Ptae) and *P. patula* (Ppat) that was plan

As an alternative to *P. patula* on the subtropical sites, *P. maximinoi* and *P. tecunumanii* have shown outstanding growth (Dvorak et al. 2000a, 2000b, Galpare et al. 2001), excellent wood properties (Malan 2006, 2010) and good tolerance to *F. circinatum* (Hodge and Dvorak 2000). The tolerance of families of *P. maximinoi* and *P. tecunumanii* from low elevation (LE) provenances to *F. circinatum* is so high (Mitchell et al. 2012c) that they need not be screened to identify tolerant families for deployment. On the other hand, there is large variation between provenances (Hodge and Dvorak 2007) and families (Mitchell et al. 2012c) of the high elevation (HE) source of *P. tecunumanii*. A number of *P. tecunumanii* (HE) provenances (Hodge and Dvorak 2007) and families (Mitchell et al. 2012c), as seedlings, are as susceptible as the general susceptibility of *P. patula* indicating the need to screen families of this source of *P. tecunumanii* to *F. circinatum*. Other sub-tropical species in the *Oocarpa* group (Price et al. 1998), such as *P. pringlei*, *P. jaliscana* and *P. oocarpa* are also tolerant to infection by *F. circinatum* in greenhouse trials (Hodge and Dvorak 2000). These have not been field-tested as extensively as *P. tecunumanii* and *P. maximinoi*, but have shown potential for commercial deployment (Darrow and Coetzee 1983). The only species that can tolerate frost and has shown good tolerance to *F. circinatum* in greenhouse trials is *P. pseudostrobus* (Hodge and Dvorak 2000, Mitchell et al. 2012c). Generally, the species does not perform as well as *P. patula*, although some families show similar growth to *P. patula* in first generation studies testing unimproved material (Camcore unpublished). This indicates potential for further improvement and commercial deployment of the species.

Hybrids between *P. patula* and tolerant species such as *P. tecunumanii*, *P. oocarpa*, *P. elliotii* and *P. pringlei* (Hodge and Dvorak 2000) are significantly more tolerant to infection by *F. circinatum* than *P. patula* (Mitchell et al. 2012b, Roux et al. 2007). Greenhouse screening studies of these hybrids have shown that there is substantial tolerance in *P. patula* x *P. tecunumanii* (LE) families. Also, despite significant variation among hybrid families of *P. patula* x *P. tecunumanii* (HE), this hybrid is more tolerant than *P. patula* (Mitchell et al. 2012b). The most susceptible *P. patula* x *P. tecunumanii* (HE) families are similar to the mean tolerance of *P. patula*. Trial results also indicate

that the variation in susceptibility of *P. patula* x *P. tecunumanii* (HE) families is mostly due to the specific combination of the two parents (Mitchell et al. 2012b). An added benefit of the *P. patula* x *P. tecunumanii* hybrid is the improvement in frost tolerance over *P. tecunumanii* (Grandos 2012) due to the frost tolerance of *P. patula* (Dvorak et al. 2000c). This has been recorded for other hybrids (Duncan et al. 1996) and consequently it is predicted that hybrids will be more tolerant of climate change (Warburton and Schulze 2006).

Significant variation in the tolerance to *F. circinatum* exists within *P. patula*. Provenances such as El Cielo, Yextla and Conrado Castillo are three of the most tolerant provenances in greenhouse trials (Hodge and Dvorak 2007). Inclusion of material from these provenances in seed orchards should improve the tolerance of commercial plantings. It is also possible to identify tolerant *P. patula* clones within those currently deployed as both trees and seedlings (Mitchell unpublished). Tolerance, however, is limited to 5% (Mitchell unpublished) which indicates that large numbers of clones need to be tested to identify a sufficient number for the initiation of a new seed orchard comprised of tolerant clones. The tolerance of *P. patula* can also be improved by identifying specific full-sib families, as opposed to identifying open-pollinated families, which produce more tolerant progeny (Mitchell et al. 2012d). Such crosses can be repeated annually. The combined results of these studies indicate that screening large numbers of *P. patula* families and clones for tolerance to *F. circinatum*, in greenhouse and field trials, can identify those with improved tolerance which can be used to establish new seed orchards. This is the most promising long-term strategy for minimizing the impact of *F. circinatum* when planting *P. patula*.

