GROWTH OF FOUR PINE SPECIES AT HIGH ALTITUDE SITES IN THE EASTERN CAPE PROVINCE

by

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DECLARATION

This thesis is the result of the author's own work and contains, to the best of his knowledge, no other work accepted for any other degree or diploma at any University, nor any material which has previously been published except where due reference is made in the text.

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ABSTRACT

The growth of four pine species *Pinus patula, P. greggii, P. elliottii* and *P. taeda* was investigated on first rotation high altitude sites in the north-eastern region of the Eastern Cape Province. The study area encompass a broad range of sites in terms of soils (texture, drainage, depth) and climate (temperature and precipitation). Afforestation across the study area proved challenging and there is a need to better understand survival, tree growth and site variables that contribute to the unique forestry environment.

Enumeration data of 539 compartments totalling 11 380 ha with an age-class distribution from 4 to 13 years were analysed using statistical analyses techniques, interpretation based on other research results and personal field experience. The dataset represents the first commercial scale growth information for the four species in the study area.

The research was designed to study the survival of the four pine species and to analyse if there were any seasonal impacts on the latter. Furthermore, the tree growth, expressed as a site index at age 10 years (SI_{10}) and basal area at age 10 years (BA_{10}), was analysed to investigate the performance of the four pine species. Lastly, the relationship between tree growth expressed in site index (SI_{10}) and basal area (BA_{10}) and site characteristics was investigated.

On average the best survival species were *P. elliottii* and *P. greggii* yielding 69% and 68% respectively, with *P. patula* yielding a 56% survival. There was no

statistically significant difference in the survival between the planting months for all species combined, however, *P. patula* showed significant differences between planting months. In addition there are statistically significant differences between the species in terms of Site Index and Basal Area and there is a relationship between growth and site variables.

Evidence leading to the following conclusions is provided:

i) *P. patula* is the worst species planted in North East Cape Forests (NECF) in terms of survival;

ii) August is the best and November the worst planting month for *P. patula*;

iii) the importance of species selection and site matching;

iv) the successful introduction of *P. greggii*;

v) tree performance can be explained with site variables, especially those derived from climatic information.

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1. INTRODUCTION

South Africa is a country of low mean annual rainfall where only 16% of the land is climatically suiTable for commercial timber production (Forestry Guidelines for South Africa, 1982). As a result, most of the natural vegetation is non-woody, with natural forests only occurring along the southern and eastern seaboards and open canopy savanna woodlands in the north-eastern interior of the country. Compared to a world mean forest cover in excess of 30% of land area, the natural closed canopy forest covers only 0,5% and savannah woodlands 19% of the total land area in South Africa (Owen and van der Zel, 2000). Historically efforts were made to conserve the remnant closed canopy forests, while developing a thriving industry based on introduced exotic timber plantation resources. These plantations presently cover slightly less than 1,4% of South Africa (Owen and van der Zel, 2000). Minimal attention was given to the natural woodlands, except in areas primarily conserved for the protection of fauna (Owen and van der Zel, 2000).

1.1. Forest Plantations in Retrospect

In 1488, when the Portuguese navigator/explorer Bartholomew Diaz and his crew sailed along the western and southern coasts of South Africa, they saw evergreen mixed-species, tall forests similar to Mediterranean macchia and sclerophylous shrubs (fynbos) being the dominant groups. One hundred years later the Dutch East India Company started exploitation of this forest to supply its base in Cape Town. Irrespective of the political powers governing the region (Portuguese, British, Dutch or Africans), the need for timber was constantly rising. The giant yellowwoods (*Podocarpus spp.*) and stinkwoods (*Ocotea bullata*) were harvested first to provide construction materials for ships, houses, bridges, railway lines, etc. The growing population also placed an increased demand on the resource through the clearing of land for agriculture and firewood.

At the turn of the last century, when Kimberley's diamonds and the Witwatersrand's gold were discovered, the demand for timber exceeded the production rates of the indigenous forests, of which only around 360 000 ha remained (Owen and van der Zel, 2000). A pioneer plantation was established in the Western Cape in 1876 to produce fuelwood for the railroads leading to the interior. This was followed by the introduction of many exotic tree species in extensive trials with the aim of selecting high production and quality merchantable timber (Forestry Guidelines for South Africa, 1982).

South African forests gained real significance in 1652 with the arrival of the Dutch in the Cape and again in 1820 when the English arrived in the Eastern Cape and Natal. Woodlands increased in significance with the colonising of the interior after 1836 (Owen and van der Zel, 2000).

The early history of the closed canopy forests was one of uncontrolled exploitation and devastation. It was not until the early 1700s and the mid 1800s that attempts were made to protect the forests of the South-Western Cape and the Eastern Cape respectively. The first Forest Act, for the Cape Colony, was promulgated in 1888 after the appointment of the first formally trained forest officer in 1880. Prior to the Union in 1910 there were four Provincial Forest Services, with the most active being in the Cape Colony (Owen and van der Zel, 2000).

Though Governor van der Stel had established a plantation of oaks at Newlands in 1670, it was not till 1875 that the first real planting of exotic timber species began. Black wattle (*Acacia mearnsii)* had been introduced from Australia in 1864 and by 1880 the bark extract was recognised as a superior tanning material. Plantings expanded into the early nineteen hundreds. By 1910 an area of 60 000 ha was commercially planted to wattle (Forestry Guidelines for South Africa, 1982; Owen and van der Zel, 2000).

After the Union in 1910, a Chief Conservator of Forests was appointed and the provincial services were brought under federal control. In the early years, up to the Second World War, forestry was almost exclusively a State affair and strongly associated with agriculture. The one exception was the wattle industry in KwaZulu-Natal, which was largely private. After the Second World War an independent Department of Forestry was established within the State. The early Union forestry services pursued a protectionist strategy towards the remaining closed canopy forests, whilst moving forward with the establishment of exotic timber plantations. During these years many small plantations (mostly large woodlots) were established along the eastern seaboard, especially in the Eastern Cape. Many of these were associated with small remnants of natural forest and made use of wattle to produce building materials for rural housing, thus protecting the forest remnants. In 1938 it was recorded that 150 000 ha of "commercial" timber plantations and the first sawmill had been established by the State. The private planted areas had increased to 370 000 ha, including 220 000 ha under wattle (Owen and van der Zel, 2000).

The Second World War brought into focus South Africa's geographic vulnerability in respect of timber supplies and in the early 1950s the State set about expanding the timber resources, especially by encouraging the private sector to plant trees. This brought about an immense surge in afforestation. By 1960 the total planted area had reached 981 640 ha, of which 720 320 ha, including 355 000 ha wattle, were privately owned (Owen and van der Zel, 2000).

By 1975 the total planted area had reached just over 1,1 million ha, of which 769 000 ha were privately owned. International markets for wattle bark peaked in 1962 and as the market declined later, large areas of wattle were converted to eucalypts or agricultural crops such as sugar cane (Owen and van der Zel, 2000).

By 1985 the Department of Forestry controlled 1,6 million ha of land, of which 263 000 ha were under commercial timber plantations. In terms of the Government of the day's policy, the eight independent and self-governing administrations controlled a further 350 000 ha of land, of which more than 150 000 ha were under plantations. The officially recorded public planted area was 333 776 ha and the area under private ownership was 800 000 ha. In 1986, 1,0 million ha of unplanted State forest mountain catchment area, along with a small plantation area, was transferred from the Department of Forestry to the Provincial Nature Conservation authorities.

In 1990 the Government decided to commercialise its timber production activities. The South African Forestry Company Limited (SAFCOL) took over approximately 500 000 ha of State forest land, of which 263 000 ha were timber plantations. The State retained 86 000 ha of land, most of which was under closed canopy natural forests, whilst the independent and self-governing administrations had a commercial and community plantation area in excess of 160 000 ha. The official total planted public plantation area was 418 023 ha. The plantations under private ownership were 952 870 ha, including a wattle area of 124 117 ha (Owen and van der Zel, 2000).

After the democratic election in 1994, the plantations of the former independent and self-governing administrations returned to the control of the Department of Water Affairs Forestry. This was intended to be a temporary measure with the objective to privatise the commercial timber interests of both SAFCOL and the Department (Owen and van der Zel 2000).

1.2. North East Cape Forests

A shortage of suitable land, competition between various land use sectors and legislation and social realities in the late 1980's led to afforestation projects in areas outside traditional forestry regions. One of these projects was the North East Cape Forests (NECF) Joint Venture, established in the districts of Elliot and Maclear in 1989. The initial project plan was to establish 66 000 ha of which 60% would consist of *Pinus* species and 40% of *Eucalyptus* species (Botha, 1996). Following a strategic review in 1993 (Zobel, 1991 and 1993), it was decided to focus on pines only. The NECF holdings encompass a broad range of sites in relation to soils (texture, drainage, depth) and climate (temperature and precipitation) (Herbert, 1997). In general, however, they differ markedly from other forestry areas in South Africa, particularly with regard to the presence of mudstone and basaltic soil parent materials, specific hydrological features, low temperatures, snow and strong winds. Afforestation across the landholdings has proven challenging and there is a need to evaluate timber growth in terms of performance across the landholdings, therefore, an understanding of the site factors and their relationship to yield of timber is necessary. The first large scale enumeration undertaken during 1998 and 1999 thus afforded me the opportunity to evaluate and test my understanding and experiences acquired as an operational forester at NECF. It furthermore presented the unique opportunity to evaluate the first large scale deployment of *P. greggii* from Mexico. This, coupled with the unique geology and often challenging climatic conditions, presented an opportunity to evaluate the unique and promising timber growth parameters of the Eastern Cape Highlands.

2. OBJECTIVES AND HYPOTHESES

Whilst it was clear that the site types are unique, there was a necessity to understand, quantify, and calibrate exactly what this uniqueness comprised. This information was needed for the development of site-specific management recommendations. Furthermore, a better understanding of the site growth parameters would assist foresters to select and optimise current available species and indicate where the highest quantity and quality timber was likely to occur.

The objective of this study was to analyse and interpret the results of the first widespread enumeration of pine stands conducted in NECF with special reference to *P. greggii* from southern Mexico. The dataset refers to 539 compartments totalling 11 379,23 ha across stands with ages ranging from 4,42 to 13,5 years. The data were evaluated through analysis and interpretation based on existing research and personal field experience during my tenure as a forester in the region. This dataset represents the first commercial scale growth information for these species in the north-eastern portion of the Eastern Cape Province.

The research was designed to address the following hypothesis:

1. There is no difference in the survival of the four pine species.
2. There is no difference in the survival of the four pine species when planted in different months.

3. There is no difference in height and basal area growth of the four species of pine.

4. There is no relationship between height growth (site index (SI_{10}) and basal area (BA_{10})) of *P. patula*, *P. greggii, P. elliottii, P. taeda* and site characteristics.

3. CHARACTERISTICS OF THE STUDY AREA AND SITE FACTORS

3.1. Description of the Study Area

The study area lies between latitudes 30°55' and 31°27' south and longitudes 28°02' and 28°21' east, along the south-eastern escarpment of the Drakensberg Mountains, as illustrated in Figure 1 and Plate 1. The Drakensberg dominate the regional topography and rise sharply from about 1 200 m a.s.l to over 2 731 m a.s.l (Cobels Kop) above the broken inland plains (1 000 – 1 100 m a.s.l.) of the Qumbu and Mt. Fletcher districts. The high escarpment is orientated approximately east-west in the vicinity of Elliot, becoming more south-west to north-east towards Ugie and then shifting to north-south in the eastern part of the North East Cape. The Tsitsa River, a tributary of the Mzumvubu River that enters the Indian Ocean approximately 140 km away at Port St. Johns, drains the eastern portion of the land. Wind from the south-east comes off the coast near Coffee Bay, a distance of some 240 km. It has to cross a series of plateaus between 1 500 m and 1 700 m a.s.l south of the study area. Altitude, distance from the coast and topographic position has a pronounced effect on rainfall as illustrated in Table 1 (Herbert, 1997). Higher rainfall occurs closer to the coast, as well as on the plateau ridges and southern aspect slopes. The relationship between altitude and rainfall, however, is complicated by topography, and microclimatic differences are influenced by rain shadows on the northern slopes (Herbert, 1997).

Figure 1. Location of the study area.

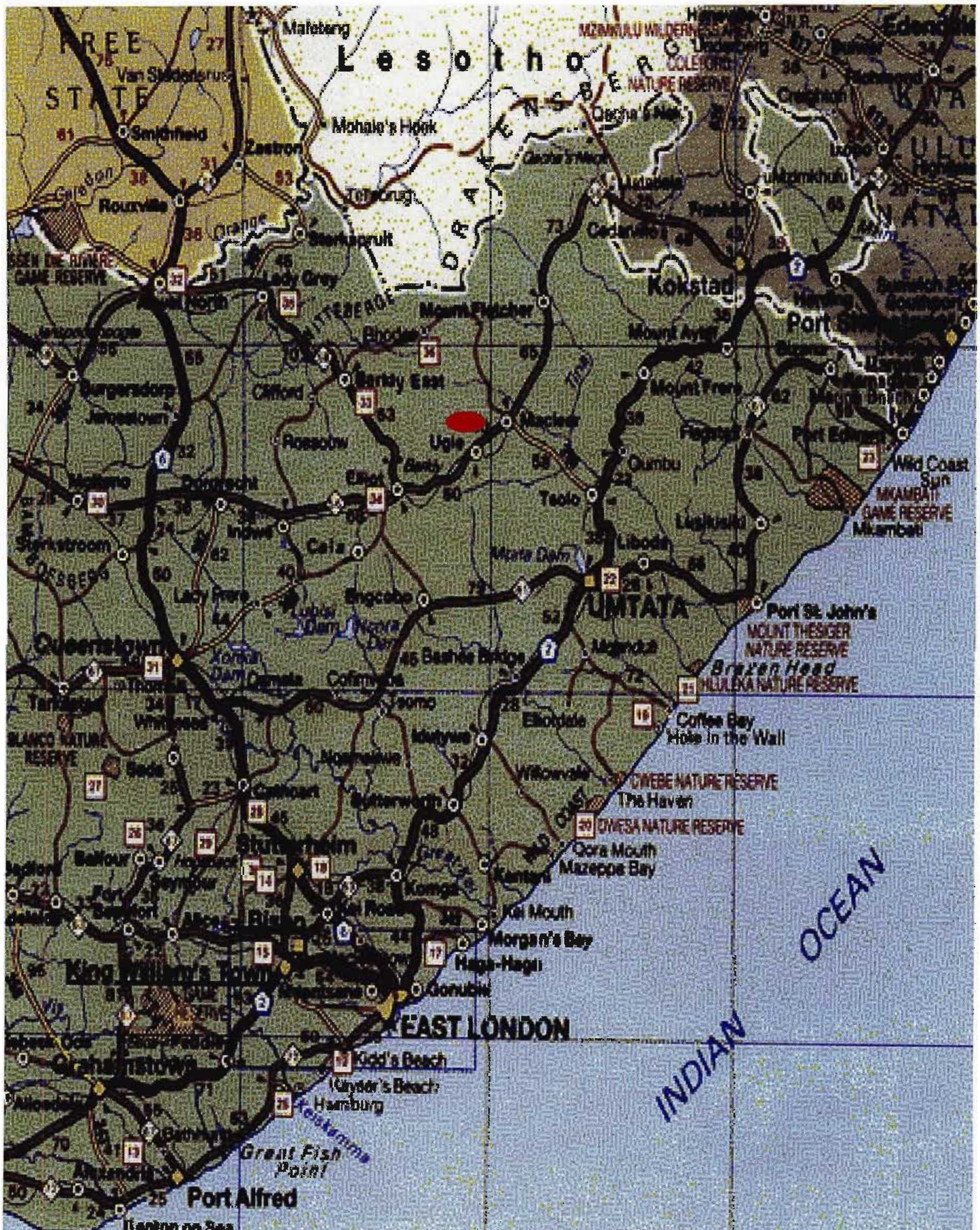


Plate 1. Illustration of the study area.

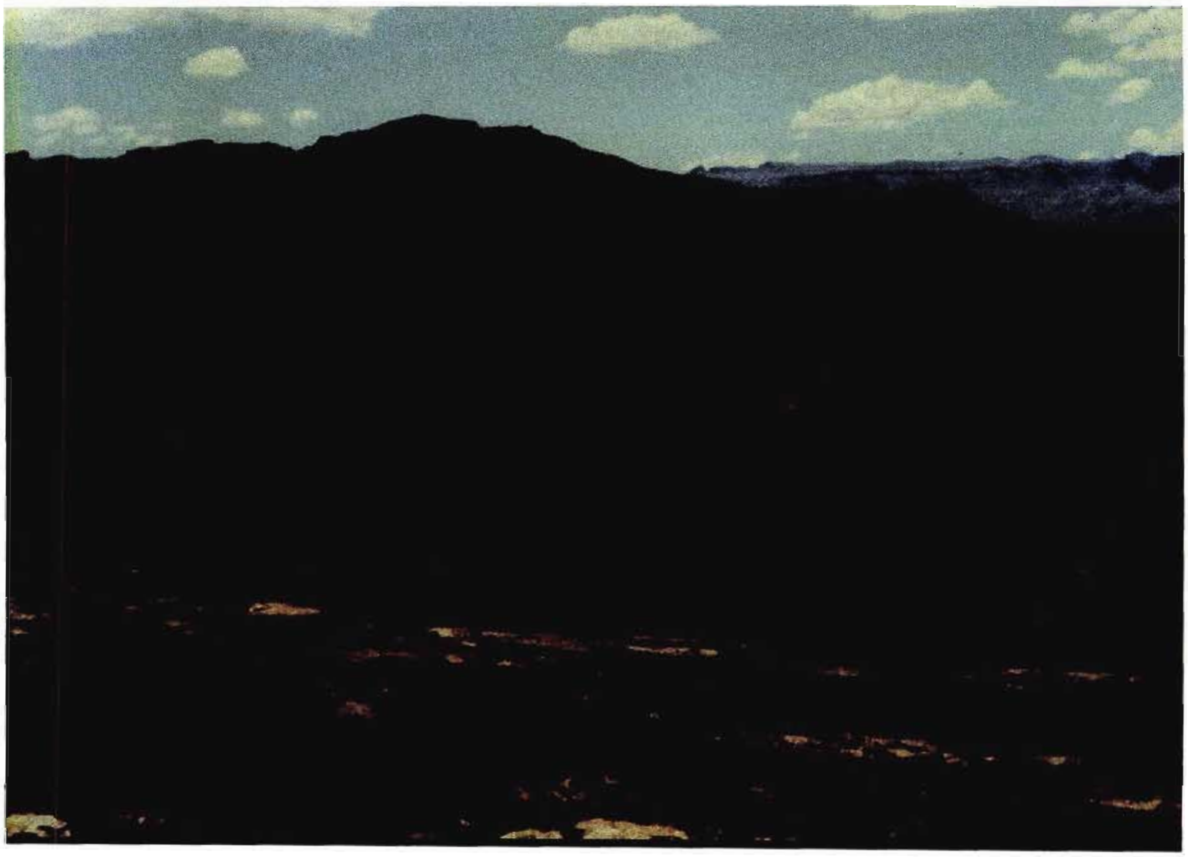


Table 1. Change in mean annual precipitation (MAP) due to altitude and distance from the Indian Ocean (Herbert 1997).

Location	Coordinates	Altitude (m)	Distance from Coast	MAP (mm)
Wilo	31°53'N 28°58'E	640	22,5	1044,0
Korana	31°54'N 28°48'E	750	35,0	802,7
Cezu	31°47'N 28°44'E	830	45,0	786,3
Qunu	31°46'N 28°38'E	880	52,5	675,2
Langeni	31°28'N 28°29'E	850	87,5	1179,8
Mhlahlana	31°25'N 28°32'E	1000	85,0	1325,1
Gubenxa Police	31°22'N 28°07'E	1257	120,0	829,4

The study area covers nine plantation management units referred to as estates. On a north-east south-west axis, they are in order: Elands Heights, Killarney, Commonage, Chillingly, Glen Cullen, Wildebees, Inglewood, Roseg and Funeray. As illustrated in Table 2, the key characteristics of the respective estates are different. Due to the geographic spread, evolution in management objectives over time and various management structures with resulting reconfiguration of boundaries, it was not possible to quantify or reflect these details in this review except for reflecting broad based parameters. Elands Heights, with its basalt soils and high altitude landscape, is different from the lower altitude estates towards Maclear, Ugie and Elliot. Funeray and Inglewood represent the drier areas specifically to the south of the main tar road between Elliot and Maclear. Commonage consists of properties leased from the municipality and due to its protected siting (from the prevailing wind), deep soils and proximity to infrastructure, is considered to represent some of the optimal growth sites in NECF. The central estates (Chillingly, Glen Cullen, Wildebees and Roseg) are geographically consolidated with diverse site conditions including a significant percentage of post-agricultural (old) lands. Killarney is the most eastern estate in the study area with a wide range of sites. The later acquisitions consist of properties with a high afforestation potential, with some of the initial acquired northern boundary properties being more marginal.

Table 2. Characteristics of the respective management units (estates).

Management Unit	**Northern Coordinate**	**Southern Coordinate**	**Area Planted (ha)**	**Dominant Geology**	**Sub Dominant Geology**
Elands Heights	30°55'N 28°14'E	30°54'N 28°11'E	1975,8	Drakensberg	Clarens/Elliot
Killarney	30°54'N 28°21'E	31°03'N 28°16'E	3195,2	Molteno	Clarens
Commonage	31°01'N 28°20'E	31°07'N 28°21'E	1474,4	Molteno	Elliot
Chillingly	31°04'N 28°17'E	31°11'N 28°16'E	2046,4	Molteno	-
Glen Cullen	31°02'N 28°11'E	31°09'N 28°12'E	4936,3	Elliot/Molteno	-
Wildebees	31°07'N 28°11'E	31°13'N 28°17'E	2291,1	Elliot	Molteno
Inglewood	31°09'N 28°13'E	31°15'N 28°21'E	1817,4	Molteno	-
Roseg	31°12'N 28°04'E	31°19'N 28°06'E	4493,6	Elliot	Molteno
Funeray	31°16'N 28°02'E	31°27'N 28°04'E	3709,3	Molteno	Elliot

3.2. Vegetation and Previous Land Use

According to Acocks (1975), the area is dominated by Highland Sourveld (unit 44a), but may also include areas transitional to drier and warmer Döhne Sourveld (unit 44b) in the lower elevations. The climate of Highland Sourveld is characterised by summer rainfall with severe winter frosts and snow at higher elevations. Hail storms are common in summer. The growing season is short and this land unit is considered to be difficult terrain for farming (Nel, 1998).

Remnants of indigenous forests suggest that, in the past, the area was dominated by forest and scrub-forest vegetation with species such as *Podocarpus latifolius*, in the main forest canopy, *Canthium ciliatum* as undergrowth and *Leucosidea sericea* in forest margins. The grassveld replaced such forests in level topography, but this has become colonized with *Protea multibracteata* and/or *P. rouppeliae* on slopes. The dominant grasses are *Themeda triandra, Tristachya hispida, Trachypogon spicatus, Heteropogon contorutus* and *Eragrostis racemosa*. This grass composition can easily be reduced to *Eragrostis planana* through trampling or *Acalypa schinzii* through over-grazing by sheep (Herbert, 1997; Forsyth *et al.*, 1996).

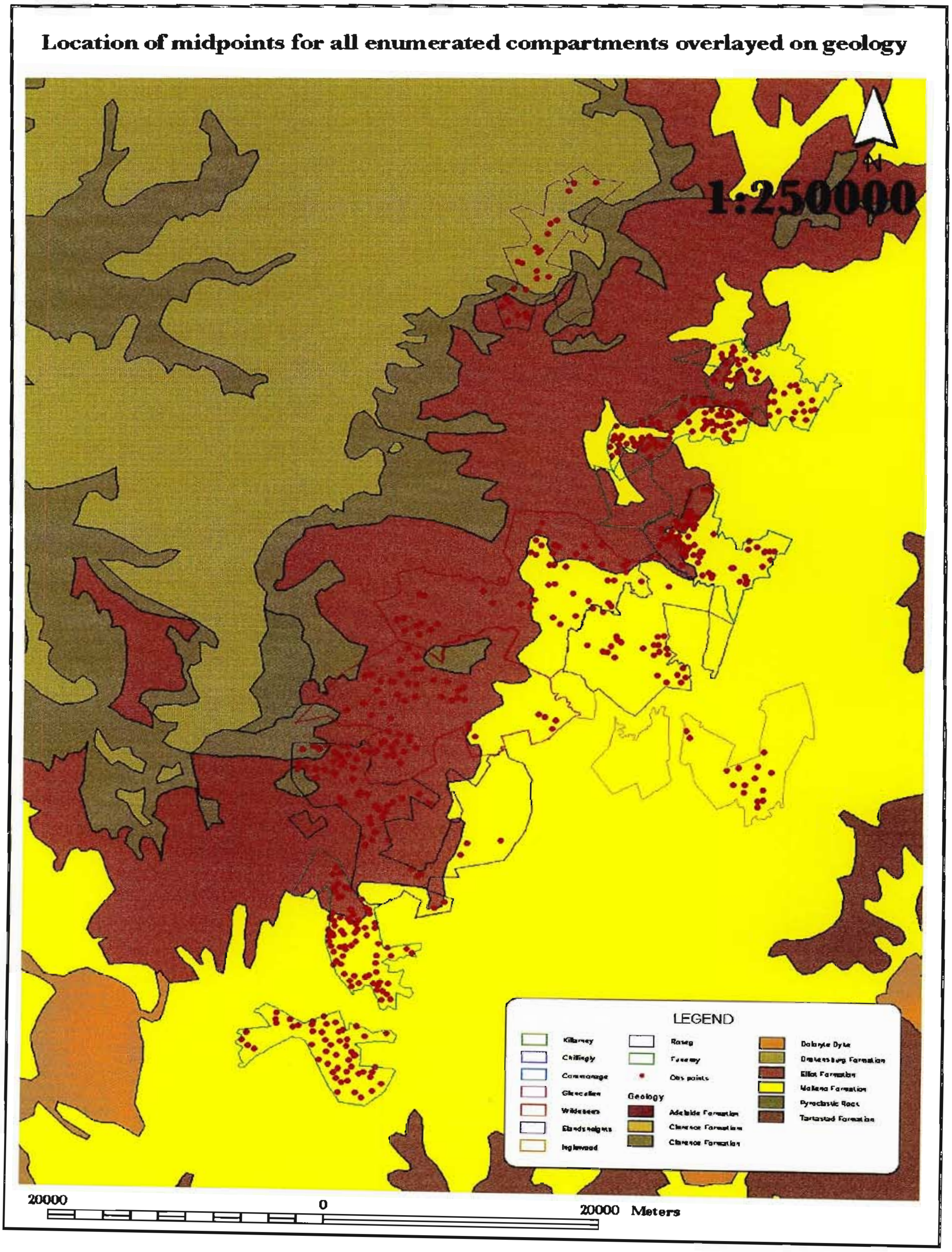
Prior to afforestation in 1989, the area was used extensively for livestock farming consisting of mixed cattle, sheep and goats. Maize cultivation was introduced, and is still practised successfully today in areas free from hail damage. Scattered woodlots of *Acacia mearnsii, Eucalyptus camaldulensis, E. pauciflora, E. viminalis, Pinus elliottii, P. patula, P. pinaster, P. radiata* and *Populus* spp. were planted (Herbert, 1997; Nel, 1996; Forsyth *et al.*, 1996). Tree growth has ranged from good to very poor according to a study of old stands (Zwolinski *et al.*, 1997). Overall, it is clear that species capable of withstanding freezing temperatures, snow and periodic drought have succeeded more consistently than the others. Trees damaged by frost, wind, drought and/or hail may be found throughout the district.

3.3. Geology and Soils

The geology of the study area is underlain by Triassic sedimentary strata belonging to the Karoo Sequence, intruded in places by sills and dykes of Jurassic dolerite (Karpeta and Johnson, 1979; Lloyd and Whitfield, 1990; Brink, 1983). Structurally there is a gentle dipping of the strata inwards towards the Drakensberg escarpment, owing to the downward force from the mass of volcanic basalt. Different sediments are typically exposed on steep south-facing slopes, while long gently sloped northern slopes may be underlined by the same sediment type or lithology for considerable distances. Quaternary alluvia (Qa) are deposited by floods in the major drainage lines, often constituting wetlands or river terraces (Herbert, 1996b and 1997).

Across the region, the Karoo Sequence sediments are divided into Molteno Formation (Trm) sandstones, mudstones and shales, and Elliot Formation (Tre) mudstones and sandstones as illustrated in Figure 2. The Molteno Formation appears from an elevation of about 900 m a.s.l. in the Maclear District and has a total thickness of 400 – 500 m. Near Chillingly and Glen Cullen, the Elliot Formation above 1 340 – 1 360 m a.s.l overlies it. These latter sediments may have a total thickness of up to 500 m (Herbert, 1997).

Figure 3. Location of midpoints for all enumerated compartments overlayed on geology.



The Molteno Formation consists of 10 – 12 upward cycles, layers of alternating sandstones and mudstones, sometimes followed by a coal or carbonaceous shale horizon. The sandstone is medium to coarse-grained, often pebbly, and light grey to yellowish-grey in colour. The sandstone is largely composed of quartz which glitters in the sun. The (softer) feldspar content is usually below 5%. The lower 1 – 2 m of sandstone is coarse-grained and poorly sorted with numerous mudstone pebbles and rounded quartzite, chert and granite clasts. This is followed by cross-bedded finer–grained sandstone grading into the over-lying mudstone. The pale-olive coloured mudstone is massive and soft. It may also contain subordinate grey shale. Each cycle of sandstone to mudstone has an average thickness of 40 - 50 m, and gives rise to large "steps" in the topography, often capped with a resistant quartzitic sandstone layer (Herbert, 1997; Karpeta and Johnson, 1979).

The Elliot Formation also consists of upward-fining cycles of sandstone, siltstone and mudstone, each cycle being about 60 m thick. Each cycle commences with approximately 1 m of poorly bedded fine to medium-grained greyish-red sandstone with mudstone clasts, followed by 20 m of fine-grained and cross-bedded sandstone. The sandstone may have up to 10% feldspar (Herbert, 1997; Karpeta and Johnson, 1979).

The sandstones pass upward into 40 m of siltstone and mudstone units of a greyish-red or (less commonly) greenish-grey colour. The Molteno sedimentary layers weathers into steep and rapidly stepped topography (Herbert, 1997; Karpeta and Johnson, 1979).

Intrusions of Jurassic Karoo dolerite (Jd) occur as occasional sills and dykes within the Molteno and Elliot sediments. Where it has made contact with mudstone, it forms a black and flinty rock called lydianite. The dykes are typically 3 – 10 m wide and are usually porphyritic in texture. Boulders of this basic, dark blue-grey, fine to medium-grained crystalline rock brake off and colluviate down-slope occasionally (Herbert, 1997; Karpeta and Johnson, 1979; Lloyd and Whitfield, 1990).

At high elevations, the pale-orange to pink fine-grained Clarens Formation sandstone is mainly in evidence as near-vertical cliffs on the edge of the escarpment and thus does not give rise to much plantable soils in most of the study area. In addition, it occurs discontinuously, unlike the other Karoo sediments. Its tendency to form sheer cliffs is due to it being well sorted in grain size and massive in form with poorly developed bedding. It has a fine to very fine-grained feltspathic sandstone or coarse siltstone content (Herbert, 1997).

The Drakensberg Formation Jurassic basalt consists of alternating bands of hard, massive, coarsely-crystalline rock and easier-weathering vesicular (air-bubble holes) varieties (de Decker, 1981). These alternations of harder and softer layers have given rise to the typically stratified or terraced appearance of the high Drakensberg. Individual flow of lavas average from 3 – 5 m in thickness, but may increase up to a maximum of 100 m. The thicker flows are generally more compact and non-vesicular and grey to greenish-black in colour as seen at Elands Heights (Herbert, 1997).

