# INVESTIGATION OF GROWTH POTENTIAL OF ALTERNATIVE *EUCALYPTUS* SPECIES FOR MID AND HIGH ALTITUDE SITES IN THE SUMMER RAINFALL REGION IN SOUTH AFRICA

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# DECLARATION

The experimental work described in this dissertation was conducted at the University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Mark Laing.

The results have not been submitted in any other form to another University and except where the work of others is acknowledged in the text, are the results of my own investigation.

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And finally I would like to extend my sincere gratitude to all tree breeders and foresters in the forestry industry (MondiBP, SAPPI and NCT) for supporting this project and their assistance with the establishment and maintenance of the trials discussed in this thesis.

## THESIS ABSTRACT

A study was undertaken to compare growth potential of three *Eucalyptus* species of natural origin in South Eastern Australia, with commercially grown species on mid and high altitude temperate sites in the summer rainfall growing zones in South Africa. The three species were *Eucalyptus globulus* subsp*. bicostata (E. bicostata), Eucalyptus cypellocarpa* and *Eucalyptus nobilis.* Nine sites were selected to represent the growing areas of South Africa experiencing cold winter drought with occasional snow falls. Improved, commercially grown pure *Eucalyptus* species and interspecific hybrid clones were included as controls in the trials to give comparative growth performances on specific sites. Both balanced and unbalanced lattice designs were used to evaluate the growth potential of the unimproved Australian species and the improved commercial controls incorporated into the trials.

Volume production and basal area growth were assessed for the three species at all sites. However, only three sub species *E.globulus* (*E. bicostata*, *E. maidenii* and *E. globulus*) showed varying levels of disease (*Mychosphaerella nobilosa*) infestation and this was therefore assessed in trials at 12 and 30 months respectively, and correlation analysis was used to study the relationship between the impact of disease infestation and growth performance. It was found that negative phenotypic correlations existed between the levels of infection and tree growth. ie greater infection slower growth.

Evaluation of genotype x environment interaction (GXE) revealed that this did not exist in the *E. bicostata* nor *E. nobilis* populations, and therefore one population of each species can be developed for all the sites tested. *E. cypellocarpa* was the only species that showed some GXE interaction implying that separate populations to be developed for different sites.

Contrary to what was expected, unimproved *Eucalyptus* species being investigated performed equally as well as the improved commercial species included as controls, thus providing potential for commercial deployment with selection and breeding.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| % | Percent |
| $^0C$ | Degrees Celsius |
| $Baha^{-1}$ | Basal area per hectare |
| CTEs | Cold Tolerant Eucalypts |
| CV% | Coefficient of variation |
| DBH | Diameter at Breast Height |
| DWAF | Department of Water and Environmental Affairs |
| FABI | Forest and Agricultural Biotechnology Institute |
| FAO | Food and Agricultural Organizations |
| $M^3ha^{-1}$ | Cubic meters per hectare |
| MAI | Mean Annual Increment |
| MAP | Mean Annual Precipitation |
| MAT | Mean Annual Temperature |
| Mo | Months |
| MONDIBP | Mondi Business Paper South Africa |
| NCT | Natal Co-operative |
| NSW | New South Wales |
| SADC | Southern African Development Co-operation |
| SAPPI | South African Pulp and Paper Industries |
| SED | Standard Error of the Difference of two Means |
| subsp. | *S*ub species |

# INTRODUCTION

## FORESTRY IN SOUTH AFRICA

The total plantation area of the Southern African Development Community (SADC) countries totals 2,481,000 ha of which 62.6% is in South Africa, 6.5% in Swaziland, 5.7% in Zimbabwe, 5.7% in Angola, 5.4% in Tanzania and the rest of the countries have less than 5%, Namibia, has no plantations. SADC is a small player in global terms but, within SADC, South Africa is a giant player in the forestry industry (Job 2002).

South Africa is a country of low mean rainfall and as a result, most of the natural vegetation is non woody, with natural forests consisting of a narrow broken belt of closed canopy forest along the southern and eastern seaboards and open canopy savannah woodlands in the north eastern interior of the country. Compared with a world mean in excess of 30%, today in South Africa, natural closed canopy forest covers only roughly 0.5% and savannah woodlands roughly 19.0% of the total land area. Historically, attention has been given to conserving the remnant of closed canopy forest areas, while developing a industry based on exotic timber plantations. These plantations presently cover less than 1.4% of South Africa's land base. Minimal attention has been given to the natural woodlands, except in areas primarily conserved for the protection of fauna (Owen 2000).

## PLANTATION FORESTRY

Using the characteristics of the fibre produced, plantations can be classified into two main categories: hardwoods and softwoods. *Eucalyptus species* (mainly *E. grandis*) and wattle (*Acacia mearnsii*) are the main hardwood species grown in South Africa. Pine (of which *Pinus patula* is the most common species) accounts for all South African softwood plantations. Depending on the eventual use of the wood, hardwoods can be grown on either short or long rotations. Hardwoods (*Eucalyptus*) for pulping purposes usually have a short rotation of 6-10 years (Edwards 2000), whereas sawlog *Eucalyptus* have a 20 - 25 year rotation (Van Zyl 2004).

Establishment of exotic plantations has been extremely successful in South Africa. Publication of thinning, pruning and management studies on the main exotic pine species grown in South Africa in 1939 by Dr Ian Craib made an important early contribution. These principles were later implemented in other Southern hemisphere countries such as New Zealand, Australia and South America's (Hinze 2004).

Regionally in South Africa, hardwood is the main species planted in KwaZulu-Natal (52.3% of all *Eucalyptus* are planted in KZN), with softwood being more prominent in Mpumalanga, Limpopo and the Western and Eastern Cape (Godsmark 2003).

Sites for commercial afforestation of *Eucalyptus* species for the pulp and paper industry are very diverse, particularly the high altitude sites which are termed low productivity sites. Severe frost, low temperatures, occasional snow, drought and unique high altitude pests and diseases such as *Mychosphaerella nobilosa* are some of the limiting site factors associated with mid and high altitude temperate sites (Swain and Gardner 2003).

There is currently little scope to expand the planted area of *Eucalyptus* species in South Africa due to a shortage of suitable land. Agricultural land takes priority over forestry for food production, and strict government policies exist concerning changes in land use. For this reason, forest productivity can only be maximised by better matching of timber species with site, better silvicultural management and the use of improved genetic material adapted to particular sites (Hinze 2004).

Recently, a major research focus has been towards investigating the growth potential of alternative *Eucalyptus* species relative to *E. grandis* for low and medium altitude sites, and to *Eucalyptus macarthurii* and *Eucalyptus nitens* for high altitude sites, particularly in areas where site productivity potential is regarded as low (Swain and Gardner 2003). It is expected that information generated from trials will yield valuable information regarding adaptability of the species to different site types when establishing commercial plantations, which will ultimately reduce the risks associated with growing timber in low potential sites.

*Eucalyptus globulus* ssp. *bicostata*, *Eucalyptus cypellocarpa* and *Eucalyptus viminalis* ssp. *nobilis* are among the species currently being investigated for growth potential on mid and high altitude sites in South Africa.

**AIMS OF THIS INVESTIGATION**

1. To assess the growth performance of *E. bicostata*, *E. cypellocarpa* and *E. nobilis* species for mid and high altitude sites, particularly in areas where site productivity is regarded as low, in the summer rainfall regions in South Africa.
2. To investigate whether provenance and family differences exist for growth traits assessed on different sites.
3. As the *E. bicostata* trials were infected by *Mycosphaerella nobilosa* at an early age, it was necessary to ascertain the relevant tolerance levels of the three *E. globulus* sub-species to this disease, and to establish whether any correlations between growth and severity of infection exists. None of the other species were infected by this pathogen, and thus were not assessed.

Due to the nature of this thesis, having been written as three discrete papers, there is some duplication in the Materials and Methods section of each Chapter.

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# Chapter 1

# LITERATURE REVIEW

## 1.1 INTRODUCTION

The natural distribution of species from the genus *Eucalyptus* is largely confined to the Australasian region (Pryor 1976). The genus comprised of more than 700 species (Fiona *et al.* 2005) and the largest portion of these (Chippendale and Wolf 1981) are endemic to Australia, with only two species exotic to Australia, in Papua New Guinea and Timor (Pryor 1981; Turnbull 1981). Hence, the genus covers a wide latitudinal range, from 7 $^{o}$ North to 43 $^{o}$ South (Turnbull and Eldridge 1983).

*Eucalyptus* species are widely adapted to a great diversity of sites, types of management systems and range of uses, both in natural forests and in plantations (Eldridge *et al.* 1993). Altogether the various species of *Eucalyptus* are now amongst the most widely planted silvicultural plants in the world. The prime reason is that, under many environmental conditions, suitably selected species grow rapidly and produce wood of value for either industrial use or to meet simpler needs such as building poles and fuel (Pryor and Johnson 1971). Exceptional growth rates of mean annual increments (M.A.I) of up to 80 $m^3ha^{-1}yr^{-1}$ have been reported in Brazil (Camphinos 1980), M.A.I of 60 $m^3ha^{-1}yr^{-1}$ for *E. grandis* grown at 1200m and 48 $m^3ha^{-1}yr^{-1}$ for *E. nitens* at 1600m, respectively, have been reported in South Africa, under research conditions (Schönau and Gardner 1991).

In Australia, only about 60 eucalypt species are classed as being economically important producers of timber, although many of the other species yield useful timber (Poynton 1979). Species trials have clearly identified the most important commercial eucalypts worldwide, the bulk of which come from the subgenus *Symphomyrtus* (Potts and Dungey 2001). Globally, several species that were previously regarded as important have fallen into disfavour, particularly from the subgenus *Monocalyptus*. In South Africa, this has been largely due to attack by pests and diseases, or poor growth performance and wood properties (Clarke 2000). Species that fall into the sub-genus *Monocalyptus* (Table 1.1), such as *E. fraxinoides*, *E. regnans*, *E. fastigata, E. oreades* and *E. elata*, grow poorly in the summer rainfall regions due to attack by *Phytophthora cinnamomii* (Clarke and Jones 1998).

The reasons for growing eucalypts in South Africa have now polarised distinctly into growing either short-rotation hardwood species for pulpwood and paper production (Clarke and Jones 1998), or growing species which are suitable for longer rotations for solid wood (Griffin 2001).

**Table 1.1 Classification of eucalypts (Pryor and Johnson 1971; Pryor 1981) grown in the summer rainfall regions of South Africa.**

| Genus | Subgenus | Section | Series | Species |
|---|---|---|---|---|
| *Eucalyptus (Myrtaceae)* | *Symphomyrtus* | Exsertaria (water courses) | Exsertae (southern river gums) | *E. camaldulensis*<br>*E. tereticornis* |
| | | Maidenaria ( cold, southern) | Viminales (mountain gums) | *E. badjensis*<br>*E. benthamii*<br>*E. bicostata*<br>*E. cypellocarpa*<br>*E. dorrigoensis*<br>*E. dunnii*<br>*E. macarthurii*<br>*E. nitens*<br>*E. nobilis*<br>*E. smithii* |
| | | Transversaria (primitive eastern) | Annulares | *E. urophylla* |
| | | | Punctatae (grey gums) | *E. biturbinata*<br>*E. longirostrata* |
| | | | Transversae (eastern blue gums) | *E. grandis*<br>*E. saligna* |
| | *Monocalyptus* | | Piperitae | *E. elata* |
| | | | Obliquae | *E. fastigata*<br>*E. fraxinoides* |

## 1.2 HISTORY OF EUCALYPTUS AS AN EXOTIC GENUS IN SOUTH AFRICA

Eucalypts were introduced into South Africa in 1823 when nine seedlings of *E. globulus* were brought to the Cape Colony from Mauritius by Sir Lowry Cole, its new governor (Poynton 1979). Since then there has been a continuous, if little planned, introduction of new species to the subcontinent. By 1979, Poynton could list 134 Eucalyptus species that had been tested in experimental plantings of a reasonable scale, 62 species had been tested in very limited trials and 42 species that had failed either in the nursery or at a comparatively early stage in the field. Very few became commercially important (Darrow 1983), with 78% of the total area devoted to eucalypts comprising of *E. grandis* (Directorate of Forestry 1981).

## 1.3 FORESTRY AND THE ECONOMY

There are approximately 1.28 mha of commercial forests in South Africa. The private and public sectors account for 76% and 24% of the total plantation area, respectively. These areas are mainly planted to exotic species of *Pinus*, *Eucalyptus* and *Acacia* (DWAF 2007).

In 2005/2006, softwood (pine) accounted for 54% of plantations, with hardwoods (predominantly *Eucalyptus* and wattle) covering 46% of all plantations. *Eucalyptus grandis* accounts for 50.9% of the total hardwood area. 46.7% of South Africa's forests are situated in the provinces of KwaZulu-Natal and Mpumalanga (DWAF 2007).

In 2006, the forest and forest products industry exported products worth R9.9 billion, which constituted 9.9% of total exports. Total imports were valued at R8.0 billion, which resulted in a positive trade balance for this sector of the economy of R1.9 billion (FSA 2007).

## 1.4 CLIMATE

South Africa extends in latitude from 22°00'S (Rhodes Drift) to 34°50'S (Cape Agulhas). The country has a wide variety of climates and has been divided into a number of silvicultural zones which are based on a combination of seasonal rainfall distribution, humidity, and temperature. Most of the eucalypt plantations are in the summer rainfall zone; winter and uniform rainfall zones account for only 2% (FAO 1979).

Within the summer rainfall zone, three climatic zones are recognised (Fig 1.2), corresponding to (1) general snow and frost risk across the landscape (cool temperate), (2) frost risk confined to low-lying areas only (warm temperate) and (3) frost-free areas (sub-tropical) (Smith *et al*. 2005).

Within the summer rainfall area, the majority of commercial plantations of eucalypts are in the humid zone, which experience light frost, at elevations over 600m and with annual rainfall over 800mm, with the exception of the Zululand coast (FAO 1979).

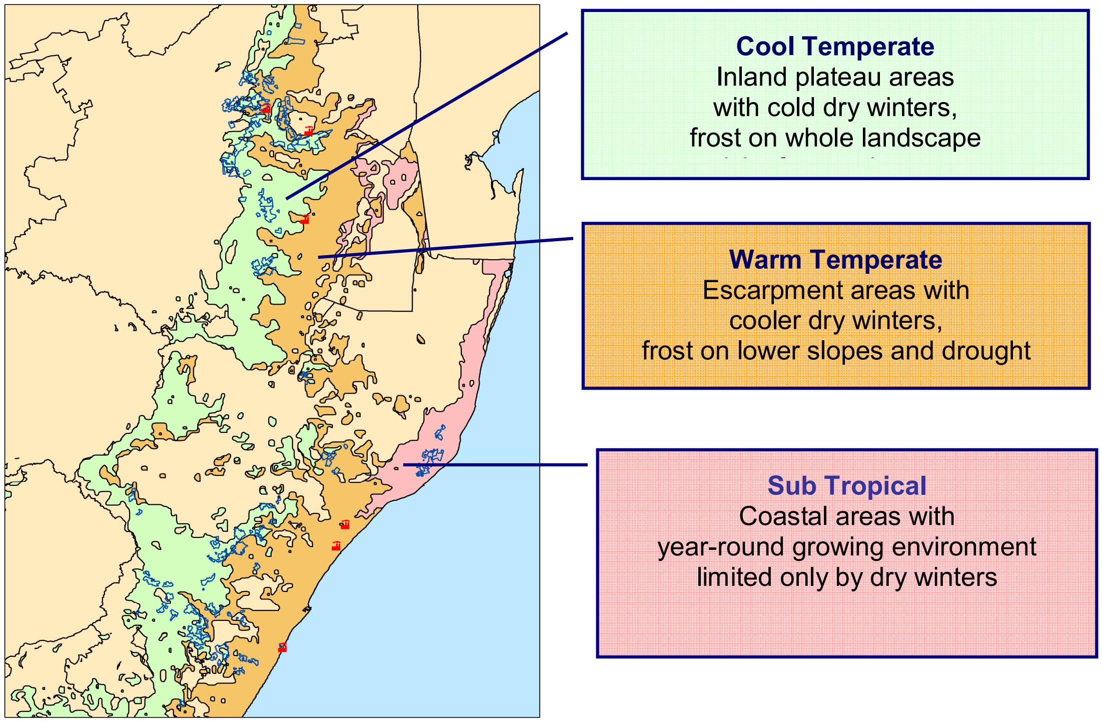


**Figure 2.1 Climatic zones in the summer rainfall region of South Africa (Reproduced courtesy of Sappi Forests, 2007)**

## 1.5 COLD TOLERANT EUCALYPTUS PLANTED AT HIGH ALTITUDE

In the summer rainfall regions of South Africa, *E. grandis* is the eucalypt species planted most commonly in commercial plantations, due to its good stem form, fast growth and desirable timber properties (Nixon 1983). Although it may tolerate mild frosts, planting of this species is not recommended in areas where the mean daily minimum temperature of the coldest month, July, is less than 4.0$^{o}$C (Schönau 1983). However, to meet the ever increasing demand for hardwood, plantings have extended into temperate areas which are not suitable for the optimum growth of *E. grandis.*

Traditionally, cold tolerant eucalypts (CTEs) such as *Eucalyptus fastigata* were planted in South Africa on high altitude sites for the production of mining timber, but as the emphasis in forestry has shifted from mining timber to pulp and paper production over the last 20 years, species which were not suitable for mining timber have now been introduced into commercial plantations for pulp and paper production (Swain and Gardner 2000). This has resulted in an increase in the percentage of short-rotation hardwoods planted in cold regions (essentially eucalypts) by the conversion of mining timber stands to pulpwood stands (Dyer 2007).

## 1.6 SPECIES AND PROVENANCE TESTING

The need to initiate large scale afforestation of high altitude temperate sites which are unsuitable for *E. grandis* began in the mid-1980's. In order to meet this goal, new *Eucalyptus* species were tested for their suitability for pulp and paper production. The major eucalypt species utilised for mining timber such as *E. fastigata*, *E. macarthurii* and, to some extent, *E. elata,* were therefore tested. In addition, *E. smithii* and *E. dunnii* from colder, high altitude areas were tested for the pulp and paper market (Swain and Gardner 2003).

Soon after the new trials were established, growth results showed that the existing commercial eucalypt species were not adapted to the environmental conditions of the newly established temperate tree growing areas (Gardner 2006). The growth and productivity of the existing commercial species were clearly affected in the high altitude areas by a combination of cold, frost, snow and/ or drought (Darrow 1996) and this supported earlier findings from trials conducted on several CTEs in frost-prone areas in KwaZulu-Natal, South Africa (Nixon 1983).

### 1.6.1 Site x species interaction trials

The growth potential of several alternative species was identified in site x species interaction trials established by the Institute for Commercial Forestry Research (ICFR) in the early 1980's in the high altitude summer rainfall growing areas in both KwaZulu-Natal and Mpumalanga (Schönau and Gardner 1991). As a result, several eucalypt species were identified as having good potential for colder commercial forestry sites. These sites were categorised into two main forestry areas namely: cold, high altitude and warmer mid-altitude sites in the summer rainfall regions of South Africa (Gardner 2006).

Two such species which were recommended for high altitude cold sites were *E. badjensis* and *E. benthamii* and subsequently, provenance/ progeny trials were established in the mid-1990s by the ICFR, further investigating both of these species (Swain 2001a; Swain 2001b).

Besides *E. badjensis* and *E. benthamii, E. nobilis* and *E. cypellocarpa* also performed well in the site x species trials and therefore were recommended for further investigation in the high altitude, cold sites of KwaZulu-Natal and Mpumalanga. As a result of this, seed was collected from specific provenances in Australia for establishment in provenance/ progeny trials in South Africa.

### 1.6.2 Seed collection from Australia in 2000 for further investigation in the summer rainfall region of South Africa

In 1997, a seed collection for *E. nobilis*, *E. cypellocarpa* and in addition, one opportunistic provenance collection of *E. bicostata* from NSW in Australia, was made for further investigation of these species in the summer rainfall region of South Africa. Subsequent seedlots of *E. bicostata* were purchased for inclusion in the trials to broaden the genetic base of this species in the provenance/ progeny trials(Gardner 2000)

The criterion for the provenance collections was to collect seed from drier outlier populations, within the latitudinal range of $28^0$ to $33^0$S in north eastern New South Wales (NSW) and south eastern Queensland, where rainfall distribution tends towards a summer maximum (Gardner 2000).

## 1.7 GROWTH ADAPTATION OF CTEs IN SOUTH AFRICA.

### 1.7.1 Introduction

Cold tolerant eucalypts were the first forest tree species planted in Mpumalanga for wood production. As early as the beginning of the $20^{th}$ century, CTEs were widely planted by mining companies and private farmers for production of mining timber. *Eucalyptus fastigata*, *E. macarthurii, E. elata* and *E. nitens* were the preferred species (Purnell 1988) because they were the only species which could grow in the mining areas, mainly located in the cold, high forests of the Mpumalanga and Gauteng provinces. Since then commercial and trial plantings of these and other CTE species has provided much information on where these species should be grown.

Market demand, risk and yield are factors taken into consideration when a species is chosen to be grown on a particular site. The initial choice of species is determined by a range of factors usually related to risk; for example, drought sensitivity, pest and disease risk, and susceptibility to frost, snowfall and hail. Much information exists in South Africa with regard to matching species to site (Smith *et al.* 2005). Table 1.2 shows a summary of growth criteria compiled by Smith *et al.* for a range of cold tolerant *Eucalyptus* in South Africa.

**Table 1.2 A summary of published growth criteria for cold tolerant *Eucalyptus* species in South Africa (Smith *et al*. 2005)**

| Source | MAT (°C) | MAP (mm) | Altitude (m) | Soil depth (mm) |
|---|---|---|---|---|
| ***E. bicostata*** | | | | |
| (Swain and Gardner 2003) | 14.0-17.0 | 800-950 | 1200-1500 | 450 |
| ***E. cypellocarpa*** | | | | |
| (Swain and Gardner 2003) | 15.0-17.0 | 800-950 | 1100-1300 | 400 |
| ***E. dunnii*** | | | | |
| (Swain and Gardner 2003) | 15.0-19.0 | 800-950 | 900-1350 | 350 |
| (Herbert 2000) | 15.5-18.5 | 822-925 | | 300 |
| ***E. fastigata*** | | | | |
| (Swain and Gardner 2003) | 14.0-17.0 | 800-950 | 1200-1600 | 450 |
| ***E. fraxinoides*** | | | | |
| (Herbert 1993) | 15.0-17.5 | 850-900 | | 600 |
| (Swain and Gardner 2003) | 14.0-16.0 | 780-900 | 1200-1700 | 300 |
| ***E. macarthurii*** | | | | |
| (Schönau and Grey 1987) | | > 850 | > 1200 | 300 |
| (Swain and Gardner 2003) | 14.0-18.0 | 780-925 | 1150-1500 | 400 |
| ***E. nitens*** | | | | |
| (Donkin 1993) | 13.0-15.5 | > 900 | > 1400 | |
| (Herbert 2000) | 13.5-15.5 | 810-899 | | 400 |
| (Swain and Gardner 2003) | 14.0-16.0 | 825-950 | > 1350 | 450 |
| ***E. nobilis*** | | | | |
| (Swain and Gardner 2003) | 14.0-17.0 | 825-950 | > 1300 | 500 |
| ***E. smithii*** | | | | |
| (Swain *et al.* 2000) | 15.0-19.0 | 850-900 | | |
| (Swain and Gardner 2003) | 15.0-18.0 | 830-950 | 1100-1500 | 400 |

### 1.7.2 Cold tolerance

The temperature regime to which a plant is exposed is among the environmental factors that affect plant growth and development (Tibbits *et al.* 1997). This is certainly true in eucalypts (Paton 1980) where, for example, growth development in *E. nitens* in Australia has been shown to be affected by the temperature regime and seed source (Shepherd *et al.* 1976).

Cold tolerance in a species is the ability to survive and grow well under the more temperate conditions found at higher altitudes. Areas suitable for growing CTE species in South Africa are usually defined as having a mean annual temperature (MAT) below a certain threshold. In practice, in the summer rainfall area, a minimum altitude of 1150m is commonly used to indicate areas suitable for cold tolerant eucalypts (Swain and Gardner 2003).

Alternatively, such sites are deemed to be those areas too cold for successful cultivation of *E. grandis*.
A species showing a certain amount of cold-hardiness does not necessarily mean that it will grow well at any MAT below the given threshold, even when key environment factors are present at the site (Swain and Gardner 2003). For example, studies have shown that *E. macarthurii* does not compare well with other CTE species such as *E. nitens* and *E. fraxinoides* when the MAT falls below a threshold of 15.5$^o$C (Schönau and Gardner 1991; Herbert 1993).

Table 1.3 provides information on the relative cold tolerance of the *Eucalyptus* species that are either currently grown, or have the potential to be grown, in the more temperate regions of South Africa.

**Table 1.3 Cold tolerant ratings of *Eucalyptus* species grown in South Africa (Swain and Gardner 2003)**

| Species | Cold tolerance rating |
|---|---|
| *E. benthamii, E. fastigata, E. fraxinoides, E. nitens, E. nobilis* | Very high |
| *E. badjensis, E. bicostata, E. dorrigoensis, E. macarthurii* | Moderately high |
| *E. cypellocarpa, E. elata, E. smithii* | Medium |
| *E. biturbinata, E. dunnii* | Low |

### 1.7.3 Frost tolerance

This is the ability of a species to resist damage by, or the ability to recover from, frost (Swain and Gardner 2003). A number of terms are used synonymously when dealing with freezing resistance. The term "hardiness" is often used with plants, particularly if they "harden" as winter approaches and subsequently de-harden (Chen and Li 1976), and it has been used extensively in reference to eucalypts (Hunt and Zobel 1978; Griffin et al. 1982; Hallam 1986). "Frost tolerance" has also been widely used in reference to eucalypts (Menzies *et al.* 1981; Raymond *et al.* 1986), and its usage would appear justified since freezing resistance is unlikely to be due to avoidance of ice formation.