Screening for tolerance to *F. circinatum* will become an increasingly important consideration when making future selections in *P. patula*. Advanced generations of *P. patula* have been developed for improved growth but the deployment of this material is severely restricted due to the presence of *F. circinatum*. It is, therefore, likely that breeders will begin focusing on identifying sub-populations of clones tolerant to *F. circinatum*. Due to the good growth of *P. patula* x *P. tecunumanii* and *P. patula* x *P.*

oocarpa, breeders are already extensively testing specific full-sib family crosses of these hybrids. This will likely extend to selecting those that are also more tolerant of frost.

Large scale production of improved material

Until tolerant clones and hybrids are developed, good nursery hygiene is critical to ensure the successful deployment of *P. patula* (Pine *Fusarium* Working Group 2004). This is best addressed by ensuring that *F. circinatum* is controlled at each step in the plant production process. This includes ensuring that the growing medium, trays, sowing shed, wooden nursery beds, soil beneath the nursery beds, and any equipment used in the plant production process are free of the pathogen. It is highly recommended that the grow-out area is sterilized between each cycle before the next crop is placed on the beds. This can effectively be done by applying a strong solution of chlorine to the area and follow up applications of chlorine can be applied to the soil beneath the seedlings during the growing period. It is also important to ensure that all plants adjacent to the newly established seedlings are free of the disease. Only when such rigorous steps are taken, can one expect to see an improvement in the control of *F. circinatum*.

Due to the limited availability of seed, tolerant *P. patula* clones, families, and hybrids, will most likely be deployed as rooted cuttings. Historically, nurseries have focused on producing large numbers of seedlings that are relatively easy to produce. The production of cuttings is more complicated. For example, newly placed shoots need to receive regular misting and have elevated root zone temperatures to improve rooting success (Mitchell 2002). Also, the volume of the pot which hedges are grown in, and nutritional status of the parental hedged plant, is important in determining the quantity and quality of shoots harvested. Hedges have limited lifespans that differ between species and hybrids. *Pinus patula*, for example, can be kept as seedlings in a hedged state for a maximum of 2.5 years before hedges must be replaced (Mitchell et al. 2004,

Mitchell and Jones 2006). The implication of this that controlled-pollinated families, which are tolerant to *F. circinatum*, need to be annually reproduced in order to continually supply the nursery with juvenile hedge material. Less is known about the maturation period for the *P. patula* hybrids and the large scale commercial deployment of these must be accompanied by research on this topic. When compared to seedling production, the technology to improve the rooting success and high throughput of cuttings is changing rapidly and nurserymen will be required to keep abreast of these changes.

Operational deployment

Table 1. Three month survival¹ of *P. maximinoi* and *P. tecunumanii*, compared with *P. patula* and other pines, in Camcore progeny trials established during early 2008.

Details	Percent survival							Mean survival
	Spitskop, B13	Tweefontein, A84		Brooklands, G2		Wilgeboom, C2		
Plantation	Spitskop, B13	Tweefontein, A84		Brooklands, G2		Wilgeboom, C2		
Location	25° 9.42.1' S 30° 50.21.82' E	25° 03.50.7' S 30° 48.51.24' E		25° 18.32.96' S 30° 45.27.29' E		24° 57.4.07' S 30° 56.25.98' E		
Altitude (m)	1470	1260		1160		980		
Mean annual temperature (°C)	16	17		18		19		
Mean annual precipitation (mm)	>1300	>1300		850-1050		1050-1300		
Climatic zone	Temperate	Sub-temperate		Warm-temperate		Sub-tropical		
Trial number	16X08A	15X08A	16X08B	15X08C	16X08C	15X08B	16X08D	
Month and year planted	01/08	01/08	01/08	03/08	03/08	02/08	02/08	
<i>P. maximinoi</i>	100.0	93.3	91.7	95.5	97.2	94.2	100.0	96.0
<i>P. patula</i>	83.3	72.2	69.4	86.1	86.1	91.7	75.0	80.5
<i>P. taeda</i>	100.0	-	94.4	-	100.0	-	94.4	97.2
<i>P. elliotii</i>	91.7	91.7	86.1	100.0	94.4	100.0	97.2	94.4
<i>P. tecunumanii</i> – low elevation	94.6	97.2	92.2	94.4	98.8	94.4	94.7	95.2
<i>P. tecunumanii</i> – high elevation	96.7	97.2	92.5	97.2	98.6	94.4	93.6	95.7

¹Trials were blanked one month after planting.