The vesicular lava is brownish-red or purple in colour and not as fresh as the massive non-vesicular bands. Thin flows of devitrified rhyolite also occur at Elands Heights on the farm Swithland. The blackish lavas appear to have weathered slowly, giving rise to shallow, often rocky yellow-brown apedal and structured subsoils. The vesicular brownish-red lavas have produced somewhat deeper soils, red apedal or weakly structured sub-soils, underlain by partially weathered rock and saprolite. The lavas weather to yield clay textured soils and are very base-rich, smectitic clays which are evident on the sticky and slippery roads (Herbert, 1997; Lloyd and Whitfield, 1990).

This diverse geology results in differences in topsoils, subsoils and saprolite depending on lithology, topography and climate. The vessiculated basalt, being more porous, weathers faster, giving rise to deeper soils and softer and better-drained saprolite than the massive non-vesicular species. The least conducive to soil formation is (the fortunately scarce) de-vitrified rhyolite. The greater resistance of non-vessiculated basalt not only gives rise to a stepped landscape with irregular ledge formation, but also to soils and saprolite of variable depth and drainage.

Since local geology provides the parent material for soil formation at a particular site, it plays an important role in soil quality (Zwolinski *et al.*, 1997). The geological parent material strongly affects soil texture, therefore the Jurrasic dolerite forms clay and silty clay textures and the Molteno and Elliot sandstones produce the sandy clay loam to sandy loam textured soils. Mudstones and siltstones of both formations have typically given rise to silty clay loam and clay loam textured soils. The most common soil texture is clay loam followed by sandy clay loam and loam, clay and sandy loam. A small area of silty clay and silty clay loam soils occur as well (M.A. Herbert, pers. comm., Fractal Forest Africa,1997 and M. Hensley, pers. comm., Institute for Soil, Climate and Water, 2000).

Topography includes all landscape positions from valley bottom to scarp and plateau, while numerous ridges descend from the escarpment to form narrow buttresses overlooking the plains. The slopes are mostly steep, especially on the flanks of ridges and spurs and soil depth appears to decrease as the slope increases. This is probably related to soil surface and sub-surface drainage. Accordingly, soil depth increases markedly on foot slopes and floodplains, but becomes shallow on ridgebacks and upper-mid slopes as illustrated by numerous rocky outcrops. It is particularly noticeable that southern slopes are frequently markedly steeper than northern ones, with generally shallow and very rocky soils.

Climate has a major influence on soil formation, both as regards precipitation and temperature. While the top of the escarpment (>2 500 m a.s.l.) is clearly the wetter site, its soils are shallow and rocky due to the mean annual temperature (MAT) being estimated below 8,9 °C. The low temperatures markedly reduce chemical weathering, the principle process for the breakdown of igneous (i.e. non-particulate) rocks. On the other hand, weathering also increases with precipitation, not only providing water for chemical solution, but also providing the deepest soil and saprolite, while the opposite applies to dry and cold sites. It is interesting to note that more concretions and plinthic subsoils are to be found along the long north facing slopes of Templer Horne and Swithland at Elands

Heights, even on deeper soils. This would suggest that their air temperatures are relatively high (increased solar radiation), but that they have a lower leaching rate (less precipitation) and are periodically very dry.

The combined effects of lithology, topography and climate find combination expression in soil development. As the rate of weathering increases, soils deepen and become more friable, developing apedal subsoils with uniform red or yellow-brown colour. The accompanying biotic conditions are conducive to higher rates of plant and animal growth, which in turn are reflected in thicker and more organic-rich soils.

Soil forms common to the North East Cape include Inanda, Hutton, Bloemdal, Magwa, Cartref, Nomanci, Kranskop, Clovelly, Glencoe, Glenrosa, Mispah, Longlands, Constantia and Bainsvlei. The Inanda, Magwa and Nomanci forms have humic topsoils with at least 1,8% organic carbon content. These soils constituted 58% of the soils encountered by Herbert (1997), normally indicating a reasonably moist, cool environment. However, the organic carbon content generally only slightly exceeded 2%, which is relatively low in comparison with traditional forestry soils (Herbert, 1997). In the Elands Heights area, the Inanda, Nomanci and Kranskop soil forms are associated with igneous basaltic parent materials, while the Magwa and Clovelly forms are exclusively found on Elliot and Clarens Formation sandstone and mudstones (Herbert, 1999). The Hutton and Mispah soil forms are mostly associated with drier and more sandy site conditions as reflected in their low topsoil organic carbon status. The poorly drained Cartref, Longlands, Constantia, Bainsvlei and Bloemdal soil forms are found in concave and lower landscape positions and have noticeably more sandy textures (Herbert, 1997). During a study at higher altitude in Elands Heights, Herbert (1999) showed that there are major differences between the basaltic soils prevalent in this area in comparison with the landholdings towards Maclear, Ugie and Elliot where sedimentary soils are prevalent. Herbert (1999) furthermore found that basaltic lithology could be further sub-divided into "normal" and ultra-basic material. The ultra-basic basalt-derived soils have clay textured A and B-horizons, with a marked increase in clay and silt content in the B-horizon i.e. luvic subsoils. The topsoil organic carbon content is very similar to that of "normal" basalt soils, however, their ultra-basic chemistry results in an exchangeable cation content of over 18 cmol(+)/kg clay, i.e. eutrophic. They have a particular high magnesium (Mg) content, even higher than that of calcium (K). The high base status of the basalt soils may also be an indication of relatively young soils with a constant input of fresh weathering material. Available phosphate (P) averages 3 mg/kg in both A and B-horizons (Herbert, 1999).

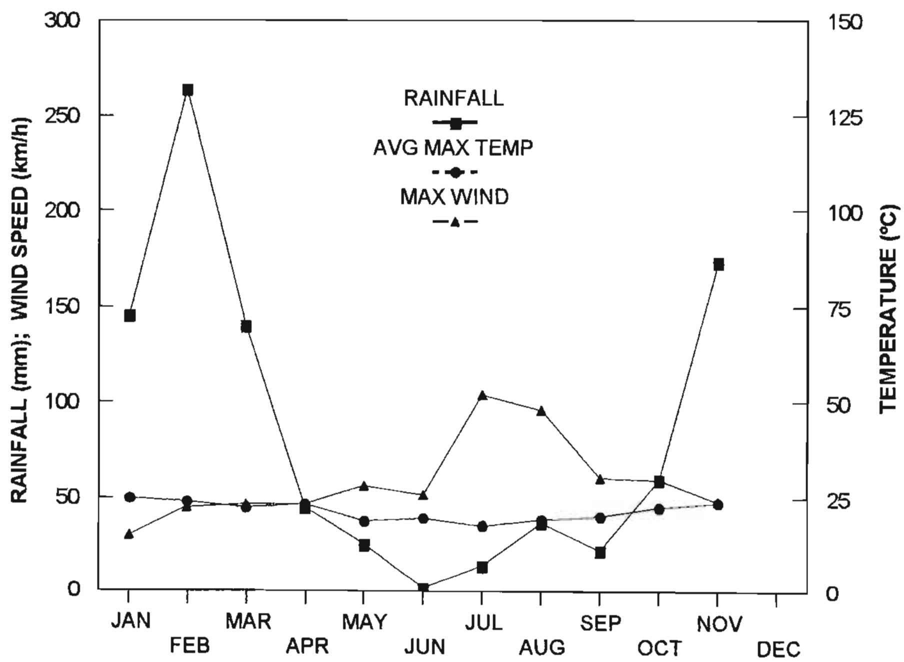
In contrast, the Clarens and Elliot Formation sandstones and mudstones have sandy clay loam to clay loam textures, often with a slight decrease in clay from A to B horizons. They are invariably dystrophic in the subsoil, with exchangeable cation contents of 4,1 and 2,7 cmol (+)/kg clay respectively. Their low pH reflects low exchangeable calcium content. Their coarser soil texture and occurrence at lower elevations (less precipitation) results in lower topsoil organic carbon (OC) contents averaging about 2,8% (Herbert, 1999).

3.4. Climate

3.4.1. Temperature

The climate of the study area is warm temperate and is typical of the high elevation summer rainfall areas of South Africa. Summers are warm with regular thunderstorms bringing most of the high annual rainfall while winters are cold and dry with frequent frosts and occasional snowfalls. Figure 3 is an example of the temperature and rainfall occurrence during 1998.

Figure 3. Maximum wind, monthly average maximum temperature and monthly average rainfall occurrence during 1998.



In the study area, temperature recording stations are located at Sheeprun (1 213 m asl.), Maclear (1 250 m asl.), Ugie (1 310 m asl.), Elliot (1 463 m asl.) and Rhodes (1 875 m asl.). Their long term average monthly maxima, means and minima are given in Table 3. The mean annual temperature (MAT) for Maclear is 15,60 °C and that for Elliot 14,15 °C, a difference of 1,45 °C. Their minimum temperatures for June are 3,70 °C and 2,00 °C respectively, a difference of 1,70 °C, but the maximum January temperature of 25,10 °C in Maclear is 0,20 °C cooler than at Elliot (25,30 °C). Thus it would appear that the temperature regime in Maclear is different to that at Elliot.

From the monthly temperature data it is evident that the warmest month is January and the coolest weather occurs during June and July. Following uniform higher temperatures from December to February, there is a steady change in air temperatures from March to November, with a moderately high annual mean monthly range of 10,30 °C (Elliot) to 11,50 °C (Sheeprun), indicating little moderating coastal influence (Herbert, 1999).

Minute by minute maximum, mean and minimum temperature, generated by the Department of Agricultural Engineering (DAE) at the University of Natal by using altitude and distance from the sea (Schulze and Maharaj, 1994), were compared with the relatively reliable records for Ugie and Elliot by Herbert (1999). These show that the model-generated MAT data appear on average to be 0,60 °C higher. The average decrease in MAT with altitude of 0,42 °C per 100 m between 1 200 m and 1 500 m is in favourable agreement with the records. Thus the DAE model appears to apply reasonably well to the study area (Herbert, 1999).

The maximum monthly temperature responds somewhat more rapidly to changes in altitude than does the minimum. This tallies with experience in the study area of high day temperatures in the valley bottoms, whereas the cold nights are more universally accounted for.

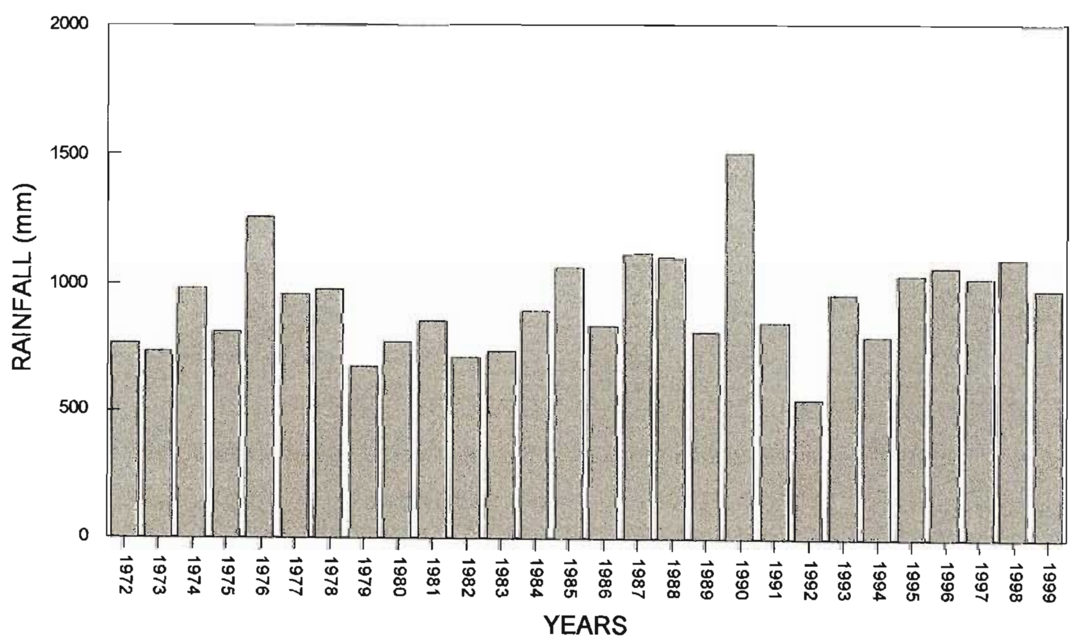
Table 3. Records and model-based monthly maximum, mean and minimum temperatures (Herbert 1997).

Location and Measuring Time	Altitude (m a.s.l.)	Temp (°C)	Month												Annual
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sheeprun *(1990 – 94)*	1 213	Max	26,7	25,8	25,3	21,8	20,0	17,4	18,3	20,1	22,3	23,2	23,9	26,1	22,58
		Ave.	20,5	19,7	19,0	15,1	12,2	9,0	9,5	11,5	14,6	16,4	17,5	19,6	15,38
		Min.	14,3	13,6	12,7	8,4	4,4	0,6	0,7	2,9	6,9	9,6	11,1	13,1	8,19
Maclear *(1988 – 93)*	1 250	Max	25,1	24,3	23,8	22,9	20,7	17,7	18,6	19,7	21,5	21,0	23,1	24,1	21,88
		Ave.	19,5	19,0	18,0	16,5	13,9	10,7	11,4	12,9	14,7	14,7	17,2	18,5	15,6
		Min.	13,8	13,7	12,2	10,0	7,0	3,7	4,2	6,0	7,8	9,3	11,3	12,8	9,32
Ugie *(1980 – 91)*	1 463	Max	25,1	24,9	23,9	22,4	20,3	17,5	17,8	19,4	20,5	21,3	22,6	24,9	21,72
		Ave.	19,3	19,1	17,8	15,1	12,1	8,9	8,8	11,1	13,3	14,8	16,5	18,7	14,62
		Min.	13,5	13,3	11,7	7,8	3,9	0,3	-0,2	2,8	6,1	8,2	10,4	12,4	7,52
Elliot *(1980 – 91)*	1 463	Max	25,3	25,0	23,3	21,6	19,1	15,8	16,3	18,0	19,6	20,8	22,7	24,7	21,02
		Ave.	19,0	18,8	17,1	14,5	11,7	8,9	8,7	10,5	12,5	14,2	16,0	18,1	14,15
		Min.	12,7	12,5	10,8	7,4	4,3	2,0	1,1	2,9	5,4	7,5	9,3	11,4	7,28
Rhodes (1990 – 94)	1 875	Max	26,2	24,8	23,3	20,7	17,6	13,7	14,9	16,0	21,0	21,3	23,1	25,5	20,68
		Ave.	18,0	17,1	14,9	11,9	9,3	7,1	7,6	8,4	11,6	12,7	15,0	17,0	12,52
		Min.	9,8	9,4	6,4	3,0	0,9	0,5	0,3	0,8	2,2	4,0	6,5	8,5	4,36
DAE* Model	1 325	Max	26,6	26,2	24,7	22,2	19,8	17,2	17,4	19,4	21,4	22,6	23,9	25,9	22,28
		Ave.	20,0	19,8	18,2	15,2	12,2	9,6	9,4	11,4	13,9	15,6	17,2	19,1	15,15
		Min.	13,4	13,4	11,8	8,3	4,7	1,9	1,5	3,5	6,5	8,7	10,5	12,3	8,04

3.4.2. Precipitation

Monthly maximum, mean and minimum precipitation and the standard deviation of the mean are shown in Table 4 for Somerville, Kromhoek, Ugie, Maclear, Werda, Stockenstroom, Woodcliffe and Ntywenka. These weather stations have long term (more than 15 years) and reliable records. They were also selected to show a range of land types, with Ntywenka located on the first major inland escarpment, Somerville on the lower plains before the Drankensberg foothills, Kromhoek, Maclear and Stockenstroom in outer foothills, Ugie and Werda on the plateau beneath the Drakensberg escarpment and Woodcliffe at the higher foothills of the Drakensberg range. Figure 4 reflects the long term rainfall from 1972 – 1999 for the region.

Figure 4. Annual rainfall for the north-eastern part of the Eastern Cape Province.



In Maclear, a variation in annual precipitation was studied by Herbert (1999). The outstanding feature was the variation from year to year. The annual precipitation has varied by 753,7 mm, and ranged from 369,1 mm to 1 122,8 mm (99% of MAP), and the standard deviation of MAP was 178,0 mm about the mean of 764,8 mm.

The distribution of average monthly precipitation for Ntywenka, Somerville, Maclear, Werda and Kilmeny (similar to Woodcliffe, but a longer recording period) showed that there were three types of sites in terms of precipitation amount and distribution, *(i)* on the high escarpment (Ntywenka, Kilmeny, Woodcliffe), *(ii)* on the foothills of the Drakensberg (Maclear, Stockenstroom) and *(iii)* on the plateau adjacent to the Drakensberg (Werda, Somerville, Ugie). Rainfall on the plateau below the escarpment peaks in November and February with a drop in January. In contrast, sites closer to the major escarpments have a clear peak of precipitation in January. Precipitation on the high (south-facing) escarpments is the greatest of all sites in any month, but is most markedly so between October and March when some 82% of annual precipitation falls. Maclear, Werda, Ugie and Stockenstroom also receive almost identical percentages (82%) of rain in these months, but the drier areas such as Somerville and Kromhoek receive only 77% and 69% of their precipitation in summer (Herbert, 1999).

Except where MAP is close to 1 100 mm, less than 50 mm of rain falls in any of the six winter months with under 25 mm per month between May and August. There is thus a regular and marked winter drought in nearly all areas. An occurrence of no rainfall has been recorded at Maclear for every month except January (wettest month). Good rains start only after September (Herbert, 1999). Figure 5 illustrates the seasonal change in precipitation from 1972 to 2000.

Figure 5. Seasonal rainfall for the north-eastern part of the Eastern Cape Province (w = April - September; s = October - March)

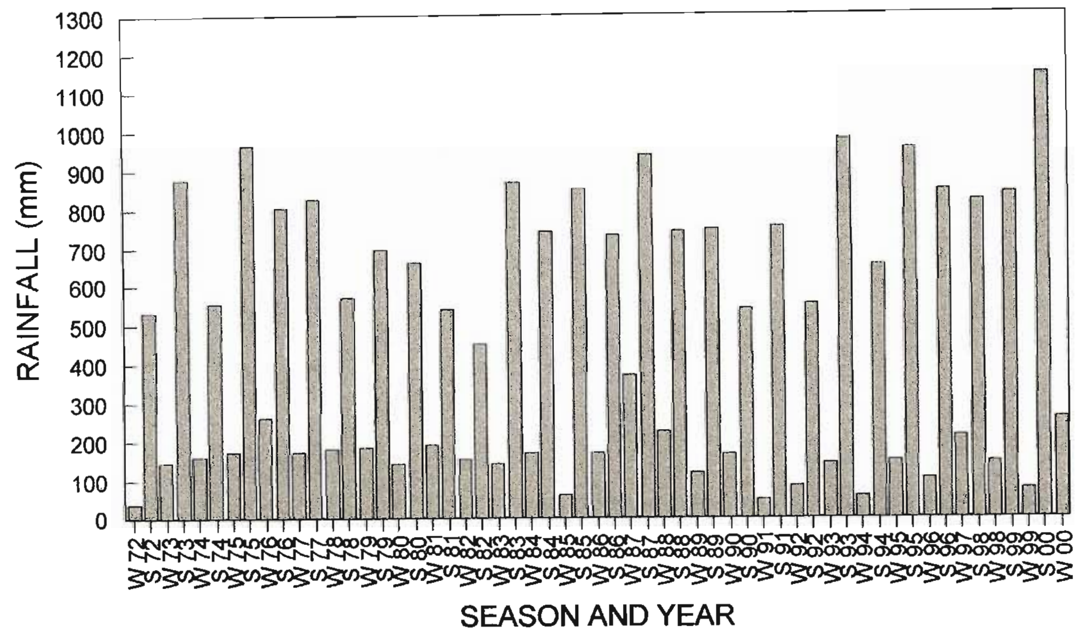


Table 4 shows that high monthly precipitation may occur, with 367,5 mm being recorded in January at Maclear, 483,5 mm in December at Woodcliffe and 384,6 mm at Ntywenka in March. These heavy rainfalls will reduce the effectiveness of rainfall due to surface runoff as well as increasing the soil erosion hazard, especially on steep slopes with sandy soils, however, they are not as disastrous as those recorded following cyclonic events in KwaZulu Natal and Mpumalanga (Herbert, 1999).

The records show that precipitation tends to increase with altitude. Low elevation areas, further from the escarpment (e.g. Somerton) have a MAP of about 660 mm. This falls mainly in the form of thundershowers and cold front rains and is not overly influenced by topography. Precipitation also generally decreases with distance from the coast and from the leading southern crest of the escarpment. These phenomena are related to the fact that moist air tends to be directed inland mainly from the south and south-east, and is accordingly intercepted as orographic rainfall and mists by escarpments facing into this direction of air mass movement. Precipitation thus decreases on the northern side of escarpments where the topography drops away, especially where there is no high ground immediately to the northwest, however, close to the Drakensberg there is less of an influence of broken topography on precipitation as clouds and mist tend to over-hang the southern aspects of the escarpment and cause widespread rain and drizzle (Herbert, 1999).

Table 4. Average monthly maximum, mean and minimum precipitation (Forsyth et al., 1996).

Location	**Alt. (m)**	**Mean Monthly Precipitation (mm)**													
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Somerville	900	Max.	167,0	203,3	192,1	114,8	153,7	148,9	22,6	58,4	226,2	120,5	173,4	157,6	1 157,4
31°12' S		Min.	32,0	41,8	32,1	1,0	1,5	0,0	0,0	0,0	0,5	0,0	9,9	25,5	428,8
28°39'E		Mean	91,7	110,3	84,7	50,0	23,8	13,0	5,5	17,3	50,7	53,1	77,5	109,0	686,6
(1892 – 1913)		Std.	40,4	44,6	40,2	30,4	34,5	33,3	6,6	17,3	50,4	38,0	50,1	37,2	140,1
Kromhoek	1 216	Max.	279,5	262,8	209,9	86,1	137,2	131,5	36,8	81,8	152,6	108,7	227,1	222,7	1 006,7
30°59'S		Min.	64,7	36,0	14,7	0,0	0,0	0,0	0,0	0,0	0,0	14,0	6,9	27,7	495,5
28°29' E		Mean	120,4	114,7	89,9	44,6	30,2	17,9	8,1	16,7	32,8	57,2	92,5	105,5	730,5
(1938 – 1965)		Std.	55,6	52,0	45,3	22,5	32,0	32,3	10,3	20,8	32,0	25,7	62,1	53,4	137,1
Ugie	1 303	Max.	246,5	308,8	247,0	164,5	55,5	94,0	71,3	117,7	98,4	180,2	217,3	278,0	1 272,3
31°12'S		Min.	38,0	29,2	15,0	8,0	0,0	0,0	0,0	0,0	0,0	0,0	20,1	21,4	456,8
28°14'E		Mean	114,1	137,2	95,7	50,6	13,3	12,0	11,4	19,8	25,3	69,3	87,5	111,4	747,6
(1963 – 1995)		Std.	65,1	71,1	60,7	38,9	16,2	21,4	16,8	25,3	25,4	49,9	52,4	81,1	273,3
Maclear	1 250	Max.	376,5	352,0	271,7	106,7	104,7	133,0	171,9	113,8	185,4	193,6	237,5	248,5	1 122,8
31°04'S		Min.	11,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	369,1
28°21'E		Mean	131,4	123,6	107,6	44,8	20,1	10,7	11,9	17,9	34,3	60,6	86,9	115,0	764,8
(1891 – 1995)		Std.	68,4	61,9	58,4	33,6	21,5	18,7	22,3	21,8	30,6	39,5	52,7	56,7	178,0
Werda	1 335	Max.	236,5	292,1	236,7	138,4	167,6	50,8	68,6	93,0	212,9	154,4	231,9	267,0	1 048,3
31°10'S		Min.	27,9	25,9	10,2	0,0	0,0	0,0	10,5	0,0	0,0	6,6	26,4	17,8	414,4
28°16'E		Mean	108,7	137,3	109,5	41,8	19,3	6,8	0,0	19,2	34,7	66,9	85,4	125,7	765,9
(1968 – 1994)		Std.	49,3	65,1	57,7	31,9	34,3	11,9	15,4	23,9	43,1	43,0	45,0	65,0	140,5
Stockenstroom	1 230	Max.	231,5	349,1	343,2	103,6	86,1	116,6	63,5	137,2	185,0	184,5	263,4	242,2	1 150,9
30°59'S		Min.	57,8	28,2	24,1	7,4	0,0	0,0	0,0	0,6	0,0	23,7	12,8	42,4	419,7
28°23'E		Mean	129,6	126,4	116,7	46,5	17,2	14,5	11,6	24,6	35,3	80,5	88,4	113,2	804,5
(1962 – 1995)		Std.	54,5	68,3	68,2	25,7	21,3	25,3	14,7	28,4	36,9	47,1	47,4	53,9	166,7
Woodcliffe	1 542	Max.	473,9	324,7	207,1	130,0	98,8	57,4	22,4	75,5	160,1	164,7	314,5	483,5	1 429,6
31°00'S		Min.	54,3	80,7	66,8	2,5	1,3	0,0	2,2	0,0	6,4	36,1	5,8	81,2	548,9
28°11'E		Mean	184,7	170,9	137,0	59,8	31,3	10,6	4,1	26,4	62,7	83,4	115,1	168,8	1 054,8
(1891 – 1911)		Std.	107,5	76,6	52,7	38,8	28,4	16,0	6,6	25,8	40,8	44,9	77,2	95,6	257,7
Ntywenka	1 378	Max.	328,3	355,9	384,6	348,5	119,9	110,0	171,3	142,6	338,0	233,2	360,0	232,2	1 549,5
31°11'S		Min.	47,9	35,5	21,0	0,0	0,0	0,0	0,0	0,0	3,0	35,1	14,2	37,1	736,5
28°37'E		Mean	149,2	152,3	142,4	62,6	28,9	14,7	18,1	26,5	60,5	109,3	141,2	155,9	1 091,6
(1923 – 1995)		Std.	66,3	65,6	67,6	51,9	29,8	20,3	27,1	30,0	53,1	47,8	76,0	66,2	172,6

Herbert (1997) examined precipitation for Sheeprun (756,0 mm), Inglewood (832,5 mm), Sunbury (792,1 mm), Mooilaagte (707,3 mm), Gatberg (913,0) and Rockwater (1 131,6 mm). From all the available data it appears that precipitation is highest on the Drakensberg escarpment and increases rapidly with altitude. Conversely, it is lowest on the plains and hills below and away from the escarpment. Using data from DAE, these observations are confirmed as two distinct data sets and statistically highly significant relationships were derived from estimating MAP from altitude. A third highly significant relationship also exists between MAP and altitude for selected recording stations close to plantations. The relationships are shown in the following equations:

For Mountains: MAP = -17 488,76 + 2 553,872 (ln Altitude) .....
[n=8; R^2 = 0,97]

For Plains: MAP = -14 997,57 + 2 190,143 (ln Altitude) .....
[n=21; R^2 =0.86]

For Weather Stations: MAP = -8 569,439 +1 311,664 (ln Altitude) .....
[n=6; R^2 =0.98]

MAP = Mean annual precipitation (mm)

Altitude = Height above sealevel (m)

The equation "For Plains" tends to underestimate MAP at low elevations, as precipitation reaches a minimum at about 650 – 700 mm per annum. In addition, weather stations such as Kromhoek, Maclear and Sheeprun indicate that sites close to the escarpment base have MAP of 750 – 800 mm, somewhat higher than the "For Mountains" equation estimates. Together this information indicates a non-linear relationship between altitude and MAP at lower elevations below approximately 1 200 m, as precipitation does not drop below certain minimum values. The equation "For Weather Stations" has a gradient flatter than those for the other two equations and may in fact represent an intermediate stage between the plains and mountains rainfall systems where precipitation increases gradually as the base of the escarpment is approached (Herbert, 1997).

From the three above equations, it was estimated that MAP on the outer "Plains" varied from about 706 mm at 1 300 m a.s.l. to 868 mm at 1 400 m a.s.l., and the "Mountains" MAP ranged from 919 mm at an elevation of 1 350 mm to 1 188 mm at 1 500 m a.s.l. The interleading sites closer to the escarpment than the "plains" had a MAP of 835 mm at 1 300 m a.s.l. and 979 mm at 1 450 m a.s.l (Herbert, 1997).

3.4.3 Comparative Climate

A very interesting study, comparing the climate of the study area with that of Piet Retief and Sabie (as traditional forestry areas) and with the emphasis on forestry potential was conducted by Thackrah and Monnik (1998). The objective of the study was to compare and contrast these areas in order to determine which, if any, climatic factors could play a role in the North East Cape.

Eight weather stations with long historical records (Monnik, *et. al.,* 1997) and as close as possible to plantation sites were identified in the Sabie, Piet Retief and North East Cape Forests areas. Climatic data from these stations were downloaded from the National AgroMet Databank (ARC-ISCW) and analyses were done on long-term mean annual/seasonal, monthly and daily basis. Interaction between the following elements were looked at:

- rainfall versus temperature
- rainfall versus heat units
- rainfall versus A-pan evaporation

Lang's climatic index (LCI) was determined for the different stations: LCI is a ratio of mean annual rainfall to mean annual temperature (mm/°C). This formula was also applied on a mean monthly rainfall/temperature basis.

Since trees respond to an interaction between suiTable water and temperature conditions, the time series from the winter dormant period to the main growing season in summer was carefully examined. This is the period when tree dieback (refer 4.10) is generally observed.

The most significant differences in climate which were found between the weather stations representing the study area and the other two sites (Piet Retief and Sabie) were as follows:

- The mean temperature at NECF (14 – 16 °C) is 2 – 3 °C lower than that at Piet Retief and Sabie, but still falls within the criteria for optimum *P. patula* and *P. elliottii* growth (Morris and Pallett, 2002).
- The mean minimum temperature for June/July at NECF is below 2 °C (or even below zero at Ugie), compared with above 4 °C in the other two areas. Unlike

Piet Retief and Sabie, NECF therefore falls well outside the criteria for optimal tree growth (daily mean minimum temperatures for July should be between 4 and 12 °C for *P. elliottii* and 6 and 12 °C for *P. patula*). This low minimum temperature in combination with the high mean monthly windrun measured at NECF during the winter could cause top dieback and the mortality of young trees.

- NECF has a much lower, and longer monthly LCI peak period compared to the other two areas. The lower rainfall per degree Celsius over the period November to February, in combination with peak evaporation in December, could cause a relatively dry period over December and January at NECF compared with the other two areas.
- The United Nations Food and Agriculture Organisation (FAO) moisture season at NECF stretches from October to April, starting later and lasts for a longer period than that observed at Piet Retief and Sabie.
- At NECF no heat units (base temperature of 10 °C) accumulated before the start of the rainfall season, compared with an accumulation of around 500 degree days in the other two sites.
- NECF has a significantly higher frequency of days with minimum temperature below 0 °C compared with the other two regions. Infield experiments showed that *P. patula* may experience water stress at –5 °C and below. One can deduce that the dieback symptoms in spring at NECF are linked to cold/water stress, which does not occur at either Piet Retief or Sabie (Thackrah and Monnik, 1998).

4. OTHER FACTORS POTENTIALLY INFLUENCING TIMBER PRODUCTIVITY

Due to the "green fields" nature of NECF, a significant learning curve formed an integral part of the period reflected in the growth data. Some of the more important issues, which might have impacted on tree growth and stand characteristics of the measured growing stock will be described in this chapter.

4.1 Old Land Syndrome including Soil Characteristics, Toxic Characteristics, Pests and Pathogens

Poor survival of pines occurred in some compartments during afforestation. Rapid mortality of *P. patula* and *P. elliottii* occurred when small container seedlings were planted in old agricultural soils. Death would often occur within five months of planting. Growth of surviving trees would be retarded and new needles were chlorotic and stunted. AccepTable survival was obtained when seedlings were planted on virgin grasslands. It was observed that some factors in the post-agricultural soils reduced root growth, increased mortality and decreased uptake of nutrients. This pathological component was then called "Old Land Syndrome". Removal of the top soil by scalping improved survival and growth (Zwolinski *et al.,* 1996).