Frost damage to planted eucalypts has been reported in New Zealand (Wilcox 1982a), Argentina (Mendonza and Alliani 1983) and South Africa (Nixon 1977; 1983; Darrow 1984). Different levels of frost resistance and frost sensitivity are often evident following frost damage of mixed *Eucalyptus* species plantations (Tibbits *et al.* 1997; Swain *et al.* 1998).

Frost damage is often severe in the Highveld of Mpumalanga and certain areas in KwaZulu-Natal, especially in the valleys and drainage areas. Most frost damage occurs in winter, following planting, in the form of tip scorching or total scorching, depending on the frequency and severity of the frost. Some species may be completely scorched and drop leaves but have the capacity to recover in the spring. This is typical of *E. macarthurii,* one of the most frost-tolerant species planted in South Africa (Jones 2002), that has been planted more extensively in Mpumalanga than in KwaZulu-Natal because the former province experiences more severe winter temperatures than the latter (SAPPI 1999).

Table 1.4 provides information on the relative frost tolerance of the eucalypt species that are either currently grown, or have the potential to be grown, in the more temperate regions of South Africa.

**Table 1.4 Frost tolerant ratings for Eucalyptus species grown in South Africa (Swain and Gardner 2003)**

| Species | Frost tolerance rating |
|---|---|
| *E. benthamii, E. dorrigoensis, E. macarthurii* | Very high |
| *E. badjensis, E. nitens, E. nobilis* | Moderately high |
| *E. cypellocarpa, E. elata, E. fastigata, E. smithii* | Medium |
| *E. bicostata, E. biturbinata, E. dunnii, E. fraxinoides* | Low |

### 1.7.4 Snow tolerance

Snow falls are associated with extremely cold weather (Tibbits *et al.* 1997) and can have both damaging (Cremer 1983) and protective effects (Eldridge *et al.* 1993) on plantation trees. Snow tolerance is the ability of a species to withstand damage by snowfalls and to be able to continue growing without any detrimental impact on stem form or wood properties. The most common snow damage to forest plantations in South Africa is stem breakage along all parts of the stem, but trees can also be bent or even uprooted. Although some trees recover from bent stems, trees with crooked or leaning stems develop a high percentage of reaction wood, which can detrimentally affect timber and pulping qualities (Gardner and Swain 1996). The severity of snow damage is related mainly to altitude, wind speed, aspect, slope and species. Other factors such as tree age and stand density may also play a role but these are not yet clearly understood (Kunz and Gardner 2001). Cremer (1983) reported that although large areas of natural forests are sometimes affected by snow fall, the overall level of damage is slight (usually breakage of branches) in terms of percentage crown loss. However, individual trees may suffer extensive crown loss or die following uprooting.

Strong species differences exist with respect to tolerance to snow damage, with some species being more prone to stem and branch damage than others (Gardner and Swain 1996; Tibbits *et al.* 1997). In a two year old species trial in southern Tasmania, *E. globulus* suffered substantially more damage than four other species (White *et al.* 1996). Species and provenance differences in snow tolerance have also been reported in South Africa (Swain and Gardner 2003). It also been reported however, that small seedlings or portions of foliage, can be protected from frost injury by the insulating effects of snow (Eldridge *et al.* 1993).

In South Africa, major damage by snow to timber plantations of all ages in the summer rainfall regions of KwaZulu-Natal and Mpumalanga has been reported (Davidson 1989; Haigh 1996), with some of the greatest losses occurring in stands nearing the end of their rotation (Gardner and Swain 1996). Inappropriate or incorrect planting of some of the main commercial species typically suffer the bulk of the snow damage (Davidson 1989). However, as snow falls are becoming more common and occurring more than once in a rotation, planting of inappropriate species should become less common as species are matched correctly to sites (Kunz and Gardner 2001).

*E. macarthurii* (Low snow tolerance) *E. nitens* (High snow tolerance)

**Figure 1.2 Snow damage on high altitude cold site in KwaZulu-Natal (Photo reproduced courtesy of RAW Gardner, ICFR, 2007)**

Table 1.5 provides information on the relative snow tolerance of the eucalypt species that are either currently grown, or have the potential to be grown, in the more temperate regions of South Africa.

**Table 1.5 Snow tolerance ratings for Eucalyptus species grown in South Africa (Swain and Gardner 2003)**

| Species | Snow Tolerance Rating |
|---|---|
| *E. nitens, E. nobilis,* | Very high |
| *E. badjensis, E. bicostata, E. cypellocarpa, E. fastigata, E. fraxinoides,* | Moderately high |
| *E. biturbinata, E. elata, E. smithii,* | Medium |
| *E. benthamii, E. dorrigoensis, E. dunnii, E. macarthurii,* | Low |

### 1.7.5 Drought tolerance

Most eucalypts evolved in localities in Australia where there is a marked water shortage for substantial parts of the year. They have therefore adapted to drought stress which can be associated with dry summer or winter months (Pryor 1976). However, Darrow (1983) reported severe drought having devastating effects on the survival and growth of eucalypts in forestry plantations in the eastern regions of Africa, and particularly South Africa. There were significant differences between the eucalypt species with regards to drought induced mortality, with *E. dunnii* and *E. smithii* showing the best potential for survival during severe drought. Table 1.6 provides information on the relative drought tolerance of the eucalypt species that are either currently grown, or have the potential to be grown, in the more temperate regions of South Africa.

**Table 1.6 Drought tolerant ratings for Eucalyptus species grown in South Africa (Swain and Gardner 2003)**

| Species | Drought tolerance rating |
|---|---|
| *E. biturbinata, E. dunnii,* | High |
| *E. badjensis, E. fastigata, E. fraxinoides, E. macarthurii,* | Moderately high |
| *E. benthamii, E. bicostata, E. cypellocarpa, E. dorrigoensis, E. nitens, E. nobilis,* | Medium |
| *E. elata* | Low |

### 1.7.6 Pests and diseases

The success of exotic plantations in the Southern hemisphere is closely linked to the separation of these plants from a wide array of important natural enemies (Bright 1998). While there are hundreds of pests and diseases that damage tree species in their native environment, relatively few of these have reached trees in exotic plantation situations (Stone 1983; Wilie and Peters 1983; Wingfield 1990).

In South Africa, diseases and insect pests have strongly influenced species that can be planted, as well as management practices (Zwolinski *et al.* 1990 ; Swart and Wingfield 1991; Denison and Kietzka 1993). For example, the *Eucalyptus* snout beetle, *Gonipterus scutellatus* Gyllenhall, was found for the first time in 1916 in a *Eucalyptus* plantation near Cape Town, South Africa, causing severe defoliation to trees (FABI 2005). As this pest has moved into the summer rainfall forestry regions, it has been found that CTE species are susceptible to this pest, although with varying levels of damage (Swain and Gardner 2003). The insect caused extensive damage to *E. viminalis* stands that existed in the 1920s and since then, the planting of this species has been very limited (Darrow 1983), although it was once highly rated for very good growth rates and superior frost resistance (Hutchins 1903; Kotze and Hubbard 1928). Although this insect is now under biological control by an introduced wasp at low altitudes (Atkinson 1999), it still causes problems for certain *Eucalyptus* species at altitudes over 1200m, and its presence has resulted in the planting of resistant species or aerial spraying programmes of insecticides.

The planting of *E. nitens* has been limited by juvenile susceptibility (particularly Victorian provenances) to fungal leafspot (*Mycosphaerella mulleriana*). This has restricted the planting of *E. nitens* on sites with a MAT greater than $16^0$C (Swain 1996). On poorly watered sites, *E. nitens* is also highly susceptible to stress related diseases, including *Endothia* and *Botryosphaeria*, and the supply of water should be conservatively estimated in order to avoid drought stress (Swain 1996).

*Eucalyptus smithii* is not suited to sites with stony, gravel soils or where soil water drainage is a problem, because this species is highly susceptible to *P. cinnamomii* root rot. Other CTEs experience the same problem when planted outside the range recommended for their optimal growth (Swain and Gardner 2003).

Table 1.7 provides information on the relative *P. cinnamomii* tolerance of the eucalypt species that are either currently grown, or have the potential to be grown, in the more temperate regions of South Africa.

**Table 1.7** ***Phytophthora cinnamomii*** **resistance ratings for** ***Eucalyptus*** **species grown in South Africa (Swain and Gardner 2003)**

| **Species** | ***Phytophthora cinnamomii*** **resistance rating** |
|---|---|
| *E. benthamii, E. bicostata, E. biturbinata, E. cypellocarpa, E. dorrigoensis, E. dunnii, E. elata* | Tolerant |
| *E. badjensis, E. macarthurii* | Moderately tolerant |
| *E. fastigata, E. fraxinoides, E. smithii* | Susceptible |

## 1.8 NATURAL DISTRIBUTION OF *EUCALYPYUS* SPECIES UNDER INVESTIGATION

*Eucalyptus bicostata* is taxonomically closely related to *E. globulus* and *E. maidenii* (Pryor and Johnson 1971; Brooker 2000). This species grows naturally in the Australian state of Victoria (Figure 1.3), which experiences winter rainfall. However, isolated stands occur in certain parts of NSW, the latter areas experiencing uniform or summer rainfall distribution patterns.

Altitude varies from near sea level in the southern part of the distribution, to about 1200m in some of the NSW stands. Mean maximum and mean minimum temperatures of the hottest and coolest months range from 25 - 32$^{o}$C and -2 - 5$^{o}$C respectively, and about 25-70 frosts occur per year at the higher elevations. Mean annual rainfall ranges from 700-1200mm, with a summer maximum in northern NSW. The species prefers a heavy soil or good quality loam, with adequate moisture (Penfold and Willis 1961; Boland *et al*. 1992).

In South Africa *E. bicostata* is recommended as a pulping species on elevated, well watered sites at altitudes which are too warm and humid for *E. nitens* to compete in terms of tree growth and wood volume, but too cool for *E. grandis* to compete with regard to the same and where winter snows are likely. The species requires an MAT of 14-18$^0$C and a mean annual precipitation (MAP) of 800-950mm for optimum growth (Swain *et al*. 1998).

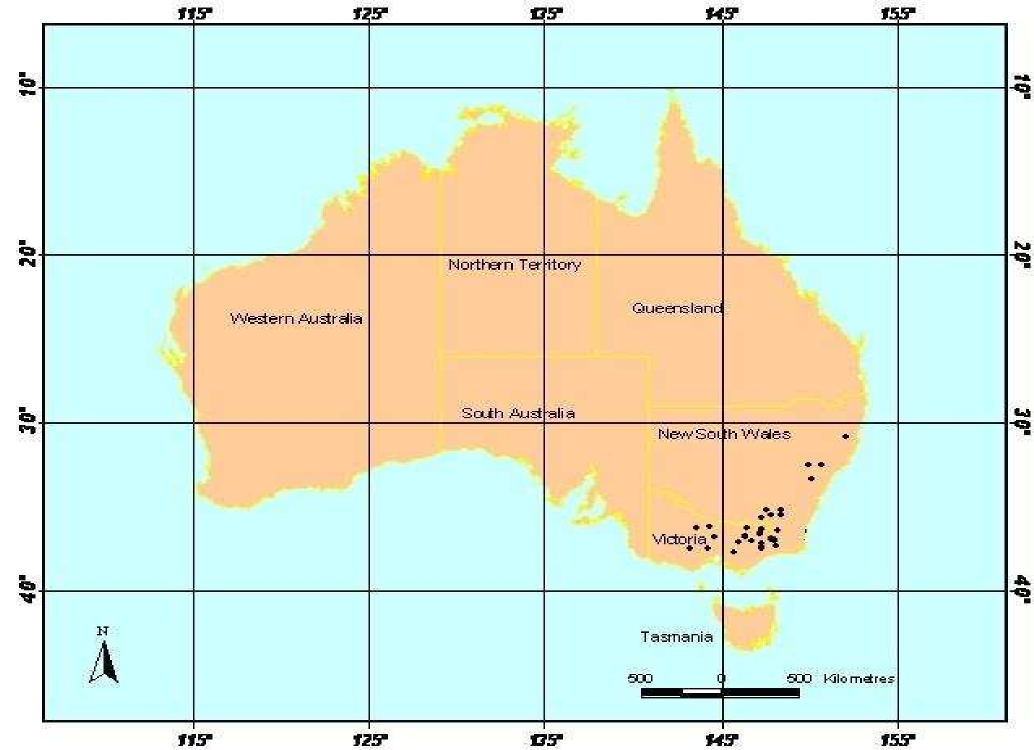


**Figure 1.3 Natural distribution of *Eucalyptus bicostata* in Australia (Boland *et al*. 1992)**

*Eucalyptus nobilis* (formerly classified as *E. viminalis* ssp. *nobilis*) is found in the more northern range of *E. viminalis*, on the tablelands and mountains of NSW (Figure1.4).The species occurs in tall open forest situations, and has a good natural stem form. It is found at high altitudes, generally from 1000m to the edge of the tree line at about 1510m.  Sites are often exposed and subject to moderate to heavy frosts and snows. The species is only found on shallow soils at high rainfall sites (Boland *et al*. 1992), but is not limited to growing in, or near, watercourses, as is the closely related *E. viminalis* (Gardner 2000).  The MAP in the area of collection ranged from 750 -1300mm and altitude ranged from 1020m (drier sites) to 1500m (wetter sites). In South Africa, this species is ideally suited to cooler sites in the summer rainfall regions with MATs ranging from 14-17$^o$C and MAPs of 825-950mm (Swain 1999).

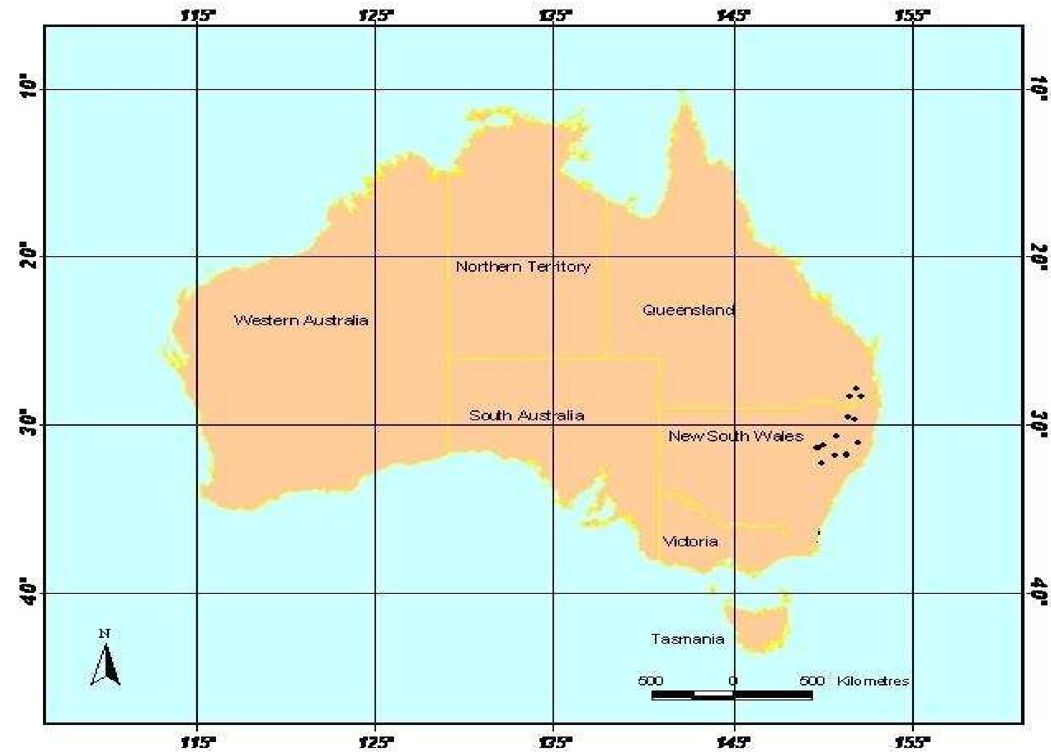


**Figure 1.4 Natural distribution of *Eucalyptus nobilis* in Australia (Boland *et al*. 1992)**

*Eucalyptus cypellocarpa* occurs naturally in Victoria, Australia, but is also found in NSW on the coastal side of the southern tablelands and adjacent to the Victorian border (Figure 1.5). Scattered populations are found throughout the central and northern tablelands of NSW. Populations are found at altitudes from just above sea level to 1200m, with the mean maximum and mean minimum temperatures of the hottest and coldest months ranging from 21-31$^0$C and -2-7$^0$C, respectively. Frosts are severe and frequent in much of the area, while light snowfalls occur in most years at higher altitudes. Mean annual rainfall is between 700-1300mm, with a winter maximum in Victoria, a fairly uniform distribution in southern NSW, and a summer maximum in northern NSW. *Eucalyptus cypellocarpa* grows on a wide range of soils, and will tolerate poor sands if there is clay underneath (Boland *et al*. 1992). In South Africa this species is expected to show good adaptation to warmer and drier conditions than those tolerated by *E. nitens* and *E. bicostata*. Plantings initially should be limited to the MAT ranges of 15-17$^o$C and MAP ranges of 800-900mm (Swain and Gardner 2003).

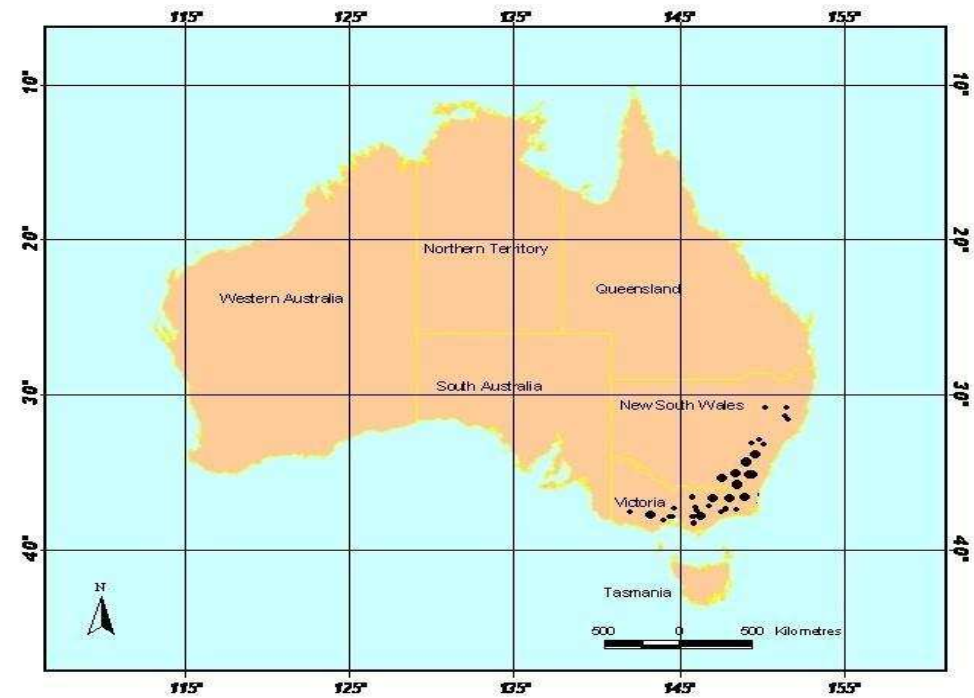


**Figure 1.5 Natural distribution of *Eucalyptus cypellocarpa* in Australia (Boland *et al*. 1992)**

There are forestry sites where it is felt that new species (once improved) can play a role in South Africa. These are sites which are typically too high and cold for commercial production of *E. grandis*; too low and warm for *E. nitens*, alternative high altitude, cold tolerant species are also needed.

Three species were previously investigated in ICFR site species interaction trials and showed potential for these sites (Gardner 2000). A series of provenance/progeny trials of these three species were established to investigate a broader range of material under South African summer rainfall growing condition.

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# Chapter 2

## GROWTH POTENTIAL OF *EUCALYPTUS GLOBULUS* SUBSP*. BICOSTATA*


### ABSTRACT

*Eucalyptus grandis* is cultivated extensively in the humid, warmer temperate, sub-tropical regions in South Africa. With forestry expanding into mid-altitude, drier and warmer, or drier and colder sites, the search to identify reasonably well performing species/provenances for such "low productivity" sites has extended to summer rainfall provenances of *Eucalyptus globulus* subsp*. bicostata*, closely related to *E. globulus*, a species known to have superior kraft pulping.

Seed from New South Wales provenances (Australia) Narrow Neck Ridge, Nullo Mountain (West) and Nullo Mountain (North) was established in provenance/progeny trials on four sites in South Africa (Windy Gap, Enon, Petrusvlei and Speenkoppies). *Eucalyptus globulus* and *E. globulus* subsp*. maidenii* were the internal controls. Trials were planted at 1667 stems per hectare, single row plots of six trees, four replications in an unbalanced lattice design. Commercial seed of other eucalypt species and clones were used as external controls. *Mycosphaerella nobilosa* susceptibility was measured at 12 and 30 months, with trunk diameter at breast height (dbh) and height at 80 months at Petrusvlei, 84 months at Enon, and 96 months at Windy Gap and Speenkoppies. Basal area and volumes were derived from these measurements. Trials were established in phases mainly due to failures of originally planted trials in extremely cold sites being destroyed by severe frost. *Mycosphaerella* infection was more severe at 12 months than 30 months. Narrow Neck Ridge provenance, which was significantly less susceptible than other provenances and controls, also outperformed other *Eucalyptus bicostata* provenances for dbh, height, basal area and volume. Top Narrow Neck Ridge provenance families performed better or similar to the best commercial controls for basal area and volume at three sites, and were approximately 35% better than these controls at the four sites tested.

The inhibitory effect of Mycosphaerella on growth emphasises the importance of site-species and site-provenance matching. Amongst the imported material tested, the more *Mycosphaerella*-tolerant Narrow Neck Ridge provenance was most suited to summer rainfall mid-altitude South African sites.

## 2.1 INTRODUCTION

*Eucalyptus* plantations in South Africa are found over a wide range of different climatic zones, with the humid warmer temperate and sub-tropical regions comprising an important part of this area (FAO 1979). Traditionally *Eucalyptus grandis* has been the most extensively cultivated hardwood species in these regions because of this species' rapid growth and acceptable wood properties (Poynton 1979).

More recently, eucalypts have been used extensively for the production of sawtimber, and pulp and paper production (Swain and Jones 2004), stimulating wide-ranging tree improvement activities in South Africa. New species and provenances have subsequently been introduced regularly into the country and evaluated for their potential use in the forestry industry (Gardner *et al*. 2000).

During the last two decades, commercial forestry in South Africa has expanded into mid-and high altitude summer rainfall sites that are drier and warmer, or drier and colder, than so-called traditional *E. grandis* forestry sites. These areas are generally referred to as "low productivity" sites (Darrow 1983). In higher regions, with altitudes greater than 1350m (Swain 1996; Swain and Gardner 2003), and Mean Annual Temperatures (MAT) greater than $13^0$C but less than $16^0$C, *E. nitens* has been the preferred species. However, areas with an MAT of less than $18^0$C and greater than 16 $^0$C, and with altitudes above 1050m to 1300m, depending on latitude, are not suited to the planting of *E. grandis,* as the sites are too cool, or *E. nitens,* as the sites are too warm (Swain and Gardner 2003). Better performing and better adapted species and provenances are therefore required for these mid-altitude sites.

*Eucalyptus globulus* subsp. *bicostata* Maiden, Blakely & J. Simm (*E. bicostata*) is closely related to *E. globulus* subsp. *globulus* (Brooker 2000), a species known worldwide to have superior kraft pulping properties (Eldridge *et al*. 1993; Potts 2004; Tibbits *et al*. 1997), and is currently being investigated for its potential use in these mid-altitude regions for pulp and paper production. *Eucalyptus bicostata* seed was first brought into South Africa by Beard in 1958. This seed originated from the foothill forests of Victoria in Australia. It was then established in trial plots in the eastern Mpumalanga Province of South Africa. In these trials, established on rather shallow soils overlying hardpan at Alkmaar and Spring Valley Estates near Iswepe, mortality was very high. These losses were attributed to a combination of frost and winter drought, which indicated that *E. bicostata* was frost susceptible (Poynton 1979). During 1998, eight month old *E. bicostata* seedlings of trials in the same areas were also severely damaged by black frost (Swain *et al*. 1998b). Early growth measurements of these latter trials also indicated that the species requires an MAT of less than $18^0$ C but greater than $14^0$ C for viable growth, and that moderate frost tolerance allowed the species to grow on sites where the cool air was able to drain off (Swain and Gardner 2003).

Due to the close relatedness of this species to *E. globulus* which is known world wide for superior kraft pulp properties referenced, this species shows potential as a good pulp producing species on cold, well watered sites where black frost not common. These sites would be those that are too warm for *E. nitens* and *E. macarthurii* to compete in terms of tree growth and wood volume, but too cool for *E. grandis* to compete in with regards to the same, and where winter snows are likely (Swain *et al*. 1998b).

This investigation was therefore undertaken to investigate the performance of Australian summer rainfall provenances and families of *E. bicostata* on mid-altitude sites in the summer rainfall regions of South Africa.