With the addition of alternatives, particularly hybrids between *P. patula* and species tolerant of *F. circinatum*, significant changes to future site-species recommendations will need to be made. These alternatives and hybrids will outperform *P. patula* on many sites and will each occupy a specific niche where *P. patula* has historically been planted. In most cases, species and provenances that are more tolerant to *F. circinatum* (Hodge and Dvorak 2007) are more susceptible to frost (Mitchell et al. 2012a). Therefore, if not exposed to frost, especially in the first year after planting, species like *P. tecunumanii* and *P. maximinoi* will survive better than *P. patula* due to their good tolerance to *F. circinatum*. This tendency has been observed in a number of Camcore trials (Table 1).

Table 2. Three month survival¹ results of hybrids between *P. patula* and *P. oocarpa* and *P. tecunumanii* compared with *P. patula* and *P. elliottii* on two sites free of frost.

Trial	98-10-H01A3	98-10-H01A1
Plantation	Spitskop, B31b	Wilgeboom C2b
Location	25° 08.8.55' S 30° 48.21.85' E	24° 57.4.07' S 30° 56.25.98' E
Altitude (m)	1300	970
Climate zone	Warm temperate	Sub-tropical
Plant date	Nov-08	Feb-08
<i>P. elliottii</i>	62%	98%
<i>P. patula</i>	55%	64%
<i>P. patula</i> x <i>P. oocarpa</i>	73%	97%
<i>P. patula</i> x <i>P. tecunumanii</i> – high elevation	81%	98%
<i>P. patula</i> x <i>P. tecunumanii</i> – low elevation	76%	98%

¹Trials were blanked one month after planting.

The *P. patula* x *P. tecunumanii* (LE) and *P. patula* x *P. oocarpa* hybrids have become a popular alternative to planting *P. patula* on the warmer sites of South Africa where they also survive better than *P. patula* (Table 2). Undoubtedly, the *P. patula* x *P. tecunumanii*