Symptoms typical of old land syndrome are widespread mortality and growth suppression of pines during the first few months after planting. The first visible sign is necrosis of needle terminals after which seedlings rapidly wilt and die. Common symptoms also include poor root development, stunting, lack of apical dominance and necrosis of the growing tip. *P. patula* was more drastically affected than the other species.

Remarkable differences in tree performance were observed between old land and neighbouring virgin lands. Boundaries would often be in straight lines and along fencerows. Well-performing trees on virgin sites occurred within a few metres of suppressed and dying trees on old lands. In many instances seedling size, origin, planting methods and planting dates were the same for both virgin land and old lands. Mortality on the old lands was frequently more than 25%. Many of the sites were repetitively replanted, some up to six times, without obtaining satisfactory tree survival. Even if survival was accepTable, tree growth would be poor resulting in suppression of small seedlings by weeds and production losses. Old lands were not identified as separate entities in this study due to the fact that the current criteria for a management compartment do not take this into consideration and such differentiation was not made consistently within the management framework reflected in the dataset.

4.1.1 Soil Physical Properties

Louw *et al.* (1994) surveyed the sites and compared physical soil properties between the old lands and virgin sites. Overall, soil clay content ranged from 10% to 28% in the topsoil and from 13% to 57% in the subsoil. On sites showing good tree survival and growth, the clay content of the top soils was slightly lower (18%) compared to higher clay content (21%) on sites where poor tree performance was observed. Average bulk densities of these soil's were 1,39 g/cm^3 and 1,45 g/cm^3, respectively. There was no clear difference in the soils penetration resistance.

However, the soil penetration resistance on the ridge (planting line) was higher than between the ridges on sites with poor tree performance. In addition to higher soil strength in the planting ridges of old lands, bigger, more numerous clods occurred on the old lands than on virgin sites. Clods were formed during the combined ripped ridge land preparation and therefore were concentrated in the planting zone (Smith and Van Huyssteen, 1992).

Soil instability was tested by taking topsoil samples from old lands and virgin sites. The samples were dried and then wet-sieved to break down unsTable aggregates. After defining their mass, the aggregates were dispersed in an ultrasonic water-bath and the mass of sand left behind on the sieve was determined. After wet sieving, the virgin topsoil contained eight times (by mass) more water sTable aggregates than the old land topsoil (Smith and Van Huyssteen, 1992).

The original method of soil cultivation involved ripping and then formation of ridges by incorporation of topsoil into a planting bed. Seedlings were planted on the top of the ridge. Since the method produced very poor results, scalping (removal of a 1 m wide strip of topsoil, 10 – 15 cm deep) was introduced. Scalping was beneficial in solving a similar problem in post-agricultural fields in Florida (Barnard *et al.*, 1995). This method produces an opposite result to ridging. With ridging, topsoil is moved toward the planting zone and over the ripped line. Seedling roots have to travel through the disturbed soil before entering undisturbed topsoil and finally reaching the B-horizon (which often has higher moisture levels than ridges). With scalping, the topsoil is moved away from the planting zone and seedlings are often planted directly into the B-horizon, closer to moist soils. Scalping moves pathogens associated with topsoil away from the planting spot, as well as providing some measure of weed control. Under drought conditions in North America, scalping increased soil moisture, improved tree access to soil water with improved survival of pines (Stransky, 1961; Stransky and Wilson, 1966). The negative side of such site preparation is that nutrients in the topsoil are moved away from the seedlings, however applying fertilisers helped to mitigate this disadvantage (Little *et al.*, 1994).

4.1.2 Soil Nutrient Status and Fertilization

Analysis of soil nutrient elements on a range of sites representative of virgin and old fields was performed by De Ronde (1992). Overall, there were no significant differences ($p<0,05$) between virgin and old land in terms of soil organic matter (1,8%), cation exchange capacity (CEC) (3,6 me/100 g) and soil acidity (pH 5,2), however differences were detected for macro-nutrients. Nitrogen, potassium and magnesium contents were greater on the virgin soils, while phosphorus and calcium contents were greater for the old lands. On some productive virgin grasslands soil acidity was as low as pH 4,3 (Nobel and Schumann, 1993).

Nitrogen fertilization of old land sites has repeatedly improved pine growth (Schumann *et al.*, 1994). For example, in one study, fertilizers (primarily nitrogen and phosphorus) increased first year heights by 22 cm (Little *et al.*, 1994). Fertilization at planting often eliminates the symptoms of yellow and stunted fascicles that develop without fertilization, however, fertilization does not seem to eliminate the sudden mortality often observed on old lands. The application of fertilizer after ridging occasionally increased mortality of *P. patula*. In one study, the application of nitrogen (13 g/tree) and phosphorus (24 g/tree) reduced survival by 22% but, as expected, growth of surviving trees was increased (Little *et al.*, 1994).

Noble and Schumann (1993) reported low nitrogen content (1,07%) in foliage and nitrogen deficiency symptoms in pines grown on old lands. Based on results from a pot experiment, they concluded that adequate nitrogen nutrition on previously cropped lands is crucial for adequate growth of pines. They hypothesized that nitrogen deficiencies in pine seedlings growing on agricultural soils were caused by: (1) impact of continuous cultivation on supply of mineralizable nitrogen, (2) intense competition from soil microflora for inorganic nitrogen, (3) inhibition of effective nitrogen uptake due to damage to roots by allelo-chemicals.

4.1.3 Toxic Chemicals

When establishment of pines failed after repetitive planting, toxic levels of agricultural chemicals were often suspected of harmful impacts (Steinbeck, 1990; Schumann *et al.*, 1994). This, however, appeared to be unfounded when soil analysis from the failed sites showed only a small residue of atrazine. When evenly distributed in the top 15 cm of soil, this is approximately 166 g active ingredient (a.i.)/ha. Atrazine is a commonly used herbicide in maize and *P. patula* seedlings are tolerant of rates of 3 kg a.i./ha (Ball, 1974).

A greenhouse study was established to determine the impact of soluble maize stove extract on lettuce (*Lactuca sativa*) and to evaluate the influence of nitrogen and phosphorus fertilization on performance of *P. patula* seedlings grown on the old land soil (Noble and Schumann, 1993). Root growth of lettuce was reduced by maize extract and growth was increased by fertilization. Steam sterilization and addition of various nitrogen fertilizers produced increases in initially low nitrogen content (1.05%) in the needles. Plant mass was also increased with the application of nitrogen (Noble and Shumann, 1993).

4.1.4 Rodent Damage

In 1993, foresters reported the escalated incidence of rodent damage during the winter and, on average, 43% of the trees died due to rodent damage on more than 900 ha. Trees in many other compartments were alive but damaged and malformed due to rodent feeding. Trees that were most damaged were growing on wet sites or next to water courses, especially in the northern part of the region, which receives higher rainfall. The vlei rat (*Otomys irroratus*) or the striped mouse (*Rhabdomys pumilio*) gnaws bark around the base on the main stem of young trees. When trees are older, the rodents climb up the stems onto the branches, which are also debarked. Both types of damage result in tree malformations and dieback. The other type of damage is caused by the Cape porcupine (*Hystrix africaeaustralis*). The base of the tree is gnawed in various places producing stem malformation and occasional ring-barking effect. The Highveld gerbils (*Tatera brandsii*) indirectly kill very young trees by burrowing activity; seedlings become covered with soil or their roots are dislodged (Weir, 1994).

Effective control of rodents was achieved by erecting raptor perches. An attempt to protect and increase the Black-backed jackal (*Canis mesomelas*) population was strongly opposed by local farmers who believe that jackals are responsible for losses in sheep stock. Some good preventative measures included control burns in areas dominated by vlei rats and removal of vegetation around young trees and early preventative prune. Other proposed methods include live trapping and mechanical protection of stems. The use of poison was rejected as an option (Weir, 1994).

4.1.5 Pathogenic Fungi

Isolations were made from roots of diseased trees, as well as from soil in the rhizopshere on various sites (Linde *et al.*, 1994). Several *Pythium* spp. were associated with tree death, but of these, only *P. irregulare* was consistently isolated from both soil and dying pines. A high population occurred on previously cultivated lands because maize, wheat and oats are known hosts to *Pythium* spp. (Scott, 1997). Site preparation that involved ridging apparently enhanced the pathogen concentrations because *P. irregulare* is most common in the top 20 cm of soil. Scalping reduced population of the pathogen around the planted trees by up to 75% (M. Wingfield, pers. comm., Tree Pathology Cooperative Programme, University of Orange Free State, 1994).

Pathogenicity tests were performed in a greenhouse on *P. patula* and *E. grandis* seedlings with *Pythium* spp. which were isolated from diseased trees. *P. irregulare* killed 100% *E. grandis* seedlings and 83% *P. patula*. *P. irregulare*, *P. tardicrescens*, *P. spinosum*, *P. acanthophoron* were also virulent in *P. patula*. Unexpectedly, *E. grandis* was susceptible to several *Pythium* spp., possibly because very young seedlings (two months old) were used in this experiment (Linde *et al.*, 1994).

4.1.6 Soil Insects

In North America, the failure of pines to become established on post-agricultural lands is occasionally related to soil insects. In particular, white grubs (*Coleoptera: Scarabaeidae*) have caused mortality in maize (Luginbill, 1938) and in pine plantations (Watts and Hatcher, 1954; Sutton and Stone, 1974; Mitchell *et al*, 1991). In South Carolina, more than 3 200 ha of newly planted pine seedlings were heavily attacked (Speers and Schmiege, 1961). In some plantations, application of an insecticide at planting reduced both pine mortality and the frequency of damage by white fringe beetle larvae (*Garphognathus* spp.) or white grubs (Bennett, 1967; Mitchell *et al*., 1991; Barnard *et al*., 1995). At five sites in Florida, the use of insecticides (carbofuran) increased tree survival with variable success (Barnard *et al*., 1995).

In South Africa, white grubs are pests on eucalypts and have sometimes also been recorded on pines. In one study, white grubs reduced survival of *E. grandis* by 13% (Govender, 1993). In South Africa, black maize beetles (*Heteronychus arator*) have caused problems in maize and in some cases ring-barked pine stems (Schumann and Noble, 1993). However, although soil fumigation with methyl bromide increased tree survival on one old land site, the application of oxamyl did not prevent tree dieback (Atkinson, 1992).

4.1.7 Soil Nematodes

Several genera of nematodes are known to damage pine seedlings (Ruehle, 1969; Ruehle, 1973; Bassus and Banimivatee, 1985). One genus killed young pine seedlings within three months of inoculation (Dwinell, 1985). Typical injury symptoms include sparse, stunted roots, needle chlorosis and stunting of the shoot (Sutherland and Webster, 1993). For example, endoparasitic nematodes (*Pratylenchus*) can produce symptoms of chlorosis, stunting and root necrosis under both field and greenhouse conditions (Marks *et al.*, 1985). Other genera feeding on pine roots may increase mortality by reducing the seedling's ability to survive other stresses such as drought (Mitchell *et al.*, 1991). For some species, root mass can be reduced by 50% (Ruehle, 1969). Nematode damage may also provide infection loci for pathogenic fungi (Ruehle, 1973; Sutherland and Webster, 1993). It should be noted that according to Sutherland and Webster (1993), nematode damage often occurs in conifer nurseries located on old agricultural fields with indigenous nematode populations.

In 1991, plant parasitic nematodes were sampled at five old land sites in NECF (Atkinson, 1992). Samples were also taken from five virgin grassland sites. More nematodes were found on post-agricultural sites than grassland sites. *Paratylenchus* were relatively abundant at several problem sites. At three of the five sites, population levels exceeded 200 nematodes per 100 ml of soil. Under greenhouse conditions, *Paratylenchus* and *Pratylenchus* can cause great damage to the feeder roots of *P. patula* (Bassus and Banimivatee, 1985). In western Mpumalanga, *Pratylenchus zeae* is the most common endoparasite in maize roots (Jordaan *et al.*, 1987).

4.1.8 Weed Control

Weeds were controlled both manually and with herbicides. Manual weeding involved hoeing of vegetation to mineral soil around the planted seedlings. This prevented weed competition in proximity to the trees and also reduced rodent damage. The chemical method involved application of glyphosate (1,9 kg a.i./ha) or gramoxone (0,9 kg a.i./ha). This application was repeated three to four times per annum. During each application, pines were protected with glass fibre or plastic cones. Occasional damage occurred when herbicides penetrated onto the inside tube (contacting the foliage) or when no care was taken to protect exposed foliage (K.M. Basset, pers. comm., North East Cape Forests, 2001). This type of damage, however, occurred most frequently on well performing trees (i.e. on trees with abundant foliage and well developed branches) and therefore can be distinguished from the old land syndrome. A combination of inexperienced forestry labour, the intensive summer weed season and abundance of weeds on old lands resulted in sub-optimal weed control regimes (Darrow, 1997).

4.1.9 Methyl Bromide Fumigation

Soil fumigation with methyl bromide (392 kg a.i/ha) improve both survival and growth of seedlings planted on post-agricultural soils in northern Florida (Barnard *et al.*, 1995), where this fumigant was used for testing hypotheses regarding old land syndrome. Generally, effective fumigation controls weeds, nematodes, pathogens and grubs without affecting soil physical properties. In Florida, fumigation improved survival of *P. elliottii* by 21% on one site and by 17% on another. Methyl bromide was tested on two old land sites in the NECF. In one study, fumigation with 972 kg a.i./ha increased seedling survival by 12% (Atkinson, 1992). In another study *P. patula* seedlings growing in fumigated soils averaged 90 cm in height compared to 51 cm for control seedlings 420 days after planting (Little *et al.*, 1994). In the second study survival was high for both treatments (95 – 96%). Due to environmental considerations this method was never deployed on a commercial scale.

4.2 Root Development

Following concerns about the lack of root development evident during destructive sampling (Van Laar, 1995) a study of pine tree root growth by means of the non-destructive minirhizotron technique was undertaken at NECF between July 1996 and March 1998 (Fyfield, 1998). The objective was to determine seasonal changes in the root growth of *P. patula*, in conjunction with various aspects of aboveground tree growth, and thereby contribute to a better understanding of factors influencing pine production. The study was undertaken at two sites, Funeray and Tree Fern Pool (Glen Cullen), with differing soil characteristics and annual rainfall. Nine transparent minirhizontron tubes were installed at each site, providing a maximum viewing depth of 1,35 m. A colour minirhizotron video camera was used on six occasions to observe and record roots which had come into contact with the tubes, beginning nearly 3 months after the tubes were installed and then at approximately 3-month intervals thereafter. Root length totals were determined for different depth intervals and expressed as mm/mm^2 of tube area viewed (Fyfield, 1998).

No tree roots were seen at the first recording in October 1996, but 3 months later, after some 500 mm of summer rainfall, pine tree roots were visible from almost every tube. Apart from the white young laterals and root tips, the roots were generally a dark purplish-brown colour. The short Y-shaped branches observed were found to be mycorrhizal roots, stimulated through infection by an ectomycorrhizal fungus, the mycelia of which could also often be seen. Since such roots represent an important component of the surface area of a root system available for nutrient absorption, their numbers were counted and expressed per mm root length (Fyfield, 1998).

A clear contrast between the rooting profiles at the two sites was evident, with most of the root growth occurring in the 0,15 – 0,45 m depth interval at Funeray, whilst at Tree Fern Pool it was much more evenly distributed down the profile. The restriction on deeper root growth at Funeray was probably a hard layer over saprolite starting at a depth of about 0,65 m, which had made tube installation there very difficult. A change in the soil profile to a yellow-red colour could be seen at that depth with the camera. The rate of root turnover, i.e. the balance between root production and death, was expressed in terms of the percentage change in root length over each 3-month time interval. A faster net root growth rate was evident in the summer compared with the winter months, particularly at Tree Fern Pool, however, the roots at Funeray appeared to compensate through a greater production of mycorrhizal roots (Fyfield, 1998).

This study thus succeeded in its primary goal, namely the application of the minirhizotron as a non-destructive root growth measurement technique. However, no significant results were obtained that could shed further light on the root development, timber productivity relationship.

In another study conducted by Terblanche (2001, in press), the effects of root deformation on tree growth and stability were investigated. "It is unaccepTable to prepare soils, plant seedlings, fertilise and weed them on sound researched information and knowledge then ending up with useless four year old pine compartments with 70% or more of the stand consisting of unsTable trees. The financial implications of such failures are disastrous" (E. Droomer, pers. comm., Manager NECF, 1994).

The impact of root deformation is not only important for tree growth and survival, but also for the resistance to wind damage. Wind damage can be divided into two distinct categories: toppling and windthrow. Mason (1979) states that toppling occurs between the ages of two and six years (the tree starts leaning) and windthrow (the tree breaks at ground level) usually when the stands are much older. Toppling is a gradual weakening of the root fibres caused by tree sway and is often preceded by socketing. In severe winds these roots will break. Toppling is generally confined to planted stands, while wind throw can also occur in naturally regenerated forests. Windthrow is accompanied by a failure of the stem at the root collar or roots being pulled out of the soil (Atterson *et al.*, 1963; Mason, 1979; Mason, 1985; Håkansson and Lindström, 1995).

Improving container design can reduce the risk of toppling (Tinus, 1981). The underlying cause of toppling is the transplanting of a seedling into a new growing medium and the alteration of the natural root development pattern (Mason, 1979). Various opinions for the cause of this phenomenon have been offered, including poor quality of tree stock, method of planting, soil and site conditions, low fertility, low root:

shoot ratios, exposure to favourable weather, weed competition and low stocking (Mason, 1985).

The next aspect to consider is the nutritional status of the trees. Nitrogen and phosphorus concentrations in open rooted *P. radiata* seedlings will drop with a decrease in the number of first order lateral roots (Nambiar, 1984). Phosphorus and potassium are less affected by number of roots and root treatment. Nambiar (1984) found that the combination of low weed control and limited root length result in low nutrient concentrations compared to high values found in intensive weed control treatments.

Following this the actual survival and growth of the transplanted seedlings is of critical importance. A healthy root system ensures effective water and mineral absorption as well as anchorage (Mason, 1985). Establishment success depends on root growth resulting in an improved nutrient and water uptake ability (Burdett *et al.*, 1983). Seedling survival depends to a large extent on the size, shape, type and efficiency of the root system (Eis, 1978).

Root quality and quantity determine stability and survival (Stone and Norberg, 1978; Mason, 1985). The structure and development of root systems is essential for the ecological and physiological requirements of forest tree species. The relevant knowledge is a necessary base for silvicultural decisions (Eis, 1978).

It is generally agreed that the understanding of root development and configuration allow for predicting of seedling survival and development in the field. Tree stability, nutrient and water uptake, tree form, growth, disease tolerance, morphology and physiology are some of the more relevant factors.

There are differences of opinion and gaps in the knowledge base and further investigations are therefore necessary. Root deformation, malformation and all the other descriptive terms used for poor root systems must be better qualified and quantified in order to accurately understand and predict tree survival and growth at NECF.

4.3 Tree Breeding and Species Choice

When Mondi Forests started a tree breeding programme in 1968 the focus was on pine, with research confined to the Mpumalanga province. The programme was initiated with the establishment of first generation clonal banks and seedling orchards of *P. patula*, *P. elliottii* and *P. taeda*. During this time *P. greggii* seed from South Mexico was also imported and established in trials. This was followed by the first progeny trials of *P. elliottii* and *P. taeda*, first generation controlled crosses sourced from the South African Forestry Research Institute (SAFRI) and open-pollentated families from Queensland, Australia in 1969. In 1971 the first series of *P. patula* progeny tests containing local SAFRI material and Mexican imports were established in Mpumalanga province. The breeding focus continued during the 1970's and resulted in the selection of second generation selection of *P. patula*, *P. elliottii* and *P. taeda* by 1977 (Dennison, 1998).

In 1990 the first pine breeding trials were established at North East Cape Forests. Trials included the *P. patula*, *P. elliottii*, *P. taeda* and *P. greggii* from the existing breeding programme in Mpumalanga and Kwazulu-Natal as well as seed sourced though the Central American and Mexican Coniferous Resource Cooperative (CAMCORE). The breeding programme introduced new and promising species and improved the available genetic material, however, due to the relatively young breeding programme, the genetic interaction with the environment was not fully expressed in the early selection (Dennison, 1998).

4.4 Growth of Pines at North East Cape Forests and their Timber Properties

Zwolinski *et.al.* (1997) conducted a study into the growth and timber properties of mature pine stands on various sites at the NECF. A unique reconstruction of pine growth on various sites of NECF was conducted, thereby providing information of strategic importance to the afforestation project. This reconstruction of growth was possible in a number of plantations established by the former landowners. In total, 21 survey sites were demarcated in stands of *P. elliottii* (14 sites), *P. patula* (6 sites) and *P. radiata* (1 site). This study involved (i) determination of tree dimensions and stem condition, (ii) collection of dendrochronological information through stem analysis, (iii) detailed surveys of soils and other site characteristics, (iv) monthly measurements of soil water status (v) sampling of wood and determination of wood properties for thermo-mechanical pulping (TMP), (vi) data analysis with the major objectives to define the current yield and mean annual increment (MAI), as well as to estimate timber yield and MAI at harvesting age of 18 years, (vii) modelling of the growth-site relationships to predict site index (SI_{18}) with site characteristics.

The resulting tree and stand characteristics (estimated at 18 years of age) are provided in Table 5 (HT_{18} = mean site index, DBH_{18} = breast height diameter, MAI_{18} = mean annual increment).

Table 5. Tree and stand characteristics at NECF estimated at 18 years of age.

Charateristics	**Species**		
	P. elliottii	***P. patula***	***P. radiata***
HT_{18} (m)	16,34	18,30	15,62
DBH_{18} (cm)	23,1	28,5	28,2
MAI_{18} (m^3/ha/hr)	14,6	16,9	16,9
Stems %: multiple	11,4	20,4	53,3
Crooked stems	5,7	7,8	33,3
Leaning stems	0,5	14,4	3,3

Despite the average MAI ranging between 14,6 and 16,0 m^3/ha/yr, pines could produce over 20 m^3/ha/yr at NECF if the site species matching is correct. The preliminary results of the growth-site relationships showed that the knowledge of soil water storage, rainfall, as well as air temperature, soil bulk density and carbon content of soils was important to understand and predict the growth of trees. Stem quality of *P. radiata* and *P. patula* was found to be poor. It was assumed that the frequent stem malformations resulted from *(i)* mechanical damage to the growing tips (hail) or *(ii)* physiological stresses induced during prolonged spring droughts. Despite that, the timber yielded high quality pulp which was attributed to specific growth conditions. In particular the *P. elliottii* pulp showed remarkably high brightness values. Based on this pilot study, *P. elliottii* was placed as a top order ranking pulpwood species to be planted at the NECF (Zwolinski *et.al.*, 1997).

The average wood density values found at NECF were significantly lower than those published by Schoeman *et al.* (1977) or Palmer *et al.* (1982) from other regions in the country, probably because of the fast growth of the trees. Schoeman *et al.* (1977) reported wood densities of 498 kg/m^3 for *P. patula* and 494 kg/m^3 for *P. elliottii*. The average wood density at NECF was 385 kg/m^3 for *P. patula* and 408 kg/m^3 for *P. elliottii* with corresponding average fibre lengths of 3,027 mm and 3,064 mm (Table 6). The higher average tracheid length can definitely be attributed to wood age and should be considered a bonus for thermo-mechanical pulping.

In some *P. patula* stands chip rejects were rather high, whilst the percentage of rejects for *P. elliottii* were much lower. Oversized chips were normally re-chipped in the commercial operation which would eliminate a large amount of oversized material. The accepTable chips were of good quality. The overall dichloromethane extractive content was slightly lower in *P. patula* (1,824%) compared to *P. elliottii* (2,043%), however, 50% of the *P. patula* stands produced values exceeding 2% with the highest value of 2,790% recorded at site 1. No abnormally high amounts of extractives could be detected in any of the wood samples. A substantial variation in total pulp yield characterised *P. patula* stands. The thermo-mechanical pulping results are shown in Table 6.

Table 6. Basic wood characteristics and thermo mechanical pulping (TMP) results for timber samples from six *P. patula* and two *P. elliottii* stands (Zwolinski *et.al.*, 1997).

Species	Site No.	Wood density (kg/m^3)	Fibre length (mm)	C Chip screening (%)			Extract Content (%)	TMP process		
				0–2 mm	2–8 mm	Rejects (>8 mm)		Total yield (%)	Shive Content (%)	Energy consumption (kWh/odt)
P. patula	1	364,3	3,048	1,02	69,79	29,19	2,790	79,0	12,5	3 383
P. patula	2	387,3	3,334	0,96	72,17	26,87	1.238	92,0	6,9	3 778
P. patula	6	396,7	2,877	0,65	64,54	34,81	2,040	81,8	14,0	2 964
P. patula	7	384,3	2,941	0,63	59,30	40,07	2,018	96,0	19,0	1 423
P. patula	17	394,9	2,866	0,84	83,11	16,05	1,247	96,0	19,0	2 284
P. patula	20	380,2	3,098	0,86	82,11	17,03	1,611	92,0	11,7	3 418
P. elliottii	4	421,8	2,949	1,34	88,83	9,83	2,478	90,8	3,0	2 850
P. elliottii	8	394,4	3,179	1,29	89,34	9,37	1,608	87,9	14,8	4 562

Table 7. Summary of thermo-mechanical papermaking characteristics (Zwolinski *et.al.*, 1997).

Property tested	*P. patula*						*P. elliottii*	
	Site 1	Site 2	Site 6	Site 7	Site 12	Site 20	Site 4	Site 8
Grammage (g/m^2)	75,14	73,02	70,94	66,98	74,93	70,27	78,55	71,38
Brightness (%)	48,3	46,4	45,6	44,8	47,6	49,4	52,5	53,2
Wetness (°SR)	38,0	38,0	38,0	38,0	38,0	38,0	38,0	38,0
Beating time (min)	60	60	65	56	57	60	67	70
Burst Index ($kPa.m^2/g$	1,26	1,22	1,09	1,36	1,13	1,55	0,96	1,16
Tear Index ($mN.m^2/g$)	7,00	6,73	6,46	5,76	5,43	6,96	6,29	6,71
Breaking length (km)	2,80	2,65	2,54	2,95	2,88	3,36	2,32	2,69
Stretch (%)	1,37	1,34	1,28	1,28	1,21	1,51	1,20	1,12

The relationship between energy consumption and shive content is the important criterium for evaluating thermo-mechanical pulping response (Clark, 1995). In this respect the *P. elliottii* stand on site 4, with only 3% shive content and rather low energy consumption, proved to be an excellent material for this type of pulping. The TMP-strength properties of some samples were superior. The wood samples of *P. patula* collected from sites 1, 2, 7 and 20 and *P. elliottii* wood on site 8 generally showed high values of burst index, tear index and breaking length compared to the wood in the other sites. Strength values compared well with TMP results published by Dommisse (1994). The Elrepho brightness values of *P. patula* pulp were similar to the values obtained by Dommisse (1994). The pulp brightness figures of *P. elliottii* at NECF were 4,5 to 5,5 points higher than those reported by Dommisse (1994), despite the fact that pine butt logs usually produce pulp of moderate optical properties (Zwolinski *et al.*, 1997).

4.5 Silvicultural Practices

4.5.1 Site Preparation

As almost all of the NECF estates had been maize or cattle farms before they were planted, there were no tree stumps or any other physical impediments on the surface at establishment. The original soil tillage was to plough strips of land along contours into which the seedlings were planted. Areas where invasive vegetation (wattle) had to be removed by clearing land was manually pitted for planting. As the region is known to experience prolonged winter droughts with short but intense rains during summer, the desire arose to trap water from these heavy rains. To accomplish this, the land preparation technique was changed to allow sub-soiling by a tractor combined with a sub-soiling plough that broke up the soil horizon to a depth of 45 cm. In most cases the plough was accompanied by a set of offset disc ploughs that were used to form a ridge of soil over the ploughed area. The technique of "rip and ridge" was adopted in order to created a physical barrier for the movement of rainwater down a slope after intense rains. The ridge would prevent the "surface flow" of water. This water would seep into the base of the upper side of the ridge and then into the "rip" or sub-soiled area below the ridge. As the soil had been loosened by sub-soiling, the water would percolate rapidly into the depth of soil and thus be retained for the use by seedlings after planting. During the drought of the early 1990's, the desire to conserve or "harvest" rain became more intense. In certain areas the "rip and ridge" technique was used to disturb soil to a depth of 1,2 m. This was originally limited to areas where soil was known to be deeper than the depth of ripping. A policy decision was made to use the "rip and ridge" procedure for all areas. Ripping was to be whatever depth could be reached down to 1,2 m. This deep "rip and ridge" procedure became the project standard until it was stopped in 1993. As with all blanket prescriptions, the "rip and ridge" procedure was not suited for many of soil conditions encountered in the NECF project (Darrow, 1997).

The ability of the sub-soiling plough to break up soil into a state suiTable for tree planting depends heavily on the moisture content of soil at the time the soil is tilled. When sub-soiled with a deep ripper, the soils resist the fracturing process and form large clods or massive blocks of soil. These clods do not break down even after years of exposure to rain. As they are of large and odd shape, the sub-soiled zone becomes filled with these large chunks. There are large pockets of air between the clods or chunks. Even with the ridging work of the disc ploughs, the texture of the soil is often not suiTable for tree planting. On the other hand, when the soils are wet, they become "plastic" and easily deformed by pressure. The use of the deep "rip and ridge" technique in wet soils resulted in a demoration of the soils in front of the plough blade. As the soil was plastic, the effect of sub-soiling was to form a deep but narrow groove through the soil. As the clay-loam is wet, the edges of the grooves are smeared with wet clay. A slick wall such as this is almost impenetrable to tree roots (Darrow, 1997).

In those areas where soil was shallower than 1,2 m, the tines of the sub-soiling plough often caught on ledges of rock or large boulders under the surface. The tines of the plough either broke, thus increasing "down-time" of tractors or they had to battle against the boulders. In some cases the boulders were pulled to the surface in the rip line making ridging difficult. Disturbance of the soil by sub-soiling and ridging increased the frequency of weed growth in the disturbed soil, although much less in "virgin" grasslands than in old agricultural lands. As the areas prepared for planting each year were very large, the control of the weeds fell behind schedule. Competition with weeds lead to higher mortality of trees and it was therefore decided in 1993 to stop the "rip and ridge" procedures until other silvicultural operations were able to "catch up" with the schedules. There were also questions raised about the survival of seedlings and their stability in the poorly formed ridges (Darrow, 1997).

As the NECF project was not able to carry out the schedule of planting at the rate originally planned and still maintain at accepTable standard of quality, the new forest manager changed the basic site preparation technique from deep "rip and ridge" technique in "virgin lands" (areas under grassveld that had not been cultivated in many years – if ever) to the "pit and plant" technique in 1993. "Pit and plant" is a technique where holes are cut into the grass sward with picks and hoes. The grass sward is removed to one side and the soil in the pit is broken up into a fine tilth. In the NECF project such pits were set out in a rectangular grid 3 m by 3 m, resulting in a planting density of 1 111 trees per ha. This method of "pit and plant" is still the standard procedure used today at NECF in grassveld areas, although limited mechanical tillage methods are practiced where weed control programs can be maintained (Darrow, 1997).

4.5.2 Quality of Plants and Planting Operations

Contracted labourers, employed and managed mostly by one forestry contractor, performed the planting work. At the peak of the planting period in 1991, the contractor employed 1600 labourers. Seedlings were planted into the middle of ridges or into the pits after the soil was loosened with a hand trowel. The accepted procedure was to open a hole, place the seedling in the hole and then to fill the loose soil around it. The soil was then packed firmly around the seedling to assure stability. In cases of planting during dry season or in winter, a super-absorbent powder was mixed into the hole before planting the seedling. One or two litres of water were poured around the planted seedling when the soil was dry or when the weather was hot and dry. This technique was used to increase the survival of seedlings by assuring the availability of soil moisture immediately after planting. Unfortunately, the starch based product used and the method of application resulted in further complications with the product forming a penetration barrier to roots. The success of seedling survival is the controlling factor to the success of a forestry project. If sufficient seedlings do not survive to create healthy, well-stocked stands of trees, there is no forestry project (Darrow, 1997).