## 2.2 MATERIALS AND METHODS

### 2.2.1 Introduction

*Eucalyptus* species were selected for sampling from provenances across their natural distribution within the northern tablelands area of New South Wales (NSW), Australia. This area showed greatest climatic similarities with selected areas in South Africa with cold, dry winters and a summer rainfall maximum.

Eucalypt forests in Australia are composed of a mixture of species, encompassing a wide age-class distribution. These characteristics complicated the process of selection and reduced efficiency. A stand was therefore chosen for selection if it was generally healthy, had an acceptable growth rate, contained high quality stems and was predominantly the desired species. Trees were selected within a stand if they were in a dominant or co-dominant crown position and had enough seed. Information that was recorded for individual trees included height, diameter at breast height, height of main stem, tree form and phenological aspects. Climatic data (precipitation, temperature, number of dry months), slope, position of tree (valley, slope, etc), altitude, latitude and longitude were also recorded. Records were kept of other species that were also present in the stand.

To reduce the possibility of collecting seed from related or inbred trees, a minimum distance of 100m was kept between each selected tree during sampling. In smaller stands, where seed bearing trees were scarce, this distance may have been reduced slightly. However, in these cases, at least three crowns were left between parent trees. Each area sampled was treated as a separate provenance using seedlot numbers to distinguish between provenances and field numbers allocated to identify individual trees (families) within the provenances (Gardner 2000). The collection was then established in a series of provenance/ progeny trials on temperate low productivity sites in the summer rainfall forestry growing region in South Africa.

A collaborative seed collection trip to northern NSW in Australia was undertaken by Robin Gardner from the Institute of Commercial Forestry Research (ICFR) in South Africa and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, during 1997. The author was part of the establishment, maintenance and data capture team from tree breeding programme.

### 2.2.2 Seed collection

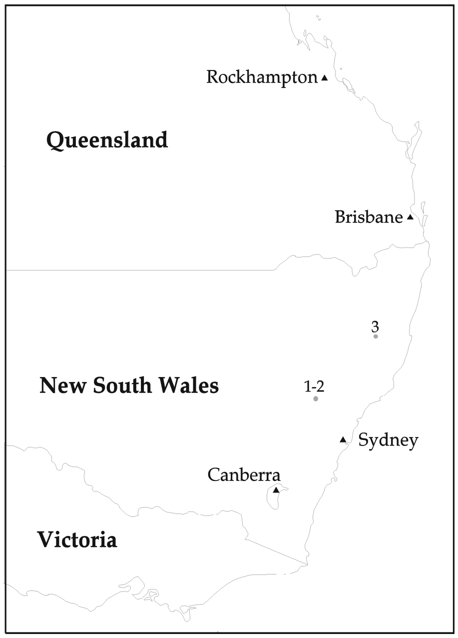
*Eucalyptus bicostata* seed was collected from five trees in the Nullo Mountain provenance on the basis of their good height and form. Following this collaborative seed collection trip, a further 18 seedlots from two provenances were purchased directly from CSIRO in 1997 (Gardner *et al*. 2000) for inclusion in a series of provenance/progeny trials that were to be established. Two provenances of *E. globulus* and one provenance of *E. globulus* subsp*. maidenii* (*E. maidenii*) were included as internal controls in the body of the trials. Improved seed of other eucalypt species and clones grown commercially in South Africa were also included in the trial series as external controls, details to be explained below. Table 2.1 provides information on the origins of the material included in the trials.

**Table 2.1 Origins of seedlots and controls included in the E. bicostata provenance / progeny trials.**

| Species | Seedlot/Clone No. | Number of families (numbering) | Provenance/Source | Average latitude (S) | Average longitude (E) | Average altitude (m) |
|---|---|---|---|---|---|---|
| ***E. bicostata:*** | | | | | | |
| | CSIRO 18587 | 8 (16-23) | Narrow Neck Ridge, Walcha SF NSW (NNR) | $30^{0}55^{'}$ | $152^{0}00^{'}$ | 925 |
| | CSIRO 19799 | 5 (1-5) | Nullo Mountain SF West, NSW ( Nullo W) | $32^{0}44^{'}$ | $150^{0}13^{'}$ | 1110 |
| | CSIRO 16305 | 10 (6-15) | Nullo Mountain SF North, NSW (Nullo N) | $32^{0}43^{'}$ | $150^{0}13^{'}$ | 1100 |
| **Internal controls:** | | | | | | |
| *E. globulus* | Tasmanian Seed Centre | Bulk (24) | King Island, TAS (KI) | $39^{0}04'$ | $144^{0}06^{'}$ | 100 |
| *E. globulus* | Tasmanian Seed Centre | Bulk (25) | Coles Bay, TAS (CB) | $41^{0}45^{'}$ | $148^{0}15^{'}$ | 30 |
| *E. maidenii* | CSIRO 18728 | Bulk (26) | Bolaro Mountain SF, NSW | $35^{0}40^{'}$ | $150^{0}02^{'}$ | 380 |
| **External controls:** | | | | | | |
| *E. biturbinata* | CSIRO 19809; 19812 | Bulk 14 families, unimproved | Girard & Chaelundi, NSW | $29^{0}28^{'}$ | $152^{0}19^{'}$ | 775 |
| *E. dunnii* | M8879 | Bulk, improved | MondiBP, SA | - | - | - |
| *E. grandis* | M7849 | Bulk, improved | MondiBP, SA | - | - | - |
| *E. grandis x nitens* | G X N 069 | Clone | CSIR, Pretoria, SA | - | - | - |
| *E. grandis x nitens* | G X N 075 | Clone | CSIR, Pretoria, SA | - | - | - |
| *E. macarthurii* | ICFR 1/95 | Bulk, improved | Jaglust, SA | - | - | - |
| *E. nitens* | 10061 | Bulk, improved | SAPPI, SA | - | - | - |
| *E. smithii* | 10040 | Bulk, improved | SAPPI, SA | - | - | - |

SA = South Africa; TAS = Tasmania; SF = State Forest

A map of the Australian provenances of *E. bicostata* included in this study is presented in Figure 2.1.




| Provenances | Latitude (S) | Longitude (E) | Altitude (m) | No. of families |
|---|---|---|---|---|
| 1.Nullo West SF | 32°44' | 150°13' | 975 | 5 |
| 2.Nullo North SF | 32°43' | 150°13' | 1100 | 10 |
| 3.Narrow Neck Ridge | 30°55' | 152°00' | 925 | 8 |

**Figure 2.1 Three *E. bicostata* provenance collection sites in New South Wales in Australia**

### 2.2.3 Trial establishment

Progeny/provenance trials were established to determine which Australian provenances are best suited to temperate, summer rainfall conditions in South Africa, and to identify top families under these conditions. All trials were planted at 1667 stems ha$^{-1}$ (2 x 3m), in single row plots of six trees, with four replications, laid out in balanced or unbalanced lattice designs. External control plots of commercial species and clones were laid out around the trials in three rows of eight trees each, but only the six trees in the inner row were measured. This layout was implemented to prevent inter-species competition within the trial, but also to provide a comparative measure. However, the data was excluded from the formal statistical analyses because the external controls were not included in the experimental design (blocking and replications) of the trial.

Four trials of *E. bicostata* families, including internal and external controls, were established in South Africa over two planting seasons, due to severe frosts destroying two of the original four trials. Trial details are provided in Table 2.2. The trials were established by the ICFR Technical Staff, which included the author. Further details of trial types and designs are presented in Table 2.3.

**Table 2.2 Trial sites established for *E. bicostata* in South Africa**

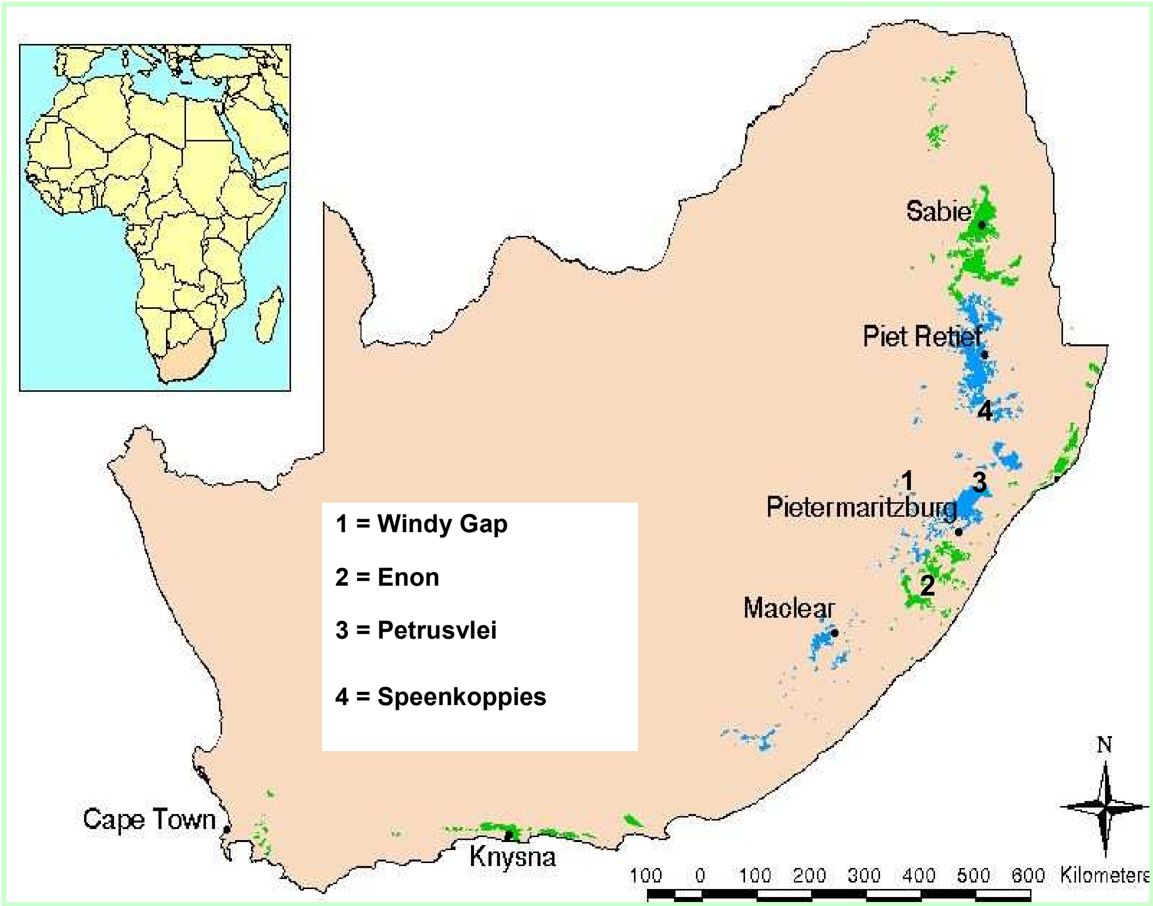
| Site locality | Planting date | No. families | Area (ha) | Latitude (S) | Longitude (E) | Altitude (m) | MAP (mm) | MAT (°C) | Soil depth (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | 04/12/97 | 26 | 0,66 | 29°38'48" | 29°34'20" | 1620 | 900 | 14,5 | 1000 |
| Enon, Richmond, KZN | 29/10/98 | 21 | 1,10 | 29°49'10" | 30°13'20" | 1150 | 980 | 16,5 | >1000 |
| Petrusvlei, Seven Oaks, KZN | 28/10/98 | 21 | 1,50 | 29°12'05" | 30°23'20" | 1320 | 960 | 14,5 | >1000 |
| Speenkoppies Moolman, MPU | 18/11/98 | 21 | 1,10 | 27°07'45" | 30°54'30" | 1210 | 894 | 16,8 | 700-1200 |

KZN = KwaZulu-Natal; MPU = Mpumalanga; MAP = Mean Annual Precipitation; MAT = Mean Annual Temperature

**Table 2.3 *E. bicostata* trial type and designs for four sites established in South Africa**

| Trial no. | Trial type | Company | Origin | Design | Reps |
|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | Provenance/ progeny trial | Sappi | Aus | Unbalanced lattice | 4 |
| Enon, Richmond, KZN | Provenance/ progeny trial | NCT | Aus | Unbalanced lattice | 4 |
| Petrusvlei, Seven Oaks, KZN | Provenance/ progeny trial | Sappi | Aus | Unbalanced lattice | 4 |
| Speenkoppies Moolman, MPU | Provenance/ progeny trial | Mondi | Aus | Unbalanced lattice | 4 |

A map of the South African trial sites for *E. bicostata* is presented in Figure 2.2




**Blue= cool temperate Green= warm temperate and sub tropical**

**Figure 2.2 Four trial sites for *E. bicostata* established in South Africa.**

### 2.2.4 Disease assessment

Due to the occurrence of the fungal pathogen *Mycosphaerella nobilosa* at all four trial sites within a few months of planting, the *E. bicostata* trees were assessed at 12 and 30mo after planting for susceptibility to the fungal pathogen. This pathogen causes severe defoliation of juvenile leaves during early growth, resulting in a long-term impact on overall growth. Leaf fungal damage was assessed by employing a four point score (0 to 3) developed by the Forestry and Agricultural Biotechnology Institute

(FABI) in Pretoria, South Africa, as follows: 0 for no infection, 1 for ≤50% of the leaves infected, 2 for infection >50% but ≤90%, and 3 for infection >90% (Morley 2001). None of the improved commercial species in the external controls displayed any susceptibility to the pathogen and were therefore excluded from the assessments.

### 2.2.5 Growth assessments

Overbark diameter at breast height (1.3m above ground) (dbh) and height measurements were recorded. These measurements were done at 80mo after planting at Petrusvlei, 84mo at Enon, 91mo at Speenkoppies and 96mo at Windy Gap. Although the trials were all measured during the same year, the ages at time of measurement differed due to the Petrusvlei, Enon and Speenkoppies being established approximately one year after the Windy Gap site. The Speenkoppies trial was measured several months after the other three trials. The dbh measurements were used to calculate the mean plot basal areas. Basal area was derived by summing the individual basal areas of trees within a plot and then converting basal area per plot ($m^2$ $plot^{-1}$) to basal area per hectare ($m^2$ $ha^{-1}$), using the following formula:

$$Baha^{-1} = dbh^2 \times \pi /144 \times 10000,$$

Where: $Baha^{-1}$ = mean plot basal area per hectare;

$dbh^2$ = diameter at breast height (1.3m above ground) in mm/10;

$\pi = 3.142$;

$\pi /144 \times 10000$ = Conversion factor which takes into account conversion of diameter measured in mm to radius and basal area in $m^2ha^{-1}$(Schönau 1982; Coetzee 1995).

Treatment means and basal areas were calculated in the same manner for the external controls.

As no volume equation is available for *E. bicostata*, the equation developed for *E. nitens* by Schönau (1982) was used to calculate timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -2.17055;

b1 = 2.07516; and

b2 = 1.42792.

The same volume equation was also used for external control species of *E. nitens x badjensis, E. cypellocarpa* and *E. dorrigoensis*, as no volume equations currently exist for these species. For the improved commercial species of *E. macarthurii* and *E. grandis* used in the external controls, volume equations developed by Schönau (1982) were used respectively;

*E. macarthurii* timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -2.03756;

b1 = 2.21147; and

b2 = 1.12502.

*E. grandis* timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -1.98193;

b1 = 1.98044; and

b2 = 1.37188.

For improved commercial species of *E. smithii*, the equation developed by Coetzee (1995) was used to calculate timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -4.6923;

b1 = 1.8802; and

b2 = 1.2217.

Data were statistically analysed using the Restricted Maximum Likelihood Method (REML) (Patterson and Thompson 1971) of the statistical software package Genstat 5 Release 4.21 (Lane and Payne 1996), using the following model for the calculation of provenance and family means:

$$y = X_A + Z_B + H_f + W_p + e,$$

Where;

| | |
|---|---|
| $y$ | = trait or data vector |
| $X_A$ | = replication effects (random), |
| $Z_B$ | = block effects (random), |
| $H_f$ | = family/provenance effects (fixed), |
| $W_p$ | = plot effects (random), |
| $e$ | = random error effects. |

Mean squares were calculated to determine whether effects were significant using the same model. This was done using the ANOVA method in Genstat as referenced. Significant replication effects, on the rare occasion that they were found, were not corrected for. Treatment means were compared using least significant differences (LSDs) at the 5% significance level. The external controls were analysed separately from the main trial data sets, and LSDs calculated for comparison of means within external controls only.

Phenotypic correlations were determined between growth traits of *E. bicostata* and *M. nobilosa* infection at 12 and 30 mo, using Pearson's correlation coefficient (Snedecor and Cochran 1980; Steel and Torrie 1981).

Type B correlations were then estimated for *E. bicostata* and internal controls, to give a clearer indication of any potential genotype by environment interaction (GEI). Where two traits are measured on different individuals within genetic groups, for example a genetic correlation between trees of the same family grown in different environments, the correlation can be designated a Type B genetic correlation (Burdon 1977). Type B correlations at the family level ($r_{Bg}$) were estimated for all possible site pairs within a species, as follows:

$$r_{Bg} = \frac{\sigma^2_{fam}}{\sigma^2_{fam} + \sigma^2_{site*fam}} \quad .$$

The ratio of family variance over the family and environment × family variance is equivalent to a Type B correlation from a paired site analysis. A Type B genetic correlation ($r_{Bg}$) of 0.67 is the level at which the GEI variance represents 50% of the total additive variance, and is the point where it is postulated that the GEI variance may be a cause for concern among tree breeders (Shelbourne 1972). Variances were obtained using the model:

$$y = X_A + Z_B + H_f + W_p + T_S + Q_{sf} + e,$$

Where;

$y$ = trait or data vector

$X_A$ = replication effects (fixed),

$Z_B$ = block effects (fixed),

$H_f$ = family/provenance effects (random),

$W_p$ = plot effects (random),

$T_s$ = site effect (fixed),

$Q_{sf}$ = site/provenance by family interaction coefficient,

$e$ = random error effects.

## 2.3 RESULTS

At all four trial sites of *E. bicostata*, it became evident at 12mo after trial establishment that *E. bicostata,* and other sub-species of *E. globulus* included in the trials as internal controls, were vulnerable to infection by the fungus *M. nobilosa,* causing leaf spot. Therefore, susceptibility to the fungal pathogen was assessed, as well as growth potential.

### 2.3.1 Assessment of *Mycosphaerella nobilosa* susceptibility

Provenance susceptibility to *M. nobilosa* was assessed at 12 and 30mo at all four sites. There were significant provenance differences ($p \leq 0.001$) in the level of *M. nobilosa* infection at both 12mo and 30mo in all four trials (Table 2.4), with the exception of Windy Gap at 12mo. Block and replication effects were not significant, with exception of replication effects at Enon at 12mo.

**Table 2.4 Mean square values of *M. nobilosa* infection at provenance level for 12mo and 30mo in four *E. bicostata* trials**

| Source | D.F. | Mean squares 12(mo) | Mean squares 30(mo) | Source | D.F. | Mean squares 12(mo) | Mean squares 30(mo) |
|---|---|---|---|---|---|---|---|
| **Windy Gap** | | | | **Enon** | | | |
| Rep | 3 | 2.04 | 2.31 | Rep | 3 | 2.01*** | 1.76 |
| Block/Rep | 20 | 1.30 | 1.67 | Block/Rep | 16 | 0.86 | 3.62 |
| Provenance | 5 | 1.30 | 6.21*** | Provenance | 5 | 1.97*** | 21.94*** |
| Error (residual) | 593 | 0.79 | 0.48 | Error (residual) | 479 | 0.19 | 0.35 |
| Total | 623 | 0.82 | 0.58 | Total | 503 | 0.24 | 0.68 |
| **Petrusvlei** | | | | **Speenkoppies** | | | |
| Rep | 3 | 0.67 | 1.20 | Rep | 3 | 0.89 | 0.30 |
| Block/Rep | 16 | 1.30 | 4.21 | Block/Rep | 16 | 0.60 | 0.50 |
| Provenance | 5 | 7.72*** | 30.43*** | Provenance | 5 | 3.36*** | 1.90*** |
| Error (residual) | 479 | 0.36 | 0.44 | Error (residual) | 479 | 0.46 | 0.30 |
| Total | 503 | 0.46 | 0.86 | Total | 503 | 0.58 | 0.40 |

*****,** represents data that is significant at $p \leq 0.001$ (99.99%), and D.F.= Degrees of freedom.

Generally, the level of infection was greater at 12mo than at 30mo at all four sites (Table 2.5). The level of infection dropped markedly between the 12 and 30mo measurements for Narrow Neck Ridge (NNR), but less so for all other provenances as well as for the internal controls.

When the susceptibility of the different provenances to *M. nobilosa* was compared, it was found that NNR provenance displayed significantly less ($p \leq 0.05$) infection than all other provenances and internal controls, at all sites, at both 12 and 30mo (Table 2.5). Contrary to expectations, the level of infection at the cooler, higher altitude site at Windy Gap was similar to that of the other three warmer, lower altitude sites at 12mo, where it was expected that *M. nobilosa* infection would have been lower for all provenances (Roux 2000[1]). However, at 30mo, the *M. nobilosa* infection at Windy Gap was significantly less than at the other three sites, as would be expected in the case of high altitude, cold sites (Table 2.6).

**Table 2.5 Mean scores of *Mycosphaerella nobilosa* infection of *E. bicostata* provenances at 12 and 30 months**

| Species (Provenance) | *Mycosphaerella nobilosa* infection score[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Windy Gap | | Enon | | Petrusvlei | | Speenkoppies | |
| | 12 (mo) | 30 (mo) | 12 (mo) | 30 (mo) | 12 (mo) | 30 (mo) | 12 (mo) | 30 (mo) |
| *E. bicostata* (Nullo W) | 2.20 a [2] | 0.96 c | 2.1 cd | 1.90 a | 2.20 b | 1.82 ab | 1.80 b | 1.27 c |
| *E. bicostata* (Nullo N) | 2.30 a | 1.12 bc | 2.2 bc | 1.90 a | 2.90 a | 1.96 a | 1.90 b | 1.12 c |
| *E. bicostata* (NNR) | 2.10 b | 0.78 c | 1.8 a | 0.70 d | 2.20 b | 0.54 d | 1.40 c | 0.61 d |
| *E. maidenii* | 2.70 a | 0.90 c | 2.0 d | 1.20 bc | 2.40 b | 1.53 c | 1.40 c | 0.98 cd |
| *E. globulus* (CB) | 2.20 a | 1.91 a | 2.1 cd | 1.40 b | 2.90 a | 1.45 c | 2.30 a | 2.00 a |
| *E. globulus* (KI) | 2.30 a | 1.36 b | 2.3 b | 1.00 c | 2.90 a | 1.65 bc | 2.50 a | 1.42 b |
| **Trial mean** | 2.30 | 0.94 | 2.1 | 1.34 | 2.80 | 1.49 | 1.90 | 1.23 |
| **SED** | 0.26 | 0.20 | 0.10 | 0.14 | 0.14 | 0.15 | 0.16 | 0.19 |
| **LSD ($p \leq 0.05$)** | 0.52 | 0.40 | 0.20 | 0.28 | 0.28 | 0.30 | 0.32 | 0.38 |
| **CV %** | 15.00 | 8.00 | 2.10 | 14.50 | 6.90 | 14.00 | 19.00 | 21.80 |

Nullo W = Nullo West provenance; Nullo N = Nullo North provenance; NNR = Narrow Neck Ridge provenance; CB = Coles Bay provenance; KI = Kings Island provenance.

[1] 0 for no infection, 1 for ≤50% of the leaves infected, 2 for infection >50% but ≤90%, and 3 for infection >90%.

[2] Scores which are significantly different from each other bear different letters of the alphabet.

[1] Professor Jolanda Roux. Associate Professor, Forestry and Agricultural Biotechnology Institute Pretoria.

**Table 2.6 Mean scores of *Mycosphaerella nobilosa* infection of *E. bicostata* for the combined site analysis at 12 and 30 months**

| Sites | 12 (mo) | Sites | 30(mo) |
|---|---|---|---|
| Petrusvlei | 2.712 a | Speenkoppies | 1.436 a |
| Windy Gap | 2.367 a | Enon | 1.410 a |
| Enon | 2.355 a | Petrusvlei | 1.410 a |
| Speenkoppies | 2.351 a | Windy Gap | 0.850 b |
| **Trial mean** | 2.446 | | 1.524 |
| **SED** | 0.169 | | 0.060 |
| **LSD (p≤0.05)** | 0.372 | | 0.012 |
| **CV %** | 8.120 | | 12.60 |

### 2.3.2 Assessment of growth properties

The growth traits, dbh and height, were measured and then used to calculate the mean plot volume and basal area per hectare, to obtain an understanding of the growth performances of the different provenances and families within the provenances at the four different sites. There were significant provenance differences ($p \leq 0.001$) among the growth traits measured for all four provenance/progeny trials (Table 2.7).