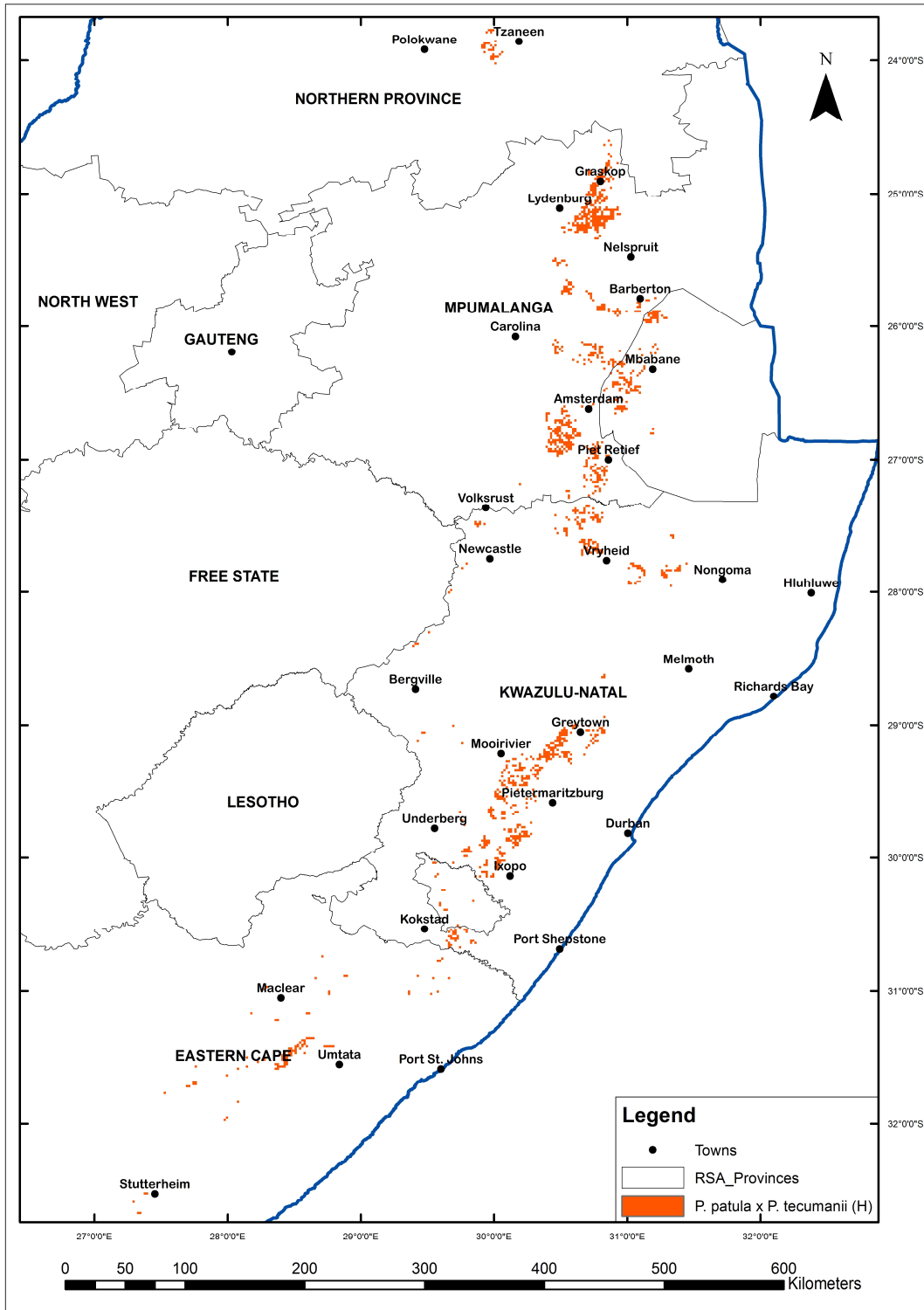


Figure 3. The predicted distribution for those afforested areas which will be climatically well suited to the *P. patula* x *P. tecunumanii* (HE) hybrid (15 – 17 °C mean annual temperature based on early trial results). These cover a large portion of land also suitable to *P. patula*.

(HE) hybrid is proving to be the most suitable alternative to *P. patula* on a wide range of sites which include those that are temperate (Mitchell unpublished). Considering that the hybrid is not as frost tolerant as *P. patula* (Granados 2012) it is likely to be best suited to sites that receive a minimum mean annual rainfall of 800 mm and a mean annual temperature of between 15.0 and 17.0 °C (Fig. 3). Not only does the *P. patula* x *P. tecunumanii* hybrid grow well (Nel et al. 2006), and is more tolerant to *F. circinatum* (Roux 2007, Mitchell et al. 2012b), but it also has solid wood properties similar to *P. patula* (Malan 2010).

Although the susceptibility of *P. patula* to *F. circinatum* has caused the loss of many millions of Rands due to the poor survival of seedlings (Mitchell et al. 2011) this has expedited the testing and development of pine hybrids and alternative species (Dvorak 2012). As has been seen with *Eucalyptus* hybrids, not only are these in many cases more tolerant to diseases (Bayley and Blakeway, 2002), they are also showing improved growth and wood properties (Malan, 1993). It is quite possible, therefore, that the added future benefits of pine hybrids and alternative species far outweigh the losses that *F. circinatum* has caused the South African forest industry.

Acknowledgements

We are grateful to Bill Dvorak (Camcore), for his useful comments and editing of this paper, and to York Timbers for providing the information on the proportion of *P. patula*, *P. elliottii* and *P. taeda* planted over the last 6 years. We are also grateful to the Institute for Commercial Forestry Research (ICFR) for providing the cadastral boundaries of the afforested regions in South Africa which were needed to compile the maps.

References

- Adlard PG. 1981. Mexico: Forest or Desert? *Commonwealth Forestry Review* 60: 127-131.
- Allan R, Higgs G. 2000. Methods of improving the survival of *Pinus patula* planted into harvest residues. *Southern African Forestry Journal* 189: 47-51.
- Barnard EL, Blakeslee GM. 1980. Pitch canker on Slash pine seedlings: A new disease in forest tree nurseries. *Plant Disease* 64: 695-696.
- Barnes RD, Mullin LJ. 1984. *Pinus patula* provenance trials in Zimbabwe: seventh year results. In: RD Barnes & GL Gibson (Eds) Provenance and genetic improvement strategies in tropical forest trees. Proc. IUFRO. Mutare, April 9-14, pp. 151-152.
- Barrett WHG. 1972. Variación de caracteres morfológicos en poblaciones naturales de *Pinus patula* Schlect. et. Cham. en Mexico. IDIA. *Suplemento Forestal* No. 7: 9-35
- Bayley AD, Blakeway F. 2002. Deployment strategies to maximise value recovery from tree improvement: The experience of two South African companies. *Southern African Forestry Journal*. 195: 11 – 22.
- Burgers TF. 1975. Mexican origins of *Pinus patula* (Schiede et Deppe). Seeds introduced in South Africa. *Forestry in South Africa* no. 16.
- Butterfield MK. 1990. Isoenzyme variation in a South African and Mexican population of *Pinus patula* Scheide & Deppe. MS Thesis. Department of Genetics, University of Natal, South Africa. 97 pp.
- Coetzee H. 1985. Provenance research on Mexican pines. *Southern African Forestry Journal* 135: 68-73.
- Crous JW. 2005. Post establishment survival of *Pinus patula* in Mpumalanga, one year after planting. *Southern African Forestry Journal* 205: 3 – 8
- Darrow K, Coetzee H. 1983. Potentially valuable Mexican pines in the summer rainfall region of Southern Africa. *South African Forestry Journal* 124 :23-35.
- de Ronde C, du Plessis M. 2002. Determining the relative resistance of selected *Pinus* species to fire damage. Forest Fire Research & Wildland Fire Safety, Viegas (ed.) 2002 Millpress, Rotterdam, ISBN 90-77017-72-0.