The NECF project did not have a nursery until 1992 nor sufficient production of planting stock until 1993 to supply its planting needs. In the first years, therefore, all of the seedlings used in the project were bought from suppliers in different forestry areas and trucked into the region. Seedlings that could not be used immediately were placed in "holding nurseries" or put wherever there was a place to keep them. Because the seedlings came from different suppliers who used different methods of production, and who grew seedlings to different standards, there were wide ranges of seedling sizes, types of containers, seedling quality and methods of transport used to deliver the seedlings. The delivery of such large numbers of seedlings made it difficult to check the quality of all of the seedlings as they arrived. Delays in planting seedlings after delivery led to problems of "root-bound" seedlings and those that were severely deficient in nutrients. Seedlings were often too large for the small containers in which they were grown, this resulted in the roots being distorted and forming a "cage". When such seedlings were planted the roots tended to grow in a pattern that was very unevenly distributed. Often deep roots, which should have grown into the trench created by the "rip and ridge" were not formed. Such trees not only did not have access to the soil water of lower depths, but they did not have "sinker roots" that gave good stability in windy conditions. A pilot study of this problem was undertaken by Theart (1993).

A further study was undertaken in 1994, when 501 compartments on six estates were sampled for rooting defects. Van Laar (1995) showed that some plantations had significantly more root defects than others. No explanation of possible cause was given. Seedlings were not always established properly in the soil, their root systems often did not have access to soil water during dry periods, the roots also were not properly distributed or oriented in the soil to give trees good stability. The trees that survived the initial planting period began to show stability problems in the second and third year. “Windthrow” occurs when roots are unable to support the tree against the wind, either because they are unevenly distributed around the tree or because they are so twisted amongst themselves that they break off from the continual swaying of the trees. Such “windthrow” still occurs in the oldest stands of eight and nine year old trees (Darrow, 1997).

Later, Van Laar (1995) concluded that wind damage was statistically significantly correlated with the type, degree and severity of root distortion in planted trees. It was impossible, however, to quantify the common causes for damage across all estates. It can, however, be said that poor planting practices by unqualified, poorly supervised field workers, linked with the use of over-mature “root-bound” seedlings, were the major causes of the distortions and resultant “windthrow” (Darrow, 1997).

Beginning with the initiation of adequate supplies of seedlings from the NECF nursery, considerable efforts were made to correct the errors of the past in seedling quality. Firstly, it was decided that smaller seedlings, with better ratios of roots to shoot development, were needed. The nursery thus supplied seedlings about 10 cm tall rather than the 20 – 30 cm tall trees that were used previously. The smaller seedlings had fewer but better roots which were not distorted. Strict control was put over the timing of the delivery of seedlings to the estate for planting. Much improved holding nurseries were built and given to various estates. They were kept small so that not more than one week’s seedling stock could be kept. This eliminated the problem of over mature and stagnated seedlings. Irrigation and fertilization schedules for the holding nurseries were developed and the local estate's staff was trained to apply them properly. Finally the holding nurseries were placed near each estate office so that the forester-in-charge could monitor the plants (Darrow, 1997).

At present, there are still questions about what the proper size should be for seedlings to be planted in areas where weed competition is high or where climatic conditions are dry and hot. There has been a tendency to use somewhat larger seedlings than those of 10 cm height, however, the physical quality of the seedlings, regardless of size, is now very good and the delivery system to the field for planting sufficient in order to avoid deterioration of quality before planting (Darrow, 1997).

4.5.3 Weed Management

Vegetation management is essential during establishment of young pine plantations as competition for water, light and nutrients severely limits tree growth (Nambiar and Zed, 1980; Richardson, 1993; Smethurst *et al.*, 1993). Large growth benefits can thus be achieved through the timely and/or selective removal of competing vegetation in newly established plantations (Richardson *et al.*, 1996; Wagner *et al.*, 1996). Since vegetation management costs may be amongst the highest associated with silvicultural operations, improvement in methods of vegetation control is an important priority for increasing overall forest productivity (Jarval, 1998).

Typically, vegetation management costs are highest during the 'establishment period', *viz.* the time between planting and canopy closure or site capture (the time at which the planted trees dominate on the site). After canopy closure the effects of shading tend to exclude all further competing vegetation and the costs of vegetation management are reduced. The rate of canopy closure in pine trees is slower than eucalypts so there is a longer period between planting and site capture. Therefore, vegetation management costs are incurred over years, as the weed communities need to be controlled over a longer period. Final yield benefits from early silvicultural inputs such as vegetation management are thus difficult to quantify in pine plantations. Managers wanting to manipulate vegetation to increase wood production must therefore choose an appropriate degree of control, which takes into account the ultimate permissible yield loss due to competition from vegetation as well as the costs involved (Rolando and Little, 2000).

Vegetation management includes the control of any plant species that detrimentally affects plantation yield; this includes both exotic and indigenous vegetation. In any control programme individual species are seldom targeted for control, more often groups of plants are controlled. This is done as certain groups of plants may be thought to be more competitive or because the herbicides used may selectively control certain plants (Little, 1998). Vegetation control, through the use of selective herbicides, allows for the development of the following broad categories: herbaceous broadleaves, grasses, woody vegetation (perennial broadleaves) and, in some instances, ferns. Grouping of plants into vegetation types allows for the testing of the hypothesis that due to the inherent growth morphology and competitive strategies of different vegetation types, their competition with pines is spatially and temporally different. If these spatial and temporal zones can be determined according to the category of vegetation, then pine vegetation management programmes could be designed to exclude different vegetation types when they are most competitive (Rolando and Little, 2000).

Studies carried out in the USA, New Zealand and Australia indicate that control of herbaceous and woody plants alter the competition balance of early successional vegetation to favour pine survival and growth (Haywood and Tiarks, 1990; Richardson, 1993; Zutter and Miller, 1998). Many of these studies have indicated that during the first three to five years after establishment, or until the trees are dominant, most competition is from grasses and broadleaf herbaceous plants, which, due to their competitive life cycle invade the plantation soon after harvesting (Tiarks and Haywood, 1986; Miller *et al.*, 1991; Wagner *et al.*, 1996). If unchecked, competition from this group of weeds is normally not sustained for more than two - three years, as the trees have access to deeper soil water, which is below the level of shallow rooted species (Sands and Nambiar, 1984). In addition, after three years the tree crowns are normally above the herbaceous weeds and the trees are able to compete more effectively for growing space. In a study to determine the effects of herbaceous versus woody plant control on *P. taeda* establishment, Tiarks and Haywood (1986) reported grasses to be the most competitive in young *P. taeda* plantations, and suggested control until canopy closure. They found hardwood species to be long term competitors with pine trees, only needing to be controlled at a later stage (after canopy closure) (Rolando and Little, 2000).

Although much research has been carried out on the effects of different methods of vegetation control on pine wood production, little research has been conducted in South Africa. The noTable exceptions include the work carried out by Morris (1994), Christie (1995) and Zwolinski (1995). A structured trial base was planned and implemented by the Institute for Commercial Forestry Research during the mid-1990's to address the lack of information related to pine-vegetation interactions, particularly for those species grown in the Eastern Cape, KwaZulu-Natal and Mpumulanga (Little, 1998). The specific objectives of these establishment trials were to:

1. Determine the effect of selective control on vegetation abundance;
2. Determine which vegetation type is the most competitive during pine seedling establishment;
3. Determine if the degree of control required is related to site conditions, and
4. Compare tree growth on plots managed according to company practice with weed-free control.

The results from this set of field trials have shown:

1. The importance of vegetation management at establishment on subsequent tree productivity and uniformity;
2. The diversity of sites and associated vegetation types used for pine tree growth, facilitating the development of various degrees of competition on different sites;
3. The direct and indirect effects of selective vegetation control on vegetation abundance, and

4. That growth response to vegetation management is affected by site and planted pine species.

The important outcome of this study was that specific mechanisms of competition will vary as a function of the climatic and soil conditions of the site and that the impact of different types of competitors on tree growth will change as the seedlings mature and compete in different spatial zones. Results also indicated that although grasses and herbaceous broadleaves were initially vigorous competitors, woody plants were the most detrimental to early pine growth. Tree growth was greatest where herbaceous and woody vegetation was controlled, that is on the weed free plots. Here there was no competition for light, water or nutrients, and tree growth occurred at a maximum rate. This is the ideal situation (Rolando and Little, 2000).

4.5.4 Fertilization

The inherent nutrient supplying capacity of sites varies due to differences in soil parent materials and organic matter content, climate, stand development and silvicultural management practices. In cool climates, stands have slow rates of litter breakdown and generally respond better to nitrogen fertilizer. Site preparation practices should be aimed at eliminating competing vegetation and increasing the rate of mineralisation of organic matter. Slash management through burning, windrowing, broadcasting or partial removal could affect the quantity of nutrients available on the site, as well as the rate of decomposition. Fertilizing generally improves growth only when weed control is practised.

Fertilization in pine stands of Swaziland is strongly age-dependent. Thinning may also affect nutrient status of plantations (Du Toit and Carlson, 2000).

Substantial research results have been published on fertilization at establishment (Donald, 1990; Morris 1986; Donald et al., 1987; Herbert, 1996a; Herbert and Schönau, 1989a and 1989b; Schönau, 1983). Phosphorus (P) was the main limiting nutrient for all three genera in the North East Cape Forests. Pines have also shown early responses to Nitrogen, Phosphorus, Potassium (NPK) mixtures, but the only sustained responses with fertilization at planting were to P applications. However, in other trials initial responses to P applied to pines at planting were not sustained (Du Toit and Carlson, 2000).

From 1990 until 1993 all stands in the study area were fertilized at planting time with various fertilizers, application techniques and application quantities. (K.M. Basset, pers. comm., North East Cape Forests, 2001). Following a management decision in 1993, fertilization of pines were discontinued until proper weed control regimes were put in place (Darrow, 1996). Limited fertilizer applications were conducted on scalped lands due to the fact that this land preparation technique removed the mineral topsoil. Several forest nutrition research projects were conducted in NECF with variable and inconclusive results.

4.6 Abiotic Risk

NECF has been exposed to severe fire damage during dry season winters, this is when the amount of fuel is largest, the fuel (dry grasses) and weather (frequent and strong winds) conditions are hazardous, and frequent controlled fires applied by farmers increase the probability for destructive fire. However, when damaging fires do occur the chance for tree survival depends on the species susceptibility to fire damage. Local experience showed that some species, such as *P. leiophylla* and *P. elliottii* are more tolerant to damage than, for example, *P. patula*. Therefore, planting species less susceptible to fire damage on hazardous sites will reduce timber and growth losses when various other means of fire prevention fail (De Ronde and Zwolinski, 1997).

It is important to note that fire, seasonal drought and seasonal floods contribute to the utilisation of available resources and thereby directly and indirectly contribute to stand variability. The resulting impact has not been quantified, but it remains an important factor in the evaluation of current stand performance in NECF.

4.7 Human Factor

When the project was initiated in 1989 not all the personnel recruited had forestry backgrounds and qualifications (Botha, 1996). It was a difficult time as infrastructure was extremely limited and the high target that was set increased the difficulty of the project. By 1993 it became obvious that the local forestry management staff was not in a position to maintain the schedules and quality standards for plantation establishment that had been envisaged in the initial years. A new management team was subsequently deployed. The first management intervention consisted of a reduction in the rate of planting to a more manageable level as well as a discontinuation of the intensive site management techniques and fertilisation until the weed management practises were in line with the new standards (Darrow, 1997).

4.8 Products and Regimes

The project was initiated with an objective of producing 1,1 million tons of thermo mechanical pulpwood on a land base of 80 000 ha based on a 60% eucalypt and 40% pine composition. Following the strategic review by Zobel in 1991 it was decided to discontinue the production of hardwood and focus on softwood for thermo mechanical pulp (TMP) production. Subsequent market movements and strategic realignment resulted in a decision to manage the plantations for a dual industrial sawlog and pulpwood regime based on an afforestation area of approximately 35 000 ha (Botha, 1996; Darrow, 1997). These strategic realignments had an impact on the silvicultural prescriptions and regimes and contributed to the variability in current stand parameters.

4.9 Land Acquisition and Suitability of Soils

Initial strategic planning entailed the purchasing of 80 000 ha of land (Harvett, 1989). The strategy behind this was to keep farm prices low (demand-supply principle). Market indications where that if less land would be purchased the price per hectare would be higher (in excess of R1 000/ha). The average price paid at the end of the land acquisition project equated to R775/ha. The strategy to keep land prices low thus worked well, however, in order to make this strategy a success the land purchases had to be conducted over a limited time period and across all the landholdings identified in early strategic reconnaissance based on soil and climate data (Mills *et.al.*, 1988). There was thus an inherent trade-off between the capital outlay for land and the quality of the afforestation potential information available in support of the purchase decision-making process, this was further complicated by the unique geology and climate parameters associated with the Eastern Cape as proven by the subsequent ongoing research.

During 1993 a re-evaluation of the NECF landholdings found 24 000 ha of the original acquired area to be unsuiTable for afforestation due to low rainfall, inaccessibility, shallow soils or steep slopes (Botha, 1996). The identified 24 000 ha represents consolidated units. NECF was authorised to alienate all marginal and uneconomical land and to replace this with land of high afforestation potential.

4.10 Top Die-back

The seasonal die-back of *P. patula* was experienced in varying degrees of intensity over significantly large areas at NECF. This was of particular concern because of the resulting depression in timber productivity (Fyfield, *et al.*, 1998).

In an attempt to quantify the factors responsible for seasonal die-back in *P. patula* at NECF, it was hypothesised that in early spring, as temperatures rise and before the rains start, an adverse relationship between tree water demand and water supply often arose, resulting in trees suffering from stress due to a water deficiency, which in turn caused the growing tip to die back. Any factors in the atmosphere–tree–soil system that aggravated this adverse relationship were therefore expected to promote die-back (Fyfield *et al.*, 1998).

In order to investigate this phenomena, Fyfield *et al.* (1998) characterized the macro and microclimate in some detail; the response of the trees to an applied nutrient treatment was determined; both the soil and tree water status were quantified as a function of water supply; and tree growth and form were monitored at an experimental site at Sonsbeek, over the period July 1997 to March 1998.

The soil physical conditions at the Sonsbeek trial site (Glen Cullen) were theoretically favourable for growing *P. patula*. Significant water extraction by roots occurred to a depth of 600 mm. This resulted in a very low value for root zone available water (RAW) compared with other NECF sites, such as Tree Fern Pool, at which much better tree growth was observed. The seemingly poor root development had probably been aggravated by the "rip and ridge" land preparation treatment, which resulted in most root growth occurring within the rip line (Fyfield *et al.*, 1998).

However, unfavourable climate had to be another contributing reason for the poor growth of trees at Sonsbeek. The region experiences lower minimum temperatures than other forestry areas in South Africa and as such can be classified as marginal in terms of the recommended temperature norms for growing *P. patula*. A high frequency of very cold nights, when the temperature drops below –5 °C and the corresponding hot days occur during winters (Fyfield *et al.*, 1998).

On the very cold nights, a departure from the normal night time stem expansion pattern was recorded with dendographs after the air temperature dropped below –5 °C, the stem expansion ceased until early morning, indicating that the tree was not able to restore from water stress during night time. This may have been due to the increase in the viscosity of water at low temperatures. At sunrise, the sharp increase in air temperature would have allowed the sap to flow again, resulting in rapid stem expansion. It was possible that this additional period of water stress experienced by trees on such cold winter nights enhanced the stress suffered by trees during the subsequent hot days, thus resulting in a situation conducive to the onset of wilting and dieback. The drier the soil was during this critical period, the more serious the watering stress was (Fyfield *et al.*, 1998).

The top and subsoil were inherently low in Phosphorus (P), Copper (Cu), Zinc (Zn) and Molikolemin (Mo) and the subsoil was low in Boron (B), these nutrient deficiencies also showed up in the foliage. Foliar nutrient compositions were monitored over a nine month trial period in three treatments. A comparison of the foliar data with published critical norms suggested the Phosphorus (P), Boron (B), Copper (Cu), Zinc (Zn) and Molikolemin (Mo) were deficient in the samples taken at the start. After fertilizing, Zinc (Zn) and Molikolemni (Mo) were still deficient in foliage, indicating that the fertilizer application was ineffective. Copper (Cu), however, was only deficient in the foliage of trees in the control plots, indicating that in this case the fertilizer application was effective (Fyfield *et al.*, 1998).

4.11 Road Construction

In order to have access to planting areas, a road network had to be developed for NECF. The first 18 months of construction and layout was under supervision of the Anglo American Civil Engineering Department, due to various reasons (financial and practical constraints), the construction of high quality roads could not take place and it was decided that no gravelling would be done, limited compaction of roads would be carried out and only culvert pipes be installed in priority waterways (Skulnik, 1991). Most of the roads were designed and built to minimum standards, meaning that after the initial mono camber cut was completed no compaction of the in-situ material took place. The above strategies lead to access difficulties to several parts of the plantations, thus resulting in sub-optimal silvicultural maintenance of these areas.

To date significant progress has been made to address the issue. The appointment of a professional engineer assisting in the upgrading of roads and thorough training of local staff and the establishment of a roads maintenance database significantly contributed to this process. The impact of a properly planned and constructed road network was one of the major contributors to improved stand quality evident in the younger stands.

4.12 Socio-Economic Parameters

The NECF project is situated in one of the most significant poverty nodes of South Africa. This, in conjunction with very low levels of literacy and skills during the start-up operations presented significant difficulty. There was virtually no labour with even basic forestry skills available and no forestry culture was present. The management staff had to recruit and train ex-agricultural labour in basic forestry skills. Due to the specialised nature and demanding profile of forestry work, this aspect undoubtfully had an impact on the quality of the oldest stands (Nel and Potgieter, 1990).

4.13 Drought, Wind, Soil Temperature, Snow and Hail

Water is the most limiting resource for most tree and forest sites in South Africa. As soil-water content declines, trees become more stressed and began to react to resource availability changes. When a certain point is reached water is so inadequately available that tree tissues and processes are damaged. Lack of water eventually leads to catastrophic biological failures and death. Growing periods with little water can lead to decreased rates of diameter and height growth, poor resistance to other stresses, disruption of food production and distribution, and changes to the timing and rate of physiological processes, like fruit production and dormancy. More than eighty percent of the variation in tree growth is because of water supply.

The term drought has not yet been universally defined. Sometimes drought is defined as a number of days with precipitation below a specific level. For example, in the Western Cape Richardson and Kruger (1990) defined drought as a period during which daily rainfall never exceeded 0,5 mm. In the Natal Midlands the occurrence of six or more consecutive days with daily rainfall less than 2 mm is proposed as a criterium for defining seasonal droughts (Schulze, 1997). The term "agricultural drought" has been used by De Jager and Schulze (1977) and defined for Natal as a period of less than 25 mm rainfall in 21 days (1,19 mm/day). These broad definitions of drought are based on long-term observations and experience, but they neither refer to a soil water status nor to specific demands for water by plants.

The term "drought" according to Coder (1999) also denotes a period without precipitation, during which the water content of the soil is reduced to such an extent that trees can no longer extract sufficient water for normal life processes. Water contents in a tree under drought conditions disrupt life processes. Trees have developed a series of prioritised strategies for reacting to drought conditions (listed in order from least damaging to most damaging response):

1. Recognizing ("sensing") soil / root water availability problems;
2. Chemically altering (osmotic) cell contents;
3. Closing stomata for longer periods;
4. Increasing absorbing root production;
5. Using food storage reserves;
6. Closing off or closedown of root activities (suberize roots);

7. Initiating foliage, branch and/or root senescence;
8. Setting-up abscission and compartment lines;
9. Sealing-off (allow to die) and shedding tissues/organs unable to maintain health.

As drought continues and trees respond to decreasing water availability, various symptoms and damage occur (Coder, 1999).

Drought will affect the width of the annual ring, the distribution of the annual ring along the trunk and branches, duration of cambial growth, proportion of xylem to phloem, as well as timing and duration of latewood production. Cambial growth slows or accelerates with rainfall (Coder, 1999).

Drought predisposes trees to pests and diseases because of lower food reserves, poorer response to pest attack and poorer adjustment to pest damage. Unhealthy trees are more prone to pest problems (Coder, 1999).

Wilting is a visible effect of drought. As leaves dry, turgor pressure in leaf cells decreases causing leaf petiole drooping and leaf blade wilting. The amount of water lost before visible leaf wilting varies by species. Temporary wilting is the visible drooping of leaves during the day followed by rehydration and recovery during the night. Internal water deficits are reduced by morning in time for an additional water deficit to be induced the following day. During long periods of dry soil, temporary wilting degrades into permanent wilting. Permanently wilted trees do not recover at night. Permanently wilted trees recover only when additional water is added to the soil. Prolonged permanent wilting kills trees (Coder, 1999).

Newly planted seedlings can be exposed to drought through transplanting stock or access to water limited soil and exposure to high evaporative demand conditions of the atmosphere (Grossnickle and Folk, 1993; Haase and Rose, 1993). Stressed seedlings have reduced leaf conductance and photosynthesis. A reduction of reserve carbohydrates and currently available photosynthate occurs, the latter of which is considered to be the primary energy source for root growth in some species (Van den Driessche, 1991).

No stock quality improvement can alleviate the stress transplants experience on afforestation and re-afforestation sites. Increased root volume may enable open rooted Douglas fir seedlings to avoid shock following transplanting (Haase and Rose, 1990). A programme defining a transplants' functional integrity could determine whether it has the capability to survive under the unfavourable conditions. Functional integrity indicates whether a transplant is damaged to the point of limiting primary physiological processes (Grossnickle and Folk, 1993) or not. Haase and Rose (1990) found that new shoot growth will decrease and days to budbreak will increase with an increase in water stress. This effect is most pronounced in the high root volume seedlings.

The impact of wind in NECF is a very important factor. The prevalence of a high wind occurrence factor as reported by Thackrah and Monnik (1998), the periodic presence of "hot berg winds" and the presence of wind speeds in excess of 180 km/hr all impact on the growth parameters. Chavasse (1978; 1979) reported that shelter is considered to be important in wind-exposed seedlings. Wind can have a detrimental effect on seedlings resulting in abrasion by soil particles in extreme cases Nänni (1960) eliminated the possibility of wind damaging young *P. patula* trees ("It can be said with certainty that the immature stand of *P. patula* is immune to wind damage.") wind is responsible for leaning and the final breakage of weakened trees (Terblanche, in press, 2001).

Young trees may create circular holes around their stems from swaying in prevailing winds, this is called socketing. Significantly more socketed *P. radiata* trees occurred in New Zealand on wind exposed sites than trees planted on sites unaffected by wind (Mason, 1985). Tree swaying will constantly damage new developing roots and compaction around the root plug can also occur. Planting trees deeper, thus reducing plant sway, can reduce this problem. Abnormal root systems can result in pronounced bow or crook in the stem as a result of bad anchorage and in windy impact. Naturally regenerated trees have excellent root systems, which can be ascribed to undisturbed root growth or protection of seedlings against the wind. Nänni (1960) recommends that soil should not be loosened when pitting. Only a small hole, large enough to accommodate the roots, is appropriate. When the seedlings are pricked out, it is recommended to plant them in conical tarred paper cups to avoid disturbance or damage at planting. This resulted in an improved growth of *Eucalyptus saligna* (Nänni, 1960).

Studies undertaken by Balneaves and de La Mare (1989) showed that more primary lateral roots developed in the leeward quadrants of the stem. A possible explanation for this rooting pattern is a rain shadow on the leeward side of trees where rain occurs in windy storms. Observations by Fraser and Gardiner (1967) did not reveal any tendency for more or bigger roots to develop on any side, even on the lee-side of the prevailing winds.

A windfall assessment done by Versfeld (1980) indicated that wet soils tend to be more susceptible to windfall than the same soil in a drier season. Increased rooting resistance on drier soils is responsible for the lower windfall counts but these better-anchored trees tend to break (Mason, 1979; Versfeld, 1980). Versfeld (1980) states that improper previous management practices, e.g. delayed thinning and exposed sites, contribute to the high windfall occurrence. Soil type is eliminated as a possible contributing factor because trees on shallower and sandy soils adjacent to damaged areas were not affected (Terblanche, in press).

In the top dieback study by Fyfield *et al.* (1998), as well as the climate comparison study by Thackrah and Monnik (1998), the impact of minimum temperature combined with water stress is highlighted. A further parameter to consider is the actual soil temperature and the impact thereof on growth and survival. The beginning of rapid root growth after planting relies on a favourable soil temperature. This begins when soil temperatures exceed 10 °C (Carlson, 1986). Soil temperatures can easily exceed 30 °C, 10 cm below ground level. Such temperatures, coupled with adequate soil moisture, can result in root death in the first season after planting (Balneaves and De La Mare, 1989). Marshall and Waring (1985) found a starch depletion in *Pseudotsuga menziesii* seedlings at temperatures exceeding 20 °C. The previously deposited starch is used to maintain older roots. Root mortality closely followed the exhaustion of starch and sugar reserves. Roots grow faster as temperature increase up to 25 °C but root decay starts at higher temperatures (Lyford and Wilson, 1966). The optimum temperature for root growth in *P. menziesii* seems to be about 12 °C - 15 °C.

In contrast, Bowen (1969) found that *P. radiata* has a suppressed root growth at 11 °C, which has a negative influence on nutrient uptake. Borland (1994) showed that soil temperatures of 7,2 °C – 12,8 °C can be detrimental to root growth and will damage roots. Freezing temperatures can cause frost damage and reduced gas exchange capability in newly planted seedlings. Water uptake capability can decline, resulting in water stress (Nambiar, 1984; Grossnickle and Folk, 1993).

The other factor of importance is snow damage. The author has personally witnessed snow damage on Elands Heights, Glen Cullen, Chillingly and Wildebees. The most severe damage was recorded on Elands Heights with *P. patula* and *P. greggii* (southern provenance) proving the most vulnerable species. A review of the literature available on snow damage of commercial forest plantations in South Africa was conducted by Kunz and Gardner (2001) in order to determine the feasibility of identifying forestry sites prone to damage by snow as well as estimating the risk of snowfall occurrence. Since 1967, extensive damage to commercial forests has occurred once in every 7,5 years on average. In general, plantations below 1 290 m a.s.l. in KwaZulu-Natal are at slight risk of snow damage. Snow damage risk increases with altitude and plantations above 1 400 m are susceptible to moderate or even severe tree damage.

The most common form of snow damage to forest plantations in South Africa is stem breakage, but trees can also be bent or even uprooted. The severity of snow damage is related mainly to altitude, wind speed, aspect, slope and species. Other factors such tree age and stand density may also play a role but these are not yet clearly understood.

In South Africa, wind direction is typically from the northwest to west during a snowstorm. Trees growing in sheltered valleys and on the leeward sides of ridges and hilltops are more prone to snow damage than those located on exposed crests and hill corners. Wind speed may be more important than wind direction and snow depth with respect to tree damage. Wind speeds of less than 9 $m.s^{-1}$ promote snow accumulation on trees, which increases the risk of tree damage.

In South Africa, north-facing slopes are warmer than south facing slopes during the winter season. The effects of aspect and slope gradient, combined with wind direction, means that trees located on steep south facing slopes are more susceptible to snow damage compared to trees on steep slopes with a northerly aspect. Evidence to date has shown that *E. grandis* and *A. mearnsii* are very sensitive tree species to snow damage, whilst *E. nitens, P. taeda* and *P. patula* are the most tolerant. Juvenile trees of *E. grandis* and *A. mearnsii* tend to bend under the snow load with very little breakage occurring, whilst young to intermediate trees suffer mainly from stem breakage. Crown breakage is more common with mature trees.

Snow damage depends on the interaction of meteorological conditions, topography, as well as certain tree and stand characteristics. The frequency of snowfall is an important characteristic. Four major snowfall events, which caused extensive damage to forest plantations in South Africa, occurred in the past 30 years. The last event occurred in July 1996 and was assessed by Gardner and Swain (1996), as well as Mason (1997), who described this event as the worst in at least 50 years. Davidson (1984; 1989) discussed both the June 1984 and the July 1988 snowfall occurrences. Davidson (1989) reported that the 1988 event was more severe than the 1984 snowfall. He also mentioned a snowfall occurrence in July 1967, which was less severe than the one in 1984 (Davidson, 1984). All four of the aforementioned snowfall events were documented in the Weather Bureau (1991) publication.

During 1996 snowfall occurrence extended from Elliot to the Greytown/Vryheid region (Gardner and Swain, 1996). In 1984, the snow fell over a region extending from the south of Kokstad to southeastern Mpumalanga and from the Drakensberg to Kranskop/Vryheid. The 1988 event was similar to that of 1984, but excluded the Kranskop, Paulpietersburg and Piet Retief districts. Table 8 shows the districts, which reported severe snow damage to trees in order of decreasing severity. For example, the worst damage to forestry occurred in the Umvoti district in both the 1984 and 1996 events.

Table 8. Districts which reported severe snow damage to commercial forest plantations ranked in order of decreasing severity (Gardner and Swain, 1997; Davidson, 1989).

1996	1988	1984
Umvoti (Greytown)	Richmond	Umvoti/Kranskop
Vryheid	Polela/Ixopo	Richmond
Estcourt	Lions River	Polela/Ixopo
Utrecht		Lions River
Impendle		Mpumalanga
Polela/Ixopo		Piet Retief
Lions River		Vryheid
Paulpietersburg		
Richmond		

Another parameter to consider in evaluating the potential impact of snow damage on the measured stand productivity is the potential risk area as defined by the snow line, the potential direction of a snow storm in conjunction with the wind speed, snow type and temperature, snow depth and altitude, aspect and slope and tree species.

Solar radiation, which is related to temperature, decreases with increasing latitude in the winter months (Schulze, 1997). Therefore, the snow line should occur at higher altitudes in the Sabie region compared, for example, to the Eastern Cape Province. However, snow did occur as low as 800 m near Richmond during the 1984 event (Davidson, 1984) causing little damage to forestry at this altitude, but widespread damage was reported above 1 100 m near Richmond and above 1 200 m elsewhere in KwaZulu-Natal. The 1988 event was reportedly worse than the 1984 event and damage occurred above 1 050 m in the Richmond area and above 1 100 m elsewhere. Plantations above 1 300 m in the Umvoti district were badly damaged during the 1996 snowfall (Mason, 1997). Similarly, trees above 1 200 m at Greytown were also badly damaged.

Gardner and Swain (1996) and Davidson (1984) have reported that wind direction was commonly from the north west and west during the snowfall. This is supported by the fact that bent and fallen stems were generally in an easterly direction (Davidson, 1984). The reason for this is that snow packs on the tree branches from the western side causing them to bend towards the east until they eventually break under the snow load. Wind speed may be more important than snow depth with respect to tree damage (Gardner, 1996). A slight breeze or no breeze at all during the snowfall usually results in severe damage to trees. Wind gusts during the snowfall can help dislodge snow if trees are able to sway freely. From the international literature, wind speeds of less than 9 $m.s^{-1}$ (Nykänen *et al.*, 1997) promote snow accumulation on trees, which increases the risk of moderate to severe damage.

Since the wind was typically from the north-west to west directions during the snowstorms, trees on the northern or western facing slopes should experience less damage because the wind helps dislodge the snow, which prevents it from building up. Trees on south and east aspects are more sheltered from the wind and should theoretically be more susceptible to breakage from the snow load. Trees located in sheltered valleys and on the leeward sides of ridges and hilltops are therefore also more prone to damage compared to those located on more exposed crests and hill corners (Gardner and Swain, 1996; Cremer, 1984).

Temperature strongly influences the water content of snow. Snow falling during conditions where the ambient air temperature is between 0 °C and < 0,6 °C results in wet snow which is sticky and thus adheres more readily to vegetation surfaces than compared to dry snow at lower temperatures. Temperatures higher than 0,6 °C may cause the snow to become wet enough to slip off tree branches, thus reducing the risk of stem breakage. If the wind speed exceeds 9 $m.s^{-1}$, the snow can be dislodged (Solantie, 1994).