**Table 2.7 Mean square values of various growth traits of provenances included in *E. bicostata* trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| **Windy Gap** | | | | | | | |
| Rep | 3 | 26.25 | 34.24 | Rep | 3 | 53.81 | 8637 |
| Block/Rep | 20 | 166.81 | 163.33 | Block/Rep | 20 | 419.70 | 51629 |
| Provenance | 5 | 1412.95*** | 1269.34*** | Provenance | 5 | 3818.95*** | 493067*** |
| Error (residual) | 480 | 24.75 | 21.18 | Error (residual) | 75 | 77.65 | 8591 |
| Total | 508 | 44.02 | 39.21 | Total | 103 | 324.99 | 41098 |
| **Enon** | | | | | | | |
| Rep | 3 | 2.33 | 2.81 | Rep | 3 | 17.64 | 3327 |
| Block/Rep | 16 | 98.04 | 170.08 | Block/Rep | 16 | 226.68 | 35485 |
| Provenance | 5 | 1386.34*** | 1859.76*** | Provenance | 5 | 2672.33*** | 440739*** |
| Error (residual) | 443 | 21.25 | 23.62 | Error (residual) | 59 | 84.56 | 11815 |
| Total | 467 | 38.38 | 48.22 | Total | 83 | 265.43 | 41910 |
| **Petrusvlei** | | | | | | | |
| Rep | 3 | 17.60 | 34.45 | Rep | 3 | 23.07 | 2783 |
| Block/Rep | 16 | 64.18 | 97.08 | Block/Rep | 16 | 95.15 | 7500 |
| Provenance | 5 | 1028.80*** | 1017.92*** | Provenance | 5 | 1703.94*** | 113955*** |
| Error (residual) | 427 | 18.11 | 15.83 | Error (residual) | 59 | 28.89 | 1904 |
| Total | 451 | 30.95 | 29.95 | Total | 83 | 142.36 | 11114 |
| **Speenkoppies** | | | | | | | |
| Rep | 3 | 42.96 | 23.66 | Rep | 3 | 24.85 | 2555 |
| Block/Rep | 16 | 41.84 | 22.17 | Block/Rep | 16 | 157.82 | 9590 |
| Provenance | 5 | 193.80*** | 135.09*** | Provenance | 5 | 2702.79*** | 147895*** |
| Error (residual) | 464 | 16.76 | 10.97 | Error (residual) | 59 | 48.95 | 3310 |
| Total | 503 | 35.03 | 21.95 | Total | 83 | 228.94 | 13203 |

*****,** represents data that is significant at $p \leq 0.001$ (99.99%) and D.F.= Degrees of freedom.

Provenance means at the different sites were compared for volume and basal area (Table 2.8). Of the two more productive sites, Enon and Windy Gap, with a higher mean annual rainfall, Enon displayed the greatest values for volume and for basal area, followed by Windy Gap. Petrusvlei and Speenkoppies were less productive sites. The *E. bicostata* NNR provenance performed significantly better ($p \leq 0.05$ than both of the *E. bicostata* Nullo Mountain State Forest provenances (Nullo N and Nullo W), at all sites. Although the internal control, *E. maidenii*, outperformed both Nullo Mountain State Forests provenances at all sites, the performance of *E. maidenii* for basal area was significantly poorer than *E. bicostata* NNR at two sites ($p \leq 0.05$), and significantly poorer than NNR for volume at three sites ($p \leq 0.05$).

**Table 2.8 Mean provenance performance for volume and basal area across sites, ranked by volume**

| Species (Provenance) | No. seed lots | Trial sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Windy Gap (96mo) | | Enon (84mo) | | Petrusvlei (80mo) | | Speenkoppies (91mo) | |
| | | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
| *E. bicostata* (NNR) | 8 | 464.60 a[1] | 45.77 a | 461.80 a | 38.87 a | 245.40 a | 31.09 a | 230.00 a | 34.09 a |
| *E. maidenii* | 1 | 186.60 b | 21.32 b | 382.00 a | 33.60 a | 131.40 b | 19.43 b | 189.93 b | 28.27 a |
| *E. bicostata* (Nullo N) | 10 | 95.10 c | 13.60 cd | 159.70 b | 10.00 bc | 43.00 c | 8.84 c | 23.29 c | 6.33 b |
| *E. bicostata* (Nullo W) | 5 | 69.90 c | 11.19 d | 102.80 b | 8.86 d | 31.20 c | 7.05 c | 22.71 c | 6.20 b |
| *E. globulus* (CB) | 1 | 41.00 c | 8.04 d | 60.80 c | 18.93 b | 87.40 c | 12.35 c | 13.12 c | 2.32 b |
| *E. globulus* (KI) | 1 | 32.25 c | 5.37 d | 45.30 c | 13.13 bc | 50.80 c | 7.98 c | 11.34 c | 4.05 b |
| **Trial mean** | | 148.30 | 17.55 | 202.10 | 20.56 | 104.10 | 14.45 | 81.73 | 13.55 |
| **SED** | | 47.16 | 4.40 | 42.33 | 4.69 | 30.58 | 2.750 | 29.74 | 3.64 |
| **LSD** ($p \leq 0.05$) | | 89.13 | 8.87 | 85.29 | 9.45 | 59.42 | 5.54 | 59.93 | 7.33 |
| **CV %** | | 44.90 | 35.40 | 29.60 | 32.20 | 41.50 | 26.90 | 51.40 | 37.90 |

[1] Treatments which are significantly different from each other bear different letters of the alphabet.

The family means for volume and basal area at the different sites were also compared, as were the external commercial controls. Family differences for all growth traits were significant ($p \leq 0.001$) at all four sites, as shown in Table 2.9.

**Table 2.9 Mean square values of *E. bicostata* family growth traits in the four provenance/progeny trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| **Windy Gap** | | | | | | | |
| Rep | 3 | 26.25 | 34.24 | Rep | 3 | 24.85 | 8337 |
| Block/Rep | 20 | 166.81 | 163.33 | Block/Rep | 20 | 157.82 | 52469 |
| Family | 26 | 326.67*** | 310.66*** | Family | 26 | 711.03*** | 106820*** |
| Error (residual) | 457 | 22.77 | 18.40 | Error (residual) | 53 | 49.58 | 6209 |
| Total | 506 | 44.02 | 39.21 | Total | 102 | 228.94 | 409988 |
| **Enon** | | | | | | | |
| Rep | 3 | 2.33 | 2.81 | Rep | 3 | 17.64 | 3327 |
| Block/Rep | 16 | 98.04 | 170.08 | Block/Rep | 16 | 226.68 | 35485 |
| Family | 20 | 375.80*** | 501.30*** | Family | 20 | 831.36*** | 133383*** |
| Error (residual) | 427 | 20.63 | 22.04 | Error (residual) | 44 | 39.16 | 5298 |
| Total | 466 | 38.38 | 48.22 | Total | 83 | 265.43 | 41910 |
| **Petrusvlei** | | | | | | | |
| Rep | 3 | 17.60 | 34.45 | Rep | 3 | 23.07 | 2783 |
| Block/Rep | 16 | 64.18 | 97.08 | Block/Rep | 16 | 95.15 | 7500 |
| Family | 20 | 280.55*** | 283.06*** | Family | 20 | 458.79*** | 36110*** |
| Error (residual) | 412 | 17.64 | 15.02 | Error (residual) | 44 | 23.82 | 1635 |
| Total | 451 | 30.95 | 29.95 | Total | 83 | 142.36 | 11114 |
| **Speenkoppies** | | | | | | | |
| Rep | 3 | 10.79 | 12.58 | Rep | 3 | 24.85 | 2555 |
| Block/Rep | 16 | 74.88 | 62.63 | Block/Rep | 16 | 157.82 | 9590 |
| Family | 20 | 347.22*** | 231.50*** | Family | 20 | 711.03*** | 39507*** |
| Error (residual) | 368 | 16.99 | 9.48 | Error (residual) | 44 | 49.58 | 3287 |
| Total | 407 | 35.45 | 22.50 | Total | 83 | 228.94 | 13203 |

*****,** represents data that is significant at $p \leq 0.001$ (99.99%) and D.F.= Degrees of freedom.

Table 2.10 presents the top 10 ranking families at each site. The Enon, Petrusvlei and Speenkoppies sites had most of the top ten performing families in common, whereas Windy Gap differed somewhat in family ranking for basal area. Family 16 appeared in the top four *E. bicostata* families at all four sites, while Families 17 and 18 appeared in the top five performing *E. bicostata* families across all sites. Of the top 10 performing families across all sites for volume and basal area, seven of the *E. bicostata* families were from NNR provenance. It was also established (Table 2.10) that the top NNR families appeared to perform relatively better than, or similarly to, the best commercial controls in the external blocks, although these could not be compared statistically. The best performance was at Windy Gap, where the top NNR family outperformed the best performing commercial control, *E. smithii*, by 35% for wood volume growth.

With regards to growth at the different sites, volume and basal area at 96mo was better at Windy Gap than at Speenkoppies. The 80mo measurements at Petrusvlei and Enon showed that growth at Enon was superior to that at Petrusvlei.

The internal control, *E. maidenii*, appeared in the top 11 performing treatments at all of the sites, the highest ranking being 6th for volume and basal area at Enon. Neither of the *E. globulus* controls appeared in the top 10 ranking treatments, with the exception of Coles Bay (CB) at Enon which appeared 9th in the ranking. When the performances of all families across all sites were assessed simultaneously, the NNR families still appeared as the top ranking families.

**Table 2.10 Performance of the top 13 and 5 worst performing families and internal controls of *E. bicostata* for basal area and volume at four sites, ranked for volume. (Although not statistically comparable, the external controls are included for relative comparisons).**

| Trial sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | Enon (84mo) | | | Petrusvlei (80mo) | | | Speenkoppies (91mo) | | |
| Family | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
| 18 | 595.1 a [1] | 57.75 | 22 | 551.9 a | 47.72 | 17 | 278.0 a | 34.90 | 18 | 287.1 a | 39.60 |
| 16 | 532.5 ab | 52.66 | 18 | 534.8 ab | 46.97 | 23 | 265.8 ab | 33.10 | 22 | 266.7 ab | 39.18 |
| 19 | 525.8 ab | 50.26 | 16 | 513.2 abc | 45.93 | 16 | 256.9 abc | 31.95 | 16 | 248.1 abc | 34.95 |
| 17 | 493.1 bc | 47.05 | 17 | 507.2 abcd | 46.27 | 18 | 253.0 abcd | 31.40 | 23 | 238.1 abcd | 35.13 |
| 22 | 462.0 bc | 44.47 | 21 | 477.9 abcd | 40.24 | 22 | 248.0 abcde | 32.13 | 17 | 215.6 bcde | 32.73 |
| 20 | 402.9 cd | 40.85 | *E. maid.* | 384.3 e | 34.18 | 21 | 231.8 abcdef | 27.45 | 21 | 190.7 cdef | 27.30 |
| 21 | 355.1 d | 36.59 | 20 | 300.9 ef | 31.56 | 20 | 193.1 f | 26.68 | *E. maid.* | 187.4 cdefg | 28.27 |
| 23 | 345.8 d | 35.94 | 23 | 245.1fg | 17.11 | *E. maid.* | 139.8 g | 19.43 | 20 | 184.4 cdefg | 29.72 |
| *E. maid.* | 226.7 e | 23.48 | *E. glob.* (CB) | 172.5 gh | 19.66 | *E. glob.* (CB) | 89.4 gh | 12.35 | 3 | 35.8 h | 10.45 |
| 3 | 179.3 f | 16.38 | 3 | 115.9 h | 15.62 | 3 | 87.4 hi | 12.35 | 11 | 31.6 h | 7.80 |
| 11 | 116.9 f | 21.73 | 11 | 97.8 hi | 13.58 | *E. glob.* (KI) | 52.5 hij | 7.98 | 12 | 25.6 h | 6.87 |
| 9 | 43.8 fg | 8.48 | *E. glob.* (KI) | 87.9 hij | 12.98 | 10 | 49.2 hij | 10.05 | 5 | 21.8 h | 6.12 |

| Trial sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | Enon (84mo) | | | Petrusvlei (80mo) | | | Speenkoppies (91mo) | | |
| **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| 5 | 43.7 fg | 9.38 | 5 | 86.4 hij | 11.17 | 5 | 46.9 hij | 9.65 | 2 | 19.5 h | 5.32 |
| Five worst performing families: | | | | | | | | | | | |
| *E. glob.* (CB) | 39.3 fg | 7.78 | 1 | 23.9 ij | 7.72 | 2 | 31.20 j | 6.47 | *E. glob.* (KI) | 14.2 h | 4.05 |
| *E. glob.* (KI) | 35.5 fg | 6.23 | 2 | 21.6 ij | 6.35 | 8 | 21.40 j | 6.73 | 14 | 10.7 h | 4.18 |
| 15 | 25.2 fg | 5.49 | 13 | 17.4 ij | 5.87 | 11 | 18.30 j | 5.28 | 13 | 10.6 h | 4.77 |
| 13 | 16.8 fg | 5.20 | 8 | 13.7ij | 4.72 | 1 | 17.50 j | 4.95 | *E. glob.* (CB) | 7.6 h | 2.32 |
| 1 | 13.3 g | 4.4 | 14 | 3.7 j | 4.86 | 13 | 1.6 j | 3.25 | 1 | 5.6 h | 3.05 |
| **Trial Mean** | 193.8 | 22.42 | | 204.5 | 21.06 | | 113.9 | 16.37 | | 98.8 | 16.29 |
| **SED** | 59.66 | 5.37 | | 52.33 | 4.68 | | 29.50 | 3.44 | | 41.40 | 4.96 |
| **LSD** ($p \leq 0.05$) | 101.90 | 9.17 | | 90.27 | 8.07 | | 50.89 | 5.93 | | 71.42 | 8.56 |
| **CV %** | 40.50 | 33.80 | | 36.10 | 31.40 | | 36.60 | 27.10 | | 52.2 | 43.00 |

| Trial sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | Enon (84mo) | | | Petrusvlei (80mo) | | | Speenkoppies (91mo) | | |
| **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| *E. smithii* | 389.9 a | 35.85 | *E. grandis* | 623.6 a | 48.60 | *E. grandis* | 274.0 a | 33.28 | *E. dunnii* | 241.1 a | 32.12 |
| *E. NXB* | 362.1 a | 34.75 | *E. smithii* | 506.4 ab | 39.21 | *E. dunnii* | 198.7 b | 24.80 | *E. grandis* | 151.8 b | 22.63 |
| *E. dorrigo* | 306.4 ab | 31.16 | *E. dunnii* | 445.8 abc | 35.82 | *E. smithii* | 182.0 b | 24.73 | *E. mac.* | 149.0 b | 25.23 |
| *E. nitens* | 226.6 abc | 30.45 | *E. mac* | 340.2 bcd | 30.20 | *E. mac.* | 169.9 bc | 25.87 | *GXN* | 131.7 b | 20.47 |
| *E. mac.* | 139.3 bc | 20.25 | *GXN 075* | 281.2 cd | 25.10 | *GXN 075* | 154.8 bcd | 20.68 | *E. smithii* | 130.9 b | 19.45 |
| *E. cyp.* | 65.9 bc | 12.42 | *GXN 069* | 276.4 cd | 25.75 | *GXN 069* | 137.7 bcd | 18.45 | *E. birturb.* | 115.1 bc | 22.05 |
| | | | *E. nitens* | 272.8 cd | 27.97 | *E. nitens* | 114.1 cd | 20.50 | *E. nitens* | 54.0 c | 4.67 |
| | | | *E. birturb.* | 195.4 d | 21.57 | *E. birturb.* | 105.9 d | 16.63 | | | |
| Trial Mean | 248.4 | 27.48 | | 367.7 | 31.78 | | 167.1 | 23.12 | | 139.1 | 20.94 |
| **SED** | 87.75 | 10.28 | | 113.90 | 7.86 | | 35.30 | 3.29 | | 38.67 | 5.12 |
| **LSD** ($p \leq 0.05$) | 176.82 | 20.71 | | 215.84 | 14.89 | | 66.89 | 6.23 | | 75.14 | 9.95 |
| **CV %** | 49.9 | 52.9 | | 43.80 | 17.4 | | 29.8 | 20.1 | | 39.3 | 34.5 |

*E. NXB = E. nitens x E. badjensis*

The overall Type B correlations for basal area (Table 2.11) varied between 0.84 and 0.98 with an average of 0.94, and the overall Type B correlations for volume varied between 0.76 and 1.01 with an average of 0.84. An $r_{Bg}$ of 1.00 would indicate a perfect correlation between the behavior of genotypes on both sites (i.e., their relative ranking remains the same) and would suggest the complete absence of GEI. The high Type B correlations estimated for all sites for both traits indicated no GEI for the *E. bicostata* genotypes tested over these four sites, which supports the findings of the individual analyses.

**Table 2.11 Type B correlation estimates ($r_{Bg}$) for all site pairs for all growth traits**

| $r_{Bg}$ | Windy Gap | Enon | Petrusvlei | Speenkoppies |
|---|---|---|---|---|
| Windy Gap | | 0.95 (0.88) | 0.98 (0.92) | 0.84 (0.93) |
| Enon | 0.86 (0.96) | | 0.90 (0.97) | 0.96 (1.00) |
| Petrusvlei | 0.81 (0.97) | 0.76 (1.00) | | 0.98 (0.98) |
| Speenkoppies | 0.88 (0.96) | 0.82 (1.00) | 1.01 (1.00) | |

* Above the diagonal – basal area and height in brackets
* Below the diagonal – volume and dbh in brackets

The lack of GEI indicted by the high $r_{Bg}$'s allowed for all four sites to be analysed as one data set, and results of the across-site analysis are presented in Table 2.12. There were no significant differences for site, nor for site x family interaction for all the growth traits except for height for the site x family interaction. This supports the lack of GEI and indicates that top performing families can be selected from those in Table 2.13.

**Table 2.12 Mean square values of various growth traits of across-site analysis of *E. bicostata* trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| Site | 3 | 556.67 | 2018.27 | Site | 3 | 458.93 | 265004 |
| Site/Rep | 12 | 14.24 | 21.02 | Site/Rep | 12 | 22.60 | 4251 |
| Family | 26 | 1266.79 | 1280.05 | Family | 26 | 2871.58 | 282614 |
| Site x Family | 60 | 24.05 | 41.21*** | Site x Family | 60 | 60.81$^{NS}$ | 7654 $^{NS}$ |
| Error (residual) | 1735 | 19.66 | 16.73 | Error (residual) | 253 | 43.74 | 4820 |
| Total | 1833 | 38.31 | 38.75 | Total | 354 | 218.59 | 29584 |

*** represents data that is significant at $p \leq 0.001$ (99.99%), and D.F.= Degrees of freedom.

**Table 2.13 Ranking of the top 13 and 5 worst performing families, with internal controls, in the across-site analysis of *E. bicostata* families for volume and basal area, ranked by volume**

| Ranking | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
|---|---|---|---|---|
| 1 | 19 | NNR, Walsha | 473.90 a | 42.74 |
| 2 | 18 | NNR, Walsha | 414.40 ab | 38.97 |
| 3 | 16 | NNR, Walsha | 382.50 bc | 36.32 |
| 4 | 22 | NNR, Walsha | 379.10 bcd | 39.40 |
| 5 | 17 | NNR, Walsha | 367.70 bcde | 36.39 |
| 6 | 21 | NNR, Walsha | 305.50 ef | 30.06 |
| 7 | 20 | NNR, Walsha | 270.40 fg | 29.59 |
| 8 | 23 | NNR, Walsha | 261.70 fg | 30.00 |
| *9* | *E. maidenii* | Bolaro Mountain | 233.10 gh | 27.27 |
| 10 | 3 | Nullo West | 104.40 i | 12.96 |
| 11 | *E. globulus* | Coles Bay | 74.40 i | 9.21 |
| 12 | 12 | Nullo North | 62.70 i | 8.88 |
| 13 | *E. globulus* | Kings Island | 50.50 i | 7.36 |
| 22 | 6 | Nullo North | 30.80 j | 5.68 |
| 23 | 15 | Nullo North | 27.30 j | 5.68 |
| 24 | 1 | Nullo West | 19.60 j | 4.87 |
| 25 | 13 | Nullo North | 15.70 j | 5.04 |
| 26 | 9 | Nullo North | 11.10 j | 4.00 |
| **Trial mean** | | | 146.20 | 17.48 |
| **SED** | | | 37.85 | 2.39 |
| **LSD** ($p \leq 0.05$) | | | 64.31 | 4.06 |
| **CV %** | | | 20.5 | 12.5 |

### 2.3.3 Correlation between *Mycosphaerella nobilosa* infection and growth

The correlation between *M. nobilosa* infection and growth was calculated to determine the relationship between these two variables (Table 2.14). Infection by *M. nobilosa* and dbh displayed a stronger negative phenotypic correlation at 30mo than at 12mo at all sites; ranging from -0.313 to -0.708 at 30mo and from -0.109 to -0.582 at 12mo (Figure 2.3a). A similar trend was identified for height; with values ranging from -0.176 to -0.717 at 30mo and -0.031 to -0.554 at 12mo (Figure 2.3b). Correlations for both dbh and height were significant, with the exception of the *M. nobilosa* infection at 12mo with both dbh and height at Windy Gap. This demonstrated that infection at later stages of tree growth, for example between 12 and 30mo, combined with infection before, or at, 12mo, was more detrimental to growth of trees at 30 to 84 and 96mo, than infection up to 12mo of age.

**Table 2.14 Correlation between *Mycosphaerella nobilosa* infection and growth characteristics, dbh and height**

| ***Mycosphaerella nobilosa* infection** | **Windy Gap** | | **Enon** | | **Petrusvlei** | | **Speenkoppies** | |
|---|---|---|---|---|---|---|---|---|
| | **30mo dbh** | **96mo dbh** | **30mo dbh** | **84mo dbh** | **30mo dbh** | **80mo dbh** | **30mo dbh** | **91mo dbh** |
| 12mo | -0.109 | -0.161** | -0.185 ** | -0.184 ** | -0.499** | -0.445 ** | -0.582** | -0.538** |
| 30mo | -0.313 ** | -0.515** | -0.535** | -0.541 ** | -0.654 ** | -0.652** | -0.708** | -0.686 ** |
| | **30mo ht** | **96mo ht** | **30mo ht** | **84mo ht** | **30mo ht** | **80mo ht** | **30mo ht** | **91mo ht** |
| 12mo | -0.031 | -0.171** | -0.165** | -0.196 ** | -0.477** | -0.427 ** | -0.554** | -0.505** |
| 30mo | -0.176 ** | -0.530** | -0.565 ** | -0.605** | -0.597** | -0.653** | -0.717** | -0.651** |

** Correlations are statistically significant ($p \leq 0.01$)

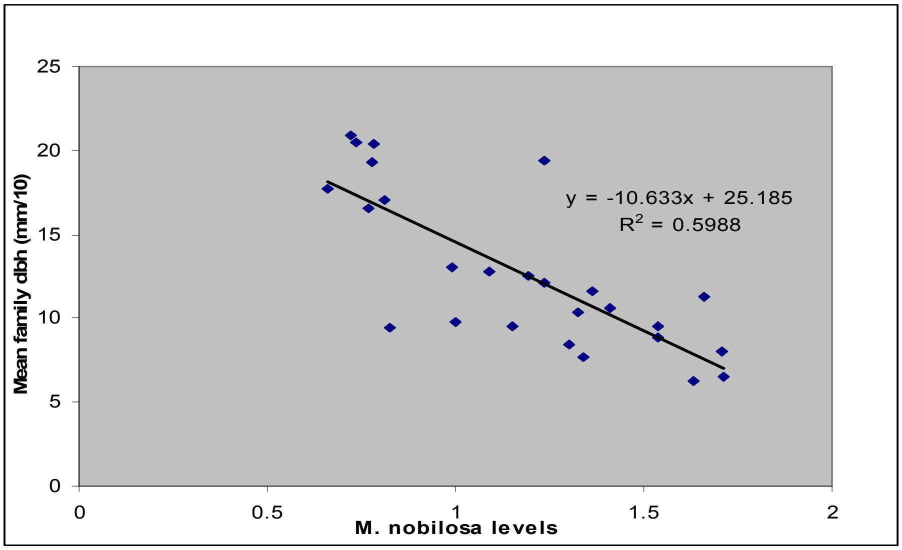



**Figure 2.3a Mean dbh plotted against *M. nobilosa* levels at 30 months, across all sites**

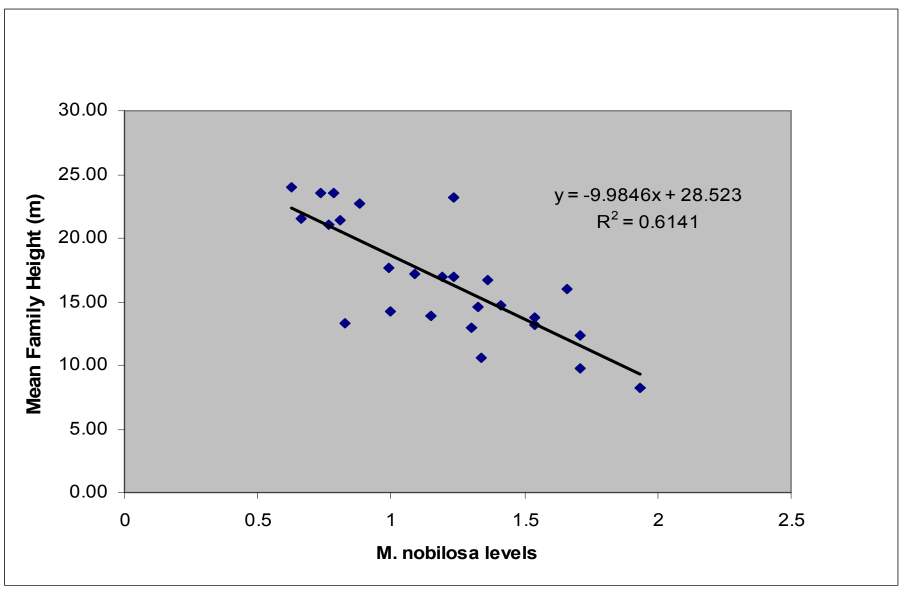



**Figure 2.3b Mean family height plotted against *M. nobilosa* levels at 30 months, across all sites**

## 2.4 DISCUSSION AND CONCLUSION

Provenance differences have been found in many cold tolerant eucalypt species tested under South African growing conditions (Gardner 2001; Swain *et al.* 1998a; Swain *et al.*

2000). Gardner (2001) noted the importance of site-species matching, as well as site-provenance matching (Swain and Gardner 2002; Swain and Gardner 2003). In this study of the growth potential of *E. bicostata,* marked differences in provenance growth performances were recorded over the four sites on which the trials were established.

