EVALUATION OF TREE PERFORMANCE, SITE CONDITIONS AND SILVICULTURAL PROCEDURES IN FOREST PLANTATIONS AT HIGH ALTITUDE SITES IN LESOTHO

by

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ABSTRACT

The permanent sample plots (PSP) and silvicultural trial plots established by the Forestry Research Section of the Forestry Department of the Ministry of Forestry and Land Reclamation in Lesotho were used as a source of information for this study. The study area is located in the forest plantations on high altitude sites in Lesotho which have the aim to determine important aspects of timber production for commercial use and to address the problem of fuel wood scarcity and energy crisis. The major objective of the study was to describe performance (survival, growth and timber volume) of exotic tree species introduced in Lesotho.

The height and diameter relationships for trees in the 33 plots of *Eucalyptus rubida* and 44 plots of *Pinus radiata* were determined by a simple linear regression. There are four plots of *Eucalyptus macarthurii*, three plots of *Pinus halepensis*, one plot of *Eucalyptus nitens* and one plot of *Pinus pinaster*. The permanent sample plots data were analysed with the use of a statistical package Genstat (7th edition). Categorical analysis were used to detect the number of live and dead trees. The correlation analysis was used to study association between site and performance variables, while multiple regression analysis was utilised to analyse relationships between site index and site variables. The growth curves developed for *E. rubida* and *P. radiata* tended to indicate a sigmoidal shape. Analysis of variance was utilised to analyse the performance of species in terms of survival and growth (HT and DBH) for the four species and provenance trials.

The early mortality rate was 2% for *E. macarthurii*, 14% for *E. rubida*, 0% for *E. nitens*. Later, it was found that the percentage of dead trees is as follows: 7% for *E. macarthurii*, 15% for *E. rubida*, 29% for *E. nitens*. It was detected that the mortality rate for eucalypts was 14% at last assessments. Similarly, it was detected that the final mortality rate for *P. halepensis*, *P. pinaster* and *P. radiata* was 2%, 19% and 20% respectively.

The mean diameter for *P. radiata* ranged between 1,87 cm at age 3,75 years and 24,49 cm at age 18 years. The mean height ranged from 1,51 m at age 0,75 yrs and 13,51 m at

age 16 years. It was discovered that the mean diameter is found between 8,0 cm at age 4,83 yrs and 14,41 cm at age 8,83 yrs for *P. halepensis*. The mean height was 2,1 m at age 4,83 years and 16,48 m at age 13,50 years. The mean diameter ranged from 7,41 cm at age 6,42 years and 15,92 cm at age 10,42 years for *P. pinaster*. Similarly, the mean height was detected to be between 5 m at age 6,42 years and 7,75 m at age 12,42 years for *P. pinaster*. It was noted that the mean diameter for *E. rubida* ranged from 2,04 cm at age 2,25 years to15,87 cm at age 11,75 years. On the same line the mean height started at 4,55 m at age 2,42 years and ended at 16,15 m at age 11,75 years. The mean diameter for *E. macarthurii* was noted to be 13,64 cm at age 10 years. It was noticed that mean height is found between 3,8 m at age 2,17 years and 16,03 m at age 10 years. It was also detected that the mean diameter started from 4,45 cm at age 2,50 years and 10,78 cm at age 6,50 years for *E. nitens*. The mean diameter ranged from 5,98 cm at age 2,50 years and from 12,05 m at age 6,50 years for *E. nitens*.

The mean annual increment (MAI) for *P. radiata* is found between 0,15 m^3/ha/yr at age 2,25 years and 21,91 m^3/ha/yr at age 6,50 years. The MAI ranged from 0,58 m^3/ha/yr at age 3,42 years and 10,81 m^3/ha/yr at age 10,42 years for *E. rubida*. It was determined that the MAI started from 0,25 m^3/ha/yr at age 2,17 years to 9,99 m^3/ha/yr at age 4,17 years for *E. macarthurii*. The MAI started from 1,59 m^3/ha/yr at age 2,50 years and to 7,54 m^3/ha/yr at age 6,50 years for *E. nitens*. It was noted that the MAI for *P. halepensis* began from 0,01 m^3/ha/yr at age 4,83 years and 3,52 m^3/ha/yr at age 13,50 years. Similarly, the MAI began from 0,73 m^3/ha/yr at age 6,42 years and 2,70 m^3/ha/yr at age 10,42 years for *P. pinaster*.

The Site indices for *E. rubida* and *P. radiata* were calculated. They ranged from 6,72 to 14,40 m and from 12,05 to 18,43 m for *E. rubida* and *P. radiata* at age 6 years and 15 years respectively.

The MAI and SI of different species justify that a viable commercial forestry can be implemented in Lesotho, if advanced selection of genetic material, improved silviculture and appropriate site species matching can be followed. It was noticed that various

silvicultural practices like proper land preparation methods, weed management and deep planting have a large impact on tree performance. Based on these results, larger afforestation projects for commercial timber production and bioenergy are recommended.

Key words: *Eucalyptus rubida*, *Pinus radiata*, growth curves, site index, tree performance, site conditions, silviculture, site classification, Lesotho, PSP

PREFACE

The research study was executed in forest plantations at high altitude sites in Lesotho and at the University of KwaZulu-Natal from January 2003 to December, 2004, under the supervision of Professor Janusz Zwolinski.

It is declared that these research investigations represent the original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Great care has been taken where use has been made of the work of others in the text is accordingly acknowledged.