Gardner and Swain (1996) stated that more than 50% breakage occurred in *E. grandis* stands where only 10 to 15 cm of snow fell. In general, slight damage to trees can be expected with snowfalls of 15 cm or less. On the other hand, snow depths in excess of 30 cm will result in an unacceptably high level of tree damage. The amount of snowfall, and therefore, damage, are related to altitude with higher altitude sites generally being at greater risk (Nykänen *et al.*, 1997). Rainfall magnitude generally increases with altitude (orographic effect). Furthermore, temperatures decrease with altitude (according to local adiabatic lapse rates), which explains the relationship between snow depth, and altitude.

According to Gardner and Swain (1996), however, snow depth is not necessarily correlated to altitude in KwaZulu-Natal. For example, forestry areas between

1 150 and 1 350 m in the Ixopo district received less than 15 cm of snow in 1996, whereas 30 cm or more fell at similar altitudes in the Umvoti district. Snow depth varied considerably at sites approximately 500 m apart with only about 150 m difference in altitude. However, this may be due to spatial variability in precipitation patterns, as well as other site factors such as slope and aspect.

Table 9 shows the July 1996 snow depth and altitude values measured by Gardner and Swain (1996) for various locations in KwaZulu-Natal which Table 10 shows potential risk of snow damage to forest plantations. These values were used to derive a linear regression model of snow depth vs. altitude which explained 93% of the variance in the data (R^2 = 0,93; Std error = 3,3; n = 9):

Snow depth (in cm) = [0.129 * Altitude (in m)] - 151

Table 9. Snow depth values for various locations in KwaZulu-Natal, July 1996 (Gardner and Swain, 1996).

Location	Altitude (m)	Snow depth (cm)
Balgowan	1 530	50
Boston	1 510	40 - 50
Donnybrook	1 350	20 - 30
Draycott (Estcourt)	1 450 – 1 600	20 - 30
Greytown	1 480	40
Petrusvlei (Greytown)	1 350	25 - 30
Pinewoods/Gowan Brae (Boston)	1400 – 1 470	> 40
Pivaanspoort (Utrecht)	1 480	40 - 50
Richmond	1 280	15

Table 10. Potential risk of snow damage to commercial forest plantations in relation to altitude for the KwaZulu-Natal region (Kunz and Gardiner, 2001).

Altitude (m)	**Potential Snow depth (cm)**	**Potential risk of snow damage to trees**
< 1290	< 15	Slight
1290 - 1400	15 - 30	Moderate
> 1400	> 30	High

Altitude is not the only factor influencing snow depth and therefore risk of snow damage. Other more localised terrain features or microclimate effects related to aspect and slope could also be important and may explain the difference in July 1996 snow depths experienced in the Ixopo and Umvoti areas between 1 150 and 1 350 m. These site factors are considered next.

Northerly facing slopes (i.e. north aspects) receive higher incoming radiation loadings if compared to southerly slopes (i.e. south aspects) during the winter months in South Africa. For example, north aspects in the Cathedral Peak area receive daily winter radiation loadings of 22 MJ m^{-2} as opposed to 9 MJ m^{-2} on south aspects (Schulze, 1997). Hence, north-facing slopes are warmer than south facing slopes. Davidson (1989) stated that the snow line on the cooler slopes is generally 100 to 200 m lower than on the corresponding warmer slopes. Based on this evidence, a general rule of thumb for KwaZulu-Natal is to avoid altitudes above 1 200 m on the warmer slopes for snow sensitive tree species (e.g. *E. grandis* and *A. mearnsii*), but decrease this threshold to about 1 100 m on the cooler south and east facing slopes. In the Greytown area, it was particularly noticeable that some of the worst damaged stands were located on south and east facing slopes and in sheltered valleys (Gardner, 1996). The Mountain Club of South Africa (MCSA, 1996) reported that the 1996 snow was a metre deep on the southerly slopes and 0,5 m deep on the northerly slopes in the Black Mountain pass (located 10 km inland from the Sani Pass in Lesotho). However, Nykänen *et al.* (1997) stated that evidence for European conditions on the role of aspect, as a determinant of snow damage is contradictory (Kunz and Gardner, 2001).

As slope gradients increase, the north aspect slopes receive higher daily radiation loadings during the winter months as the angle of the solar radiation to the ground surface becomes less oblique. Therefore, a north facing 5 °C slope is cooler than a 25 °C slope. On the other hand, southern aspects receive less radiation as slope gradients increase due to the "shadowing" effect. The effect of slope, combined with wind direction, means that the trees located on steep south facing slopes should experience the greatest snow damage (and steep northerly slopes the least). The effect of slope on radiation loadings for east and west aspects is minimal.

Mason (1997) mentioned that trees on slopes or in valleys in the Umvoti area were almost all broken in a downhill direction. He described this as a "domino" effect since when one tree broke under the snow load, the neighbouring tree would also break due to the lack of support, causing a cascading effect down the slope. Due to the effect of wind sheltering, trees in the middle of the slope are more susceptible to damage.

Gardner and Swain (1996) rated species resistance to snow damage (Table 11) based on the 1996 event and information provided by Davidson (1984; 1989) on the earlier snowfall occurrences.

Table 11. Resistance to snow damage of various tree species (Gardner and Swain, 1996).

Species	**Resistance to snow damage**	**Typical percentage damage**
E. nitens, P. taeda, P. patula	Very tolerant	5
E. fraxinoides, E. fastigata, P. elliottii	Tolerant	5 - 20
E. smithii, E. badjensis	Moderately tolerant	20 - 35
E. macarthurii, E. benthamii, E. dunnii, P. radiata	Slightly tolerant	35 - 50
E. grandis, A. mearnsii	Sensitive	50 – 100

Tree taper and crown characteristics are the main factors that control the resistance of trees to snow damage: slightly tapering stems, asymmetric crowns and rigid horizontal branching are all associated with high risk (Nykänen *et al.*, 1997). Päätalo *et al.* (1999) stated that trees with a taper of less than 1:100 that have highly elevated crowns are particularly susceptible to damage. Of the cold-tolerant eucalypt species grown in South Africa, *E. dunnii* has very little taper (Swain *et al.*, 2000). This may partially explain why this species is prone to snow damage. Trees with longer, narrower crowns (e.g. *E. nitens* and *E. fraxinoides*) suffer less damage than spreading, heavier crowns (e.g. *E. grandis* and *A. meansii*). *A. mearnsii* generally has a heavier crown than *E. grandis* (Pettit, 1996). Juvenile trees with heavy crowns, as well as pendulous branches (e.g. *P. patula),* seemed less susceptible to damage compared to light-crowned species having horizontal or ascending branches such as *P. taeda* (Davidson, 1989). Although the tolerance to snow damage of *P. greggii* (southern provenance) has not been recorded in the available studies the author believes that it is the most sensitive of the four species measured.

Further parameters that should be considered when evaluating the potential for snow damage is tree age, tree height and stand density. With regard to *E. grandis* and *A. mearnsii*, it is clear from the literature that juvenile trees (0 to 2 years) tend to bend under the snow load with very little breakage occurring (Gardner, 1996). Young to intermediate trees (2 to 8 years) suffer mainly from stem breakage, whilst the boughs and crowns of mature trees (> 8 years) usually break. The degree to which bent stems will recover and straighten in the future depends on the severity of the snow load and species type (Davidson, 1984; 1989). The risk of snow damage increases with tree height (Nykänen *et al.*, 1997; Päätalo *et al.*, 1999). Tall, thin trees are more susceptible than short, thick trees to snow damage (Davidson, 1984; 1989). Some authors have stated that the dominant trees within a stand are commonly damaged by snow. However, the evidence of the effect of stand height is conflicting and it is clear that height cannot be used as the sole explanation for damage (Nykänen *et al.*, 1997).

Stands with wider espacements or large stand openings are at higher risk of snow damage due to the increased wind loading in the sparser stands (Davidson, 1989). For the same reason, heavily thinned stands would also be more vulnerable to snow damage. Päätalo *et al.* (1999) suggested that slightly tapering high-risk trees should be removed during thinning operations. In contrast, Davidson (1989) reported that inadequate spacing due to postponed thinnings results in more snow damage to pines due to snow accumulation on the too dense crown canopy. In this situation, a "domino" effect may occur as the breaking of a heavily snow laden branch or stem can damage branches or stems of neighbouring tress, which Nykänen *et al.* (1997) refer to as group collapse. According to Nykänen *et al.* (1997), young dense stand can suffer heavier damage than sparse stands. The reason for this is that trees in dense stands are more likely to develop high-risk slightly tapering stems and shorter, asymmetric crowns. As with tree height, the effect of stand density is conflicting and similarly, this variable cannot solely be used to explain tree damage.

A further important damage category in the Eastern Cape is hail. According to Evans, (1978) the occurrence of severe hailstorms is restricted to certain regions of the world and is especially a feature of sub-tropical latitudes in areas of broken topography. Much of the Highveld and Middleveld of Swaziland is prone to this climatic damaging factor and devastation has occurred to both agricultural and forestry crops (Murdoch *et al.*, 1963).

Undoubtedly the most important damage caused by hail to trees in Swaziland is the resulting infection of wounds and scars by *Sphaeropsis sapinea*, which frequently kills *P. patula*. Severe storms in April 1975 led to the destruction of several hundred hectares of *P. patula* in northern Swaziland. Van der Westhuizen (1968) regards *Sphaeropsis sapinea* as the single most serious pathogen in pine plantations in South Africa. However, damage is by no means always lethal and the effect of hail is frequently expressed in growth, as Evans (1978) found when analysing past height increments and patterns of nodal development.

Reduction in height growth and occurrence of dead tops following hail damage has been reported elsewhere (Riley, 1954; Linzon, 1962). In this instances there were few visible signs of the damage five years later and could easily be overlooked in a mensurational survey. If not known this could lead to serious underestimation of the site index (Evans, 1978).

5. SAMPLING METHODS

In order to obtain growth data on a representative scale for the NECF landholdings, 22 690 plots, each covering a circular area of 250 m², were measured. They were distributed over 539 commercial compartments totalling 11 344,93 ha, representing a sample intensity of 5%.

5.1 Sampling

The following particulars of each compartment were determined in a systematic sampling system, shown in Figure 6 and described by Von Gadow and Bredenkamp (1991):

- The average stem diameter at breast height (DBH) overbark

  Diameter measures are necessary to determine the volume of felled trees and logs. The diameter of standing trees, conventionally measured at a height of 1,30 m above ground level, is known as diameter at breast height, (DBH). The height of 1,30 m was selected for reasons of convenience and formally adopted by the International Union of Forestry Research Organisation (IUFRO). The mean diameter of a sample plot and stand is calculated as the mean quadratic diameter, which is the diameter corresponding with the basal area of the mean tree. The reason being that the use of the arithmetic mean diameter underestimates the mean volume of the trees within a plot (Bredenkamp and van Laar, 1993).

- The average height (HT) of the trees

  A Suunto hypsometer, an instrument based on elementary trigonometric principles, was used to measure standing tree height. This requires the measurement of the horizontal distance between the operator and the tree, with the aid of an optical rangefinder, as well as the angles between the horizontal and the top and the base of the tree respectively. The angle between the operator and the top of the tree should be less than 45 degrees since this minimises parallax. No trees with excessive lean and deformation or dead tops were measured. The mean height of the stand was defined as the estimated height of the tree with the mean basal area. It was obtained by fitting a regression equation to a sample of 30 height measurements and corresponding diameters in each compartment. Because of non-linearity of the relationship, both variables were transformed with log (height) as response variable and the reciprocal of DBH as predictor. A regression analysis was used to estimate the height corresponding to the root mean square DBH. This was reflected as mean height. Furthermore, the dominant height was defined as the regression height of the 20% thickest trees that were recorded in each compartment (Bredenkamp and van Laar, 1993).

- The average number of stems per hectare (SPHA)

  The stems per hectare for each plot were counted as shown in Figure 7. The average number of stems per hectare for each compartment were calculated based, on all measured plots.

A sampling intensity of 5% was considered as sufficiently representative and cost-effective as reflected in current Mondi Forests Policy.

5.2 The Circular Plot Method

Sampling can be done in various ways. For the purposes of this study the circular sample plot method was selected. The following considerations were taken into account:

- Method is applicable across species, regimes and other site parameters;
- It deals effectively with variable spacing;
- The experience in Mondi Forest has shown the method to produce superior results to earlier methodologies (K. Chiswell, B. Esler, B. Pienaar, pers. comm., Mondi Forests, 2000).

The following equipment was used:

- DBH Callipers
- Hypsometer with range finder template
- Measuring tape (100 m)
- Psion data logger
- Compartment list and estate maps
- Compass

Establishment of Sampling Plots

The relevant estate maps were produced for selecting compartments based on tree age and species. Thereafter, the directional tree rows were defined and the placement of the plots planned accordingly. If no suiTable tree rows existed, the cruise direction and placement of plots were determined by using a compass.

The first plot was placed 30 meters in from the edge of the compartment. The range finder stick was placed at the centre point of the plot. The radius of 8,92 m was defined by using a range finder to demarcate a plot. The area of the circle plot was therefore calculated using the conventional circle area formula.

Area $= \pi r^2 = 3{,}14 \times 8{,}92^2 = 250\ m^2$

Plots were spaced at 50 m intervals in a row and at 100 m intervals between rows (Figure 6), measuring 500 m^2 per hectare, resulting in a 5% sampling intensity. One member of the team defined the perimeter of the plots with the range finder, while the second member measured the DBH of each tree falling within the plot (Figure 7). The third member of the team captured the data with a psion data logger. The person recording the readings on the data logger verbally repeated all measurements to ensure that they were correctly recorded. DBH/HT pairs were taken per plot in order to establish a DBH/HT regression for each compartment.

Figure 6. Schematic diagram of plot layout.

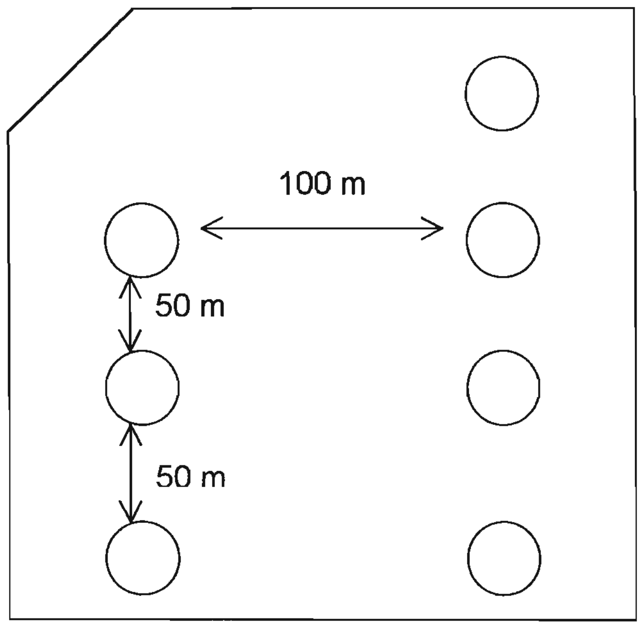
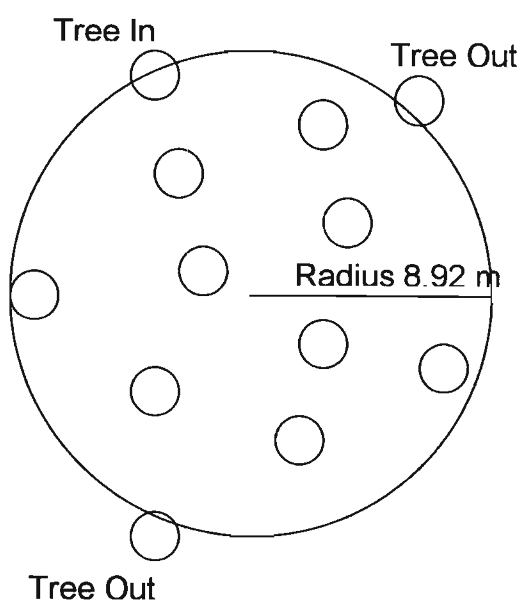


Figure 7. Schematic diagram of a plot with trees.



These data were also used to calculate an average height by using the average DBH as previously described. A minimum of 30 DBH/height (HT) pairs were measured per compartment, thus for example if a compartment was 5 ha in size the minimum DBH/HT pairs per plot would be:

30/(5x2) = 3 DBH/HT pairs

30 DBH/HT pairs covering a range of diameters are generally regarded as a guideline to obtain a statistically viable DBH/HT regression.

5.3 Error factors

On slopes, DBH measurements were always taken a 90° angle to the slope. The DBH callipers were always held at right angles to the longitudinal axis of the tree stem. The reading was taken while the instrument was pressed against the tree. If the sectional area were not circular, two diameter readings were taken, at right angles to each other and the average recorded.

Hypsometer height readings were taken as per the standard methodologies with the necessary considerations and precautions for slope and distance.

6. THE SURVIVAL OF FOUR PINE SPECIES

6.1 Introduction and Objectives

Accurate prediction of mortality is an essential part of any stand growth prediction system. Large economic gains can be achieved by preventing increment loss due to bad survival through the selection of efficient site preparation methods elimination of blanking, reduction of planting density and early thinnings. Unfortunately, tree mortality is one of the most variable and difficult stand characteristics to predict. Lee (1971) distinguished between irregular mortality, caused by insects, windfall, fire and other factors, and regular mortality, which results from within-stand competition for scarce resources. Senescence is another important cause of regular mortality (Belli and Ek, 1988). Numerous mortality models in forest ecosystems describe only regular mortality using age and diameter as the most important predictors (Monserud, 1976; Bailey, 1986). The other variables used include competition and vitality indices (Hara, 1985; Belli and Ek, 1988) and site quality (Somers *et al.*, 1980). These models have been developed to predict tree mortality that occurs during natural thinning. Not considering the establishment phase, it is reasonable to expect a sigmoidal survival curve with a high level of mortality during the self-thinning phase (Piet and Christensen, 1987). However, there is no merit for regular mortality models in intensively managed tree plantations where low initial stocking, artificial thinning, and clearfelling prevent regular mortality. Under such circumstances a high incidence of mortality usually occurs during the few months after planting as a result of a complexity of factors including seedling qualities, site environment and planting methods.

So far prediction of seedling mortality after planting has been hampered by a lack of information concerning factors of importance, mainly seedling size, vigour, and competition indices (Belli and Ek, 1988). It is suggested that transplanting stress is the most important of all factors affecting post-planting mortality. Transplanting stress causes physiological imbalances, changes in photosynthate allocation, and exhaustion of carbohydrate reserves. Trees die when they cannot acquire or mobilize sufficient resources to heal injuries or otherwise sustain life (Waring, 1987). Poor root-soil contact is probably the major reason for transplanting stress (Sands, 1984). The initial transplanting stress may result in enhanced dieback of trees if followed by temperature extremes, competition for resources with vegetation or pest and pathogen attacks. It is essential to ensure low mortality of trees after planting in a short rotation plantation crop because blanking is not economically justified and each of the planted trees is expected to contribute to timber yields (Bailey, 1986; Donald *et al.*, 1988).

The objectives of this research were thus to determine *(i)* if there were any survival differences for the studied pines and planting dates, *(ii)* if so, whether they were statistically significant.

6.2 Methods

The following hypotheses were investigated:

(i) H_0: There is no difference in the survival of the four pine species.

(ii) H_0: There is no difference in the survival of the four pine species planted in various months.

In order to investigate the hypothesis the stand density parameter (trees/ha) was calculated for each compartment and relevant data sets were compiled for each species. The data were analysed by using the SAS statistical package (SAS Institute Inc., 2001). The Proc Univariate procedure (SAS Institute Inc., 2001) was performed to obtain basic descriptive statistics for the paramteter under investigation, including number of plots (observations), mean, minimum, maximum and standard errors. Survival was then analysed using various techniques. Initially a chi-square analysis was done to test for the hypothesis that the survival counts were the same across the species. The Proc Freq procedure (SAS Institute Inc., 2001) was used to carry out the analysis. An arcsine transformation was then applied to the percentage survival of trees by assuming that 100 % survival correspond to 1 111 trees per ha. The arcsine transformed data were then tested for normality using the Shapiro-Wilk's W-statistic. The homogeneity of variance was also tested using Levene's test. The data were subsequently subjected to an analysis of variance using the Proc GLM procedure (SAS Institute Inc., 2001). The Tukey's Honestly Significantly Different (HSD) test was then used to separate the species survival means.

It was also investigated whether the month of planting had any impact on the survival of the different species. Personal experience showed that planting season could play a role in tree survival due to the pronounced seasonal climate differences, weed competition and seasonal regimes of plant available water. After an arcsine transformation of tree survival, testing for normality and homogeneity of variance, the survival of each species was subjected to an one-way analysis of variance considering planting month as the treatment. Subsequently the data were split into the four different species and analysed. Finally, Tukey's HSD test was used to separate significantly different means between the planting months.

6.3 Results

The basic descriptive statistics of survival for the respective pine species are shown in Table 12, while Table 13 shows tree survival for various planting months. On average the best surviving species were *P. elliottii* and *P. greggii* yielding 69% and 68% respectively. Although the poor survival (64%) of *P. taeda* could partially be explained through the high site requirements for this species in South Africa, the poor performance of *P. patula* (56%) was disappointing.

The chi-square goodness-of-fit test resulted in a chi-square value of 8,533 at p = 0,036. The survival differed across the species and therefore the hypothesis, H_0: there is no difference in the survival between the four species of pines, was rejected.

Table 12. Summary of tree survival by species.

Species	No. of observations	Survival (Trees/ha)			
		Minimum	Mean	Maximum	Standard Error
P. elliottii	81	496	712	1104	14,16
P. greggii	63	460	701	958	15,89
P. patula	383	350	663	984	5,66
P. taeda	11	342	666	835	37,80

Table 13. Summary of tree survival by planting month.

Month Planted	Species	No. of Observations	Survival (Trees/ha)			
			Mean	Minimum	Maximum	Standard error
January	*P. patula*	16	650	433	817	95,28
	P. greggii	4	674	560	721	76,47
	P. elliottii	10	730	575	877	99,69
	P. taeda	0	-	-	-	-
February	*P. patula*	20	690	445	824	95,64
	P. greggii	6	808	593	889	115,62
	P. elliottii	1	748	748	748	-
	P. taeda	1	342	342	342	-
March	*P. patula*	35	600	521	886	80,42
	P. greggii	11	717	570	958	102,49
	P. elliottii	14	666	492	784	83,31
	P. taeda	5	674	617	738	48,47
April	*P. patula*	37	640	381	975	137,51
	P. greggii	3	650	579	768	102,67
	P. elliottii	13	723	579	1104	148,19
	P. taeda	0	-	-	-	-

Month Planted	Species	No. of Observations	Survival (Trees/ha)			
			Mean	Minimum	Maximum	Standard error
May	*P. patula*	22	669	486	871	89,95
	P. greggii	1	460	460	460	-
	P. elliottii	9	696	535	1073	164,33
	P. taeda	0	-	-	-	-
June	*P. patula*	25	678	350	931	132,99
	P. greggii	1	709	709	709	-
	P. elliottii	6	707	583	1010	153,99
	P. taeda	0	-	-	-	-
July	*P. patula*	25	675	527	900	109,21
	P. greggii	1	560	560	560	-
	P. elliottii	2	701	659	743	59,40
	P. taeda	0	-	-	-	-
August	*P. patula*	30	719	487	918	128,75
	P. greggii	1	542	542	542	-
	P. elliottii	0	-	-	-	-
	P. taeda	1	768	768	768	-
September	*P. patula*	48	668	444	896	113,57
	P. greggii	2	844	807	880	51,62
	P. elliottii	1	487	487	487	-
	P. taeda	0	-	-	-	-
October	*P. patula*	52	663	524	984	104,63
	P. greggii	15	662	462	957	154,04
	P. elliottii	10	713	597	999	113,17
	P. taeda	0	-	-	-	-

Month Planted	Species	No. of Observations	Survival (Trees/ha)			
			Mean	Minimum	Maximum	Standard error
November	*P. patula*	36	633	467	1041	103,11
	P. greggii	17	725	554	883	100,31
	P. elliottii	3	816	567	1041	237,96
	P. taeda	1	835	835	835	-
December	*P. patula*	38	624	369	975	107,05
	P. greggii	1	556	556	556	-
	P. elliottii	11	663	496	868	106,71
	P. taeda	3	671	647	718	41,00

The result of the analysis of variance of the survival data is presented in Table 14 and it confirmed the chi-square results. The null hypothesis was rejected confirming highly significant survival differences between the pine species.

Table 14. Results of the analysis of variance at the arcsine transformed survival date for the four species of pines.

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Model	3	0,2587	0,0862	5,42	0,001
Error	534	8,5000	0,0159		
Corrected Total	537	8,7587			

Table 15. Means of the tree survival for the four pine species (different letter index shows statistically different means at p ≤ 0,05, using Tukey's HSD Test).

Species	**Number of Observations**	**Mean Survival (%)**
P. elliottii	81	69^{A}
P. greggii	63	68^{A}
P. taeda	11	64^{AB}
P. patula	383	56^{B}

From the above it can be seen that the survival of *P. patula* is significantly lower than that of *P. elliottii* and *P. greggii.* The survival of *P. taeda* does not differ significantly from the other three species.

There was no statistically significant difference in tree survival between the planting months for all species combinded (Table 16). Each of the four species measured was then analysed separately. The analysis of the *P. patula* survival showed significant differences between the planting months (Table 17), whilst no significant differences were found in the survival of *P. greggii P. elliottii* and *P. taeda*, for the planting months.

Table 16. Results of the analysis of variance of tree survival with planting month as the treatment, for all pine species.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-value**	**Pr>F**
Model	11	206720,374	18792,761	1,39	0,1757
Error	526	7135428,431	013565,453		
Corrected Total	537	7342148,805			

Table 17. Results of the analysis of variance for *P. patula* survival with planting month.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-value**	**Pr>F**
Model	11	276807,478	25164,316	2,07	0,0220
Error	372	4532452,519	12184,012		
Corrected Total	383	4809259,997			

The results of the Tukey's HSD test for the mean survival of *P. patula* for various months showed that trees planted in August have a statistically significantly higher survival rate than trees planted in January, April and November (Table 18). Trees planted in March survived better than trees planted in April and November, and trees planted in February survived better than those planted in November. The results indicate that late summer and late winter planting of *P. patula* in the north-eastern part of the Eastern Cape produced the best survival. The differences were not large and the overall survival was unsatisfactory from an operational perspective for any of the planting months.

Table 18. Mean survival of *P. patula* for various planting months (different letter index shows statistically different means at $p \leq 0,05$, using Tukey's HSD Test).

Month	**Number of Observations**	**Mean Survival (%)**
August	30	$0,65^{A}$
March	35	$0,63^{AB}$
February	20	$0,62^{ABC}$
June	25	$0,61^{ABCD}$
July	25	$0,61^{ABCD}$
May	22	$0,60^{ABCD}$
September	48	$0,60^{ABCD}$
October	52	$0,60^{ABCD}$
January	16	$0,59^{BCD}$
April	37	$0,58^{CD}$
November	36	$0,57^{D}$

6.4 Discussion and Conclusions

Stand Density

Stand density of the current commercial plantings in NECF is highly variable due to unplanted gaps and poor tree survival. The bulldozer clearance of the former wattle stands, pushed into brush piles, created unplanted gaps. This took place due to significant pressures on the field staff that left little time to either burn or bury these piles prior to afforestation. The nature of the sandstone geology and its localised obtrusions also resulted in numerous open areas within compartment boundaries having a further detrimental impact on stand density.

Another practice that influenced the stand density and introduced a level of variability was the ripping and ridging technique practiced between 1989 - 1993. Due to the way this technique was implemented so-called "short rows" and a deviation from the 3 m spacing between rip-lines were common and contributed to low stand density.

The low stand density was also due to high initial tree mortality.

The interaction of management decisions and the unique climate, geology and soils culminated in the knowledge base not present before 1994. The impact of harmfull factors (fire, hail, drought, snow, rodents and diseases), "old land syndrome", inadequate site preparation, poor plant and planting quality, insufficient weed management, unbalanced fertilisation, incorrect species choice, incomplete logistic infrastructure, unspecified products and regimes, inexperienced labour and economies of scale had an impact on tree survival and added to the complexity of survival data analysis. Although some of the natural elements continue to play a role, the operational procedures were largely inproved from 1994 onwards.

The current analysis showed that there is a statistically significant difference between the survival of the different species, with *P. patula* being significantly worse than *P. elliottii* and *P. greggii*. This reflects the field observations that

P. patula is very sensitive to various site factors in particular poorly drained soils, cold exposed sites, high elevation sites, old agricultural lands, weed infested sites and sites affected by hail, fire, wind, snow and drought. This has a significant impact on the afforestation success since *P. patula* is the main species established in NECF due to its favourable timber properties. The site sensitivity of the surveyed *P. patula* stands could also be an expression of its poor genetic adaptation, since the majority of the genotypes originated from the Sabie area. The comparitive climate study done by Thackrah and Monnik (1998) found a 2 ^{0}C lower mean minimum temperature, lower and longer Langs Climatic Index (LCI) period, longer and later rainfall season, no accumulation of heat units before the start of the rainfall season and a higher frequency of days with minimum temperatures below 0 ^{0}C than those found Sabie. The current *P. patula* seedstock therefore originated from a different climate zone.

<u>Planting Month</u>

The investigation into the impact of planting month on the survival is complex with only *P. patula* showing a statistically significant response to planting month. The month of August represents the optimal month for *P. patula* establishment. This could be due to the fact that this enables the seedlings the longest growth season overall, as well as benefiting optimally from the early spring rains before the intensive weed flushes start in October. November proved to be the worst month to establish *P. patula* in terms of survival. This could be due to this period being in the middle of the most intensive weed growth period (Little *et. al.,* 1994), the short interval before the January heat and the very wet conditions prevalent during this time of the year.

In conclusion, it is clear from the investigation that *P. patula* is the worst species planted in NECF in terms of survival. It is thus recommended that *P. patula* be scheduled for third quarter plantings and that the optimal planting window be further investigated. Furthermore it would be of value to monitor and investigate mortality rates after initial establishment and prior to any blanking operations, since this might give further insight into the mechanisms involved in its mortality. The need for further research in this respect is highly validated by unacceptably low stand densities in the region. It must be noted that *P. patula* provenance trials established at North East Cape Forests could provide valuable information on potentially superior provenances.

7. THE PRODUCTIVITY OF FOUR PINE SPECIES

7.1 Introduction and Objectives

The expansion of the Foresty Industry in South Africa into non-traditional forestry regions, such as the north-eastern part of the Eastern Cape Province, during the last decade resulted in unique afforestation experiences. These new ventures presented several new challenges to forestry research, particularly due to the absence of long-term forestry research data and local experience. In order to optimise the forestry environment in the region a sound knowledge of site quality and production potential was of strategic importance. The currently established pine stands represent the first rotation of afforestation and thus the first opportunity to evaluate site quality and production potential across the landholdings.

The objective of this part of the study was to determine if there were any statistically significant differences between the site productivity of the four measured species in NECF. In order to study the site productivity of the four pine species, commercial pine stands were enumerated and the results matched to available site information. Due to the relative young age of the commercial pine stands, height and diameter at breast height (DBH) measurements were used to evaluate the site productivity of the four measured pine species.

The following hypothesis was formulated:

H_0: There is no difference in the growth of the four species of pines as expressed in terms of site index and basal area.

7.2 Methods

Dominant Height

The height/DBH relationship by comparment was determined by regression analysis. The dominant height, which is the regression height of the 20% largest DBH trees, was then calculated. Finally the two-parameter Chapman-Richards growth function was used to determine height at the reference age of 10 years. This variable was termed site index (SI_{10}) and was used to characterise site productivity. Parameter estimates used in the site index model were derived from trials (correlated curve trend and permanent sample plots) established as part of the Mondi Forests growth and yield modelling protocol for specific tree species in KwaZulu Natal.

The two-parameter Chapman-Richards function (Richards, 1959) looks as follows:

$$SI_{10} = b_0 * (1 - \exp(b_1 * age))$$

Where: SI_{10} = Site Index at reference age 10

Age = age of compartment at time of measurement

The parameter estimates, b_0 and b_1, were provided by Mondi Forests (B. Pienaar, pers. comm., Mondi Forests, 2001).

Basic summary statistics of SI_{10} by species were obtained using the MEANS procedure (SAS Institute Inc., 2001).