Narrow Neck Ridge (NNR) provenance emerged from this investigation as the most suitable of the three *E. bicostata* provenances for planting on mid-altitude sites in the summer rainfall region of South Africa for the traits assessed. The provenance was appreciably more tolerant of the leaf spot disease, *M. nobilosa,* than the other provenances studied. This is possibly because, due to their better growth, these trees develop mature foliage earlier than the other provenances, and are thus able to escape the disease in the juvenile leaf phase by developing a healthy canopy of mature foliage to support normal tree growth earlier in their development than the other provenances.

A similar situation exists with *E. nitens*, where the provenances from the winter rainfall province of Victoria in Australia were very susceptible to *M. mulleriana* in ICFR provenance/progeny trials, and were subsequently outperformed by the more tolerant summer rainfall provenances from NSW. Similar to what was found with *E. nitens* (Lundquist and Purnell 1987; Hunter *et al.* 2004), infection also affects tree growth negatively in *E. bicostata*, as was evident by the high negative correlations found between dbh and height and disease infection in this trial series. Early age infection did not affect later growth as much as late infection. This may indicate that the trees are less able to recover from the disease when it occurs for several years during the early stages of tree growth after establishment. At Petrusvlei and Speenkoppies, however, the 12 month infection had almost as much influence on current and later growth than at Windy Gap and Enon. This may be due to the generally poorer growth at the former two sites, where negative impacts due to disease would be more significant than on trees with better growth.

Despite marked site differences, NNR provenance displayed a similar good growth trend at all four sites. Windy Gap site differed from the other sites in having a lower MAT and higher rainfall and despite this, the NNR provenance still outperformed the two other *E. bicostata* provenances at this site. The difference in performance between the top NNR families and the top external commercial controls at Windy Gap was also greater than at other sites. This confirmed the potential of *E. bicostata* families from the NNR provenance as possible viable alternatives to the commercial species currently grown on this site. At the low rainfall site of Speenkoppies, *E. bicostata,* known to prefer well-watered soils (Boland *et al.* 1985), still outperformed the improved commercial alternatives, despite displaying poorer growth when compared to the other three sites.

Since the top performing, unimproved *E. bicostata* material performed as well as, or better than, the improved commercial controls at three of the sites (excluding Enon), this suggests that, with selective improvement and breeding of certain provenances, *E. bicostata* could play an important role, either as a pure alternative hardwood species, or as a hybrid partner with species such as *E. nitens*, in the cool summer rainfall regions of South Africa. This will then have the advantage of deploying the *E. nitens* hybrid to lower altitude sites where it is too warm for pure *E. nitens* and drier than the optimum sites for the other pure species, and might be a good option for climate change. Should the pulping properties of *E. bicostata* prove to be superior to those of *E. macarthurii,* hybrid combinations of these two species may improve the popularity and profitability over pure *E. macarthurii*.

The good growth results and adaptability of the NNR provenance of *E. bicostata* emphasises the importance of provenance/progeny trials. Although other commercially important traits, such as pulping properties, still need investigation, it is probable that these will be acceptable, due to the close genetic relatedness of the species to *E. globulus* (Pryor and Johnson 1971) which is well known for its excellent kraft pulping properties (Eldridge *et al*. 1993; Tibbits *et al*. 1997; Potts 2004). These results therefore suggest that the NNR provenance of *E. bicostata* may be a suitable alternative hardwood species for cool summer rainfall regions of South Africa.

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# Chapter 3

# GROWTH POTENTIAL OF *EUCALYPTUS CYPELLOCARPA*


**ABSTRACT**

Due to the need for alternative eucalypt species on certain forestry sites in South Africa, a series of three provenance/progeny trials of *Eucalyptus cypellocarpa* was established by the ICFR (Institute for Commercial Forestry Research) during 1997 and 1999, in the cool and warm temperate climate zone of KwaZulu-Natal and Mpumalanga provinces in South Africa. Trees from Australian seed sources were assessed for growth performances relative to the improved commercial *Eucalyptus* species currently grown on the different sites.

Seed from New South Wales provenances (Australia) Hanging Rock, Nullo Mountain and Wingello State Forests and Kaputar Mountain National Park was established in provenance/progeny trials at Windy Gap, Petrusvlei and Speenkoppies in South Africa. Trials were planted at 1667 stems per hectare, single row plots of six trees, four replications in an unbalanced lattice design. Commercial seed of other eucalypt species and clones were used as external controls. Diameter at breast height (dbh) and height at 96 months at Windy Gap, and 72 months at both Petrusvlei and Speenkoppies was measured. Basal area and volumes were derived from these measurements.

There were distinct provenance differences for growth under the different site conditions with Hanging Rock provenance generally performing well across all sites. Genotype by environment interaction was present indicating that the genotypes performed differently at different sites. Thus, ideally, separate populations of *E. cypellocarpa* should be developed for the cold and warm sites in South Africa, respectively.

## 3.1 INTRODUCTION

South Africa is a country endowed with a variety of climatic zones, with the humid warmer temperate and sub-tropical regions comprising a significant component of this area (FAO 1979). *Eucalyptus grandis* has been the most extensively cultivated hardwood species in these regions because of this species' rapid growth and acceptable wood properties (Poynton 1979).

Eucalypts in South Africa have been used extensively for the production of sawtimber and pulp and paper (Swain and Jones 2004), with a resultant increase in tree improvement initiatives aimed at maximising production. New species and provenances are regularly being introduced in South Africa and evaluated for their potential use in the forestry industry on various land types (Gardner *et al*. 2000).

During the 1980s and 1990s, the major forestry companies in South Africa expanded their forestry land-base in the summer rainfall region considerably. Some of the new land acquisitions, particularly mid and high-altitude summer rainfall sites that are drier and warmer, or drier and colder, than traditional *E. grandis* forestry sites, are generally referred to as "low productivity" sites (Darrow 1983). At altitudes greater than 1350m (Swain 1996; Swain and Gardner 2003) and with a Mean Annual Temperatures (MAT) greater than $13^0$C but less than $16^0$C, *E. nitens* has been the commercially preferred species. However, areas with a MAT of less than $18^0$C and altitudes ranging from 1050m to 1300m are neither suitable for the planting of *E. grandis* nor *E. nitens* (Swain and Gardner 2003). Therefore, the search for alternative *Eucalyptus* species more suitable for these mid-altitude sites is an ongoing process.

*Eucalyptus cypellocarpa* has the potential to grow on mid-high altitude sites similar to where the recent Institute for Commercial Forestry Research (ICFR) *E. bicostata* trials were established in South Africa (Chapter 2). *Eucalyptus cypellocarpa* seed was collected from trees in the same regions in New South Wales (NSW) in Australia as where *E. bicostata* seed was obtained. In contrast to the well-watered collection sites of *E. bicostata*, however, *E. cypellocarpa* seed was obtained from dry slopes. It was therefore expected that *E. cypellocarpa* would show better adaptation to warmer and drier conditions in South Africa than those tolerated by *E. nitens* and *E. bicostata* (Swain and Gardner 2003).

An investigation was thus undertaken to test the performance of Australian summer rainfall provenances and families of *E. cypellocarpa* on mid-altitude sites in the summer rainfall regions in South Africa.

## 3.2 MATERIALS AND METHODS

### 3.2.1 Introduction

*Eucalyptus* species from provenances across their natural distribution within New South Wales (NSW), Australia, were sampled because of the climatic similarities with selected areas in South Africa that experience cold, dry winters and a summer rainfall maximum.

Eucalypt forests in Australia mainly occur in mixed stands, and this can complicate the selection process on the seed bearing trees. A stand was therefore chosen if it consisted predominantly of the desired species, and had good characteristics. Climatic information (precipitation, temperature, number of dry months), slope, position of tree (valley, slope, etc), altitude, latitude and longitude were also recorded. Numbers were allocated to identify individual trees (families) within the provenances during the seed collection (Gardner 2000). The collection was then established in a series of provenance and progeny trials at temperate, low productivity sites in the summer rainfall forestry growing region in South Africa.

This investigation involved the assessment of growth performances of summer rainfall provenances of *E. cypellocarpa* L. Johnson from NSW in Australia on high altitude, cold sites in the summer rainfall region of South Africa.

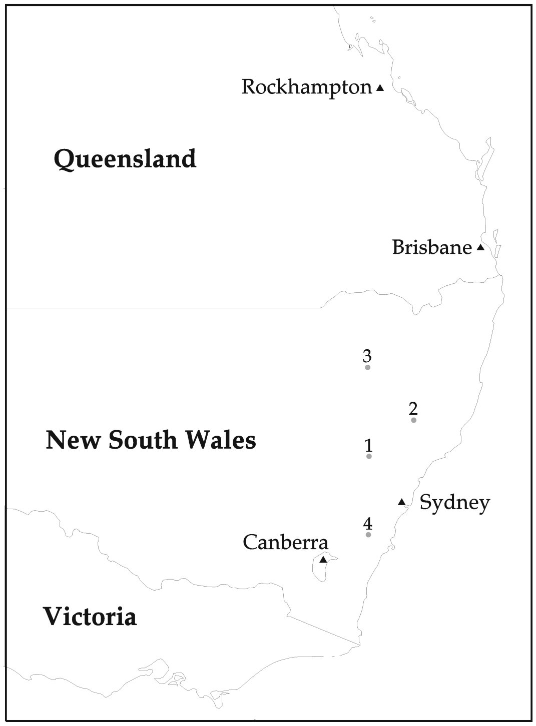
### 3.2.2 Seed collection

Seed was collected from 32 *E. cypellocarpa* families from three provenances and 10 families of *E. volcanica* from one provenance (Gardner *et al*. 2000) in Australia. Originally *E. cypellocarpa* and *E. volcanica* were classified as one species until a revision separated the two into distinct species (Johnson and Hill 1990; Gardiner and Schofield 1997; Gardner *et al*. 2000) and therefore, *E. volcanica* was included as an internal control. Thus, a total of 42 families of *E. cypellocarpa* and *E. volcanica* were established in trials, the origins of which are presented in Table 3.1. A map of the Australian provenances of *E. cypellocarpa* and *E. volcanica* included in this study is presented in Figure 3.1.

**Table 3.1 Origins of seedlots and controls included in the *E.cypellocarpa* provenance / progeny trials**

| Species | Seedlot/Clone No. | Number of families (numbering) | Provenance/Source | Average latitude (S) | Average longitude (E) | Average altitude (m) |
|---|---|---|---|---|---|---|
| ***E. cypellocarpa:*** | | | | | | |
| | 19803 | 10 (11-20) | Hanging Rock SF | $31^{o}50'$ | $151^{o}20'$ | 900 |
| | 19798 | 10 (1-10) | Nullo Mountain SF | $32^{o}80'$ | $150^{o}20'$ | 950 |
| | 19624 | 12 (31-42) | Wingello SF | $34^{o}70'$ | $150^{o}20'$ | 800 |
| ***E. volcanica*** | 19804 | 10 (21-30) | Kaputar Mountain NP | $30^{o}30'$ | $150^{o}10'$ | 1300 |
| **External controls:** | | | | | | |
| *E. bicostata* | - | Bulk | CSIRO, AUSTRALIA | - | - | - |
| *E. dunnii* | M8879 | Bulk | MondiBP, SA | - | - | - |
| *E. dorrigoensis* | - | Bulk | CSIRO, AUSTRALIA | - | - | - |
| *E. grandis* | M7849 | Bulk | MondiBP, SA | - | - | - |
| *E. grandis x nitens* | G x N 075 | Clone | CSIR, Pretoria, SA | - | - | - |
| *E. macarthurii* | ICFR 1/95 | Bulk | Jaglust, SA | - | - | - |
| *E. nitens* | 10061 | Bulk | SAPPI, SA | - | - | - |
| *E. smithii* | 10040 | Bulk | SAPPI, SA | - | - | - |

SA = South Africa; TAS = Tasmania; SF = State Forest NP = National Park.




| Provenances | Latitude (S) | Longitude (E) | Altitude (m) | No. of families |
|---|---|---|---|---|
| 1. Nullo Mtn SF | 32°45' | 150°12' | 900-1080 | 10 |
| 2. Hanging Rock SF, Nundle | 31°28' | 151°10' | 800-1200 | 10 |
| 3. Mt Kaputar NP | 30°17' | 150°09' | 960-1300 | 10 |
| 4. Wingello SF | 34°44' | 150°11' | 800 | 12 |

**Figure 3.1 Three *E. cypellocarpa* (1, 2 and 4) provenances and one *E. volcanica* (3) provenance collection site in New South Wales in Australia**

### 3.2.3 Trial establishment

Progeny/provenance trials were established to determine which Australian provenances are best suited to temperate, summer-rainfall conditions in South Africa, and to identify top families under these conditions. All trials were planted at a stocking rate of 1667 stems per hectare in single row plots of six trees, with four replications, laid out in balanced or unbalanced lattice designs. The external commercial control plots were laid out around the trials in three rows of eight trees each, measuring only the six trees in the inner row. This layout was implemented to prevent inter-species competition within the trial, but to still provide a comparative measure, although excluded from statistical analyses because the external controls were not included in the experimental design (blocking and replications) of the trial.

Three trials of *E. cypellocarpa* were established in South Africa over two planting seasons, site and trial design details of which can be found in Tables 3.2.and 3.3 respectively.

**Table 3.2 Trial sites established for *E. cypellocarpa* in South Africa**

| Site locality | Planting date | No. of families | Area (ha) | Latitude (S) | Longitude (E) | Altitude (m) | MAP (mm) | MAT (°C) | Soil depth (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | 05/12/97 | 42 | 1.95 | 29°38' | 29°34' | 1625 | 900 | 14,7 | 1000 |
| Petrusvlei, Seven Oaks, KZN | 24/11/99 | 38 | 1.50 | 29°12' | 30°23' | 1320 | 960 | 16,0 | >1000 |
| Speenkoppies, Moolman, MPU | 14/12/99 | 38 | 1.05 | 27°08' | 30°53' | 1220 | 898 | 16,8 | 1200 |

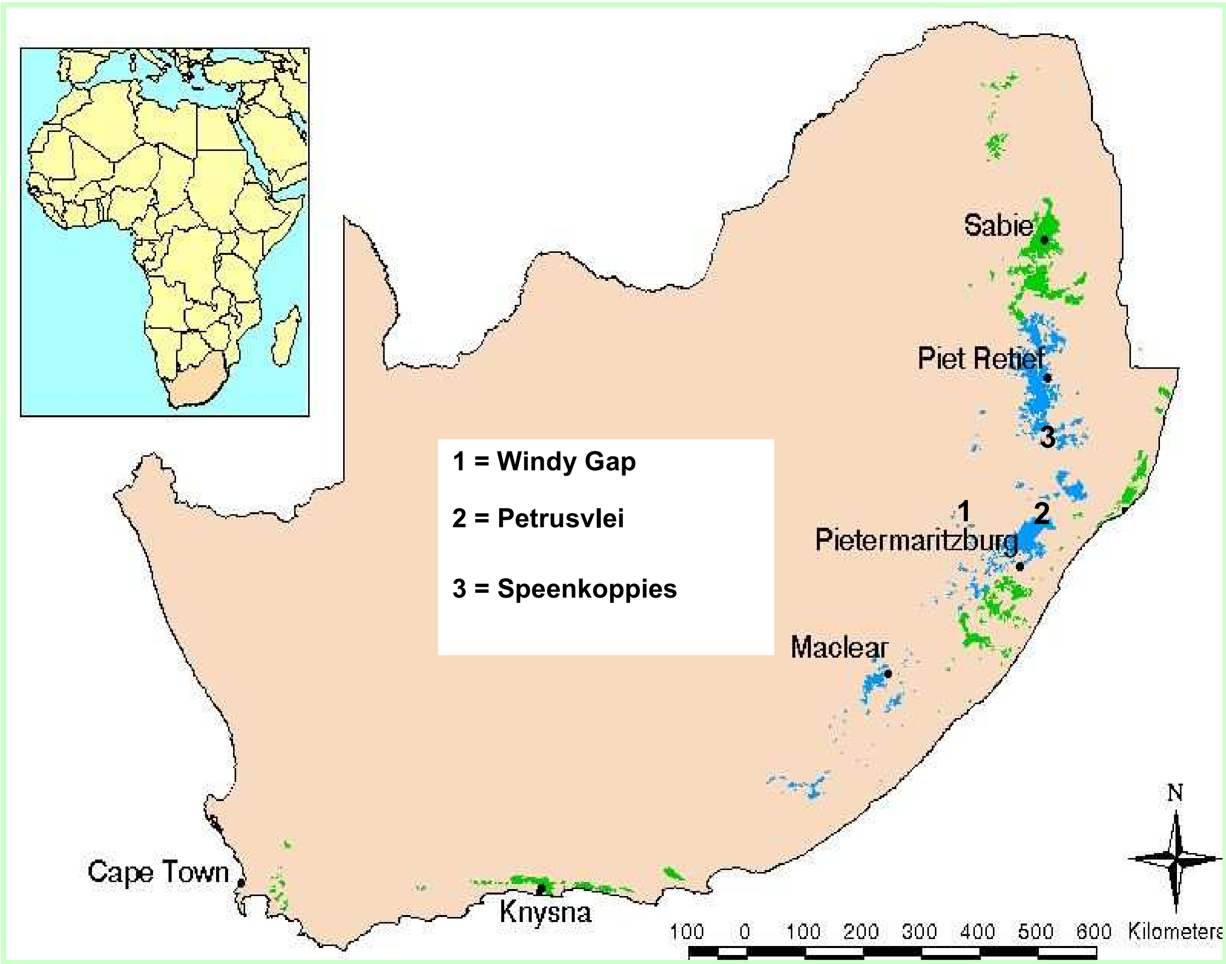
KZN = KwaZulu-Natal; MPU = Mpumalanga; MAP = Mean Annual Precipitation;
MAT = Mean Annual Temperature.

**Table 3.3 *E. cypellocarpa* trial type and designs for three sites established in South Africa**

| Locality | Trial Type | Company | Origin | Design | Reps |
|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | Provenance/Progeny Trial | SAPPI | Aus | 6x7 latt | 4 |
| Petrusvlei, Seven Oaks, KZN | Provenance/Progeny Trial | SAPPI | Aus | Unbal latt | 4 |
| Speenkoppies, Moolman, MPU | Provenance/Progeny Trial | MONDIBP | Aus | Unbal latt | 4 |

Unbal latt = unbalanced lattice design

A map of the South African trial sites for *E. cypellocarpa* is presented in Figure 3.2.




**Blue= cool temperate   Green= warm temperate and sub tropical**

**Figure 3.2 Three trial sites of *E. cypellocarpa* established in South Africa**

**Methods**

### 3.2.4 Growth assessments

Overbark diameter at breast height (1.3m above ground level) (dbh) and height measurements were recorded. These measurements were recorded at 72mo at both Petrusvlei and Speenkoppies, and at 96mo at Windy Gap. The dbh measurements were used to calculate the mean plot basal areas. Basal area was derived by summing the individual basal areas of trees within a plot and then converting basal area per plot ($m^2$ $plot^{-1}$) to basal area per hectare ($m^2$ $ha^{-1}$), using the following formula:

$$Baha^{-1} = dbh^2 \times \pi /144 \times 10000$$

Where:

$Baha^{-1}$ = Mean plot basal area per hectare;

$dbh^2$ = Diameter at breast height (1.3m) in mm/10;

$\pi$ = 3.142; and

$\pi$ /144 x 10000 = Conversion factor which takes into account conversion of diameter measured in mm to radius and basal area in $m^2ha^{-1}$ (Schönau 1982; Coetzee 1995).

Treatment means and basal areas were calculated in the same manner for the external controls.

Because no volume equation is available for *E. cypellocarpa*, the equation derived for *E. nitens* by Schönau (1982) was used to calculate volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50 mm tip diameter in $m^3$;

D = dbh in mm;

H = total height in m;

b0 = -2.17055;

b1 = 2.07516; and

b2 = 1.42792.

The same volume equation was also used for external control species of *E. nitens x badjensis, E. grandis x nitens, E. nobilis* and *E. bicostata* as no volume equations are currently available for these species.

For the improved commercial species of *E. macarthurii* and *E. grandis* used in the external controls, volume equations developed by Schönau (1982) was used respectively;

*E. macarthurii* timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -2.03756;

b1 = 2.21147; and

b2 = 1.12502.

*E. grandis* timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -1.98193;

b1 = 1.98044; and

b2 = 1.37188.

For improved commercial species of *E. smithii*, the equation developed by Coetzee (1995) was used to calculate timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -4.6923;

b1 = 1.8802; and
b2 = 1.2217.

Data were statistically analysed using the Restricted Maximum Likelihood Method (REML) (Patterson and Thompson 1971) of the statistical software package Genstat 5 Release 4.21 (Lane and Payne 1996), using the following model for the calculation of provenance and family means:

$$y = X_A + Z_B + H_f + W_p + e,$$

Where;

| | |
|---|---|
| $y$ | = trait or data vector |
| $X_A$ | = replication effects (random), |
| $Z_B$ | = block effects (random), |
| $H_f$ | = family/provenance effects (fixed), |
| $W_p$ | = plot effects (random), |
| $e$ | = random error effects. |

Mean squares were calculated to determine whether effects were significant using the same model. This was done using the ANOVA method in Genstat as referenced. Significant replication effects, on the rare occasion that they were found, were corrected for. Treatment means were compared using least significant differences (LSDs) at the 5% significance level. The external controls were analysed separately from the main trial data sets, and LSDs calculated for comparison of means.

Type B correlations were then estimated for *E. cypellocarpa,* to give a clearer indication of any potential genotype x environment interaction (GEI). Where two traits are measured on different individuals within genetic groups, for example a genetic correlation between trees of the same family grown in different environments, the correlation can be designated a Type B genetic correlation (Burdon 1977). Type B correlations at the family level ($r_{Bg}$) were estimated for all possible site pairs within a species, as follows:

$$r_{Bg} = \frac{\sigma^2_{fam}}{\sigma^2_{fam} + \sigma^2_{site*fam}}$$

The ratio of family variance over the family and environment × family variance is equivalent to a Type B correlation from a paired site analysis. A Type B genetic correlation ($r_{Bg}$) of 0.67 is the level at which the GEI variance represents 50% of the total additive variance, and is the point where it is postulated that the GEI variance may be a cause for some concern among tree breeders (Shelbourne 1972). Variances were calculated using the following model:

$$y = X_A + Z_B + H_f + W_p + T_S + Q_{sf} + e,$$

Where;

| | |
|---|---|
| $y$ | = trait or data vector |
| $X_A$ | = replication effects (fixed), |
| $Z_B$ | = block effects (fixed), |
| $H_f$ | = family effects (random), |
| $W_p$ | = plot effects (random), |
| $T_s$ | = site effect (fixed), |
| $Q_{sf}$ | = site by family interaction coefficient, |
| $e$ | = random error effects. |

## 3.3 RESULTS

The growth traits, dbh and height, were measured in the *E. cypellocarpa* trials and the mean plot volume and basal area per hectare calculated. The significant replication effects found at Speenkoppies for height were not corrected for. There were significant differences ($p \leq 0.001$) among provenances for the various growth traits measured in all three trials (Table 3.4).

**Table 3.4 Mean square values of various growth traits of provenances included in *E. cypellocarpa* trials**

| Source | D.F. | Mean squares Dbh | Mean squares Height | Source | D.F. | Mean squares Baha | Mean squares Volume |
|---|---|---|---|---|---|---|---|
| **Windy Gap** | | | | | | | |
| Rep | 3 | 19.32 | 25.83 | Rep | 3 | 81.46 | 319 |
| Block/Rep | 24 | 28.62 | 26.46 | Block/Rep | 24 | 71.06 | 7600 |
| Provenance | 3 | 506.58*** | 192.72*** | Provenance | 3 | 751.61*** | 35851*** |
| Error (residual) | 648 | 20.91 | 15.39 | Error (residual) | 123 | 82.81 | 5611 |
| Total | 678 | 23.33 | 1661 | Total | 153 | 94.05 | 6418 |
| **Petrusvlei** | | | | | | | |
| Rep | 3 | 7.30 | 78.55 | Rep | 3 | 42.54 | 1428 |
| Block/Rep | 28 | 88.02 | 133.04 | Block/Rep | 24 | 104.78 | 4729 |
| Provenance | 3 | 1414.21*** | 747.64*** | Provenance | 3 | 1935.65*** | 81538*** |
| Error (residual) | 1501 | 15.04 | 10.70 | Error (residual) | 137 | 34.98 | 1650 |
| Total | 1535 | 19.09 | 14.51 | Total | 167 | 79.29 | 3546 |
| **Speenkoppies** | | | | | | | |
| Rep | 3 | 93.04 | 271.46*** | Rep | 3 | 81.15 | 5164 |
| Block/Rep | 24 | 49.40 | 42.52 | Block/Rep | 24 | 39.42 | 1750 |
| Provenance | 3 | 641.20*** | 320.98*** | Provenance | 3 | 854.40*** | 24789*** |
| Error (residual) | 602 | 13.01 | 7.27 | Error (residual) | 121 | 35.97 | 1102 |
| Total | 632 | 17.81 | 11.35 | Total | 151 | 53.68 | 1770 |

*****,** represents data that is significant at $p \leq 0.001$ (99.99%) and D.F = Degrees of freedom.

Generally, for the growth traits assessed, the Windy Gap site showed the best growth followed by Petrusvlei and then Speenkoppies (Table 3.5). This is supported by significant mean square values for site for both volume and basal area in Table 3.7. It should be noted that performance at the Speenkoppies site was markedly poorer than at Petrusvlei and Windy Gap, and this could be attributed to fire damage at 18mo following the establishment of the trial (Gardner and Swain 2005), as well as this site being substantially warmer and drier than Petrusvlei. Site differences were apparent in that the trees at Petrusvlei, although 24mo younger, had higher volumes and basal areas than the Windy Gap trees.