- Department of Agriculture, Forestry and Fisheries (DAFF). 2010. Report on commercial timber resources and primary roundwood processing in South Africa 2008/9. The Directorate, Forestry Technical and Information Services, Private Bag X93, Pretoria, 0001, South Africa.
- Duncan PD, White TL, Hodge GR. 1996. First-year freeze hardiness of pure species and hybrid taxa of *Pinus elliottii* (Engelmann) and *Pinus caribaea* (Morelet). *New Forests* 212: 223-241.
- Dvorak WS, Donahue JK, Vasquez JA. 1995. Early performance of Camcore introductions of *Pinus patula* in Brazil, Colombia and South Africa. *Southern African Forestry Journal* 174:23-33.
- Dvorak WS, Hodge GR, Gutiérrez EA, Ororio LF, Malan F, Stanger TK. 2000a. *Pinus tecunumanii*. In: Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative, College of Natural Resources, NCSU, Raleigh, NC, USA. Pp 107 – 127.
- Dvorak WS, Gutiérrez EA, Galpare WJ, Hodge GR, Ororio LF, Bester C, Kikuti P. 2000b. *Pinus maximinoi*. In: Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative, College of Natural Resources, NCSU, Raleigh, NC, USA. pp 107 – 127.
- Dvorak WS, Hodge GR, Kietzka JE, Malan F, Osorio LF, stanger TK. 2000c. *Pinus patula*. In: Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative, College of Natural Resources, NCSU, Raleigh, NC, USA. Pp 148 – 173.
- Dvorak WS. 1997. The improvement and breeding of *Pinus patula*. In: Proc. 24th Southern Forest Tree Improvement Conference. June 9-12, Orlando, FL. pp: 53-68.
- Dvorak WS. 2012. The Strategic Importance of Applied Tree Conservation Programs to the Forestry Industry in South Africa. In Press: *Southern Forests*, 2012 vol 741.
- Galpare WJ, Hodge GR, Dvorak WS. 2001. Genetic parameters and provenance variation of *Pinus maximinoi* in Brazil, Colombia, and South Africa. *Forest Genetics* 8: 159-170.

- Grandos DC. 2012. Geographical Variation of Cold Hardiness in *Pinus patula* Provenances and Genetic Inheritance of Cold Hardiness in *Pinus patula* x *Pinus tecunumanii* Hybrids. MS Thesis. Department of Forestry and Environmental Resources. NC State University. Raleigh, NC. USA <http://www.lib.ncsu.edu/resolver/1840.16/7688>
- Hodge GR, Dvorak WS. 2000. Differential responses of Central American and Mexican pine species and *Pinus radiata* to infection by the pitch canker fungus. *New Forests* 19: 241-258.
- Hodge GR, Dvorak WS. 2007. Variation in pitch canker resistance among provenances of *Pinus patula* and *Pinus tecunumanii* from Mexico and Central America. *New Forests* 33:193 – 206.
- Kotze JJ. 1926. *Pinus patula*, Schl & Cham., Its introduction into and growth in South Africa. *South African Journal of Science*. Vol. XXXIII. pp:455-466.
- Malan FS. 1993. The wood properties and qualities of three South African-grown Eucalypt hybrids. *South African Forestry Journal* 167: 35-44.
- Malan FS. 2006. The wood properties and sawn-board quality of South African-grown *Pinus maximinoi* (HE Moore). *Southern African Forestry Journal* 208: 39 – 48.
- Malan FS. 2010. Corewood in South African pine: necessity and opportunities for improvement. *Southern Forests* 72: 99–105.
- Mitchell RG. 2002. The effect of bottom heat on rooting *Pinus patula* and *Pinus elliottii* x *Pinus caribaea* stem cuttings in South Africa. *Southern African Forestry Journal* 196: 21-26.
- Mitchell RG, Jones NB. 2006. The effects of ontogenetic maturation in *Pinus patula* – Part II: Hedge cycling and field performance. *Southern African Forestry Journal* 207: 3-6.
- Mitchell RG, Zwolinski J, Jones NB. 2004. A review on the effects of donor maturation on rooting and field performance of conifer cuttings. *Southern African Forestry Journal* 201: 53-64.
- Mitchell RG, Steenkamp ET, Coutinho TA, Wingfield MJ. 2011. The pitch canker fungus: implications for South African forestry. *Southern Forests* 73: 1-13.