An analysis of variance was applied to the SI_{10}. The assumptions underlying the analysis of variance were confirmed. These assumptions are that the height data are normally distributed, and the variance across treatments is homogenous. The residual error terms were normally and independently distributed. Respectively, Shapiro-Wilk's W-statistic and Levene's Homogeneity of variance tests were used to determine whether these assumptions had been met. In cases where the homogeneity of variance assumption was not met, the Welch ANOVA was applied. In cases where the data were not normally distributed a suiTable transformation was used to normalise the data (SAS Institute Inc., 2001).

An analysis of variance was conducted to determine whether there were any statistically significant differences between species for SI_{10}. Tukey's HSD Test was used to separate treatment means.

Basal Area at Age 10 Years

The Basal Area (BA) of a tree is defined as the cross sectional area (over bark) of the stem at 1,3 m height above the ground. The Basal Area per hectare was calculated as the BA of the mean tree multiplied by the stems per hectare (Von Gadow, Bredenkamp, 1991).

A modified multiple regression (Basal Area) growth function (Harrison, 1991) and exponential difference form survival function (Pienaar and Shriver, 1981) were used to determine basal area per hectare at 10 years of age. The parameter estimates used were derived from trials (correlated curve trend and permanent sample plot) established as part of the Mondi Forests growth and yield modelling protocol.

The relevant Basal Area function is as follows:

$BA_{10} = \exp(b_0 * (1 - Age_1/Age_2) + \ln(BA_1) * (Age_1/Age_2) + b_2 * (\ln(TPH_2) - \ln(TPH_1) * (Age_1/Age_2)) + b_3 * (\ln(HD_2) - \ln(HD_1) * (Age_1/Age_2)) + b_4*((\ln(TPH_2) - \ln(TPH_1))/Age_2) + b_5*((\ln(HD_2) - \ln(HD_1))/Age_2))$

The exponential difference form survival function is:

$TPH_2 = TPH_1 * \exp(b_1 * ((Age_2 / 10)$ ^$b_2 - (Age_1 / 10)$ ^$b_2))$

Where:

BA_1 = Basal Area per hectare (m^2/ha) at point of calibration Age_1

BA_{10} = Basal Area per hectare (m^2/ha) at reference age 10 years

Age_1 = Age at time of measurement (years)

Age_2 = Age at point of projection (10 years)

HD_1 = Dominant height (m) at point of calibration Age_1

HD_2 = Dominant height (m) at point of projection Age_1

TPH_1 = Trees per hectare at point of calibration

TPH_2 = Trees per hectare at point of projection (10 years)

The parameter estimates b_0, b_1, b_2, b_3, b_4 and b_5 were provided by Mondi Forests (B. Pienaar, pers. comm., Mondi Forests, 2001).

Basic summary statistics of the BA_{10} estimated by species were obtained using the MEANS procedure (SAS Institute Inc., 2001).

The same procedure as with the analysis of site index was followed. An analysis of variance was applied to basal area. The assumptions underlying the analysis of variance were confirmed. These assumptions are that the basal area data are normally and independently distributed, the variance across treatments is homogenous; the residual error terms are normal and independently distributed. Respectively, Shapiro-Wilk's W-statistic and Levene's Homogeneity of Variance Test were used to determine whether these assumptions were met (SAS Institute Inc., 2001).

In cases where the homogeneity of variance assumption was not met, the Welch Anova was applied. In cases where the data was not normally distributed a suiTable transformation was used to normalise the data. An analysis of variance was conducted to determine whether there are any statistically significant differences between species for BA_{10}. Tukey's HSD test was then used for separating mean BA_{10} for the four species.

7.3 Results and Discussion

Basic summary statistics of SI_{10} by species and for all species are shown in the Table 19.

Table 19. Basic summary statistics for site index (SI_{10}) by species.

Species	N	Minimum	Mean	Maximum	Standard error
P. elliottii	80	6,64	11,27	15,26	0,15
P. greggii	63	7,68	13,34	16,77	0,22
P. patula	384	8,44	13,50	20,36	0,08
P. taeda	11	9,06	12,66	16,52	0,61
All	538	6,64	13,13	20,36	0,08

The analysis of variance, (Table 20) shows that there are highly significant differences in SI_{10} between the four species of pines. Tukey's HSD test was then used to separate the means. The results are shown in Table 21.

Table 20. Analysis of variance of site index (SI_{10}) with pine species as the treatment.

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Model	3	333,3759	111,1253	42,86	<0,0001
Error	534	1384,4860	2,5927		
Corrected Total	537	1717,8619			

Table 21. Mean site index (SI_{10}) for the four pine species and results of Tukey's HSD test (different letter index shows significant differences between the means at $p \leq 0,05$).

Species	N	Mean SI_{10} (m)
P. patula	384	$13,50^{A}$
P. greggii	63	$13,34^{A}$
P. taeda	11	$12,66^{A}$
P. elliottii	80	$11,27^{B}$

The results show that the SI_{10} of the species *P. patula*, *P. greggii* and *P. taeda* are similar and significantly different to that of *P. elliottii*. This result confirms observations made by Poynton (1979) describing *P. elliottii* as a slower growing species than *P. patula* and *P. radiata*. At the same time, *P. greggii* compares well with growth of *P. patula*. It must be brought into consideration, however, that *P. elliottii* is predominantly planted on the marginal sites (shallower, steeper sites) in NECF, and this may have an additional impact on it's height growth.

Basic summary statistics of the basal area are shown in the Table 22.

Table 22. Basic summary statistics for basal area (BA_{10}) for all four pine species.

Species	N	Minimum	Mean	Maximum	Standard error
P. elliottii	80	4,18	19,36	29,40	0,56
P. greggii	63	12,24	22,21	34,06	0,69
P. patula	384	1,02	18,56	36,38	0,24
P. taeda	11	9,68	16,40	22,35	01,27
All species	538	1,02	19,07	36,38	0,21

The analysis of variance showed that there were highly significant differences between the growth responses as measured by BA_{10} for the four species of pines.

Table 23. Analysis of variance of basal area with the pine species as the treatment.

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Model	3	802,80	267,60	11,61	<0,0001
Error	534	12303,99	23,04		
Corrected Total	537	13106,79			

The results of the Tukey's HSD test showed that BA_{10} of *P. greggii* and *P. elliottii* are not statistically different from those of *P. patula* and *P. taeda,* while *P. greggii* is performing significantly better than *P. patula* and *P. taeda*. It is difficult to explain the low BA_{10} of *P. taeda* (Table 24). It is possible that the relatively limited *P. taeda* sample size, the demanding site requirements for this species, as well as the failure of the species observed on very cold or marginal sites could be responsible for it's poor growth. The superior performance of *P. greggii* over that of *P. patula* is consistent with the Mondi Tree Breeding trial results (E. Kietzka, pers. comm., Mondi Forests, 2001), as well as the results from the CAMCORE trial series in NECF (Dvorak, *et. al.*, 1996). This supports the drive behind the introduction of the Mexican species, with *P. greggii* in the forefront of the quest for species that could optimise the productivity under the unique site conditions in NECF.

Table 24. Mean basal area (BA_{10}) for the four pine species and results of Tukey's HSD test (Different letter index shows significant differences at $p \leq 0,05$).

Species	**N**	**Mean BA_{10} (m^2/ha)**
P. greggii	63	$22,205^{A}$
P. elliottii	80	$19,362^{AB}$
P. patula	384	$18,564^{B}$
P. taeda	11	$16,369^{B}$

This study proved that there are statistically significant differences between the species in terms of site index and basal area.

The use of *P. patula* for afforestation in NECF must be reviewed assuming that it remains an important species in the project, but only on optimal sites. It is furthermore important to note that the poor performance of *P. taeda* was confirmed, and it occurred possibly due to inappropriate genotype used. *P. taeda* is not currently a priority species in the project. Should this change, it is recommended that further investigations be conducted and appropriate provenances, families or clones are used.

Although these measurements only represent the mid rotation point, it seems that the introduction of *P. greggii* (from southern Mexico) has been successful in terms of improved growth. The stem form and pulping qualities are still under investigation.

7.4 Conclusion

In conclusion, this analysis reconfirmed the importance of species selection and the subsequent economic importance of site-specific species selection. The introduction of *P. greggii* has proved to be successful at this stage, although judgement must be reserved until the rotation ends.

8. THE RELATIONSHIP BETWEEN THE GROWTH OF PINES AND SITE CONDITIONS

8.1 Introduction and Objectives

Afforestation in South Africa is practised over a very wide range of growing conditions with regard to latitude, altitude, climate, lithology, typography, soils and biotic factors. This leads to a diversity of site conditions in terms of tree growth (Grey, 1987; Grey *et.al.,* 1979; Grey, 1978; Schönau, *et. al.,* 1987; Hensley, 1996; Hensley, 1997). The objective of this part of the study was to investigate the relationship, or lack thereof, between the performance (as expressed in terms of Site Index (SI_{10}), Basal Area (BA_{10}) and survival) of the four pine species in North East Cape Forests and a multitude of site variables.

The following hypothesis was investigated:

H_0: There is no relationship between the growth (SI_{10}, BA_{10} and survival) of *P. patula*, *P. greggii, P. elliottii, P. taeda* and site characteristics.

8.2 Methods

The response variables are defined after Monnik (pers. comm., Institute for Soil, Climate and Water, 2001), Schulze *et. al.* (1994), Schulze (1997), Schönau *et. al.,* (1984) and Schulze *et. al.* (1985).

The following variables were used:

Areaeff =	The planemetric area as demarcated by the compartment perimeter expressed in hectares.
Latitude =	The latitude coordinate of the midpoint of each measured compartment.
Longitude =	The longitudal coordinate of the midpoint of each measured compartment.
Altitude =	The altitude (m a.s.l.) as measured at the midpoint of each recorded compartment.
Rain (Month) =	Long-term mean rainfall (mm) for each month as sourced from the Agricultural Research Council.
RainTot =	Long-term cummulative mean rainfall for summer months (mm).
MXTJan =	Average monthly maximum temperature for January (°C).
MXTJul =	Average monthly maximum temperature for July (°C).
MXTAnn =	Average annual maximum temperature (°C).
MNTJan =	Average monthly minimum temperature for January (°C).
MNTJul =	Average monthly minimum temperature for July (°C).
MN2Jan =	Long-term average of the monthly minima minimum temperature for January (°C).
MN2Jul =	Long-term average of the monthly minima minimum temperature for July (°C).
MMXTJan =	Long-term average of the monthly maxima maximum temperature for January (°C).
MMXTJul =	Long-term average of the monthly maxima maximum temperature for July (°C).

HUJan = Heat units above a base temperature of 10 °C for January.

HUJul = Heat units above a base temperature of 10 °C for July.

HUAnn = Heat units above a base temperature of 10 °C for a year.

DEM = Altitude (m a.s.l.) using the 100 m altitude grid available from the ISCW.

Valind1km = Average altitude for a 1 km radius minus actual altitude for the compartment mid-point. Indicates position of a point in relation to surrounding topography. Negative values indicate the point is in a valley, near zero indicates mid-slope and positive indicates hilltop positions.

Valind3km = Average altitude for a 3 km radius minus actual altitude for the compartment mid-point. Indicates position of point in relation to surrounding topography. Negative values indicate the point is in a valley, near zero indicates mid-slope and positive indicates hilltop positions.

Slope = Slope (0° - 90°) for 3,0 m x 3,0 m grid cells around point.

Altmean3km = Mean altitude for all grid points in a 3 km radius.

Altmean1km = Mean altitude for all grid points in a 1 km radius.

Altmax3km = Maximum altitude for a 3 km radius.

Altmax1km = Maximum altitude for a 3 km radius.

Altmin3km = Minimum altitude for a 3 km radius.

Altmin1km = Minimum altitude for a 1 km radius.

Hillshade = HillShade is an estimation of solar irradiance calculated on an hourly basis using solar azimuth (angle from north) and solar elevation (angle between horizontal surface and the sun).

HS(hour) = HillShade 06:00 to 18:00.

Hill_Shade_6_9 = Sum of HS06+HS07+HS08+HS09.

Hill_Shade_10_14= Sum of HS10+HS11+HS12+HS13+HS14.

Hill_Shade_15_18= Sum of HS15+HS16+HS17+HS18.

Sunsum = All the hourly values summed. No weighting according to sun intensity. Assumes clear skies. [HS06] + [HS07] + [HS08] + [HS09] + [HS10] + [HS11] + [HS12] + [HS13] + [HS14] + [HS15] + [HS16] + [HS17] + [HS18].

Sunweighted = The hourly hillside values first weighted according to the sin of the solar elevation in radians. This gives a greater weight to irradience at noon compared to just after dawn.

Enumage = The age of each compartment at the time of survey.

SPHA = The average surviving stems per hectare for each compartment.

DBHMean = The mean overbark diameter at breast height for each compartment.

DomHeight = The mean dominant height for each compartment.

SI_{10} = Mean Site Index at reference age of 10 as projected by the relevant Mondi regression models.

Basal area = The mean basal area of each compartment.

Hd-age10 = The height measurements standardised to a reference age of 10 years.

BA_age10 = The basal area measurements standardised to a reference age of 10 years.

ERD_MIN= The effective minimum rooting depth for the dominant soil form in each compartment, measured at 30 cm intervals from 0 to 1,5 m soil depth.

ERD_MAX= The effective maximum rooting depth for the dominant soil form in each compartment, measured at 30 cm intervals from 0 to 1,5 m soil depth.

AMELRD_MIN = The effective minimum rooting depth of the soil, if the limiting layer can be ameliorated through mechanical site preparation. Measured at 30 cm intervals from 0 to 1,5 m.

AMELRD_MAX = The effective maximum rooting depth of the soil, if the limiting layer can be ameliorated through mechanical site preparation. Measured at 30 cm intervals from 0 to 1,5 m.

CL_TOP_MIN = The average minimum clay percentage in the A-horizon, measured at 30 cm intervals from 0 to 1,5 m this reflects the lower tolerance level for the reflected interval.

CL_TOP_MAX = The average maximum clay percentage in the A-horizon, measured at 30 cm intervals from 0 to 1,5 m.

CLAY_E_MIN = The average minimum clay percentage in the E-horizon, measured at 30 cm intervals from 0 to 1,5 m.

CLAY_E_MAX = The average maximum clay percentage in the E-horizon, measured at 30 cm intervals from 0 to 1,5 m.

CL_SUB_MIN = The average minimum clay percentage in the B-horizon measured at 30 cm intervals from 0 to 1,5 m this reflects the lower tolerance level for the reflected interval.

CL_SUB_MAX = The average maximum clay percentage in the B-horizon, measured at 30 cm intervals from 0 to 1,5 m this reflects the higher tolerance level for the reflected interval.

TAW = Calculated mean Total Available Water (TAW) for all observations points mapped. The unit of measure is in millimetres of water and it provides a guideline figure showing the amount of available water (between field capacity and wilting point).

LITH_X = The dominant lithology (X) associated with each enumerated compartment. Where X, the dummy variable, can be (i) MOLT = Molteno Formation (ii) CLAR = Clarens Formation, (iii) DRAK = Drakensberg Formation, (iv) ELLM = Elliot and Molteno Formations mixed.

ASP_N = 315 °< aspect <45 °, dummy variable.

ASP_E = 45 ° < aspect < 135 °, dummy variable.

ASP_S = 135 ° < aspect 225 °, dummy variable.

ASP_W = 225 ° < aspect <315 °, dummy variable.

PLANTMONTH = Month in which compartment was planted, dummy variable.

PLANT_QTR1 = Compartment planted in January, February or March, dummy variable.

PLANT_QTR2 = Compartment planted in April, May or June, dummy variable.

PLANT_QTR3 = Compartment planted in July, August or September, dummy variable.

PLANT_QTR4 = Compartment planted in October, November or December, dummy variable.

The general descriptive statistics for the variables used in the analysis are provided in Table 25.

Table 25. General descriptive statistics for the variables used in the analysis.

Variable	N	Mean	Std Dev	Minimum	Maximum
Areaeff	538	21,14020	15,81165	0,4000	103,10000
Latitude	503	-31,14566	0,16223	-31,46092	30,80661
Longitude	503	28,20355	0,12603	27,98101	28,41829
Altitude	455	1427	109,04904	1250	1870
RainSep	537	40,49552	0,61825	38,82440	42,19140
RainOct	537	74,88856	3,90419	68,04670	90,47670
RainNov	537	103,52826	4,02327	95,70790	118,54140
RainDec	537	118,55705	4,80574	108,99290	137,00550
RainJan	537	130,08472	7,06589	116,89070	148,92970
RainFeb	537	125,97932	5,63498	114,69140	142,78060
RainMar	537	116,13688	3,73491	107,19100	130,46100
RainApr	537	49,64103	1,57347	46,09000	54,27640
MxtJan	537	25,31423	0,79109	22,56810	26,96370
MxtJul	537	16,70106	0,69236	13,16530	17,81120
MxtAnn	537	21,17255	0,70773	17,95730	22,44120
MntJan	537	12,96647	0,71051	9,47560	14,04040
MntJul	537	1,85266	0,72806	-1,951000	3,15670
Mn2Jan	537	7,52914	0,85141	3,54810	8,65520

Variable	N	Mean	Std Dev	Minimum	Maximum
Mn2Jul	537	-5,02156	0,70052	-8,91690	3,44910
MmxtJul	537	22,68401	0,79923	18,81910	23,88940
MmxtJan	537	33,13078	0,83141	29,20650	34,40420
HuJan	537	280,72167	21,09938	189,05080	317,66050
HuJul	537	280,72167	21,09938	189,05080	43,68620
HuAnn	537	1881	202,53430	1007	2232
Dem	537	1421	103,85643	1265	1895
Valin1km	537	1,48640	13,71199	-49,75310	47,08640
Valin3km	537	-0,21346	36,29584	-141,5092	174,60510
Slope	537	5,99617	3,67495	0,18220	22,33150
Aspect1km	537	159,20517	106,19219	0,25590	359,89510
Aspect	537	168,15875	109,62576	0	358,26430
Altmin3km	537	1333	84,18703	1168	1711
Altmin1km	537	1374	97,85011	1205	1841
Altmean3km	537	1421	97,41958	1265	1879
Altmean1km	537	1419	101,48330	1277	1897
Altmax3km	537	1554	134,58579	1330	2006
Altmax1km	537	1471	108,79218	1306	1971
HS06	537	40,75791	21,42866	0	108
HS07	537	94,49534	19,80136	23	156
HS08	537	143,65922	17,81553	75	197
HS09	537	186,0149	15,06453	125	227
HS10	537	218,44134	11,85881	166	247

Variable	N	Mean	Std Dev	Minimum	Maximum
HS11	537	238,46555	8,88290	195	254
HS12	537	244,93669	7,42548	202	254
HS13	537	236,98883	8,72977	194	252
HS14	537	215,45451	11,76932	165	241
HS15	537	181,83240	15,10627	128	225
HS16	537	138,53259	18,07662	76	197
HS17	537	88,29423	20,72040	0	158
HS18	537	34,54562	21,95225	0	112
SUNSUM	537	2062	28,93484	1865	2086
SUNWEIGHTE	537	1563	33,26351	1354	1594
ENUMAGE	538	7,59645	1,04850	4,42	13,5
SPHA	538	674,84944	116,92960	342	1104
DBHMEAN	538	16,53149	2,25195	8,03	23,7
DOMHGT	538	10,51835	1,70937	5,68	15,32
SI	538	19,93848	3,36005	5,1	31,4
BASAREA	538	14,82039	4,97723	0,13	29,34
Hd_age10	538	13,12874	1,78857	6,64363	20,36095
BA_age10	538	19,0647	4,94039	1,02002	36,37814
Dq_age10	538	19,00035	2,90126	4,153	30,81402
ERD_MIN	538	82,75465	38,56890	0	151
ERD_MAX	538	98,32714	32,50310	0	151
AMELRD_MIN	538	73,97584	46,63110	0	151
AMELRD_MAX	538	86,22305	44,09219	0	151

Variable	N	Mean	Std Dev	Minimum	Maximum
CL_TOP_MIN	538	21,22677	7,66383	0	55
CL_TOP_MAX	538	32,14126	8,17035	0	55
CLAY_E_MIN	538	0,17844	1,45374	0	12
CLAY_E_MAX	538	0,37175	3,02862	0	25
CL_SUB_MIN	538	27,86617	11,99118	0	60
CL_SUB_MAX	538	40,14498	14,32677	0	70
TAM	538	3,43123	16,57307	0	114

Before starting the construction of a multiple regression model for BA_{10} the descriptive statistics were summarised and the correlation of growth data with the independent variables (i.e. site variables) investigated. Pearson's Correlation Coefficient of the PROC CORR procedure (SAS Institute Inc., 2001) was used for the correlation analysis.

A correlation analysis was done in two steps. In the first phase, the growth data were correlated with the site data for all species combined. During the second phase, the relationships between the growth data of each species and the site parameters were tested. The purpose of the first phase was to determine whether there were any factors that described the overall site-growth relationship for all pine species. The purpose of the second phase was to establish those variables that were species specific. All three growth variables, basal area, site index and survival, were correlated with the site variables. Significant correlations assisted in selecting variables for the multiple regression analysis.

Multiple regression analysis was used to define the relationship between site and growth variables and to build three models for each of the response variables: survival, SI_{10} and BA_{10}. The PROC REG procedure (SAS Institute Inc., 2001) was used to fit the multiple regression models. There are several basic assumptions underlying the use of multiple regression. Firstly, there should be a linear relationship between the independent and dependant variables. This was investigated by plotting the dependant variables against each of the independent variables by using PROC PLOT (SAS Institute Inc., 2001). The second assumption is that no multicollinearity exists between the independent variables. This assumption was tested by looking at the tolerance statistics of the estimates. The tolerance was computed by regressing one independent variable, against the rest of the significant independent variables, expressed as the coefficient of non-determination. The rule used was that tolerance values lower than 0,2 indicated that the associated independent variable was correlated with one or more of the independent variables. Where tolerance was below the threshold value of 0,2 the variable was rejected from the model. This was done until a model was obtained, where the independent variables were uncorrelated. The TOL option in the MODAL statement of PROC REG (SAS Institute Inc., 2001) was used to do the above. The third assumption is that the error terms are distributed normally and independently. This assumption was tested by using the Shapiro-Wilk's W-statistic provided in PROC UNIVARIATE (SAS Institute Inc., 2001) and Pearson's rho correlation coefficient calculated through the PROC CORR procedure (SAS Institute Inc., 2001).

Due to the stringent requirements of multiple regression noted above, independent variables were manually entered and removed from the regression model to ensure that the assumptions listed were met during each variable selection step.

The relationship between site variables and the growth of *P. patula*, *P. greggii*, *P. elliottii* and *P. taeda* were investigated with the hypothesis that there was no relationship between growth factors and the measured site variables. SI_{10} and BA_{10} were used to define growth in conjunction with survival. The correlation analysis identifying a number of site variables of relevance in defining survival, SI_{10} and BA_{10}. The investigation of different combinations of variables through the stepwise screening of multiple regression models yielded the optimal subset of variables for the prediction of stand characteristics.

8.3 Results and Discussion

The results of the correlation analysis are shown in Table 26 for all species combined and in Table 27 for each pine species seperately.

Table 26. Correlation analysis for BA_{10}, SI_{10}, survival and site variables for all species combined (*p<0.05; **p≤0.01; ***p≤0.001).

Site Variable	Pearson's Correlation Coefficient (r)		
	BA_{10}	SI_{10}	Survival
Latitude	0,12*	0,23***	0,30***
Altitude	-0,03	-0,12*	-0,18***
RainSep	0,01	0,07	0,13**
RainOct	0,11*	0,19***	0,29***

Site Variable	Pearson's Correlation Coefficient (r)		
	BA_{10}	SI_{10}	Survival
RainNov	0,07	0,14**	0,26***
RainDec	0,13**	0,23***	0,35***
RainJan	0,17***	0,22***	0,34***
RainFeb	0,12**	0,25***	0,34***
RainMar	0,09*	0,16**	0,20***
RainApr	0,01	0,01	0,30
MxtJan	0,10	0,40	0,11*
MxtJul	0,20	0,09*	0,18***
MxtAnn	0,10	0,70	0,18***
MntJan	-0,01	0,06	0,17***
MntJul	-0,01	0,03	0,06
Mn2Jan	0,01	0,09*	0,18***
Mn2Jul	0,04	0,06	0,10*
MmxtJul	0,03	0,09*	0,17***
MmxtJan	-0,01	0,03	0,11*
HuJan	0,01	0,08*	0,18***
HuJul	0,06	0,14**	0,22***
HuAnn	0,02	0,09*	0,19***
Dem	-0,01	-0,07	-0,14*
Valin1km	0,06	-0,03	0,03
Valin3km	0,04	0	0,05
Slope	0,06	0,07	0,07

Site Variable	Pearson's Correlation Coefficient (r)		
	BA_{10}	SI_{10}	Survival
Aspect1km	-0,02	0,01	-0,08*
Aspect	0,04	-0,04	-0,06
Altmin3km	-0,07	-0,12*	-0,23***
Altmin1km	-0,05	-0,09*	-0,17***
Altmean3km	-0,03	-0,08	-0,17**
Altmean1km	-0,02	-0,07	-0,15**
Altmax3km	-0,02	-0,02	-0,06
Altmax1km	0	-0,04	-0,11*
HS06	-0,05	0	0,09*
HS07	-0,04	0,01	0,08*
HS08	-0,04	0,01	0,09*
HS09	-0,05	0,01	0,09*
HS10	-0,06	0	0,08*
HS11	-0,07	-0,01	0,06
HS12	-0,06	-0,02	0,01
HS13	-0,02	-0,02	-0,05
HS14	0,01	-0,02	-0,08*
HS15	0,02	-0,01	-0,09*
HS16	0,03	-0,01	-0,10*
HS17	0,04	-0,01	-0,10*
HS18	0,03	-0,01	-0,10*
SUNSUM	-0,09*	-0,04	-0,04

Site Variable	Pearson's Correlation Coefficient (r)		
	BA_{10}	SI_{10}	Survival
SUNWEIGHTE	-0,06	-0,02	-0,01
ERD_MIN	-0,07	0,12*	0,04
ERD_MAX	-0,07	0,10*	-0,02
AMELRD_MIN	-0,04	0,09*	0,11*
AMELRD_MAX	-0,02	0,08	0,10*
CL_TOP_MIN	0,01	0,04	0,07
CL_TOP_MAX	0,01	0,06	0,07
CLAY_E_MIN	-0,10*	-0,05	-0,09*
CLAY_E_MAX	-0,10*	-0,05	-0,09*
CL_SUB_MIN	-0,02	0,03	0,02
CL_SUB_MAX	0	0,05	0,02
TAW	-0,07	0,02	-0,08
TOT_RAIN	0,11*	0,20***	0,30***
HILL_SHADE_6_9	-0,04	0,01	0,09*
HILL_SHADE_10_14	-0,06	-0,02	0
HILL_SHADE_15_18	0,03	-0,01	-0,10*
PLANT_MONTH	-0,02	0,03	-0,09*

Table 27. Pearson's correlation coefficients analysis for BA_{10}, SI_{10}, survival and site variables for each of the four pine species (*p<0.05; **p≤0.01; ***p≤0.001).

Site Variable	*P. patula*			*P. greggii*			*P. elliottii*			*P. taeda*		
	BA10	**SI10**	**Survival**	**BA10**	**SI10**	**Survival**	**BA10**	**SI10**	**Survival**	**BA10**	**SI10**	**Survival**
Latitude	0,14*	0,28***	0,34***	0,03	-0,12	0,29*	-0,08	-0,11	0,23*	-0,08	0,14	-0,22
Altitude	0,05	-0,12*	-0,23***	-0,02	-0,33*	0	-0,04	-0,01	-0,04	-0,26	-0,22	-0,16
RainSep	0,05	0,09	0,14*	-0,40*	-0,26*	0,05	-0,01	-0,03	0,11	0,50	0,55	0,76**
RainOct	0,23***	0,24***	0,31***	-0,21	-0,05	0,40*	-0,06	-0,08	0,16	0,30	0,49	0,82**
RainNov	0,21***	0,19**	0,27***	-0,23	-0,07	0,36*	-0,06	-0,12	0,15	0,28	0,58	0,86**
RainDec	0,25***	0,31***	0,38***	-0,18	-0,11	0,36*	-0,09	-0,13	0,25	0,25	0,53	0,85**
RainJan	0,26***	0,32***	0,38***	-0,12	-0,18	0,32*	-0,01	-0,06	0,21	0,68*	0,53	0,57
RainFeb	0,20***	0,32***	0,37***	-0,12	-0,14	0,34*	-0,07	-0,10	0,26*	0,24	0,60	0,94***
RainMar	0,17**	0,19**	0,17**	-0,22	-0,07	0,40*	0	-0,06	0,13	0,31	0,47	0,81**
RainApr	0,14**	0,03	-0,01	-0,25*	-0,16	0,28*	-0,03	-0,09	0,05	0,31	0,50	0,77**
MxtJan	-0,04	-0,01	0,11*	0,14	0,19	0,12	-0,02	0,01	0,14	0,01	0,36	0,04
MxtJul	-0,03	0,05	0,21***	0,01	0,26*	0,09	0,02	0,05	0,12	0,02	0,01	-0,05
MxtAnn	-0,04	0,03	0,19**	0,02	0,24	0,13	-0,03	0	0,15	0,06	0,22	0,27
MntJan	-0,04	0,03	0,18**	0	0,30*	0,10	-0,02	0	0,10	0,19	0,19	0,26
MntJul	-0,05	0,01	0,10	-0,02	0,27*	-0,03	0,08	0,15	-0,10	-0,21	-0,65*	-0,95***
Mn2Jan	-0,03	0,06	0,21***	0,01	0,30*	0,13	0,03	0,05	0,06	0,09	0,14	0,15

Site Variable	P. patula			P. greggii			P. elliottii			P. taeda		
	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival
Mn2Jul	-0,01	0,05	0,15**	-0,03	0,23	-0,04	0,13	0,17	-0,07	-0,07	-0,63*	-0,94***
MmxtJul	-0,02	0,06	0,20***	0,01	0,28*	0,58	0,05	0,07	0,07	0,01	-0,11	-0,22
MmxtJan	-0,07	-0,03	0,11***	0,07	0,30*	0,08	0,03	0,08	0,09	0,02	0,07	-0,16
HuJan	-0,04	0,05	0,20***	0,02	0,25*	0,12	0	0,02	0,12	0,05	0,19	0,22
HuJul	0,01	0,12*	0,27***	0	0,24	0,07	0,05	0,09	0,11	-0,05	-0,36	-0,57
HuAnn	-0,03	0,06	0,22***	0,01	0,25*	0,10	0	0,04	0,14	0,03	0,06	0,03
Dem	0,04	-0,02	-0,16**	0	-0,32*	-0,04	-0,04	-0,07	-0,06	-0,10	0,28	0,47
Valin1km	0,09	-0,06	0,03	0,10	-0,23	0,01	0,02	-0,04	0,14	-0,09	0,08	0,17
Valin3km	0,10*	-0,01	0,10	0,13	-0,25*	-0,09	-0,13	-0,02	0,07	-0,44	-0,16	-0,12
Slope	0,06	0,27***	0,14**	-0,04	-0,10	-0,04	0,11	0,04	-0,15	-0,14	-0,13	-0,39
Aspect1km	-0,06	-0,04	-0,10	0,04	0,13	0,04	0,14	0,15	-0,13	-0,15	0,15	-0,48
Aspect	-0,06	-0,06	-0,11*	0,24	0,05	0,02	0,22*	0,04	0,07	-0,16	0,08	-0,49
Altmin3km	-0,06	-0,11*	-0,29***	-0,01	-0,24	-0,02	0,06	-0,04	-0,12	0,46	0,10	0,20
Altmin1km	0	-0,08	-0,21***	-0,01	-0,25*	-0,03	-0,03	-0,07	-0,05	0,05	0,27	0,41
Altmean3km	0,01	-0,03	-0,21***	-0,05	-0,26*	-0,01	0,05	-0,07	-0,11	0,47	0,38	0,43
Altmean1km	0,03	-0,03	-0,17**	-0,02	-0,29*	-0,04	-0,03	-0,06	-0,10	0,04	0,27	0,38
Altmax3km	0,05	0,05	-0,10*	-0,22	-0,17	0,13	0,05	-0,09	-0,11	0,38	0,46	0,53
Altmax1km	0,05	0,05	-0,13**	-0,07	-0,28*	-0,01	0,01	-0,07	-0,14	0,25	0,29	0,41
HS06	0	0,09	0,10	-0,10	-0,19	0,02	-0,22*	-0,04	0,03	-0,02	-0,01	0,21