The *E. cypellocarpa* provenance from Hanging Rock significantly ($p \leq 0.05$) outperformed the Nullo Mountain provenance for both volume and basal area at both Petrusvlei and Speenkoppies. In contrast, at the coldest high altitude site, the Nullo Mountain provenance was ranked first in volume growth and did not differ significantly from the

Hanging Rock and Wingello provenances. At Windy Gap, the Nullo Mountain provenance was the best performing provenance for both volume and basal area. This is supported by the significant site x provenance fixed effects in Table 3.7.

When the mean volume and basal area for the *E. cypellocarpa* provenances were compared to that of Kaputar Mountain provenance of the internal control species, *E. volcanica*, the *E. cypellocarpa* provenances significantly outperformed the *E. volcanica* provenance ($p \leq 0.05$) across all sites, with the exception of the *E. cypellocarpa* Nullo Mountain provenance at Petrusvlei.

**Table 3.5 Mean provenance performance for volume and basal area at three sites, ranked by volume**

| Trial sites (age) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | Petrusvlei (72mo) | | | Speenkoppies (72mo) | | |
| **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| Nullo Mtn | 150.81 a | 22.64 | Hanging Rock | 154.39 a | 25.75 | Hanging Rock | 70.40 a | 15.13 |
| Wingello | 149.24 a | 20.27 | Wingello | 134.79 a | 22.15 | Wingello | 64.73 ab | 12.79 |
| Hanging Rock | 136.93 a | 19.74 | Nullo Mtn | 81.00 b | 13.95 | Nullo Mtn | 49.00 b | 10.57 |
| Kaputar Mountain NP * | 66.53 b | 11.49 | Kaputar Mountain NP * | 42.35 b | 8.56 | Kaputar Mountain NP * | 13.59 c | 4.51 |
| **Trial Mean** | 125.87 | 18.53 | | 103.11 | 17.60 | | 49.43 | 10.75 |
| **SED** | 15.97 | 2.05 | | 8.82 | 1.30 | | 8.04 | 1.41 |
| **LSD (*p*≤0.05)** | 37.68 | 4.83 | | 20.76 | 3.06 | | 18.92 | 3.32 |
| **CV %** | 17.94 | 15.66 | | 12.10 | 10.45 | | 23.00 | 18.55 |

Mtn = Mountain; NP = National Park

* *E. volcanica* seedlots

At a family level, there were significant ($p\leq0.001$) differences among the growth traits measured in all the three trials, with the exception of volume growth ($p\leq0.05$) at both Windy Gap and Speenkoppies, as presented in Table 3.6. The significant replication effects found for both dbh and height at Windy Gap were corrected for.

**Table 3.6 Mean square values of various growth traits of *E. cypellocarpa* families for three provenance/progeny trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| **Windy Gap** | | | | | | | |
| Rep | 3 | 93.04*** | 271.46*** | Rep | 3 | 81.46 | 372 |
| Block/Rep | 24 | 49.40 | 42.52 | Block/Rep | 24 | 71.06 | 7440 |
| Family | 41 | 68.54*** | 37.86*** | Family | 41 | 182.86*** | 8354* |
| Error (residual) | 567 | 12.67 | 6.87 | Error (residual) | 85 | 58.16 | 5468 |
| Total | 632 | 17.81 | 11.35 | Total | 153 | 94.05 | 6451 |
| **Petrusvlei** | | | | | | | |
| Rep | 3 | 20.51 | 5.83 | Rep | 3 | 42.54 | 1428 |
| Block/Rep | 24 | 32.43 | 16.78 | Block/Rep | 24 | 104.78 | 4729 |
| Family | 41 | 85.33*** | 41.12*** | Family | 41 | 206.72*** | 9001*** |
| Error (residual) | 705 | 11.79 | 6.75 | Error (residual) | 99 | 21.46 | 1014 |
| Total | 773 | 16.37 | 8.88 | Total | 167 | 79.29 | 35.46 |
| **Speenkoppies** | | | | | | | |
| Rep | 3 | 93.04 | 271.46 | Rep | 3 | 81.15 | 372 |
| Block/Rep | 24 | 48.40 | 42.52 | Block/Rep | 24 | 39.42 | 7440 |
| Family | 37 | 70.44*** | 39.34*** | Family | 41 | 118.79*** | 8354* |
| Error (residual) | 568 | 12.67 | 6.87 | Error (residual) | 85 | 27.93 | 5468 |
| Total | 632 | 17.81 | 11.35 | Total | 153 | 53.68 | 6451 |

*****, *******, represents data that is significant at $p\leq0.05$ (95%) and, $p\leq0.001$ (99.99%), respectively. D.F.= Degrees of freedom.

Mean square values for the combined site analysis indicated significant ($p\leq0.001$) site, provenance, family, site x provenance and site x family interaction effects for basal area and volume (Table 3.7).

**Table 3.7 Mean square values for combined site analysis for *E. cypellocarpa* including provenances and families**

| Source | D.F. | Mean squares Baha | Source | D.F. | Mean squares Volume |
|---|---|---|---|---|---|
| Site | 2 | 3001.21*** | Site | 2 | 199847*** |
| Site/Rep | 9 | 68.39 | Site/Rep | 9 | 2304 |
| Provenance | 3 | 3230.00*** | Provenance | 3 | 123915*** |
| Site x Provenance | 6 | 399.17*** | Site x Provenance | 6 | 19847*** |
| Error (residual) | 453 | 50.85 | Error (residual) | 447 | 2933 |
| Total | 473 | 88.24 | Total | 467 | 4758 |
| Site | 2 | 30001.21*** | Site | 2 | 199847*** |
| Site/Rep | 9 | 68.39 | Site/Rep | 9 | 2304 |
| Family | 42 | 365.65*** | Family | 41 | 14612*** |
| Site x Family | 78 | 97.07*** | Site x Family | 78 | 4595*** |
| Error (residual) | 342 | 35.65 | Error (residual) | 337 | 2505 |
| Total | 473 | 88.24 | Total | 467 | 4758 |

*, ***, represents data that is significant at $p \leq 0.05$ (95%) and, $p \leq 0.001$ (99.99%), respectively. D.F.= Degrees of freedom.

When the means for volume and basal area of the *E. cypellocarpa* families across provenances were compared, it was found that there were significant family differences ($p \leq 0.05$) for both traits at all sites (Table 3.8). Only one *E. cypellocarpa* family (11) appeared in the top ten families ranked for volume at all three sites. However, six families appeared in the top 20 families ranked by volume at all three sites. At the two warmer sites, Petrusvlei and Speenkoopies, seven families were in common in the top ten, of which four were from Hanging Rock and three were from Wingello State Forest. Furthermore, seven families that ranked in the top 20 for volume at Windy Gap were not listed in the top 20 at both Petrusvlei and Speenkoppies.

When the performances of the improved commercial controls were compared to those of the unimproved *E. cypellocarpa* families, it was found that these differed according to site (Table 3.8). At Petrusvlei, the top families outperformed all commercial controls, but at both Windy Gap and Speenkoppies, the top commercial controls outperformed the *E. cypellocarpa* families.

Only two of the *E. volcanica* families (28 and 29) from Kaputar Mountain provenance appeared in the top 20 at Windy Gap, and none at Petrusvlei or Speenkoppies.

When the growth performances of the commercial species currently grown in these areas; ie *E. nitens* at Windy Gap and *E. dunnii* at Petrusvlei and Speenkoppies, were compared with the top *E. cypellocarpa* families, this showed that *E. nitens* at Windy Gap and *E. dunnii* at Speenkoppies outperformed the best *E. cypellocarpa* families. In contrast, at Petrusvlei, the *E. cypellocarpa* families outperformed the commercially planted *E. dunnii*.

**Table 3.8** **Performance of the top 20 and 5 worst performing treatments for volume and basal area in three *E. cypellocarpa* trials, ranked for volume. (Although not statistically comparable, the external controls are included for relative comparisons).**[1] = *E. volcanica* Seedlot

| Trial sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | | Petrusvlei (72mo) | | | | Speenkoppies (72mo) | | | |
| Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
| 10 | Nullo Mountain SF | 214.19a | 27.28 | 19 | Hanging Rock | 237.09a | 36.19 | 18 | Hanging Rock | 109.11a | 21.00 |
| 31 | Wingello SF | 192.00ab | 30.26 | 11 | Hanging Rock | 228.51a | 35.68 | 11 | Hanging Rock | 107.85ab | 22.34 |
| 28 | Kaputar Mountain [1] | 187.55ab | 29.68 | 35 | Wingello SF | 171.62b | 26.70 | 32 | Wingello SF | 102.97abc | 19.13 |
| 8 | Nullo Mountain SF | 183.21ab | 27.64 | 41 | Wingello SF | 153.85bc | 24.86 | 19 | Hanging Rock | 90.26abcd | 18.64 |
| 14 | Hanging Rock | 183.00ab | 28.12 | 33 | Wingello SF | 153.50bc | 23.95 | 35 | Wingello SF | 85.71abcd | 16.61 |
| 36 | Wingello SF | 181.16ab | 14.36 | 13 | Hanging Rock | 153.39bc | 25.62 | 12 | Hanging Rock | 83.97abcd | 16.50 |
| 7 | Nullo Mountain SF | 180.69ab | 33.48 | 42 | Wingello SF | 153.37bc | 24.09 | 42 | Wingello SF | 83.67abcd | 16.54 |
| 29 | Kaputar Mountain [1] | 175.35ab | 12.52 | 32 | Wingello SF | 146.88bc | 23.74 | 5 | Nullo Mountain | 71.44abcd | 15.32 |
| 11 | Hanging Rock | 165.88ab | 30.08 | 18 | Hanging Rock | 145.14bc | 23.33 | 6 | Nullo Mountain | 71.42abcd | 14.53 |
| 5 | Nullo Mountain SF | 150.14ab | 20.64 | 12 | Hanging Rock | 142.69bc | 23.45 | 7 | Nullo Mountain | 71.39abcd | 14.86 |
| 2 | Nullo Mountain SF | 144.81ab | 21.48 | 20 | Hanging Rock | 137.38bc | 23.34 | 40 | Wingello SF | 66.16 cd | 13.92 |
| 1 | Nullo Mountain SF | 144.60ab | 16.25 | 17 | Hanging Rock | 133.90bc | 23.13 | 39 | Wingello SF | 63.23 d | 11.98 |
| 13 | Hanging Rock | 139.90ab | 25.58 | 39 | Wingello SF | 131.82c | 22.16 | 1 | Nullo Mountain | 62.48 d | 12.13 |
| 34 | Wingello SF | 138.85ab | 29.79 | 37 | Wingello SF | 127.88c | 22.85 | 16 | Hanging Rock | 61.98 d | 13.42 |
| 9 | Nullo Mountain SF | 134.38ab | 18.01 | 16 | Hanging Rock | 125.44c | 21.92 | 36 | Wingello SF | 59.84 d | 11.79 |
| 12 | Hanging Rock | 133.00ab | 15.38 | 1 | Nullo Mountain | 125.41c | 19.47 | 34 | Wingello SF | 58.81 d | 11.41 |
| 16 | Hanging Rock | 130.77b | 14.04 | 34 | Wingello SF | 124.53c | 20.86 | 14 | Hanging Rock | 58.72 d | 14.18 |
| 6 | Nullo Mountain SF | 124.11b | 24.48 | 14 | Hanging Rock | 122.55c | 23.07 | 20 | Hanging Rock | 55.33 d | 12.46 |
| 18 | Hanging Rock | 123.45b | 21.01 | 15 | Hanging Rock | 120.47c | 21.21 | 41 | Wingello SF | 54.93 d | 13.62 |
| 3 | Nullo Mountain SF | 115.39b | 20.20 | 38 | Wingello SF | 120.29c | 20.28 | 31 | Wingello SF | 53.78 d | 11.79 |

| Trial sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Windy Gap (96mo) | | | | Petrusvlei (72mo) | | | | Speenkoppies (72mo) | | | |
| Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
| Five worst performing families: | | | | | | | | | | | |
| 33 | Wingello SF | 28.05 | 17.16 | 9 | Nullo Mountain | 33.81 | 6.43 | 30 | Kaputar Mountain | 10.56 | 3.57 |
| 26 | Kaputar Mountain [1] | 27.29 | 13.48 | 4 | Nullo Mountain | 32.84 | 7.10 | 26 | Kaputar Mountain | 9.48 | 2.28 |
| 41 | Wingello SF | 22.02 | 12.39 | 26 | Kaputar Mountain | 10.39 | 2.82 | 27 | Kaputar Mountain | 6.13 | 1.64 |
| 40 | Wingello SF | 17.26 | 14.51 | 28 | Kaputar Mountain | 7.00 | 1.65 | 28 | Kaputar Mountain | 5.52 | 2.80 |
| 42 | Wingello SF | 16.45 | 26.14 | 27 | Kaputar Mountain | 4.62 | 1.25 | 29 | Kaputar Mountain | 1.42 | 0.66 |
| **Trial Mean** | | 111.42 | 18.77 | | | 104.00 | 17.18 | | | 49.12 | 10.65 |
| **SED** | | 51.86 | 5.61 | | | 22.62 | 3.24 | | | 22.98 | 4.05 |
| **LSD ($p \leq 0.05$)** | | 87.34 | 9.45 | | | 38.10 | 5.46 | | | 38.70 | 6.82 |
| **CV %** | | 46.67 | 34.47 | | | 21.65 | 18.86 | | | 44.13 | 37.93 |
| *E. nitens x badjensis* | | 339.00 a | 33.66 | *E. dunnii* | | 196.19a | 27.96 | *E. dorrigoensis* | | 157.84a | 27.39 |
| *E. macarthurii* | | 292.63 a | 32.50 | *E. grandis* | | 196.66a | 26.87 | *E. dunnii* | | 148.18a | 25.24 |
| *E. nitens* | | 254.69 a | 27.85 | *E. nitens* | | 177.74a | 18.34 | *E. grandis* | | 141.90a | 22.71 |
| *E. smithii* | | 251.10 a | 29.15 | *GXN 075* | | 168.00a | 23.45 | *E. smithii* | | 99.67 b | 14.22 |
| *E. nobilis* | | 223.24 ab | 27.65 | *E. smithii* | | 164.29a | 22.97 | *GXN 075* | | 74.11 b | 14.24 |
| *E. bicostata* | | 130.00 b | 17.85 | *E. nobilis* | | 132.59a | 21.83 | *E. macarthurii* | | 59.89 b | 14.27 |
| *GXN 075* | | 104.66 b | 20.07 | *E. macarthurii* | | 134.78a | 21.77 | *E. bicostata* | | 6.77 c | 3.21 |
| **Trial Mean** | | 203.00 | 24.42 | | | 167.20 | 23.31 | | | 98.34 | 17.33 |
| **SED** | | 67.39 | 7.907 | | | 34.33 | 4.12 | | | 22.86 | 4.05 |
| **LSD ($p \leq 0.05$)** | | 127.71 | 14.99 | | | 66.71 | 8.01 | | | 44.42 | 7.87 |
| **CV %** | | 46.95 | 45.79 | | | 29.03 | 24.99 | | | 32.87 | 33.05 |

The overall Type B (Table 3.10) correlations for basal area varied between 0.47 and 0.89 with an average of 0.73, and the overall Type B correlations for volume varied between 0.53 and 0.97 with an average of 0.76. An $r_{Bg}$ of 1.00 would indicate a perfect correlation between the behaviour of genotypes on all three sites (i.e., their relative ranking remains the same) and suggest the complete absence of GEI. The low Type B correlations estimated between Windy Gap and Petrusvlei indicates GEI for these two sites, which is supported by the changes in ranking of the families for both traits at these two sites. It is not appropriate, therefore, to do a combined site analysis where family performance is evaluated across all three sites for this trial series, but rather where individual family performance is evaluated at each site. The combined site analysis comparing family performance at individual sites, and showing the marginal means i.e. difference in the family mean at an individual site from the combined site mean, is presented in Table 3.11.

**Table 3.10 Type B correlation estimates ($r_{Bg}$) for all site pairs for all growth traits measured**

| $r_{Bg}$ | Windy Gap | Petrusvlei | Speenkoppies |
|---|---|---|---|
| **Windy Gap** | | 0.47 (0.44) | 0.84 (0.91) |
| **Petrusvlei** | 0.53 (0.57) | | 0.89 (0.82) |
| **Speenkoppies** | 0.97 (0.89) | 0.80 (0.77) | |

* Above the diagonal – basal area and height in brackets

* Below the diagonal - volume and dbh in brackets

The Windy Gap and Petrusvlei sites had positive marginal means for all families ranked in the top 20 for volume. In the combined site analysis, family 10 was ranked first with marginal means of +96.42 at the Windy Gap site, but did not appear in the top 20 at both Petrusvlei and Speenkoppies. At the Speenkoppies site, every family had a negative marginal mean for volume (Table 3.11).

**Table 3.11 Combined site analysis of the top 20 and 5 poorest performing *E. cypellocarpa* families for volume, with marginal means for each site included.**

| Family | Combined site volume ($m^3ha^{-1}$) | Windy Gap | | Petrusvlei | | Speenkoppies | |
|---|---|---|---|---|---|---|---|
| | | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] |
| 11 | 171.77 a | 10 | 214.19a **(+96.42)** | 19 | 237.09a **(+119.32)** | 18 | 109.11a **(-8.66)** |
| 32 | 141.63 ab | 31 | 192.00ab **(+50.37)** | 11 | 228.51a **(+86.88)** | 11 | 107.85ab **(-33.78)** |
| 19 | 141.29 ab | 28 | 187.55ab **(+46.26)** | 35 | 171.62b **(+30.33)** | 32 | 102.97abc **(-38.32)** |
| 35 | 131.87 abc | 8 | 183.21ab **(+51.34)** | 41 | 153.85bc **(+21.98)** | 19 | 90.26abcd **(-41.61)** |
| 7 | 130.88 abcd | 14 | 183.00ab **(+52.12)** | 33 | 153.50bc **(+22.62)** | 35 | 85.71abcd **(-45.17)** |
| 38 | 130.18 abcd | 36 | 181.16ab **(+50.98)** | 13 | 153.39bc **(+23.21)** | 12 | 83.97abcd **(-46.21)** |
| 39 | 124.63 bcd | 7 | 180.69ab **(+56.06)** | 42 | 153.37bc **(+28.74)** | 42 | 83.67abcd **(-40.96)** |
| 18 | 123.51 bcd | 29 | 175.35ab **(+51.84)** | 32 | 146.88bc **(+23.37**) | 5 | 71.44abcd **(-52.07)** |
| 13 | 122.15 bcde | 11 | 165.88ab **(+47.73)** | 18 | 145.14bc **(+22.99)** | 6 | 71.42abcd **(-50.73)** |
| 12 | 121.06 bcdef | 5 | 150.14ab **(+29.08)** | 12 | 142.69bc **(+21.63)** | 7 | 71.39abcd **(-49.67)** |
| 31 | 119.08 bcdefg | 2 | 144.81ab **(+25.73)** | 20 | 137.38bc **(+18.30)** | 40 | 66.16cd **(-52.92**) |
| 42 | 118.32 bcdefg | 1 | 144.60ab **(+26.28)** | 17 | 133.90bc **(+15.58)** | 39 | 63.23 d **(-55.09**) |
| 2 | 118.26 bcdefg | 13 | 139.90ab **(+21.64)** | 39 | 131.82c **(+13.56)** | 1 | 62.48 d **(-55.78)** |
| 14 | 115.36 bcdefgh | 34 | 138.85ab **(+23.49)** | 37 | 127.88c **(+12.52)** | 16 | 61.98 d **(-53.38)** |
| 1 | 114.05 bcdefgh | 9 | 134.38ab **(+20.33)** | 16 | 125.44c **(+11.39)** | 36 | 59.84 d **(-54.21**) |
| 10 | 112.23 bcdefgh | 12 | 133.00ab **(+20.77)** | 1 | 125.41c **(+13.18)** | 34 | 58.81 d **(-53.42)** |
| 34 | 110.73bcdefgh | 16 | 130.77b **(+20.04)** | 34 | 124.53c **(+13.80)** | 14 | 58.72 d **(-52.01)** |
| 20 | 97.93 bcdefgh | 6 | 124.11b **(+26.18)** | 14 | 122.55c **(+24.62)** | 20 | 55.33 d **(-42.60)** |
| 17 | 97.46 bcdefgh | 18 | 123.45b **(+25.99)** | 15 | 120.47c **(+23.01)** | 41 | 54.93 d **(-42.53)** |
| 5 | 97.30 bcdefgh | 3 | 115.39b | 38 | 120.29c | 31 | 53.78 d |

| Family | Combined site volume ($m^3ha^{-1}$) | Windy Gap | | Petrusvlei | | Speenkoppies | |
|---|---|---|---|---|---|---|---|
| | | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] | Family | Volume ($m^3ha^{-1}$) (marginal mean) [1] |
| | | | **(+18.09)** | | **(+22.99)** | | **(-43.52)** |
| Five worst performing families: | | | | | | | |
| 29 | 39.45 i | 33 | 28.05c **(-11.40)** | 9 | 33.81d **(-5.64)** | 30 | 10.56e **(-28.89)** |
| 30 | 36.66 i | 26 | 27.29c **(-9.37)** | 4 | 32.84d **(-3.82)** | 26 | 9.48e **(-27.18)** |
| 26 | 36.12 i | 41 | 22.02c **(-14.10)** | 26 | 10.39d **(-25.73)** | 27 | 6.13e **(-29.99)** |
| 28 | 17.56 i | 40 | 17.26c **(-0.30)** | 28 | 7.00d **(-10.56)** | 28 | 5.52e **(-12.04)** |
| 27 | 12.73 i | 42 | 16.45c **(+3.72)** | 27 | 4.62d **(-8.11)** | 29 | 1.42e **(-11.31)** |
| **Trial Mean** | 90.94 | | 111.42 | | 104.00 | | 49.12 |
| **SED** | 26.45 | | 51.86 | | 22.62 | | 22.98 |
| **LSD** ($p \leq 0.05$) | 44.54 | | 87.34 | | 38.10 | | 38.70 |
| **CV %** | 35.20 | | 46.67 | | 21.65 | | 44.13 |

[1] Difference between individual site mean and combined site mean

## 3.4 DISCUSSION AND CONCLUSIONS

The data obtained from this investigation supported the concept that provenance and family differences are important criteria to be considered when selecting seed sources (Swain and Gardner 2002; Swain and Gardner 2003). This is because, in this study, although one of the provenances, Hanging Rock, performed reasonably well at all sites, distinct provenance differences were apparent for the warmer and drier sites, Petrusvlei and Speenkoppies, when compared to the colder, high altitude site of Windy Gap. It thus became clear that particular *E. cypellocarpa* provenances were better adapted to high altitude cold sites. The growth of the Nullo Mountain provenance at Windy Gap site was much better than at either Petrusvlei or Speenkoppies. The low Type B correlation between Windy Gap and Petrusvlei suggests there is site x genotype interaction, as does the family ranking changes when comparing provenance performances at Windy Gap, Petrusvlei and Speenkoppies.

These results also demonstrate that provenances that originated from certain areas in NSW, particularly zones which fall within uniform or summer rainfall distributions, adapt well to a similar environment in South Africa. Since this species originated from NSW, where the climate is similar to the more temperate forestry sites in the summer rainfall zone of South Africa, the trees are able to grow rapidly during the warm summer months (Darrow 1984). This trend has also been reported for *E. nitens* (Swain *et al.* 1998), *E. smithii* (Swain *et al.* 2000), *E. fastigata* and *E. badjensis* (Gardner *et al*. 2000).

Based on the outcome of this study comprising material from four provenances on three different sites, certain *E. cypellocarpa* provenances and families could be a viable alternative to *E. dunnii* on certain sites, i.e., warm temperate with occasional drought and low rainfall. Other *E. cypellocarpa* provenances and families could be viable alternatives in areas similar to Windy Gap, i.e., temperate high altitude cold sites, where *E. nitens* is the species currently commercially planted. Due to the presence of GEI indicating that the genotypes performed differently at these three different sites with markedly different environmental conditions, the development of different populations of *E. cypellocarpa* should possibly be considered for these two different sites types.

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# Chapter 4

## GROWTH POTENTIAL OF *EUCALYPTUS VIMINALIS* SUBSP*. NOBILIS*


### ABSTRACT

The Institute for Commercial Forestry Research (ICFR) established two provenance/progeny trials in KwaZulu-Natal and Mpumalanga provinces in 1997 to investigate the potential of *Eucalyptus viminalis* subsp. *nobilis* (*E. nobilis)* as an alternative eucalypt species for high altitude cold sites which experience severe frost and occasional snowfalls.