- Mitchell RG, Wingfield MJ, Hodge GR, Steenkamp ET, Coutinho TA. 2012a. Susceptibility of provenances and families of *Pinus maximinoi* and *Pinus tecunumanii* to frost in South Africa. *New Forests*, DOI: 10.1007/s11056-012-9306-z.
- Mitchell RG, Wingfield MJ, Hodge GR, Steenkamp ET, Coutinho TA. 2012b. Tolerance of *Pinus patula* x *Pinus tecunumanii*, and other pine hybrids, to *Fusarium circinatum* in greenhouse trials. *New Forests*, DOI 10.1007/s11056-012-9355-3.
- Mitchell RG, Wingfield MJ, Hodge GR, Steenkamp ET, Coutinho TA. 2012c. Selection of *Pinus* spp. in South Africa for tolerance to infection by the pitch canker fungus. *New Forests* 43:473-489.
- Mitchell RG, Wingfield MJ, Steenkamp ET, Coutinho TA. 2012d. Tolerance of *Pinus patula* full-sib families to *Fusarium circinatum* in a greenhouse study. *Southern Forests*, under review.
- Morris A. 2011. The Pitch Canker Fungus in South Africa and what we are doing about it. Camcore Annual Business and Technical Meeting, December 4-10, 2011, Mantra Hotel, Mooloolaba, Queensland, Australia.
- Nel A, Kanzler A, Dvorak W. 2006. Development of a commercial breeding program for *Pinus tecunumanii* in South Africa. In: Fikret Isik (ed) Proceedings of the IUFRO Division 2 Joint Conference: Low Input Breeding and Conservation of Forest Genetic Resources: Antalya, Turkey, 9-13 October 2006. pp 158-161.
- Nyoka BI. 2003. Biosecurity in forestry: a case study on the status of invasive forest trees species in Southern Africa. Forest Biosecurity Working Paper FBS/1E. Forestry Department. FAO, Rome (unpublished).
- Pine *Fusarium* working Group. 2004. Forestry takes bold steps towards combating *Fusarium circinatum*. Article in *Wood SA/Timber Times*, November 2004. <http://www.timbersa.co.za>.
- Poynton RJ. 1979. Tree planting in Southern Africa. Vol 1: The Pines. Department of Forestry, Pretoria, South Africa.
- Price RA, Liston A, Strauss SH. 1998. Phylogeny and systematics of *Pinus*. In: Richardson DM (ed.), Ecology and Biogeography of *Pinus*. Cambridge University Press. UK. pp:49-68.

- Roux J, Eisenberg B, Kanzler A, Nel A, Coetzee V, Kietzka E, Wingfield MJ. 2007. Testing of selected South African *Pinus* hybrids and families for tolerance to the pitch canker pathogen, *Fusarium circinatum*. *New Forests* 33: 109 – 123.
- Schulze RE, Maharaj M, Warburton ML, Gers CJ, Horan MJC, Kunz RP, Clark DJ. 2007. *South African Atlas of Climatology and Agrohydrology*, Water Research Commission, WRC Report 1489/1/08.
- Swart WJ, Knox-Davies PS, Wingfield MJ. 1985. *Sphaeropsis sapinea*, with special reference to its occurrence on *Pinus* spp. in South Africa. *Southern African Journal of Forestry*, December, 1985; 1-8.
- Warburton M, Schulze R. 2006. Climate change and the South African commercial forestry sector: and initial study. Report to Forestry SA, *ACRUcons Report 54*, December 2006. School of Bioresources Engineering and Environmental Hydrology University of KwaZulu-Natal, Pietermaritzburg, South Africa.
- Wormald TJ. 1975. *Pinus patula*. Tropical Forestry Paper No. 7. Oxford Forestry Institute, University of Oxford, UK. P 172.