Site Variable	*P. patula*			*P. greggii*			*P. elliottii*			*P. taeda*		
	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival
HS07	0	0,08	0,09	-0,10	-0,15	0,03	-0,22*	-0,03	0,04	0,07	-0,10	0.16
HS08	-0,01	0,05	0,09	-0,11	-0,11	0,06	-0,23*	-0,03	0,05	0,06	-0,10	0,19
HS09	-0,03	0,02	0,08	-0,13	-0,17	0,08	-0,22*	-0,04	0,07	0,05	-0,09	0,22
HS10	-0,04	-0,03	0,06	-0,15	0,01	0,12	-0,21	-0,03	0,07	0,04	-0,10	0,25
HS11	-0,07	-0,10*	0,03	-0,15	0,14	0,15	-0,14	-0,02	0,08	0,02	-0,09	0,31
HS12	-0,09	-0,21***	-0,04	-0,08	0,22	0,12	-0,02	0,01	0,06	-0,01	0,04	0,40
HS13	-0,06	-0,22***	-0,10	-0,01	0,23	0,06	0,10	0,02	0,02	-0,03	0,06	0,14
HS14	-0,03	-0,17**	-0,12*	0,04	0,20	0,01	0,16	0,04	-0,01	-0,05	0,09	-0,07
HS15	-0,01	-0,13*	-0,11*	0,08	0,17	-0,02	0,19	0,04	-0,02	-0,04	0,09	-0,14
HS16	0	-0,09	-0,11*	0,10	0,14	-0,05	0,20	0,05	-0,04	-0,04	0,10	-0,18
HS17	0,01	-0,07	-0,11*	0,11	0,10	-0,07	0,19	0,05	-0,05	-0,02	0,10	-0,20
HS18	0,01	-0,03	-0,09	0,11	0,04	-0,18	0,25*	0,06	-0,04	-0,09	0,10	-0,32
SUNSUM	-0,11*	-0,27***	-0,09	-0,11	0,19	0,04	-0,04	0,05	0,08	-0,03	0,04	0,31
SUNWEIGHTE	-0,09	-0,23***	-0,06	-0,09	0,22	0,11	-0,03	0,02	0,07	0,02	-0,04	0,36
ERD_MIN	-0,06	0,04	0,08	0,28*	0,20	0,03	-0,17	0,07	0,03	-0,26	0,04	0,26
ERD_MAX	-0,09	0,01	-0,01	0,24	0,19	0,07	-0,13	0,04	-0,06	-0,32	-0,11	0,09
AMELRD_MIN	-0,01	0,06	0,14**	0,24	0,08	0,01	-0,18	0,06	0,12	-0,20	0,30	0,60
AMELRD_MAX	0	0,04	0,11*	0,20	0,03	0,07	-0,16	0,01	0,13	-0,20	0,30	0,60
CL_TOP_MIN	0,05	0,07	0,05	0,01	-0,11	0,05	0,04	-0,06	0,20	0,38	0,54	0,81**

Site Variable	*P. patula*			*P. greggii*			*P. elliottii*			*P. taeda*		
	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival	BA_{10}	SI_{10}	Survival
CL_TOP_MAX	0,01	0,09	0,01	-0,13	-0,16	0,22	-0,05	-0,20	0,20	0,19	0,27	0,48
CLAY_E_MIN	-0,11*	-0,10*	-0,10*	0	0	0	0	0	0	0	0	0
CLAY_E_MAX	-0,11*	-0,10*	-0,09	0	0	0	0	0	0	0	0	0
CL_SUB_MIN	0	0,04	0,03	-0,04	-0,11	-0,13	-0,09	0,04	0,08	-0,30	-0,02	0,20
CL_SUB_MAX	-0,03	0,04	0,01	-0,06	-0,03	-0,03	-0,09	0,08	0,06	-0,26	-0,12	0,08
TAW	-0,15**	-0,02	-0,10*	0,03	0,16	0,03	0,03	-0,09	-0,14	0	0	0
TOT_RAIN	0,23***	0,26***	0,31***	-0,20	-0,10	0,38*	-0,06	-0,11	0,12	0,29	0,55	0,88**
HILL_SHADE_6_9	-0,01	0,07	0,09*	-0,11	-0,14	0,04	-0,23*	-0,03	0,05	0,04	-0,07	0,19
HILL_SHADE_10_14	-0,09	-0,21***	-0,04	-0,08	0,22	0,12	-0,02	0,01	0,06	0	-0,05	0,38
HILL_SHADE_15_18	0,01	-0,08	-0,11*	0,10	0,11	-0,09	0,22	0,05	-0,04	-0,05	0,10	-0,22
PLANT_MONTH	0,05	-0,04	-0,10*	-0,17	0.14	-0,09	-0,10	-0,18	-0,04	-0,35	0,10	0,42

The multiple regression analysis yielded a number of significant models presented in Table 28. Models 1 – 3 refer to all species combined, while models 4 – 15 are derived for each of the four pine species.

Table 28. Multiple regression models of site and growth relationships for all pines combined and by individual pine species investigated.

Model No.	Model	Statistics				
		df	R^2	RMSE	F	p
1.	Survival (all species)= -687,25464+1,77355**TOT_RAIN**+0,13227**HUANN**-36,26958**ASP_W**+23,11208**PLANT_QTR1**	(4;531)	0,1663	107,3627	26,5	<0,0001
2.	SI10(all species)=-1,50680+0,22568**MXTJUL**+0,00541**ERD**+0,01671**TOT_RAIN**-0,47064**PLANT_QTR2**	(4;531)	0,0774	1,72	11,14	<0,0001
3.	BA10(all species)=48,56339-0,01432**SUNSUM**-0,37161**CLAY_E_MIN**-1,08961**ASP_W**+1,76745**PLANT_QTR3**	(4;531)	0,0456	4,8472	6,34	<0,0001
4.	Survival (P.patula)=-934,69224+1,88383**TOT_RAIN**+5,04006**SLOPE**+0,16952**HUANN**+0,14602**HILL_SHADE_6_9**	(4;377)	0,2102	100,3604	25,1	<0,0001
5.	Survival (P.greggii)=-356,82961+1,62180**TOT_RAIN**	(1;380)	0,0966	106,9070	40,65	<0,0001
6.	Survival (P.taeda)=-3016,30811+5,84121**TOT_RAIN**	(1;9)	0,7691	63,4924	29,97	0,0004
7.	Survival (P.elliottii)= -155,84851+6,91366**RAINFEB**	(1;79)	0,0693	122,6326	5,81	0,0183
8.	SI10(P.patula)=2,90514-0,00256**ALTITUDE**+0,02200**TOT_RAIN**+0,11827**SLOPE**-0,46408**ASP_W**-0,56881**ASP_N**	(5;376)	0,1848	1,4694	17,05	<0,0001
9.	SI10(P.greggii)=19,64489-0,00460**ALTITUDE**	(1;61)	0,0777	1,72053	5,14	0,0269
10.	SI10(P.taeda)=-9,17054-4,21663**MN2JUL**	(1;9)	0,3954	1,6532	5,89	0,0382
11.	SI10(P.elliottii)=11.21921+4.03823**LITH_MOLE**	(1;78)	0,1156	1,2568	10,2	0,0020
12.	BA10(P.patula)=-0,50367+0,03109**TOT_RAIN**-0,03999**TAM**-0,88119**LITH_MOLT-1,18112ASP_W+1,56991PLANTQTR_3**	(5;376)	0,1102	4,4271	9,31	<0,0001
13.	BA10(P.greggii)=19,60841+0,03725**ERD**	(1;61)	0,0787	5,3181	5,21	0,0260
14.	BA10(P.taeda)= NO SIGNIFICANT VARIABLE WAS FOUND					
15.	BA10(P.elliottii)=25,83414-0,01384**HILL_SHADE**-6-9	(1;78)	0,0516	4,8639	4,24	0,0428

8.4 Conclusion

Survival

The results in Table 28 show that the positive relationship between survival and increasing rainfall (TOT_RAIN) is consistent across the models for all species combined (model 1) and the individual species models (models 4 – 6). This is also consistent with the basic knowledge on plant needs for growth, namely water, nutrients and light energy obtained from results of other growth studies in the region (Zwolinski, *et.al.*, 1997). The specific relationship with rain in February as a positive interaction for *P. elliottii* survival is interesting since February is traditionally the wettest month in the study area. This could possibly be due to the fact that *P. elliottii* has been established on the most marginal sites and tolerates waterlogged soils relatively well.

The positive relationship with the annual heat units (HUANN) for the survival of all species combined and *P. patula* underlines the importance of available energy to the plant in order to optimise photosynthesis and thereby growth. This relationship is also consistent with altitude, since the (HUANN) decreases with increasing altitude ($r = -0{,}955$ $p \leq 0{,}001$). This also emphasizes the importance of site-species matching on the higher altitude sites. The results indicate that *P. patula* is more dependant on high heat units compared to the other pines (Tables 27 and 28).

The other important site variable in terms of survival is the aspect of each site. This variable was relevant to the survival of all species combinded (Model 1) but did not feature in individual species models. The negative correlation between the survival and the western aspect could be due to the fact that lower temperatures on western slopes prolong tree water stress due to higher water viscosity and delayed uptake by trees (Fyfield, *et. al.,* 1998). The western aspect receives the late afternoon sun resulting in prolonged losses of water. A further relevant factor is the lower precipitation (rain and mist) on the western slopes, as well as gradual effects of desiccating 'berg' winds from the north-west direction (Herbert, 1997). It is believed that HILL_SHADE_6_9 is relevant to the survival of *P. patula* (model 4) in a similar way as discussed for the western aspect.

The positive relationship between survival of all species and planting in summer (PLANT_QTR1) could be due to the fact that this represents the time period with the highest soil moisture in combination with cloud free days (high heat units), thereby creating optimal growth conditions (K.A. Monnik, pers. comm., Institute for Soil, Climate and Water, 2001). It is important to interpret this in conjunction with the findings in chapter 6 for *P. patula*, where August proved to be the optimal planting month and conversely November the worst. This also opens a management window of opportunity in terms of scheduling planting, as well as re-emphasizing the complexity of the interaction between environmental factors and plant stress.

The other variable of statistical importance is the positive impact of slope on the survival of *P. patula*. This finding confirms the general consensus on positive impact of well drained soils on *P. patula's* performance, which is best on sites with steeper slopes and soils which are better drained (Herbert, 1996d).

Site Index

In terms of SI_{10}, the cumulative summer rainfall (TOT_RAIN) showed a positive effect with the SI_{10} for all species (model 2) and for *P. patula* (model 8). Similar to survival, the optimal growth conditions would depend on plant available water. The negative response of SI_{10} for *P. patula* or *P. greggii* to altitude (models 8 and 9), are likely due to climatic factors, with specific reference to low minimum temperatures and low heat units (E. Kietzka, pers. comm., Mondi Forests, 2001). Mondi Forests Ltd. in conjunction with the CAMCORE have already deployed the northern (higher altitude) provenances of *P. greggii* on a commercial scale to improve pine performance in the study area.

The positive impact of the average monthly maximum temperature for July (MXTJUL) on SI_{10} for all species (model 2) indicates that the warmer the winter, the better the height growth. The negative responses of *P. taeda* SI_{10} to the longterm average of the monthly minima minimum temperature for July (MN2JUL) indicates that the lower the absolute minimum temperatures, the lower the height growth (model 10). It could be reasoned that this relates to lower minimum soil temperatures which, through various physiological processes, resulted in induced water and nutrient deficiencies (Fyfield *et.al.*, 1998). This also indicates the incorrect selection of sites for *P. taeda* and potential negative impacts of frost damage.

The positive relationship between response of SI_{10} to effective rooting depth for all species combined (model 2) is due to increased root development, water availability and tree stability on deep soils. There was a difference between

PLANT_QTR2 and PLANT_QRT1, PLANT_QRT3 confirmed for SI_{10} response. Poor performance of the second quarter plantings could be due to the fact that plants in early winter are exposed to cold seasonal droughts and frost, resulting in reduced root biomass and consequently poorer height growth. Prolonged transplanting stresses therefore may produce longterm growth impacts likely to be maintained until harvesting, thus resulting in substantial economic losses.

The negative response of *P. patula* SI_{10} to the western (ASP_W) and northern (ASP_N) aspects could be explained with the impact of prolonged low temperatures and lower water availability. The SI_{10} for *P. elliottii* on soils originating from mixed Molteno and Elliot parent material (LITH_MOLE) (model 11), the two formations, both of sedimentary origin, improves soil texture for plant growth if mixed (M. Hensley, pers. comm., Institute for Soil, Water and Climate, 2001).

Basal Area

BA_{10} is negatively affected by the sum of the hillshade solar irradiance values (SUNSUM) for all species (model 3). A similar impact is created by the hillshade solar irradiance calculated as the sum of the values from 06:00 to 09:00, (HILL_SHADE6_9) for the *P. elliotii* (model 15). The potential solar radiation was calculated as a function of latitude, slope, aspect, topographic shading, and time of year, monthly average cloudiness and sunshine hours (K.A. Monnik, pers. comm., Institute for Soil, Climate and Water, 2001). It is not clear why this negative correlation between modelled solar irradiance and basal area occurs. In theory, since solar irradiation represents energy measurement, plants should respond positively with an increase in hillshade value (or solar irradiance value). Possibly coincidently the higher hill shade ratio occurred on poor quality sites.

Frittss (1976) explained topography-related cambial growth differences with water deficiency on sun-exposed sites. The danger of the eastern aspect associated with frost damage might be an important factor explaining the early morning hillshade impact on basal area of *P. elliottii* (Morby, 1984; Kozlowski, 1971). *P. elliottii* is planted well above the optimal altitude range recommended in South Africa (Zwolinski and Hinze, 2001) and low minimum temperature is likely a growth limiting factor. Trees that are exposed to early sunshine (high hillshade) may become photosynthetically active and more sensitive to frost stress and damage. In the mountains, such conditions may have a detrimental impact on radial growth and basal area (Frittss, 1976), especially since *P. elliottii* originates from low altitudes sites of up to 150 m a.s.l. (Poynton, 1979).

The effect of the clay percentage in the E-horizon (CLAY_E_MIN) on BA_{10} for all species (model 3) was negative. This could reflect the fact that high clay contents in E-horizons resulted in water logging and hard setting soil properties. Such soils undergo a marked *in situ* net removal of colloidal matter (Soil Classification Working Group, 1991). Such soils do not represent optimal growth conditions and trees maybe under frequent stress.

The BA_{10} of all species (model 3) was significantly lower on the western aspect sides when compared with the other sites. Also the third quarter planting window (PLANT_QTR3) yielded higher BA_{10} for all species (model 3) than the other planting quarters. This could be ascribed to the fact that this planting window will leave the tree with the longest growth period prior to plant stresses like weed competition or unfavourable climatic conditions in the following winter.

The BA_{10} for *P. patula* is positively influenced by the total rainfall (TOTRAIN) and negatively affected by the total available soil water (TAW). The Molteno formation parent material resulted in lower BA_{10} compared to the other lithologies (model 12). The impact of rainfall on tree performance was already discussed. According to model profiles by M. Hensley (pers. comm., Institute for Soil, Climate and Water, 2001) the Molteno formation generally forms shallower, lower productivity soils. This was confirmed by Herbert (1997), 1999) who also highlights the fact that the Molteno sandstones tend to limit rooting depth. Furthermore, the BA_{10} of *P. greggii* responds positively to higher effective rooting depth (ERD), in other words there is an increase in BA_{10} with an increase in soil depth (model 13). The deeper the soil, the greater plant available water and nutrients. The fact that *P. greggii* specifically shows this response could be due to the fact that it is normally planted on soils considered to be marginal for *P. patula*.

In conclusion it is evident that there are significant relationships between growth and site variables. It is, however, important to note that weak coefficients of determination were obtained. The difficulty to comprehensively explain growth variables despite the large dataset could be due to several reasons. In the first place there were diverse silvicultural and management procedures affecting tree performance which could not be included in the analysis. The available soil information contributed little to the understanding of survival, height and basal area in the region.

The results confirm the statement made by M. Hensley (pers. comm., Institute for Soil, Climate and Water, 2001) that according to the data available at present there do not seem to be many differences in tree growth on different kinds of soil.

It is also believed that there are various factors influencing the growth and survival of trees in the study area that are not yet understood, despite in-depth research over the last decade. One of these factors, as previously mentioned, is the impact of minimum soil temperature on root development and nutrient uptake. A thorough understanding of the tree physiological processes involved in the complex tree growing environment in the study area would significantly contribute to our understanding and subsequent sustainable timber productivity in the region.

9. RECOMMENDATIONS FOR FURTHER RESEARCH

This study showed that tree performance can be explained with site variables, especially those derived from climatic information. It is the author's belief that soil temperature, specifically minimum soil temperature during the dryer winter months, is a driving factor in terms of tree survival and stand performance in the Eastern Cape. Provisional results from a micro-climatic study showed the occurrence of minimum temperatures, at ground level which may be detrimental to tree growth (K.A. Monnik, pers. comm., Institute for Soil, Climate and Water, 2001). It is recommended that a detailed study into soil temperature regimes and the related tree physiological processes be conducted with special reference to silvicultural and forest management.

The study also confirmed the pronounced impact of management decisions on tree performance. The nature of NECF sites is such that there are no error margins. There is very little room for flexibility in terms of establishment and maintenance of plantations. If sound forestry principles and well thought through management strategies are consistently maintained the north-eastern part of the Eastern Cape Province can sustain a very productive afforestation project.

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APPENDIX 1 Example of site variables investigated.

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Pell	A02A	199107	1340	0.18	220.91	Molteno	Ab0123	90
Pell	A05B	199203	1330	2.84	0.00	Molteno	Ad0128	50
Pell	A08	199107	1340	2.70	280.01	Molteno	Cc0106	30
Pell	A11A	199110	1330	3.06	88.99	Molteno	Ab0176	30
Pell	A26A	199106	1350	6.47	30.38	Elliot	Ab0307	120
Pell	A27A	199106	1410	7.33	278.84	Elliot	Ab0315	60
Pell	B24A	199203	1670	5.11	154.72	Elliot	Ad0199	120
Pell	B26A	199110	1450	8.42	195.41	Elliot	Ib0131	30
Pell	B29C	199110	1410	17.76	91.21	Elliot	Cc0115	50
Pell	B30A	199104	1450	21.81	180.49	Elliot	Ad0200	90
Pell	B41A	199105	1280	6.14	75.84	Molteno	Ab0237	110
Pell	B45B	199103	1340	12.83	165.28	Elliot	Ib0118	60
Pell	B46	199103	1410	18.06	166.44	Elliot	Ab0235	120
Pell	C01A	199203	1390	10.51	208.71	Elliot	Ad0209	50
Pell	F21	199103	1320	8.24	198.44	Molteno	Ad0012	30
Pell	G02	199109	1315	5.08	275.91	Molteno	Ab0778	121
Pell	G20	199111	1320	8.24	198.44	Molteno	Ab0010	121
Pell	A19A	199205	1420	14.28	341.76	Elliot/Molteno	Ab0784	60
Pell	B03	199203	1520	8.94	216.87	Elliot	Ib0120	10
Pell	B08	199203	1340	2.10	274.14	Elliot	Ad0214	60
Pell	B11	199010	1360	9.89	182.00	Elliot	Ad0136	40
Pell	B13	199010	1320	6.37	224.08	Molteno	Ab0136	60
Pell	C19	199104	1370	6.89	171.78	Molteno	Ad0542	90
Pell	C24B	199103	1360	4.35	16.29	Molteno	Ab0149	121
Pell	C25	199101	1340	9.32	182.80	Molteno	Ab0778	121
Pell	E09	199206	1660	3.68	53.53	Elliot	Ab0283	70
Pell	E17	199111	1400	9.55	76.19	Elliot	Bb0108	70
Pell	E24	199103	1400	8.24	125.54	Elliot	Ab0278	120
Pell	F20	199302	1351	8.24	125.54	Molteno/Elliot	Ab0555	121
Pell	G03B	199104	1410	6.86	348.27	Elliot	Ab0137	121
Pell	B01C	199101	1440	3.54	316.79	Molteno	Bb0220	60
Pell	B02C	199003	1480	2.08	68.63	Molteno	Bb0220	60
Pell	B02D	199005	1480	0.26	144.46	Molteno	Fb0128	20
Pell	B03A	198912	1450	6.69	189.46	Elliot	Ad0535	30
Pell	B04A	198912	1430	5.38	75.58	Molteno	Af0116	120
Pell	B04B	198912	1430	5.38	75.58	Molteno	Af0116	120
Pell	B04C	198912	1460	2.38	144.27	Molteno	Fb0128	20

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Pell	B04C	198912	1460	2.38	144.27	Molteno	Fb0128	20
Pell	B08D	199201	1475	5.54	78.41	Molteno	Fb0128	20
Pell	B09A	199003	1455	7.49	314.20	Molteno	Fb0128	20
Pell	B09B	199003	1500	4.59	333.43	Molteno	Ab0771	30
Pell	E02A	199101	1530	5.32	92.91	Molteno	Af0005	70
Pell	E04A	199106	1500	8.53	299.64	Molteno	Af0007	80
Pell	E04C	199105	1590	6.64	257.17	Molteno	Hd0007	90
Pell	E05D	199101	1480	8.62	125.34	Molteno	Ag0007	60
Pell	E06A	199101	1500	5.35	35.22	Molteno	Af0003	100
Pell	E07A	199105	1530	11.47	238.09	Molteno	Af0015	90
Pell	E08B	199104	1500	5.59	224.19	Molteno	Ag0008	90
Pell	E08C	199104	1595	3.64	226.01	Molteno	Ag0003	60
Pell	E09B	199112	1510	1.04	240.26	Molteno	Ag0015	90
Pell	E12A	199104	1520	7.65	216.16	Molteno	Ag0008	90
Pell	E15C	199110	1338	11.05	216.47	Molteno	Ag0016	60
Pell	E15D	199110	1370	11.05	216.47	Molteno	Ag0018	60
Pell	E19B	199205	1380	11.39	70.32	Molteno	Fb0002	30
Pell	E23A	199211	1440	11.25	108.63	Molteno	Fb0003	60
Pell	E25A	199210	1440	7.20	168.89	Molteno	Ag0027	30
Pell	E26B	199210	1380	5.16	297.90	Molteno	Fb0008	30
Pell	E29A	199205	1400	5.28	11.58	Molteno	Fb0007	60
Pell	E30A	199205	1390	8.97	43.17	Molteno	Fb0003	60
Pell	E33C	199204	1460	11.74	346.87	Molteno	Af0015	90
Pell	J14B	199010	1410	6.85	350.22	Molteno	Ab0670	30
Pell	J15A	198704	1340	0.94	344.05	Molteno	Ab0667	121
Pell	J15C	198704	1340	3.32	45.00	Molteno	Ab0667	121
Pell	J16A	198704	1340	2.55	316.97	Molteno	Ab0667	121
Pell	J17B	199005	1370	7.71	149.71	Molteno	Ab0667	121
Pell	J19C	198504	1350	2.91	152.53	Molteno	Ab0667	121
Pell	H01B	199012	1420	9.00	115.92	Elliot	Fa0016	10
Pell	H02B	199012	1420	7.17	164.28	Elliot	Ab0001	120
Pell	H07	199006	1380	9.23	173.84	Elliot	Ab0816	60
Pell	H15B	199001	1380	4.37	138.58	Elliot	Ab0814	121
Pell	J05	199012	1440	14.13	194.04	Elliot	Ac0008	121
Pell	J12	199012	1540	9.29	150.57	Elliot	Ac0009	30
Pell	J13A	199012	1400	9.72	151.46	Elliot	Ac0007	30
Pell	J14	199104	1440	5.68	9.78	Molteno	Ab0036	30
Pell	J15	199104	1460	11.94	329.77	Molteno	Ab0036	30
Pell	J17	199101	1480	12.11	24.85	Elliot	Ab0034	121

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Pell	J23A	199006	1420	13.63	303.89	Molteno	Fa0076	30
Pell	J26B	199012	1510	5.45	64.50	Molteno	Ac0001	60
Pell	J28B	199101	1480	5.50	62.74	Molteno	Ac0001	60
Pell	J36A	199201	1460	4.31	353.29	Elliot	Fa0001	5
Pell	J37A	199103	1560	12.93	350.10	Elliot	Fa0001	5
Pgreg	B27	199212	1760	7.83	203.07	Drakensberg	Ab0824	151
Pgreg	B30B	199203	1770	1.47	52.02	Drakensberg	Ab0376	30
Pgreg	B34	199211	1790	1.03	180.00	Drakensberg	Aa0030	5
Pgreg	B07	199203	1370	10.45	179.30	Elliot	Ab0162	121
Pgreg	B09A	199203	1330	11.05	157.01	Elliot	Ab0162	121
Pgreg	D04A	199401	1310	4.64	344.74	Molteno	Ad0345	30
Pgreg	D07A	199401	1330	7.65	357.88	Molteno	Ab0447	90
Pgreg	D08A	199411	1300	2.74	317.66	Molteno	Ab0446	121
Pgreg	D10A	199401	1320	5.72	313.18	Molteno	Ab0447	90
Pgreg	D11	199504	1300	3.81	355.16	Molteno	Ab0447	90
Pgreg	D13	199504	1280	3.54	9.06	Molteno	Ab0446	121
Pgreg	D18	199402	1310	5.46	307.79	Molteno	Ad0297	90
Pgreg	D19	199403	1280	0.55	130.84	Molteno	Ab0440	60
Pgreg	D21B	199402	1350	4.72	45.00	Molteno	Ab0218	120
Pgreg	D23A	199402	1380	2.30	140.71	Elliot	Ab0440	60
Pgreg	D25	199402	1390	5.54	63.78	Elliot	Ab0440	60
Pgreg	D30	199402	1400	10.53	354.20	Elliot	Ab0437	90
Pgreg	D31	199403	1315	4.31	0.86	Elliot	Ab0437	90
Pgreg	D32A	199403	1320	15.29	67.70	Elliot	Db0020	10
Pgreg	D33A	199403	1330	6.28	319.14	Elliot	Db0020	10
Pgreg	D34A	199402	1360	6.46	274.21	Molteno	Ad0302	30
Pgreg	D39A	199403	1355	8.51	284.35	Molteno	Ad0303	30
Pgreg	D40A	199403	1305	9.88	340.50	Molteno	Ad0190	60
Pgreg	D41B	199403	1290	6.10	112.62	Molteno	Ab0481	60
Pgreg	D46B	199403	1290	4.19	312.61	Molteno	Ab0479	121
Pgreg	E01A	199411	1310	3.92	30.53	Molteno	Ab0501	90
Pgreg	E05	199409	1440	16.50	58.07	Molteno	Ab0501	90
Pgreg	E07	199411	1340	8.01	81.50	Molteno	Ab0501	90
Pgreg	E09	199409	1520	2.54	35.54	Molteno	Fd0187	10
Pgreg	E13	199410	1355	7.77	27.23	Molteno	Ab0500	121
Pgreg	E18	199404	1340	3.56	305.79	Molteno	Ab0505	30
Pgreg	E23B	199406	1280	2.25	85.36	Molteno	Ab0487	90
Pgreg	E48B	199411	1270	2.91	315.00	Molteno	Ab0489	60
Pgreg	D38A	199311	1350	22.33	161.01	Elliot	Ic0017	10

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Pgreg	D39	199301	1420	17.64	165.04	Elliot	Fa0102	25
Pgreg	G20	199305	1420	5.09	282.46	Elliot	Ca0008	30
Pgreg	G23A	199308	1460	5.72	34.38	Elliot	Bb0194	40
Pgreg	A03A	199411	1410	6.28	94.57	Elliot	Ab0773	121
Pgreg	A03B	199411	1405	6.28	94.57	Elliot	Ab0773	121
Pgreg	A07A	199410	1430	4.76	358.26	Elliot	Ab0773	121
Pgreg	A07D	199411	1450	4.76	358.26	Molteno	Ab0772	90
Pgreg	E24A	199210	1385	11.25	108.63	Molteno	Fb0003	60
Pgreg	E24B	199210	1400	2.16	59.62	Molteno	Fb0003	60
Pgreg	E27B	199210	1390	5.47	292.75	Molteno	Fb0007	60
Pgreg	B04	199410	1335	4.19	242.70	Molteno	Db0017	20
Pgreg	B05	199411	1370	5.79	329.42	Molteno	Ab1015	120
Pgreg	C15A	199311	1330	3.62	83.37	Molteno	Ab1015	120
Pgreg	C16	199311	1310	2.85	331.70	Molteno	Ab1015	120
Pgreg	D01A	199310	1290	11.96	68.82	Molteno	Db0019	20
Pgreg	D04A	199310	1300	6.04	343.72	Molteno	Db0017	20
Pgreg	D05A	199310	1295	8.04	264.06	Molteno	Db0017	20
Pgreg	D09	199311	1270	5.18	46.01	Molteno	Af0048	90
Pgreg	D10	199310	1320	6.04	337.83	Molteno	Db0017	20
Pgreg	D14A	199310	1300	10.18	146.31	Molteno	Af0036	90
Pgreg	D15A	199310	1310	6.49	53.93	Molteno	Db0019	20
Pgreg	D16	199311	1280	2.00	143.65	Molteno	Db0019	20
Pgreg	D18	199310	1365	3.87	68.55	Molteno	Af0038	121
Pgreg	D19	199310	1300	11.55	73.56	Molteno	Db0017	20
Pgreg	D21A	199310	1320	7.58	186.56	Molteno	Db0017	20
Pgreg	A22	199407	1460	1.48	97.25	Molteno	Af0072	120
Pgreg	F03A	199311	1440	6.86	29.55	Elliot	Ac0019	100
Pgreg	F03B	1993.11	1400	6.86	29.55	Elliot	Ac0018	60
Pgreg	F03C	199311	1480	6.86	29.55	Elliot	Ab0336	90
Ppat	A07	199211	1870	12.07	177.09	Drakensberg	Ab0561	60
Ppat	A11	199212	1840	9.66	223.39	Drakensberg	Ab0626	60
Ppat	B12A	199211	1860	6.42	31.33	Drakensberg	Ab0623	120
Ppat	B16	199212	1850	6.30	180.00	Drakensberg	Aa0018	20
Ppat	B24	199212	1785	7.83	203.07	Drakensberg	Ad0567	60
Ppat	B29A	199212	1770	6.37	51.26	Drakensberg	Aa0030	5
Ppat	B36	199204	1710	4.11	63.03	Drakensberg	Ab0372	60
Ppat	B37	199204	1705	2.10	66.25	Drakensberg	Ab0372	60
Ppat	B43A	199112	1700	1.10	149.93	Drakensberg	Ab0385	60
Ppat	B45A	199201	1710	3.89	97.59	Drakensberg	Ab0389	30