Seed from seven New South Wales provenances of *E. nobilis* and one *Eucalyptus viminalis* provenance from Kaputar Mountain National Park (Australia) was established in provenance/progeny trials at Windy Gap and The Bends in South Africa. Trials were planted at 1667 stems per hectare, single row plots of six trees, four replications in an unbalanced lattice design. Commercial seed of other eucalypts and clones were used as external controls. Diameter at breast height (dbh) and height at 96 months were measured at both sites. Basal area and volumes were derived from these measurements.

There were distinct provenance differences for growth at both sites, with three *E. nobilis* provenances from Butter Leaf, Chaelundi, Forest Land and Styx River generally performing well on high altitude cold sites. There was no genotype x environment interaction present, indicating that the genotypes performed similarly at both sites.

## 4.1 INTRODUCTION

The humid warmer temperate and sub-tropical regions comprise a significant proportion of *Eucalyptus* plantations in South Africa (FAO 1979). *Eucalyptus grandis* has traditionally been the most extensively cultivated hardwood species in these regions because of this species' rapid growth and acceptable wood properties (Poynton 1979).

More recently, eucalypts have been used extensively for the production of sawtimber and pulp and paper (Swain and Jones 2004), stimulating wide-ranging tree improvement activities in South Africa. New species and provenances are regularly introduced into the country and evaluated for their potential use in the forestry industry (Gardner *et al*. 2000).

During the 1980s and 1990s, commercial forestry in South Africa expanded into mid- and high altitude summer rainfall sites that are drier and warmer, or drier and colder, than traditional *E. grandis* forestry sites. These areas are often referred to as "low productivity" sites (Darrow 1983). In higher regions with altitudes greater than 1350 m (Swain 1996; Swain and Gardner 2003) and Mean Annual Temperatures (MAT) greater than $13^0$C but less than $16^0$C, *Eucalyptus nitens* has been the economically viable species of choice. However, areas with an MAT of less than $18^0$C and altitudes ranging from 1050m to 1300m are still considered unsuitable for the planting of *E. grandis* or *E. nitens* (Swain and Gardner 2003). Therefore the search for more suitable species and provenances for these mid-altitude sites continues.

In addition to *E. bicostata* and *E. cypellocarpa*, *E. viminalis* subsp. *nobilis* (*E. nobilis*) has the potential to grow in the summer rainfall regions in South Africa. However, in contrast to the natural habitats of the *E. bicostata* and *E. cypellocarpa* trees in New South Wales in Australia, *E. nobilis* trees were identified on sites prone to drought, severe frost and snow. Therefore, it was anticipated that provenances of *E. nobilis* should have the potential to grow on high altitude sites with fairly deep soils, but where heavy frost and snow occur (Swain and Gardner 2003).

An investigation was thus undertaken to test the performance of Australian summer rainfall provenances and families of *E. nobilis* at high altitude, cold sites in the summer rainfall regions in South Africa.

## 4.2 MATERIALS AND METHODS

### 4.2.1 Introduction

Eucalypt forests in Australia comprise a mixture of species, encompassing a wide age-class distribution, and these characteristics complicate the process of selection for seed collections, as well as reducing efficiency. A stand was therefore chosen for selection if it was generally healthy, had an acceptable growth rate, contained high quality stems and was predominantly the desired species. Trees were selected within a stand if they were in a dominant or co-dominant crown position and had enough seed. Information that was recorded for individual trees included height, diameter at breast height, height of main stem, tree form and phenological aspects. Climatic data (precipitation, temperature, number of dry months), slope, position of tree (valley, slope, etc), altitude, latitude and longitude were also recorded. Record was kept of other species that were also present in the stand.

To reduce the possibility of collecting seed from related or inbred trees, a minimum distance of 100m was kept between each selected tree during sampling. In smaller stands or stands, where seed bearing trees were scarce, this distance may have been reduced slightly. However, in these cases at least three crowns were left between parent trees. Each area sampled was treated as a separate provenance using seedlot numbers to distinguish between provenances and field numbers allocated to identify individual trees (families) within the provenances (Gardner 2000).

The collection was then established in a series of provenance and progeny trials at temperate low productivity sites in the summer rainfall forestry growing region in South Africa.

This investigation involved the assessment of growth performances of summer rainfall provenances of *E. viminalis* subsp. *nobilis* L. Johnson and K. Hill (*E. nobilis*) from NSW in Australia on high altitude, cold sites in the summer rainfall region of South Africa.

A collaborative seed collection trip to northern NSW in Australia was undertaken by the Institute of Commercial Forestry Research (ICFR) in South Africa and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, during 1997. One of the aims of the collection was to collect seedlots of *E. nobilis*. Originally *E. nobilis* and *E. viminalis* were classified as one species, until a later revision separated the two into distinct species (Gardiner and Schofield 1997; Gardner *et al*. 2000; Johnson and Hill 1990). Therefore, seed was also collected from *E. viminalis* to include these as internal controls in the trial series.

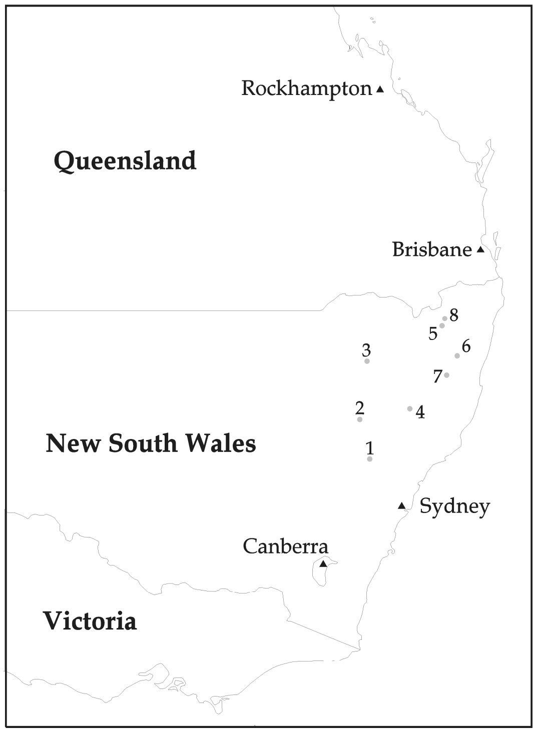
### 4.2.2 Seed collection

Seed was collected from 77 *E. nobilis* families from eight provenances in Australia. Seed from 16 additional families of *E. nobilis* from selections made in site species trials in 1990/1991 were also included.

For the internal controls, five *E. viminalis* families from one Australian provenance, one family from selections made in ICFR site species trials in 1990/1991, and one bulk treatment of 10 trees of the *E. viminalis* provenance from Wareen in Australia were included.

Thus, a total of 100 families of both *E. nobilis* and *E. viminalis* were established in trials. Improved seed of other eucalypt species and clones grown commercially in South Africa was also included in the trial series as external controls, as detailed in Table 4.1.

A map of the Australian provenances of *E. nobilis* included in this study is presented in Figure 4.1.




| Provenances | Latitude (S) | Longitude (E) | Altitude (m) | No. of families |
|---|---|---|---|---|
| 1. Nullo Mtn SF | 32°44' | 150°13' | 1100-1120 | 10 |
| 2. Coolah Tops | 31°44' | 149°58' | 1020-1040 | 10 |
| 3. Mt Kaputar | 30°16' | 150°09' | 960-1300 | 10 |
| 4. Nundle | 31°28' | 151°14' | 1260 | 10 |
| 5. Butter Leaf SF | 29°23' | 152°03' | 1080 | 1 |
| 6. Chaelundi SF | 30°08' | 152°26' | 1160 | 10 |
| 7. Styx River SF | 30°37' | 152°10' | 1000 | 12 |
| 8. Forest Land SF | 29°12' | 152°07' | 1250 | 12 |

**Figure 4.1 Seven *E. nobilis* (1-2 and 4- 8) and one *E. viminalis* (3) provenance collection sites in New South Wales in Australia**

**Table 4.1 Origins of seedlots and controls included in the *E. nobilis* provenance / progeny trials**

| Species (Provenances) | Seedlot/clone No. | Average latitude (S) | Average longitude (E) | Average altitude (m) | No. of families (numbering) |
|---|---|---|---|---|---|
| ***E. nobilis*** **:** | | | | | |
| Butter Leaf SF | 19807 | 29°60' | 150°00' | 1050 | 1 (41) |
| Chaelundi SF | 19811 | 30°10' | 152°40' | 1150 | 11 (42-49) |
| Coolah Tops | 19801 | 31°70' | 150°00' | 1000 | 10 (11-20) |
| Forest Land SF | 19467 | 29°20' | 152°10' | 1250 | 12 (71-82) |
| Kaputar Mountain NP | 19805 | 30°30' | 150°10' | 1350 | 10 (21-30) |
| Nullo Mountain SF | 19800 | 32°70' | 150°02' | 975 | 10 (1-10) |
| Nundle | 19806 | 31°50' | 151°30' | 1100 | 10 (31-40) |
| Styx River SF | 19452 | 36°30' | 152°20' | 1000 | 13 (58-70) |
| Deepwater | 15098* | 29°19' | 152°06' | 1100 | 6 (83-88) |
| Armidale | 15099* | 30°29' | 152°18' | 1200 | 10 (89-98) |
| ***E. viminalis*** **:** | | | | | |
| Wattle Flat | 19795 | | | | 5 (53-57) |
| Ex-DEA, Weltevreden MPU | 33804* | | | | 1 (99) |
| Wareen via Numeralla, NSW | Bulk of 10 trees | | | | 1 (100) |
| **External controls** | | | | | |
| *E. smithii* | 10040 | Bulk | SAPPI, SA | | |
| *E. nitens x E. badjensis* | 4/96-97 VRD | | AUSTRALIA | | |
| *E. dorrigoensis* | - | Bulk | CSIRO, AUSTRALIA | | |
| *E. nitens* | 10061 | Bulk | SAPPI, SA | | |
| *E. macarthurii* | ICFR 1/95 | Bulk | Jaglust, SA | | |
| *E. cypellocarpa* | - | Bulk | CSIRO, AUSTRALIA | | |
| *E. grandis x E. nitens* | *G X N 075* | Clone | CSIR, Pretoria, SA | | |
| *E. bicostata* | - | Bulk | CSIRO, AUSTRALIA | | |
| *E. grandis* | M7849 | Bulk | MondiBP, SA | | |
| *E. dunnii* | M8879 | Bulk | Mondi BP, SA | | |

SF = State forest; NP = National park; NSW = New South Wales; SA = South Africa

* = Ex 1990/91 site-spp trials

### 4.2.3 Trial establishment

Progeny/provenance trials were established to determine which Australian provenances are best suited to temperate summer rainfall growing conditions in South Africa, and to identify top families under these conditions. All trials were planted at a stocking rate of 1667 stems $ha^{-1}$, in single row plots of six trees, with four replications laid out in balanced or unbalanced lattice designs. The external commercial control plots were laid out around the trials in three rows of eight trees each, measuring only the six trees in the inner row. This layout was implemented to prevent inter-species competition within the trial, but to still provide a comparative measure, although excluded from statistical analyses because the external controls were not included in the experimental design (blocking and replications) of the trial.

Two trials of *E. nobilis* were established in South Africa over two planting seasons, site details and trial design information of which are presented in Tables 4.2 and 4.3 respectively.

**Table 4.2 Trial sites established for *E. nobilis* in South Africa.**

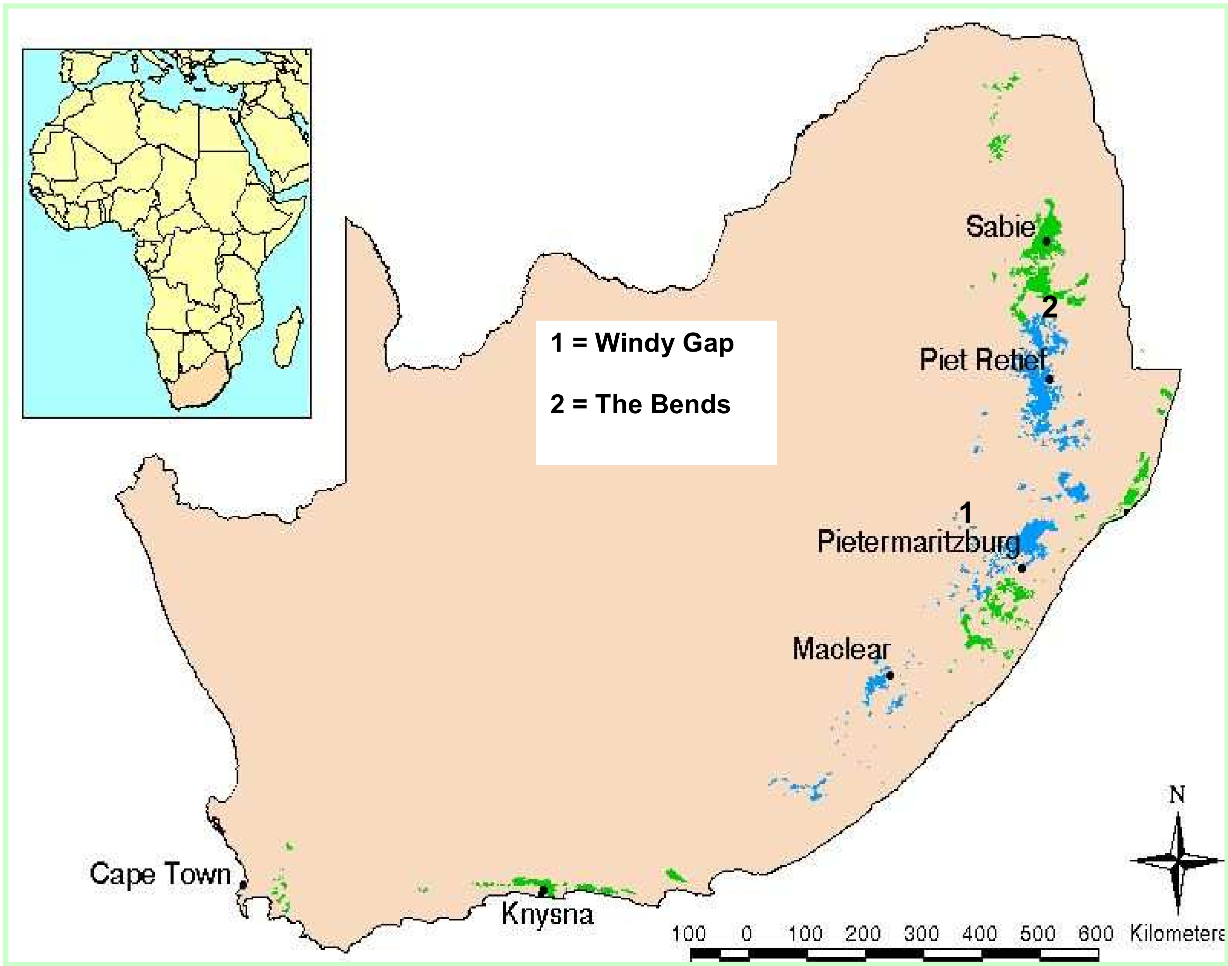
| Site locality | Planting date | No. of families | Area (ha) | Latitude (S) | Longitude (E) | Altitude (m) | MAP (mm) | MAT (°C) | Soil depth (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | 02/12/97 | 100 | 1.43 | 38°45' | 34°30' | 1610 | 900 | 14,6 | 1000 |
| The Bends, Iswepe, MPU | 13/11/97 | 100 | 2.20 | 45°08' | 33°39' | 1390 | 890 | 16,6 | 800 |

KZN = KwaZulu-Natal; MPU = Mpumalanga; MAP = Mean annual precipitation; MAT = Mean annual temperature.

**Table 4.3 *E. nobilis* trial type and designs for two sites established in South Africa**

| Locality | Trial Type | Company | Origin | Design | Reps |
|---|---|---|---|---|---|
| Windy Gap, Himeville, KZN | Provenance/Progeny Trial | SAPPI | Aus | 10x10 balanced lattice | 4 |
| The Bends, Iswepe, MPU | Provenance/Progeny Trial | SAPPI | Aus | 10x10 balanced lattice | 4 |

A map of the South African trial sites for *E. nobilis* is presented in Figure 4.2.




**Blue= cool temperate   Green= warm temperate and sub tropical**

**Figure 4.2  Two trial sites for *E. nobilis* planted in South Africa**

### 4.2.4 Growth assessments

Overbark diameter at breast height (1.3m) (dbh) and height measurements were recorded. These measurements were recorded at 66mo for both the Windy Gap and The Bends trials. The dbh measurements were used to calculate the mean plot basal areas. Basal area was derived by summing the individual basal areas of trees within a plot and then converting basal area per plot ($m^2$ $plot^{-1}$) to basal area per hectare ($m^2ha^{-1}$) using the following formula:

$$Baha^{-1} = dbh^2 \times \pi / 144 \times 10000,$$

Where: $Baha^{-1}$ = mean plot basal area per hectare;

$dbh^2$ = diameter at breast height (1.3m above ground) in mm/10;

$\pi$ = 3.142;

$\pi$ /144 x 10000 = Conversion factor which takes into account conversion of diameter measured in mm to radius and basal area in $m^2ha^{-1}$ (Schönau 1982; Coetzee 1995).

Treatment means and basal areas were calculated in the same manner for the external controls.

As no volume equation is available for *E. nobilis*, the equation derived for *E. nitens* by Schönau (1982) was used to calculate volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm;

H = total height in m;

b0 = -2.17055;

b1 = 2.07516; and

b2 = 1.42792.

The same volume equation was also used for external control species of *E. nitens x badjensis, E. cypellocarpa* and *E. dorrigoensis*.

For the improved commercial species *E. macarthurii,* used in the external controls, the volume equation developed by Schönau (1982) was used:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -2.03756;

b1 = 2.21147; and

b2 = 1.12502.

For improved commercial species of *E. smithii*, the equation developed by Coetzee (1995) was used to calculate timber volume:

$$Log\ V = b0 + b1\ logD + b2\ log\ H,$$

Where: V = total volume to 50mm tip diameter in $m^3$;

D = dbh in mm/10;

H = total height in m;

b0 = -4.6923;

b1 = 1.8802; and

b2 = 1.2217.

Data were statistically analysed using the Restricted Maximum Likelihood Method (REML) (Patterson and Thompson, 1971) of the statistical software package GenStat 5 Release 4.21 (Lane and Payne 1996), using the following model for the calculation of provenance and family means:

$$y = X_A + Z_B + H_f + W_p + e,$$

Where;

$y$ = trait or data vector

$X_A$ = replication effects (random),

$Z_B$ = block effects (random),

$H_f$ = family/provenance effects (fixed),

$W_p$ = plot effects (random),

$e$ = random error effects.

Mean squares were calculated to determine whether effects were significant using the same model. This was done using the ANOVA method in Genstat as referenced. Significant replication effects, on the rare occasion that they were found, were not corrected for. Treatment means were compared using least significant differences (LSDs) at the 5% significance level.

Type B correlations were then estimated for *E. nobilis* to give a clearer indication of any potential genotype by environment interaction (GEI). Where two traits are measured on different individuals within genetic groups, for example a genetic correlation between trees of the same family grown in different environments, the correlation can be designated a Type B genetic correlation (Burdon 1977). Type B correlations at the family level ($r_{Bg}$) were estimated for all possible site pairs within a species, as follows:

$$r_{Bg} = \frac{\sigma^2_{fam}}{\sigma^2_{fam} + \sigma^2_{site*fam}} .$$

The ratio of family variance over the family and environment × family variance is equivalent to a Type B correlation from a paired site analysis. A Type B genetic correlation ($r_{Bg}$) of 0.67 is the level at which the GEI variance represents 50% of the total additive variance, and is the point where it is postulated that the GEI variance may start to be a cause for some concern among tree breeders (Shelbourne 1972).

## 4.3 RESULTS

Diameter at breast height (dbh) and height were measured in the *E. nobilis* trials, and the mean plot volume and basal area per hectare calculated. The significant replication effects for height at The Bends were not corrected for. There were significant provenance differences ($p \leq 0.001$) among the various growth traits assessed in both trials (Table 4.4).

**Table 4.4 Mean square values of various growth traits of provenances included in *E. nobilis* trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| **Windy Gap** | | | | | | | |
| Rep | 3 | 73.00 | 10.55 | Rep | 3 | 122.7 | 226 |
| Block/Rep | 36 | 22.46 | 13.91 | Block/Rep | 36 | 134.1 | 3327 |
| Provenance | 12 | 129.99*** | 48.67*** | Provenance | 12 | 426.0*** | 11243*** |
| Error (residual) | 1690 | 17.03 | 7.88 | Error (residual) | 348 | 117.2 | 2054 |
| Total | 1741 | 18.02 | 8.29 | Total | 399 | 128.8 | 2454 |
| **The Bends** | | | | | | | |
| Rep | 3 | 18.95 | 81.64*** | Rep | 3 | 59.55 | 4075 |
| Block/Rep | 40 | 22.91 | 12.89 | Block/Rep | 40 | 50.25 | 2235 |
| Provenance | 12 | 268.95*** | 43.30*** | Provenance | 12 | 722.83*** | 24264*** |
| Error (residual) | 1740 | 8.79 | 3.50 | Error (residual) | 342 | 38.99 | 1303 |
| Total | 1795 | 10.86 | 4.09 | Total | 397 | 60.95 | 2114 |

*****,** represents data that is significant at p≤0.001 (99.99%), respectively,

When the volume and basal area means of the *E. nobilis* provenances were compared, it was found that there were significant (*p*≤0.05) provenance differences for both traits at both sites (Table 4.5).

When the provenance means for volume and basal area of the *E. nobilis* provenances were compared to that of the Kaputar Mountain and Wattle Flat provenances from the internal control species *E. viminalis*, it was found that the *E. nobilis* provenances generally performed significantly (*p*≤0.05) better than the *E. viminalis* provenances at both trial sites. However, the *E. viminalis* bulk seedlot internal control from Wareen in NSW (Australia) was ranked first for both growth traits at Windy Gap and second for volume at The Bends.

With regards to the *E. nobilis* provenances, Butter Leaf, Forest Land, Chaelundi and Styx River provenances performed significantly (*p*≤0.05) better than the other provenances for volume at The Bends. No substantial provenance variation was recorded amongst these four provenances for both growth traits. The Nullo Mountain and Nundle provenances of *E. nobilis* were not significantly different from the higher ranked provenances at the high altitude, cold site of Windy Gap. However, at The

Bends, a site that experiences more severe frost than Windy Gap, Nullo Mountain and Nundle provenances were significantly outperformed by the top ranking provenances. The two lowest ranking provenances at both sites were the *E. nobilis* Coolah Tops and Kaputar Mountain provenances. These two low ranking provenances were significantly outperformed ($p \leq 0.05$) by the top four *E. nobilis* provenances at Windy Gap, and by the top seven *E. nobilis* provenances at The Bends.

**Table 4.5 Mean provenance performance of *E. nobilis* for volume and basal area across sites, ranked by volume**

| Windy Gap | | | The Bends | | |
|---|---|---|---|---|---|
| **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| ExWareen [2] | 171.30 a | 31.88 | Forest Land | 128.50 a | 24.82 |
| Deepwater [1] | 136.90 b | 25.07 | ExWareen [2] | 128.03 a | 19.30 |
| Chaelundi | 120.20 bc | 27.12 | Butter Leaf | 127.81 a | 23.48 |
| Forest Land | 114.70 bcd | 22.94 | Chaelundi | 126.86 a | 24.40 |
| Butter Leaf | 114.50 bcde | 22.49 | Styx River | 104.78 ab | 20.48 |
| Styx River | 110.60 bcdef | 21.97 | Deepwater [1] | 91.03 bc | 24.09 |
| Nullo Mountain | 103.00 cdef | 20.69 | Armidale [1] | 84.85 bcd | 17.70 |
| Nundle | 101.30 cdef | 20.09 | Ex-DEA [1] [2] | 84.83 bcd | 15.88 |
| Armidale [1] | 92.80 cdef | 19.42 | Nullo Mountain | 76.83 cde | 15.74 |
| WattleFlat [2] | 90.40 def | 18.49 | Nundle | 72.87cdef | 15.64 |
| Ex-DEA [1] [2] | 88.00 dcf | 18.68 | WattleFlat [2] | 64.38 def | 13.93 |
| Kaputar Mountain NP | 81.20 f | 17.67 | Coolah Tops | 51.88 f | 11.35 |
| Coolah Tops | 65.90 f | 13.99 | Kaputar Mountain NP | 57.75 ef | 12.71 |
| **Trial Mean** | 107.00 | 20.92 | **Trial Mean** | 92.34 | 18.42 |
| **SED** | 16.22 | 4.18 | **SED** | 13.78 | 2.36 |
| **LSD** ($p \leq 0.05$) | 28.91 | 7.45 | **LSD** ($p \leq 0.05$) | 24.56 | 4.21 |
| **CV %** | 21.44 | 28.26 | **CV %** | 21.10 | 18.12 |

[1] Ex-1990/91 *E. nobilis* site-spp trials [2] *E. viminalis* Seedlots

When family means were compared at both sites, significant differences ($p \leq 0.05$) for both growth traits were recorded at both sites (Table 4.6). The significant replication effects for dbh at Windy Gap, and height and volume at The Bends were corrected for. When the top 30 ranking families were compared, there were 16 *E. nobilis* families common to both sites (Table 4.7) Three *E. nobilis* families namely, 2, 5 and 9 from Nullo Mountain State Forest provenance, appeared in the top 30 families at Windy Gap, but were absent from the top 30 at The Bends. None of the *E. nobilis* Coolah Tops families appeared in the top 30 at Windy Gap, whereas one appeared in the top 30 at The Bends. This provenance performed poorly overall.

**Table 4.6 Mean square values of various growth traits of *E. nobilis* for the two provenance/progeny trials at Windy Gap and The Bends**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| | | | | **Windy Gap** | | | |
| Rep | 3 | 72.87*** | 10.93 | Rep | 3 | 1227.70* | 226 |
| Block/Rep | 36 | 24.15 | 14.07 | Block/Rep | 36 | 134.10 | 3327*** |
| Family | 99 | 40.33*** | 17.60*** | Family | 99 | 182.30*** | 4452*** |
| Error(residual) | 1637 | 16.41 | 7.57 | Error (residual) | 262 | 108.20 | 1613 |
| Total | 1774 | 17.98 | 8.26 | Total | 399 | 128.80 | 2454 |
| | | | | **The Bends** | | | |
| Rep | 3 | 18.95 | 81.64*** | Rep | 3 | 46.02 | 4075*** |
| Block/Rep | 36 | 22.91 | 12.29 | Block/Rep | 36 | 42.92 | 2235 |
| Family | 99 | 44.83*** | 11.06*** | Family | 99 | 149.36*** | 4607*** |
| Error(residual) | 1653 | 8.52 | 3.33 | Error (residual) | 254 | 37.59 | 1100 |
| Total | 1795 | 10.61 | 4.09 | Total | 396 | 66.02 | 2114 |

*****,** represents data that is significant at $p \leq 0.001$ (99.99%), * = significant at $p \leq 0.1$ (99%) and D.F.= Degrees of freedom.

Three *E. nobilis* families, namely 50, 79 and 81 appeared in the top ten families, when ranked according to volume at both sites, with both Families 79 and 81, originating from Forest Land State Forest.

An inspection of the performances of *E. nobilis* families selected from a site-species interaction trial series during 1990 to 1991 (Deepwater and Armidale) revealed that these families appeared at a range of positions in the ranking of the top 30 families. At The Bends, one of the Deepwater families (85) was ranked highest.

**Table 4.7 Ranking of the top 30 and 5 worst performing families of *E. nobilis* for volume at two sites, with respective basal areas included. (Although external controls cannot be statistically compared, they are included for a relative comparison).**

| Windy Gap | | | | The Bends | | | |
|---|---|---|---|---|---|---|---|
| Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) | Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
| 60 | Styx River SF | 198.50 a | 33.62 | 87 | Deepwater [1] | 170.72 a | 31.54 |
| 85 | Deepwater [1] | 186.80 ab | 33.97 | 50 | Chaelundi SF | 163.57 ab | 28.58 |
| 79 | Forest Land SF | 175.30 abc | 31.36 | 48 | Chaelundi SF | 158.14 abc | 29.42 |
| 100 | Wareen [2] | 171.20 abcd | 31.84 | 79 | Forest Land SF | 155.30 abcd | 31.00 |
| 51 | Chaelundi SF | 164.70 abcde | 30.24 | 44 | Chaelundi SF | 154.55 abcde | 28.76 |
| 38 | Nundle | 155.20 abcde | 29.21 | 63 | Styx River SF | 152.78 abcdef | 27.63 |
| 2 | Nullo Mountain SF | 154.70 abcde | 28.67 | 80 | Forest Land SF | 146.98 abcdefg | 27.14 |
| 81 | Forest Land SF | 151.60 bcde | 27.38 | 81 | Forest Land SF | 145.16 abcdefg | 27.87 |
| 42 | Chaelundi SF | 151.30 bcde | 28.66 | 71 | Forest Land SF | 141.10 abcdefg | 27.06 |
| 50 | Chaelundi SF | 149.80 bcde | 28.96 | 45 | Chaelundi SF | 138.66 abcdefg | 26.91 |
| 21 | Kaputar Mountain NP | 148.10 bcde | 28.86 | 85 | Deepwater [1] | 135.53 abcdefg | 26.22 |
| 48 | Chaelundi SF | 146.20 bcde | 27.36 | 75 | Forest Land SF | 135.53 abcdefg | 26.73 |
| 89 | Armidale [1] | 144.00 bcde | 27.07 | 73 | Forest Land SF | 131.38 abcdefg | 25.37 |
| 5 | Nullo Mountain SF | 142.10 bcde | 28.18 | 52 | Chaelundi SF | 131.05 abcdefg | 23.66 |
| 67 | Styx River SF | 139.20 cde | 28.19 | 84 | Deepwater [1] | 130.96 abcdefg | 24.03 |
| 87 | Deepwater [1] | 136.90 cde | 25.32 | 41 | Butter Leaf SF | 130.28bcdefg | 23.65 |
| 72 | Forest Land SF | 135.50 cde | 27.71 | 77 | Forest Land SF | 125.07 bcdefg | 21.99 |
| 33 | Nundle | 135.10 cde | 25.61 | 51 | Chaelundi SF | 124.79 bcdefg | 25.49 |
| 77 | Forest Land SF | 132.90 cde | 26.17 | 46 | Chaelundi SF | 123.47 bcdefg | 22.60 |
| 88 | Deepwater [1] | 132.50 cde | 24.14 | 74 | Forest Land SF | 122.85 cdefg | 22.65 |

| Windy Gap | | | | The Bends | | | |
|---|---|---|---|---|---|---|---|
| **Family** | **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Family** | **Provenance** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| 26 | Kaputar Mountain NP | 130.10 de | 25.29 | 78 | Forest Land SF | 121.14 cdefg | 23.25 |
| 59 | Styx River SF | 130.00 de | 26.49 | 31 | Nundle | 118.42 cdefg | 23.25 |
| 71 | Forest Land SF | 130.00 de | 25.32 | 62 | Styx River SF | 118.13 cdefg | 23.00 |
| 46 | Chaelundi SF | 128.10 de | 24.64 | 68 | Styx River SF | 117.91 cdefg | 20.65 |
| 58 | Styx River SF | 127.70 de | 24.80 | 88 | Deepwater [1] | 115.67 defg | 21.77 |
| 65 | Styx River SF | 127.40 de | 25.07 | 58 | Styx River SF | 113.38 fg | 23.15 |
| 31 | Nundle | 125.50 e | 22.44 | 89 | Armidale [1] | 113.00 fg | 22.54 |
| 84 | Deepwater [1] | 125.30 e | 21.87 | 76 | Forest Land SF | 112.85 fg | 24.06 |
| 75 | Forest Land SF | 123.60 e | 24.88 | 66 | Styx River SF | 112.38 g | 20.54 |
| 9 | Nullo Mountain SF | 122.00 e | 25.49 | 11 | Coolah Tops | 111.36 g | 22.83 |
| Five worst performing families: | | | | | | | |
| 8 | Nullo Mountain SF | 54.10 | 12.32 | 57 | Wattle Flat | 36.49 | 9.15 |
| 29 | Kaputar Mountain NP | 52.70 | 12.28 | 22 | Kaputar Mountain NP | 36.39 | 6.13 |
| 15 | Coolah Tops | 47.80 | 10.46 | 16 | Coolah Tops | 35.20 | 8.06 |
| 16 | Coolah Tops | 34.40 | 7.22 | 2 | Nullo Mountain SF | 25.51 | 5.70 |
| 22 | Kaputar Mountain NP | 30.10 | 7.79 | 17 | Coolah Tops | 16.07 | 4.78 |
| **Trial Mean** | | 102.00 | 20.92 | | | 91.11 | 18.11 |
| **SED** | | 26.94 | 7.43 | | | 24.25 | 4.39 |
| **LSD ($p \leq 0.05$)** | | 44.72 | 12.34 | | | 40.26 | 7.29 |
| **CV %** | | 28.43 | 38.50 | | | 25.90 | 24.72 |

[2] = *E. viminalis* seedlot – Bulk of 10 [1] **=** Ex-1990/91 *E. nobilis* site-spp trials SF= State Forest NP=National Park

| Windy Gap | | | The Bends | | |
|---|---|---|---|---|---|
| **Control** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** | **Control** | **Volume ($m^3ha^{-1}$)** | **Basal area ($m^2ha^{-1}$)** |
| *E. smithii* | 389.90 a | 35.84 | *E. smithii* | 176.90 a | 30.58 |
| *E.nitens x badjensis* | 362.10 b | 34.76 | *E. dorrigoensis* | 153.50 ab | 25.61 |
| *E. nitens* | 306.40 abc | 30.46 | *E. nitens* | 132.40 ab | 23.04 |
| *E. dorrigoensis* | 226.60 abcd | 31.17 | *GXN 075* | 114.10 ab | 21.79 |
| *E. macarthurii* | 139.90 d | 20.22 | *E. bicostata* | 107.10 b | 20.45 |
| *E. cypellocarpa* | 65.90 d | 12.41 | *E. macarthurii* | 93.90 b | 18.42 |
| **Trial Mean** | 248.40 | 27.48 | | 117.00 | 18.34 |
| **SED** | 87.75 | 10.28 | | 34.04 | 4.39 |
| **LSD** ($p \leq 0.05$) | 176.82 | 20.72 | | 68.59 | 8.85 |
| **CV %** | 49.95 | 52.90 | | 41.15 | 33.85 |

Only one *E. viminalis* internal control bulk seedlot (100) from Wareen appeared in the top 30 families at Windy Gap, but was absent from the top 30 at The Bends. Two families, 21 and 26, of *E. nobilis* from Kaputar Mountain National Park provenance appeared in the top 30 ranking at Windy Gap, but were absent from the top 30 ranking at The Bends.

In a comparison of the yield performances of the improved commercial external control species/clones *E. smithii*, *E. nitens* x *E. badjensis*, *E. dorrigoensis* and *E. nitens* with the *E. nobilis* families at Windy Gap, the external controls outperformed the top ranking *E. nobilis* families (Table 4.7). Interestingly, *E. nitens*, the commercially preferred species for Windy Gap, was not the top ranked performer of the external control species, but was outperformed by the external control *E. smithii*, although the difference was not significant. However, at The Bends, when the growth performances of the top 15 *E. nobilis* families were compared to that of the top external controls at The Bends, it was found that the differences in growth were negligible. Only the performances of the external controls *E. smithii* and *E. dorrigoensis* were comparable with the top *E. nobilis* and *E. viminalis* families. The other external controls, including the currently preferred species *E. macarthurii*, displayed much poorer growth than the top ranking *E. nobilis* families ($p \leq 0.05$).

The overall Type B correlation for basal area and height (in brackets) was 1.07 (0.87), and for volume and dbh (in brackets) was 1.22 (0.83). An $r_{Bg}$ of 1.00 would indicate a perfect correlation between the behaviour of genotypes on both sites (i.e., their relative ranking remains the same) and suggests a complete absence of GEI. Due to the nature of the variance component estimates, the genetic correlation may, in practice, exceed unity (although, in theory, this is not possible) (Hettasch *et al.* 2007).

The high Type B correlations estimated for both sites, for both traits, indicated that there was no GEI for the *E. nobilis* genotypes tested over these two sites, which supported the findings of the individual analyses. The lack of GEI allowed for both sites to be analysed as one data set, and top performing families can be selected from the results of this analysis rather than the individual site analyses. Results of the combined site analysis are presented in Tables 4.8 and 4.9. The non-significant site x family interaction in Table 4.8 supports the lack of GEI.

**Table 4.8 Mean square values of various growth traits of across-site analysis for *E. nobilis* trials**

| Source | D.F. | Mean squares | | Source | D.F. | Mean squares | |
|---|---|---|---|---|---|---|---|
| | | Dbh | Height | | | Baha | Volume |
| Site | 1 | 501.92 | 318.51 | Site | 1 | 1296.84 | 22448 |
| Site/Rep | 6 | 46.26 | 50.56 | Site/Rep | 6 | 91.13 | 2151 |
| Family | 100 | 70.62 | 27.08 | Family | 100 | 251.16 | 7400 |
| Site x Family | 97 | 20.01 $^{NS}$ | 7.83 $^{NS}$ | Site x Family | 97 | 69.50$^{NS}$ | 2129$^{NS}$ |
| Error (residual) | 3511 | 15.48 | 5.49 | Error (residual) | 593 | 72.84 | 1448 |
| Total | 3725 | 14.57 | 6.34 | Total | 797 | 96.48 | 2310 |

$^{NS}$ not significant and D.F.= Degrees of freedom.

**Table 4.9 Combined site analysis of top 30 performing *E. nobilis* families for volume and basal area, ranked by volume**

| Family | Provenance | Volume ($m^3ha^{-1}$) | Basal area ($m^2ha^{-1}$) |
|---|---|---|---|
| 79 | Forest Land SF | 164.73 a | 31.11 |
| 85 | Deepwater [1] | 160.80 ab | 30.21 |
| 50 | Chaelundi SF | 158.67abc | 28.86 |
| 48 | Chaelundi SF | 156.04 abcd | 28.38 |
| 60 | Styx River SF | 154.26 abcde | 27.46 |
| 87 | Deepwater [1] | 154.16 abcdef | 28.10 |
| 81 | Forest Land SF | 147.37 abcdefg | 27.95 |
| 51 | Chaelundi SF | 144.40 abcdefgh | 28.07 |
| 100 | Wareen **( )** | 137.89 abcdefghi | 26.47 |
| 71 | Forest Land SF | 136.64 abcdefghi | 26.27 |
| 42 | Chaelundi SF | 135.27 abcdefghi | 25.46 |
| 63 | Styx River SF | 134.32 abcdefghi | 23.94 |
| 75 | Forest Land SF | 130.80 bcdefghi | 26.01 |
| 77 | Forest Land SF | 128.79 bcdefghi | 24.04 |
| 84 | Deepwater [1] | 128.07 cdefghi | 22.97 |
| 45 | Chaelundi SF | 127.23 cdefghi | 24.44 |
| 46 | Chaelundi SF | 125.95 defghi | 23.60 |
| 89 | Armidale [1] | 124.85 defghi | 24.76 |
| 52 | Chaelundi SF | 124.82 defghi | 22.76 |

| Family | Provenance | Volume ($m^3ha^{-1}$) | | Basal area ($m^2ha^{-1}$) |
|---|---|---|---|---|
| 21 | Kaputar Mountain NP | 123.52 | defghi | 24.19 |
| 88 | Deepwater [1] | 123.31 | efghi | 23.03 |
| 80 | Forest Land SF | 122.94 | efghi | 23.26 |
| 41 | Butter Leaf SF | 121.54 | fghi | 23.31 |
| 31 | Nundle | 121.29 | ghi | 22.93 |
| 72 | Forest Land SF | 120.85 | ghi | 25.01 |
| 58 | Styx River SF | 120.53 | ghi | 24.06 |
| 38 | Nundle | 120.31 | ghi | 24.25 |
| 44 | Chaelundi SF | 114.66 | i | 23.20 |
| 83 | Deepwater [1] | 113.03 | i | 22.99 |
| 92 | Armidale [1] | 112.74 | i | 23.20 |
| 14 | Coolah Tops | 44.78 | j | 9.72 |
| 57 | Wattle Flats | 41.10 | j | 10.24 |
| 17 | Coolah Tops | 37.00 | j | 8.48 |
| 22 | Kaputar Mountain NP | 31.84 | j | 6.70 |
| 16 | Coolah Tops | 31.42 | j | 7.65 |
| **Trial Mean** | | 96.64 | | 19.64 |
| **SED** | | 19.66 | | 4.28 |
| **LSD** ($p \leq 0.05$) | | 32.63 | | 7.20 |
| **CV %** | | 27.80 | | 24.05 |

## 4.4 DISCUSSION AND CONCLUSION

This study revealed that there were marked differences in the growth of *E. nobilis* provenances tested on high altitude cold sites in summer rainfall regions in South African. Gardner (2001) reported significant growth differences between provenances of cold tolerant eucalypts species which were investigated in site-species interaction under South African growing conditions.

In this study, *E. nobilis* provenances that originated from widely separated sites performed differently for the growth traits assessed in both trials. This confirmed the importance of site-species matching, as well as site-provenance matching, when determining the use of unimproved seed sources for commercial deployment in South African summer rainfall regions.

Provenances collected from Butter Leaf, Chaelundi, Forest Land and Styx River emerged from this investigation as more suitable *E. nobilis* provenances for planting on high altitude, cold sites in the summer rainfall region of South Africa, than the other *E. nobilis* provenances studied. They generally performed well for both growth traits measured at the two cold and frost prone trial sites.

The Coolah Tops provenance of *E. nobilis* and the Kaputar Mountain National Park provenance of *E. nobilis* are not recommended for deployment in the summer rainfall regions of South Africa, because they performed the worst in both trials.

These data also revealed that there were marked differences in performance between the top ranked *E. nobilis* families and the external commercial controls at the different sites. At Windy Gap, the top improved external commercial controls outperformed the *E. nobilis* families. At The Bends site, however, top performing *E. nobilis* families performed as well as the top performing external commercial controls. This again confirmed the importance of site-species matching, as well as site-provenance matching, on forestry sites in South Africa (Swain and Gardner 2003). The relatively good performance of the *E. nobilis* families relative to the external commercial controls at The Bends confirmed the potential of selected provenances of *E. nobilis* as an alternative species to currently preferred commercial species grown at some cold and frost-prone sites.

The *E. viminalis* (ex-Wareen) bulk seedlot included as the internal control performed as well as, or better than, *E. nobilis* families for the growth traits measured and in some cases, even better. It was previously reported that commercial deployment of *E. viminalis* in the high altitude, cold sites in the summer rainfall region in South Africa was limited by the presence of *Gonipterus scutellatus* (snout beetle) (Hutchins 1903; Kotze and Hubbard 1928; Tooke 1955; Darrow 1996; Swain *et al*. 1999). However, no damage by this high altitude insect pest was noted in either trial.

This investigation further revealed that *E. nobilis* provenances could be a viable alternative to *E. nitens* and *E. macarthurii* on some high altitude sites, with fairly deep soils that experience occasional heavy frost and snow.

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# Chapter 5

## OVERVIEW OF RESEARCH

The genus *Eucalyptus* is diverse and naturally occurs mostly in Australia. It comprises more than 700 species that have evolved over many years (Brooker 2000; Fiona *et al*. 2005). The different species of the genus have adapted to a wide range of different climatic conditions and are found in almost every region of the Australian continent (William and Woinarski 1997). Some *Eucalyptus* species have evolved to be adapted to highly specific environmental conditions, showing a limited distribution, while others are less specialised and occur over a wide range of environmental conditions ( Eldridge *et al*. 1993; Doughty 2000; Barbour *et al*. 2001).

The main interest worldwide in this genus is for its fast growth and range of products of economic value, particularly the production of solid wood as well as pulp for paper products (Doughty 2000; Potts 2004). Globally, *Eucalyptus* species are grown in almost all tropical and subtropical areas, and are cultivated in many other climates (Turnbull 1999).

In South Africa, *E. globulus* was the first eucalypt species to be introduced into the country, and it was basically used for sawtimber. With the increased demand for mining timber, the popularity of the species diminished as it was not suited to planting near mines, due to their main location at higher altitudes. In addition, the impact of *M. nobilosa* leaf spot disease was severe in South Africa during the 1930's, which halted further establishment of *E. globulus* plantations (Crous 1998). Therefore, more suitable species for mining timber were introduced. Late in the twentieth century, there was a shift from mining timber to pulp and paper production in South Africa, bringing about an extension of commercial forestry into other areas and extensive plantings of *E. grandis*, which is known for its good pulping properties and fast growth. More recently, the forestry industry has recognised that the growth of the industry will require further extension into non *E. grandis* growing areas that are generally referred to as low productivity areas;  areas with altitudes above 1200m. This shift has necessitated research into sourcing potentially more suited species for these sites.

In this investigation, three species *E. bicostata*, *E. cypellocarpa* and *E. nobilis* were assessed for their potential for deployment into mid and high altitude, low productivity sites. These three species were selected because of their performances in site-species interaction trials during the 1990s (Gardner *et al*. 2000). All provenances of the species originated from New South Wales in Australia. New South Wales is particularly suited to the selection of provenances for testing, because this state comprises three distinct rainfall distribution patterns; summer, uniform and winter. Furthermore, geographically, eucalypts are found from low lying areas near the coast, to high altitude, mountainous areas inland. *Eucalyptus* species have thus developed a wide range of adaptations to these conditions, making them highly suitable for exotic site matching.

This study revealed that, as expected, more than one species has the potential for deployment on more than one of the sites assessed. *Eucalyptus bicostata* generally does well on well watered soils (Boland *et al*. 1985), however, in this investigation *E. bicostata*, contrary to what was expected, also did well on a site with occasional drought. This species thus proved to be the most versatile of the three species tested, performing well on high altitude, cold sites; warm mid altitude sites and warm mid altitude sites with occasional drought. *Eucalyptus nobilis* proved to be suited to only high altitude, cold sites.  On the other hand, *E. cypellocarpa* proved to be most suited for planting on mid-altitude warmer sites where extended dry periods did not occur, which is in contrast to previous findings where *E. cypellocarpa* displayed some drought tolerance. These species differences should be taken into account when species are selected for forestry sites in South Africa.

Schönau (1983) showed that, for an apparently versatile species such as *E. grandis*, the recommended climatic conditions for planting in South Africa should closely approximate those in its natural habitat in Australia. As was expected in this study, provenances originating from New South Wales showed a high degree of variability in growth potential amongst the three *Eucalyptus* species investigated. Some provenances performed generally well across more than one site type, while others were very specific to a particular site type. *Eucalyptus cypellocarpa* and *E. nobilis* provenances that originated from Nullo Mountain in New South Wales displayed excellent growth potential, particularly on high altitude cold sites. In contrast, the growth potential of Nullo Mountain State Forest provenances of *E. bicostata* was disappointing. For *E. bicostata*, Narrow Neck Ridge provenance proved to be exceptionally versatile, performing well on all sites tested; cold, high altitude well watered sites, as well as warmer mid altitude sites with or without drought. This provenance also displayed tolerance to the fungal pathogen *M. nobilosa*, and it is probably due to this tolerance that the provenance performed well. The four *E. nobilis* provenances Butter Leaf, Forest Land, Chaelundi and Styx River, all closely situated in New South Wales, displayed equivalent growth performances on sites that experience cold as well as frost. Growth performances of *E. nobilis* provenances that originated from Coolah Tops were generally poorer, as were those of the Mount Kaputar provenance of the internal controls of *E. viminalis* and *E. volcanica*.

Within provenances, a wide range of individual family differences existed in the three species investigated in this trial series. This was also noted in the early growth results (height) for this species (Swain *et al.* 1999). Top ranked families were in most cases from the best performing provenances on particular trial sites. *Eucalyptus bicostata* families from Narrow Neck Ridge provenances showed consistency in ranking over the different site types, while the best performing families of *E. cypellocarpa* and *E. nobilis* changed ranks across different site types, particularly on the high altitude cold sites and mid-altitude warm sites indicating that they are more adaptable to specific sites. For both species, Nullo Mountain provenances performed well at the high altitude cold site at Windy Gap, while on the slightly warmer sites, the growth performance was average.

A summary of the results obtained in this investigation is provided in Table 5.1. The different climatic and geographic conditions that suit the different species are provided.

**Table 5.1 Summary of results of *E. bicostata, E. cypellocarpa* and *E. nobilis* provenance/progeny trials**

| Descriptors | Site | | | | |
|---|---|---|---|---|---|
| | **Windy Gap** | **Enon** | **Petrusvlei** | **Speenkoppies** | **The Bends** |
| **Climatic and geographical description** | | | | | |
| Climatic zone | cool temperate | warm temperate | warm temperate | warm temperate | warm temperate |
| MAP (mm) | High (900mm) | High (980mm) | High (960mm) | Low (894mm) | Low (890mm) |
| MAT ($^{o}$C) | 14.7 | 16.5 | 16.0 | 16.8 | warm |
| Soil depth | deep | deep | deep | deep | shallow |
| Altitude | high | mid | mid | mid | high |
| Drought | no | no | no | yes | no |
| Cold | yes | no | no | no | yes |
| Frost | severe | Only in valleys | Only in valleys | Only in valleys | Severe |
| Snow | frequent | rarely | rarely | rarely | frequent |
| **Forestry information** | | | | | |
| Site productivity | high | high | average | low | average |
| Current preferred species | *E. nitens* | *E. smithii*<br>*E. grandis* | *E. dunnii*<br>*E. grandis* | *E. dunnii* | *E. macarthurii* |
| **Performance of investigated species** | | | | | |
| *E. bicostata* | good | good | good | average | - |
| *E. cypellocarpa* | average | - | good | poor | - |
| *E. nobilis* | average | - | - | - | good |
| **Potential alternatives** | | | | | |
| *E. bicostata* | ✓ | ✓ | ✓ | ✓ | ✓ |
| *E. cypellocarpa* | | | ✓ | | |
| *E. nobilis* | ✓ | | | | ✓ |

**CONCLUSION**

Based on the growth performances of the three eucalypt species investigated, the following can be concluded:

- All three species have the potential for deployment onto low productivity summer rainfall sites.
- Some provenances are better adapted to specific sites than others.
- Some families within the better performing provenances appeared to outperform some of the commercially grown preferred species on these land types, indicating that some of this material may have a role to play on certain sites in commercial forestry in South Africa.
- The inherent genetic variation in the three species allows for opportunities for improvement by selective breeding.

However, the successful deployment of any of these species will require that, besides the assessment of growth traits, other traits of economic importance for the pulp and paper industry, such as wood and pulping properties, be evaluated. It is further recommended that this genetic resource has to be conserved in some format as commercial deployment will only be effected if the pulping properties prove to be economically viable, and this exercise will take some time.

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