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	C01	199104	1680	18.23	219.90	Clarens	Ab0406	30
Ppat	C04	199109	1690	9.61	20.60	Clarens	Ab0403	60
Ppat	C07	199104	1700	9.64	9.52	Elliot	Ad0277	60
Ppat	C08	199105	1690	7.82	65.32	Elliot	Ab0403	60
Ppat	C11A	199109	1780	9.19	278.97	Elliot	Ad0282	30
Ppat	C12	199110	1660	6.29	347.80	Elliot	Ad0274	90
Ppat	C13	199110	1700	10.98	336.98	Elliot	Ab0400	121
Ppat	C14	199110	1650	3.04	353.93	Elliot	Ad0274	90
Ppat	C15	199111	1640	3.80	336.04	Elliot	Ad0274	90
Ppat	A03	199106	1340	2.76	335.85	Molteno/Elliot	Ab0102	90
Ppat	A04A	199107	1350	0.77	90.00	Molteno	Ab0102	90
Ppat	A05A	199107	1330	1.29	36.87	Molteno	Ab0102	90
Ppat	A06	199107	1350	3.76	259.22	Elliot	Ab0127	60
Ppat	A07	199110	1370	4.56	300.26	Molteno	Ad0161	50
Ppat	A09	199101	1350	2.82	284.74	Molteno	Ab0121	121
Ppat	A11C	199110	1340	8.89	27.47	Molteno	Ab0439	60
Ppat	A12	199110	1340	3.69	90.88	Molteno	Ab0162	121
Ppat	A13	199110	1340	3.69	90.88	Elliot	Ad0033	121
Ppat	A14	199106	1400	3.69	90.88	Elliot	Ad0035	60
Ppat	A16A	199110	1380	7.61	253.37	Elliot	Ab0162	121
Ppat	A17A	199110	1360	5.60	244.90	Elliot	Ab0162	121
Ppat	A18	199110	1375	3.03	231.91	Molteno	Ab0162	121
Ppat	A19	199110	1380	3.66	347.68	Elliot	Ab0162	121
Ppat	A20	199110	1410	4.93	271.33	Elliot	Ab0162	121
Ppat	A22A	199106	1360	11.01	75.17	Elliot	Ab0299	120
Ppat	A24A	199106	1300	4.91	43.94	Elliot	Ab0313	60
Ppat	A29A	199110	1380	7.14	318.11	Molteno	Ab0301	110
Ppat	A30	199110	1350	7.81	12.78	Molteno	Ab0301	110
Ppat	A32A	199106	1300	2.85	291.67	Elliot	Ab0314	60
Ppat	B01A	199110	1340	3.01	128.02	Elliot	Ab0120	121
Ppat	B06A	199203	1420	10.06	173.03	Elliot	Ab0162	121
Ppat	B11	199203	1390	14.87	95.00	Elliot	Ab0310	70
Ppat	B20	199110	1390	6.83	151.11	Elliot	Ab0319	120
Ppat	B27A	199110	1420	5.17	172.75	Elliot	Ab0323	90
Ppat	B27B	199110	1410	4.67	172.88	Elliot	Ad0259	70
Ppat	B29A	199110	1410	17.76	91.21	Elliot	Cc0113	40
Ppat	B31A	199110	1420	21.29	129.38	Elliot	Ad0207	60
Ppat	B33C	199110	1350	9.93	258.31	Molteno	Ab0321	120

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	B34A	199110	1290	8.66	166.05	Molteno	Ab0437	90
Ppat	B39A	199106	1310	7.75	74.54	Molteno	Ab0229	70
Ppat	B43	199106	1285	5.27	115.77	Molteno	Ab0225	120
Ppat	B44B	199104	1290	6.39	130.17	Molteno	Ab0218	120
Ppat	C03	199102	1320	4.25	267.58	Molteno	Ab0220	120
Ppat	C05	199102	1350	3.87	234.46	Molteno	Ad0193	120
Ppat	C06B	199104	1320	6.99	258.90	Molteno	Ab0224	120
Ppat	C06D	199104	1330	6.08	181.93	Molteno	Ab0218	120
Ppat	C07A	199104	1315	8.26	251.57	Elliot	Ab0170	90
Ppat	C08A	199104	1310	4.18	281.89	Molteno	Ib0131	30
Ppat	C10A	199102	1295	8.08	159.60	Molteno	Ab0321	120
Ppat	C11B	199102	1260	5.09	177.61	Molteno	Ab0199	121
Ppat	C13	199012	1330	5.51	106.29	Molteno	Ab0198	121
Ppat	C14	199012	1320	6.78	147.36	Molteno	Ab0198	121
Ppat	C15A	199012	1380	2.37	187.77	Molteno	Ab0198	121
Ppat	C16A	199104	1360	5.97	248.63	Molteno	Ab0198	121
Ppat	C17B	199101	1350	3.31	132.99	Molteno	Ab0200	121
Ppat	C18B	199010	1300	9.56	93.81	Molteno	Ab0198	121
Ppat	C19A	199110	1300	6.37	260.63	Molteno	Ab0200	121
Ppat	C20	199012	1335	4.31	32.74	Molteno	Ad0198	120
Ppat	C21B	199012	1350	2.77	101.31	Molteno	Ab0218	120
Ppat	C23A	199102	1370	3.71	101.69	Molteno	Ab0224	120
Ppat	C24	199012	1330	2.62	90.00	Molteno	Ab0206	121
Ppat	C25	199102	1330	3.18	278.13	Elliot	Ab0198	121
Ppat	C26A	199102	1360	2.45	266.99	Elliot	Ab0199	121
Ppat	C26B	199102	1330	5.08	166.55	Elliot	Ab0203	121
Ppat	C28A	199101	1320	2.05	231.34	Elliot	Ib0115	60
Ppat	C29A	199101	1330	9.41	200.98	Elliot	Ad0192	60
Ppat	C32A	199102	1340	6.89	107.70	Elliot	Ab0189	120
Ppat	D01A	199401	1310	17.59	160.63	Molteno	Ad0306	90
Ppat	E19A	199303	1310	2.71	64.65	Molteno	Ab0501	90
Ppat	E26A	199308	1300	2.64	46.97	Molteno	Ab0487	90
Ppat	E30A	199303	1290	4.70	50.49	Molteno	Ab0489	60
Ppat	E36	199303	1290	0.86	192.99	Molteno	Ab0487	90
Ppat	E37	199303	1330	6.59	21.12	Molteno	Ab0489	60
Ppat	E42	199303	1320	8.41	332.35	Molteno	Ab0489	60
Ppat	E43	199303	1290	3.86	39.29	Molteno	Ab0486	121
Ppat	E46	199201	1280	4.33	294.73	Molteno	Ab0487	90
Ppat	E49A	199303	1310	6.69	270.00	Molteno	Ab0487	90

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	D13A	199010	1290	2.17	123.23	Molteno	Ad0104	60
Ppat	E02A	199112	1380	5.68	302.07	Molteno	Ab0097	121
Ppat	E03A	199103	1315	5.08	275.91	Molteno	Ab0097	121
Ppat	F02A	199103	1295	1.83	30.96	Molteno	Ab0038	121
Ppat	F02B	199104	1285	2.02	9.16	Molteno	Ab0038	121
Ppat	F03A	199104	1290	3.01	21.19	Molteno	Ab0038	121
Ppat	F03B	199103	1310	6.95	32.96	Molteno	Ab0038	121
Ppat	F05C	199008	1355	3.03	27.55	Molteno	Ab0043	60
Ppat	F09A	199110	1335	3.37	316.55	Molteno	Ab0014	30
Ppat	F16	199109	1420	3.80	311.31	Molteno	Ab0333	121
Ppat	F17A	199109	1390	8.93	126.67	Molteno	Ab0010	121
Ppat	F17B	199109	1360	7.33	206.78	Molteno	Ab0038	121
Ppat	F18A	199109	1310	7.54	225.00	Molteno	Ab0041	90
Ppat	F19A	199109	1340	6.75	112.78	Molteno	Ab0038	121
Ppat	F20A	199110	1410	5.13	319.97	Molteno	Ab0038	121
Ppat	G01A	199103	1335	3.37	316.55	Molteno	Ab0778	121
Ppat	G16	199109	1303	5.08	275.91	Molteno	Ab0010	121
Ppat	G17B	199109	1332	3.37	316.55	Molteno	Ab0028	120
Ppat	G17D	199111	1322	8.24	198.44	Molteno	Ab0028	120
Ppat	G21	199108	1305	3.01	21.19	Molteno	Ib0014	10
Ppat	G25A	199109	1326	3.37	316.55	Molteno	Ab0028	120
Ppat	G25B	199109	1313	7.54	225.00	Molteno	Ab0028	120
Ppat	G32B	199108	1314	7.54	225.00	Molteno	Ab0028	120
Ppat	A01	199104	1360	2.50	267.80	Molteno	Ab0782	121
Ppat	A09	199104	1360	2.89	57.72	Molteno	Ab0782	121
Ppat	A11A	199205	1360	4.20	309.81	Molteno	Ab0782	121
Ppat	A18	199205	1380	1.73	39.56	Elliot	Ad0782	120
Ppat	A20A	199205	1380	5.65	71.57	Elliot	Ab0782	121
Ppat	B01A	199111	1360	5.72	301.57	Elliot	Ab0243	121
Ppat	B06	199101	1330	2.43	302.01	Elliot	Ab0243	121
Ppat	B07B	199111	1370	3.48	64.86	Elliot	Ab0782	121
Ppat	B10A	199010	1440	7.77	207.30	Elliot	Ad0133	70
Ppat	B15	199111	1320	1.41	0.00	Molteno	Ab0142	121
Ppat	C02A	199011	1340	1.29	27.90	Molteno	Ab0782	121
Ppat	C03A	199011	1360	3.21	10.22	Molteno	Ab0782	121
Ppat	C10	199112	1360	3.13	22.62	Molteno	Ab0149	121
Ppat	C11	199112	1300	5.12	72.03	Molteno	Ab0157	30
Ppat	C12	199103	1340	2.08	106.50	Molteno	Ab0782	121
Ppat	C15	199012	1340	3.03	63.43	Molteno	Ab0785	30

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	C21	199203	1360	3.79	309.64	Molteno	Ab0778	121
Ppat	E03A	199110	1370	5.08	352.09	Molteno	Ab0453	121
Ppat	E04	199110	1380	3.95	52.28	Molteno	Ab0820	120
Ppat	F09	199304	1360	6.93	70.56	Elliot	Ad0399	60
Ppat	F14A	199303	1380	4.16	12.85	Elliot	Ab0650	150
Ppat	G05A	199308	1440	2.72	255.65	Elliot	Ab0605	110
Ppat	G06A	199209	1440	7.62	129.44	Elliot	Ab0605	110
Ppat	G13	199308	1380	4.61	292.99	Elliot	Bb0175	60
Ppat	G15	199309	1380	2.68	62.82	Elliot	Ab0521	120
Ppat	G18A	199210	1400	2.14	27.65	Elliot	Ba0033	60
Ppat	G19A	199211	1400	2.52	276.01	Elliot	Ba0034	90
Ppat	G21	199305	1420	8.44	287.92	Elliot	Ab0659	90
Ppat	G24	199305	1400	5.17	296.57	Elliot	Ba0033	60
Ppat	J02A	199203	1440	1.84	14.74	Elliot	Ab0056	120
Ppat	J04A	199203	1360	4.45	37.88	Elliot	Ab0053	90
Ppat	J05	199203	1360	7.13	117.35	Molteno	Cc0150	10
Ppat	J06A	199011	1340	2.65	72.30	Molteno	Ab0782	121
Ppat	J07	199011	1320	1.65	38.66	Elliot	Ab0782	121
Ppat	J08B	199011	1320	1.47	32.47	Elliot	Ab0782	121
Ppat	J09	199011	1320	0.61	281.89	Elliot	Ab0782	121
Ppat	J10	199010	1380	11.86	146.94	Molteno	Ad0545	60
Ppat	J11	199011	1340	2.45	181.64	Molteno	Ab0782	121
Ppat	C20	199410	1340	1.64	327.09	Molteno	Ab0095	121
Ppat	C21	199412	1350	3.68	176.35	Molteno	Ab0095	121
Ppat	C22B	199311	1320	4.93	271.30	Molteno	Ab0095	121
Ppat	C23	199311	1325	2.93	279.25	Molteno	Ab0095	121
Ppat	D01	199211	1400	7.22	184.96	Elliot	Ab0095	121
Ppat	D02	199211	1380	5.17	258.29	Elliot	Cc0111	30
Ppat	D03A	199107	1380	4.72	250.08	Elliot	Ab0189	120
Ppat	D03B	199308	1400	8.23	237.05	Elliot	Ab0192	90
Ppat	D15A	199207	1430	12.67	189.42	Elliot	Ab0182	90
Ppat	E02	199211	1370	3.75	23.96	Elliot	Ab0189	120
Ppat	E06	199109	1580	12.44	43.48	Elliot	Fd0128	20
Ppat	E07	199909	1400	6.53	35.81	Elliot	Ab0189	120
Ppat	E08A	199107	1390	6.37	69.38	Elliot	Ad0178	80
Ppat	E10	199206	1620	11.55	20.56	Elliot	Ab0278	120
Ppat	E11	199107	1660	15.91	8.21	Elliot	Ab0189	120
Ppat	E12	199105	1585	10.71	26.19	Elliot	Ab0189	120
Ppat	E13	199107	1345	0.90	240.95	Elliot	Ab0189	120

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	E14A	199209	1710	12.73	168.18	Elliot	Ad0141	30
Ppat	E15	199111	1340	2.81	157.31	Elliot	Ab0177	121
Ppat	E19	199111	1380	7.63	50.36	Elliot	Ad0115	121
Ppat	F16A	199308	1380	6.83	135.64	Elliot	Ab0554	121
Ppat	F21	199310	1436	6.83	135.64	Molteno	Ab0554	121
Ppat	G04A	199105	1375	6.64	122.80	Elliot	Ab0137	121
Ppat	G06A	199105	1390	4.64	82.57	Elliot	Ab0790	90
Ppat	G08	199105	1390	2.53	268.45	Elliot	Ab0790	90
Ppat	G09	199105	1400	0.81	32.91	Elliot	Ab0790	90
Ppat	G11	199101	1385	2.10	27.65	Elliot	Ab0817	121
Ppat	G12	199105	1390	5.53	252.68	Elliot	Ab0817	121
Ppat	G14	199105	1395	0.97	273.81	Elliot	Ab0817	121
Ppat	G15	199105	1405	1.62	83.16	Elliot	Ab0817	121
Ppat	G17	199009	1385	2.09	299.05	Elliot	Ab0789	90
Ppat	G18	199009	1375	4.80	29.25	Elliot	Fa0076	30
Ppat	G19A	199103	1385	0.58	349.99	Elliot	Ab0790	90
Ppat	G19B	199308	1405	2.72	30.38	Elliot	Ab0278	120
Ppat	G20	199009	1395	1.63	307.41	Elliot	Ab0790	90
Ppat	G22A	199009	1420	2.86	21.04	Elliot	Ab0790	90
Ppat	G23	199009	1420	3.14	1.17	Elliot	Ab0790	90
Ppat	G24A	199308	1500	13.99	350.30	Elliot	Ab0793	60
Ppat	A01B	199004	1455	4.00	160.35	Elliot	Ab0773	121
Ppat	A02A	199004	1440	6.28	94.57	Elliot	Ab0773	121
Ppat	A04A	199003	1450	2.25	253.81	Elliot	Ab0773	121
Ppat	A04D	199212	1490	7.99	248.86	Elliot	Ad0535	30
Ppat	A05A	199212	1470	6.77	238.28	Elliot	Ab0773	121
Ppat	A06	199212	1430	4.76	358.26	Elliot	Ab0770	60
Ppat	A12	199002	1510	4.13	242.53	Molteno	Ag0010	30
Ppat	B01B	199001	1440	5.04	274.03	Molteno	Ab0773	121
Ppat	B05A	198912	1500	3.57	239.74	Molteno	Ab0773	121
Ppat	B05B	199010	1470	7.57	204.86	Molteno	Bb0221	121
Ppat	B05C	199005	1470	7.47	235.95	Molteno	Ad0772	60
Ppat	B07A	199004	1440	3.92	318.99	Molteno	Ad0536	60
Ppat	B07B	199004	1480	5.09	249.44	Molteno	Ad0535	30
Ppat	B08A	199007	1465	4.94	351.03	Molteno	Bb0220	60
Ppat	B08C	199201	1465	4.89	96.84	Molteno	Fb0128	20
Ppat	B08F	199201	1460	3.82	103.52	Molteno	Fb0128	20
Ppat	B08H	199007	1480	2.46	138.58	Molteno	Fb0128	20
Ppat	B08I	199007	1465	0.98	113.96	Molteno	Fb0128	20

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	B09C	199003	1420	9.76	129.19	Molteno	Ab0772	90
Ppat	B10A	199002	1460	3.23	24.08	Molteno	Ab0770	60
Ppat	B11A	199003	1430	5.25	277.55	Molteno	Ad0535	30
Ppat	B12A	199003	1460	6.01	278.13	Molteno	Ad0535	30
Ppat	B13A	199003	1440	6.69	72.47	Molteno	Ab0773	121
Ppat	B13B	199003	1450	10.17	78.69	Molteno	Ab0773	121
Ppat	B14A	199004	1495	6.69	277.13	Molteno	Ab0771	30
Ppat	B15B	199011	1455	3.05	288.43	Molteno	Ad0535	30
Ppat	B15C	199011	1450	0.18	288.84	Molteno	Ab0773	121
Ppat	B16A	199006	1485	5.46	58.17	Molteno	Ad0536	60
Ppat	B16B	199006	1490	6.00	42.40	Molteno	Ab0771	30
Ppat	B18	199006	1505	3.46	258.69	Molteno	Ab0773	121
Ppat	B20A	199006	1495	3.13	46.47	Molteno	Cb0154	30
Ppat	B20B	199005	1485	3.68	61.11	Molteno	Af0116	120
Ppat	B22A	199104	1510	3.68	339.86	Molteno	Af0116	120
Ppat	B23A	199005	1535	3.69	344.74	Molteno	Af0116	120
Ppat	B24	199005	1515	3.85	51.79	Molteno	Ab0773	121
Ppat	B25	199008	1545	5.21	313.36	Molteno	Ab0773	121
Ppat	B26	199007	1530	3.48	38.99	Molteno	Cc0148	30
Ppat	B27	199005	1540	3.83	299.29	Molteno	Cb0145	60
Ppat	B28A	199009	1465	2.41	344.48	Molteno	Cb0154	30
Ppat	B29A	199011	1485	3.22	357.71	Molteno	Fb0128	20
Ppat	C02	199008	1555	2.39	241.50	Molteno	Cb0154	30
Ppat	C03A	199008	1570	2.97	4.76	Molteno	Ag0079	50
Ppat	C03B	199009	1555	5.90	43.45	Molteno	Cb0154	30
Ppat	C04A	199008	1570	1.87	260.31	Molteno	Af0116	120
Ppat	C04B	199009	1590	0.84	91.33	Molteno	Ab0773	121
Ppat	C05A	199010	1550	2.61	176.31	Molteno	Ag0079	50
Ppat	C06A	199009	1525	6.10	74.36	Molteno	Cb0154	30
Ppat	C06B	199009	1495	0.61	16.93	Molteno	Ab0773	121
Ppat	C07A	199010	1505	3.03	28.61	Molteno	Ab0773	121
Ppat	C07B	199010	1505	2.57	48.01	Molteno	Ag0080	60
Ppat	C07D	199010	1525	3.43	55.71	Molteno	Ab0773	121
Ppat	C08	199010	1505	6.00	317.60	Molteno	Ag0079	50
Ppat	C09A	199010	1510	4.90	316.51	Molteno	Af0116	120
Ppat	C10	199010	1525	1.35	59.04	Molteno	Cb0154	30
Ppat	C11A	199010	1525	0.82	153.44	Molteno	Ab0771	30
Ppat	C11B	199010	1520	1.22	198.44	Molteno	Ab0771	30
Ppat	C12	199010	1490	4.69	71.05	Molteno	Cb0154	30

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	C13A	199009	1510	0.75	30.96	Molteno	Ab0773	121
Ppat	C14A	199011	1485	3.93	182.82	Molteno	Cb0154	30
Ppat	C15	199011	1501	3.93	182.82	Molteno	Af0116	120
Ppat	C16	199011	1472	3.93	182.82	Molteno	Af0116	120
Ppat	D01B	199111	1350	4.76	308.88	Molteno	Af0106	90
Ppat	D03C	199111	1385	5.58	100.30	Molteno	Ag0105	30
Ppat	D05A	199111	1340	8.00	281.31	Molteno	Af0107	60
Ppat	D06A	199111	1380	8.02	242.78	Molteno	Ag0102	60
Ppat	D12A	199111	1450	3.03	87.27	Molteno	Ag0104	60
Ppat	D13A	199111	1435	3.55	348.31	Molteno	Af0104	121
Ppat	D15B	199112	1390	4.67	18.43	Molteno	Af0104	121
Ppat	D16C	199112	1435	4.54	276.34	Molteno	Fc0100	20
Ppat	D17A	199112	1480	8.06	311.86	Molteno	Ag0102	60
Ppat	D18A	199112	1540	9.05	287.67	Molteno	Ag0102	60
Ppat	E01A	199010	1520	6.64	39.61	Molteno	Ag0102	60
Ppat	E01B	199010	1500	3.22	35.54	Molteno	Af0003	100
Ppat	E05A	199101	1510	2.93	178.75	Molteno	Ag0001	50
Ppat	E05B	199102	1490	6.01	58.80	Molteno	Ag0001	50
Ppat	E05C	199012	1530	2.96	64.29	Molteno	Ag0007	60
Ppat	E10A	199102	1520	1.04	240.26	Molteno	Af0012	90
Ppat	E10D	199102	1420	9.92	50.01	Molteno	Af0012	90
Ppat	E11A	199102	1465	9.92	50.01	Molteno	Ag0014	90
Ppat	E11B	199103	1471	9.92	50.01	Molteno	Ag0014	90
Ppat	E13A	199104	1520	7.37	237.62	Molteno	Ag0008	90
Ppat	E13C	199110	1510	7.95	248.68	Molteno	Ag0008	90
Ppat	E13E	199104	1510	7.37	239.47	Molteno	Ag0008	90
Ppat	E14A	199104	1510	4.23	355.86	Molteno	Ag0008	90
Ppat	E14F	199104	1480	6.93	230.91	Molteno	Ag0008	90
Ppat	E15A	199106	1513	11.05	216.47	Molteno	Ag0014	90
Ppat	E15B	199102	1465	11.05	216.47	Molteno	Ag0014	90
Ppat	E15F	199204	1481	11.05	216.47	Molteno	Ag0023	90
Ppat	E17B	199204	1440	5.08	55.30	Molteno	Fb0005	60
Ppat	E19A	199204	1480	5.71	27.43	Molteno	Ag0024	60
Ppat	E22	199204	1520	5.08	178.67	Molteno	Hd0009	90
Ppat	E31A	199203	1525	8.06	148.52	Molteno	Ag0008	90
Ppat	E32A	199203	1540	8.63	9.95	Molteno	Af0012	90
Ppat	G03A	199007	1490	8.00	168.50	Elliot	Ad0554	90
Ppat	G05	199008	1510	6.74	52.97	Molteno	Ib0209	0
Ppat	G06A	199007	1500	2.08	291.80	Elliot	Ad0554	90

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	G07B	199008	1540	7.51	307.03	Elliot	Ib0209	0
Ppat	G13A	199007	1480	5.41	148.30	Elliot	Ab0804	121
Ppat	G15	199009	1485	9.59	62.85	Elliot	Ab0804	121
Ppat	G16	199009	1490	5.70	96.34	Elliot	Ib0209	0
Ppat	G17F	199009	1480	4.40	180.00	Elliot	Ib0209	0
Ppat	G24A	199008	1500	8.14	356.85	Elliot	Ab0804	121
Ppat	G25A	199008	1345	8.29	231.89	Molteno	Ad0004	60
Ppat	G30B	199009	1380	11.19	209.45	Molteno	Ab0804	121
Ppat	G31B	199008	1530	5.77	135.00	Molteno	Ad0553	60
Ppat	G32A	199008	1500	6.85	83.05	Molteno	Ib0209	0
Ppat	G32B	199008	1550	3.42	12.38	Molteno	Ib0209	0
Ppat	G32C	199008	1540	6.89	279.64	Molteno	Ad0553	60
Ppat	G33A	199008	1490	5.61	14.68	Elliot	Ab0804	121
Ppat	G33B	199008	1480	3.77	77.97	Elliot	Ab0804	121
Ppat	G33C	199008	1480	6.06	105.36	Elliot	Ab0804	121
Ppat	G34A	199008	1500	8.44	96.10	Elliot	Ab0804	121
Ppat	G35B	199008	1540	6.35	227.56	Elliot	Ab0804	121
Ppat	G36	199008	1480	6.37	220.10	Elliot	Ab0804	121
Ppat	G37	199004	1400	10.81	207.29	Elliot	Fd0231	10
Ppat	G38	199004	1440	12.63	220.48	Elliot	Fd0231	10
Ppat	G39B	199008	1490	11.05	187.50	Elliot	Ab0804	121
Ppat	H11	199009	1320	3.83	153.00	Molteno	Ib0010	0
Ppat	H13A	199009	1280	5.95	188.13	Molteno	Af0094	60
Ppat	H14A	199011	1340	1.07	39.29	Molteno	Ab0006	121
Ppat	H15A	199009	1375	1.39	353.99	Molteno	Ab0007	90
Ppat	H15B	199009	1375	3.42	19.80	Molteno	Ab0006	121
Ppat	H16A	199009	1325	5.61	75.58	Molteno	Ab0006	121
Ppat	H16B	199009	1290	5.16	110.61	Molteno	Ab0006	121
Ppat	H17A	199009	1280	6.65	219.56	Molteno	Ab0008	60
Ppat	H17B	199009	1250	9.70	114.88	Molteno	Fa0036	10
Ppat	H18	199009	1290	4.36	11.31	Molteno	Ab0006	121
Ppat	H19A	199009	1280	2.55	11.31	Molteno	Ab0006	121
Ppat	H22A	199009	1360	7.63	1.02	Molteno	Fa0004	30
Ppat	H23	199009	1370	5.41	38.00	Molteno	Fa0004	30
Ppat	H24A	199009	1350	5.85	100.12	Molteno	Ab0008	60
Ppat	H25	199009	1380	1.96	226.97	Molteno	Ab0007	90
Ppat	J04A	199007	1440	5.23	353.66	Elliot	Ab0795	90
Ppat	J05	199007	1400	4.82	14.93	Molteno	Ab0796	121
Ppat	J06	199006	1400	8.48	52.31	Molteno	Ab0797	121

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	J07A	199007	1470	5.29	334.89	Elliot	Ab0796	121
Ppat	J07C	199007	1440	5.29	334.89	Elliot	Ab0798	60
Ppat	J08A	199007	1500	7.41	16.82	Elliot	Ab0796	121
Ppat	J08B	199007	1500	7.41	16.82	Elliot	Ab0796	121
Ppat	J10A	199005	1440	3.79	110.56	Elliot	Ab0795	90
Ppat	J10B	199007	1470	3.99	308.37	Elliot	Ab0798	60
Ppat	J11	199007	1450	7.61	37.88	Molteno	Ib0207	10
Ppat	J12A	199006	1400	10.42	86.74	Molteno	Ab0796	121
Ppat	J12B	199006	1390	3.83	16.61	Molteno	Ab0796	121
Ppat	J13B	199006	1390	12.99	26.94	Molteno	Ab0797	121
Ppat	J13C	199209	1390	12.99	26.94	Molteno	Ab0667	121
Ppat	J14A	199210	1420	4.88	114.44	Molteno	Ab0801	90
Ppat	J16B	199204	1340	2.28	310.43	Molteno	Hd0077	90
Ppat	J17A	199005	1380	7.10	126.55	Molteno	Ab0667	121
Ppat	J18A	199006	1390	8.06	52.22	Molteno	Ab0667	121
Ppat	J18B	199209	1370	7.73	69.72	Molteno	Ab0667	121
Ppat	J20A	199204	1360	4.32	18.43	Molteno	Ab0667	121
Ppat	J23A	199003	1360	4.07	195.52	Molteno	Ab0667	121
Ppat	J23B	199003	1345	7.93	195.07	Molteno	Ab0803	90
Ppat	J23C	199003	1340	6.17	192.01	Molteno	Ib0207	10
Ppat	J25A	199003	1350	6.44	192.65	Molteno	Ab0803	90
Ppat	J29A	199005	1310	9.10	197.07	Elliot	Ad0551	50
Ppat	A33A	199207	1480	1.48	97.25	Molteno	Af0072	120
Ppat	A34	199207	1460	1.30	310.49	Molteno	Af0072	120
Ppat	F11C	199304	1370	6.86	29.55	Molteno	Ab0364	30
Ppat	F15A	199303	1430	9.19	300.29	Molteno	Ab0360	110
Ppat	H01A	199002	1400	10.01	111.48	Elliot	Ab0003	60
Ppat	H02A	199002	1420	12.63	187.34	Elliot	Fd0229	10
Ppat	H03	199002	1440	16.85	200.85	Elliot	Ab0791	90
Ppat	H10	199010	1360	0.82	319.76	Elliot	Ab0814	121
Ppat	H14B	199001	1380	2.48	47.49	Elliot	Ab0814	121
Ppat	H15A	199001	1380	0.92	50.71	Elliot	Ab0814	121
Ppat	H16B	199106	1380	3.64	78.69	Elliot	Ab0814	121
Ppat	H17	199004	1360	2.72	154.98	Elliot	Ad0556	30
Ppat	H21A	199102	1380	2.45	330.07	Elliot	Ad0547	90
Ppat	H24C	199308	1380	1.33	101.31	Elliot	Ab0786	90
Ppat	H25A	199106	1420	5.13	315.00	Elliot	Ad0547	90
Ppat	H26	199106	1400	6.91	166.76	Elliot	Ad0547	90
Ppat	H27	199106	1400	3.58	14.04	Elliot	Ab0787	60

Species	Comp. No.	Establish Date	Height	Slope	Aspect	Lithology	FSD Dominant Soil Form	ERD_MIN
Ppat	H28	199106	1380	1.37	354.09	Elliot	Ab0786	90
Ppat	H29	199106	1400	2.48	116.57	Elliot	Ab0786	90
Ppat	H30	199106	1420	4.37	152.45	Elliot	Ab0786	90
Ppat	H31	199101	1380	1.64	281.31	Elliot	Ab0787	60
Ppat	J01	199012	1540	11.38	56.69	Molteno	Ac0006	60
Ppat	J02A	199012	1540	5.09	357.93	Molteno	Ac0006	60
Ppat	J03	199012	1540	9.39	348.23	Molteno	Ab0034	121
Ppat	J04A	199012	1480	10.38	32.31	Elliot	Ib0165	10
Ppat	J06	199012	1380	4.14	106.99	Elliot	Ab0016	121
Ppat	J08	199010	1380	3.53	309.56	Elliot	Cc0151	30
Ppat	J09A	199010	1370	0.86	296.57	Elliot	Ab0789	90
Ppat	J10A	199009	1380	2.38	323.13	Elliot	Ab0790	90
Ppat	J11	199104	1460	16.40	159.96	Elliot	Ac0007	30
Ppat	J13B	199012	1420	9.72	141.93	Elliot	Ac0009	30
Ppat	J16B	199104	1520	8.61	353.26	Elliot	Ab0034	121
Ppat	J18	199012	1380	7.01	140.26	Elliot	Ia0001	60
Ppat	J19	199012	1420	7.52	349.78	Elliot	Ab0017	90
Ppat	J20A	199012	1400	4.06	15.40	Elliot	Ab0015	121
Ppat	J21	199012	1380	4.61	125.79	Elliot	Ia0001	60
Ppat	J31A	199003	1440	7.80	294.25	Elliot	Ab0791	90
Ppat	J37B	199012	1560	6.81	350.10	Molteno	Ac0006	60
Ptae	D05	199112	1475	3.68	155.85	Elliot	Ab0790	90
Ptae	D06	199203	1445	15.30	223.78	Elliot	Fd0129	30
Ptae	D07	199203	1450	13.45	60.80	Elliot	Ab0177	121
Ptae	D09	199112	1450	11.08	113.33	Elliot	Ab0269	120
Ptae	D11A	199112	1450	11.08	113.33	Elliot	Ab0269	120
Ptae	D12A	199203	1450	13.73	253.56	Elliot	Ab0269	120
Ptae	D13	199203	1545	7.02	83.66	Elliot	Ab0790	90
Ptae	D14A	199203	1420	10.80	122.05	Elliot	Ab0177	121
Ptae	E23	199308	1405	5.99	120.34	Elliot	Ab0278	120
Ptae	G01	199111	1420	4.27	11.06	Elliot	Ab0278	120
Ptae	E15H	199102	1513	11.05	216.47	Elliot	Ag0024	60