Signed: ....
Mokete M. Pama (candidate).

Signed:...
Professor Janusz Zwolinski (supervisor).

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LIST OF VARIABLES (ABBREVIATIONS) AND ACRONYMS

ADFSL	Anglo De Beers Forest Services Lesotho
ALT	Vertical distance from sea level (m)
a.s.l.	Above sea level in metres
ASPECT	Slope direction from North at 360° or 0°
Assess no.	Assessment number
BAH	Basal area per hectare (m^2/ha)
BA/plt	Basal area per plot (m^2)
CCWR	Computing Centre for Water Research
CFI	Continuous Forest Inventory
Coppic	Coppice
CAI	Current annual Increment (m^3/ha/yr)
DAE	Department of Agricultural Engineering
DBH	Diameter (cm) at breast height over bark at 1.3 m from ground Level
Dom	Dominant
ERD	Effective rooting depth (cm)
EM	*Eucalyptus macarthurii*
EN	*Eucalyptus nitens*
ER	*Eucalyptus rubida*
FAO	Food and Agricultural Organisation
FTB	Forestry and Timber Bureau
GOL	Government of Lesotho
GPS	Global Positioning System
GTZ	Gesellschaft fur Techische Zusammenarbeit
HD	Dominant height (m)
HT	Total standing tree height (m)
Htop	Top height (m)
HUAS	Heat Units from April to September at base 10 °C
HUOM	Heat Units from October to March at base 10 °C

ICFR	Institute for Commercial Forestry Research
ISCW	Institute for Soil Climate and Water
LCI	Lang's Climatic Index (mm/°C)
LCC	Land capability classification
LSS	Land suitability classification
LAT	Latitude (south) (degrees, minutes, seconds)
LONG	Longitude (East) (degrees, minutes, seconds)
MFRI	Malawi Forestry Research Institute
MAI	Mean Annual Increment (m^3/ha/yr) (t/ha/yr)
MAP	Mean Annual Precipitation (mm)
MAT	Mean annual temperature (°C)
m^2	Metre squared
OC	Organic carbon
ODA	Overseas Development Administration
PAI	Periodic annual increment (m^3/ha/yr)
PSP	Permanent sample plot
PH	*Pinus halepensis*
PP	*Pinus pinaster*
PR	*Pinus radiata*
Plt	Plot
Regen.	Regeneration
SASA	South African Sugar Association
SAWS	South African Weather Service
Seedlin	Seedling
SI	Site Index (m), dominant height at base age_6 and age_{15}
SR	Solar radiation (MJ/m^2/day)
SBEEH	School of Bio resources, Engineering and Environmental Hydrology
SD	Stand density
SPH	Stems per hectare
TPH	Trees per hectare

TPCP	Tree Pathology Cooperative Programme
UKZN	University of Kwa-Zulu-Natal
UNESCO	United Nations Educational Scientific and Cultural Organisation
USDA	United States Department of Agriculture
Vol.	Volume
VPH	Volume per hectare (m^3/ha)
WRC	Water Research Commission
WRI	Wattle Research Institute
Yr	Year

LIST OF EQUATIONS

EQUATION **PAGE**

CHAPTER ONE

INTRODUCTION

1.1 Forestry In Lesotho In The Past, Present And Future

Heywood (1908), the Conservator of Forests in the Eastern Cape, produced the earliest report on forestry in Lesotho. By that time a wide variety of trees had been introduced, particularly around missions, trading stores and government stations. The earliest planting was probably at Morija where trees over hundred years old are still standing. Whether the country carried out much woodland establishment in earlier times is a matter of debate but judging from remaining relics of woodland in the lowlands, in the Senqu valley and in less accessible cliffed areas, it appears as though there could have been significant woodland resources, particularly in the lowlands and foothills. These have been depleted by man either for fuel or been destroyed during farming, by grazing and by fire.

From 1930 to 1940, there was a major campaign to promote the planting of grey poplar (*Populus canescens*) in dongas and below sandstone cliffs. Such areas continue to produce significant amounts of fuel and poles for local people. Soil conservation activities started in 1936 and associated with these was the establishment of grey poplar stands, such as the one at Matsieng. These activities were expanded in the 1950s and 1960s when millions of tree seedlings were produced and either distributed to farmers or established in conservation areas, particularly near dams and in dongas. These woodlots were handed over to local chiefs and communities. Unfortunately, as a result of damage by grazing, fire or felling, the areas under such forests are now comparatively small. There was no built-in system of management which would ensure that the trees were protected and the areas reafforested after felling (Figure 1 and 2).

The Lesotho Woodlot Project was developed out of a feasibility study on forest development undertaken by W.R. Long in 1972 and financed by the Anglo American Corporation of South Africa. On the 7th December 1972, an agreement was signed between the Right Honourable Dr. Leabua Jonathan, the Prime Minister of the Government of Lesotho and Mr. Harry Oppenheimer, Chairman of the Anglo American Corporation of South Africa for a twelve-year project of forest development commencing on 1st April 1973. The existing Forestry Section of the Soil Conservation Division and all its resources were incorporated into the project, which was charged with establishing a forest service to service all sectors of the government. Subsequently, in 1973, the Overseas Development Administration (ODA) of the United Kingdom became a partner in the project with the Government of Lesotho (GOL) and Anglo de Beers Forest Services (Lesotho) LTD. (ADBFSL).

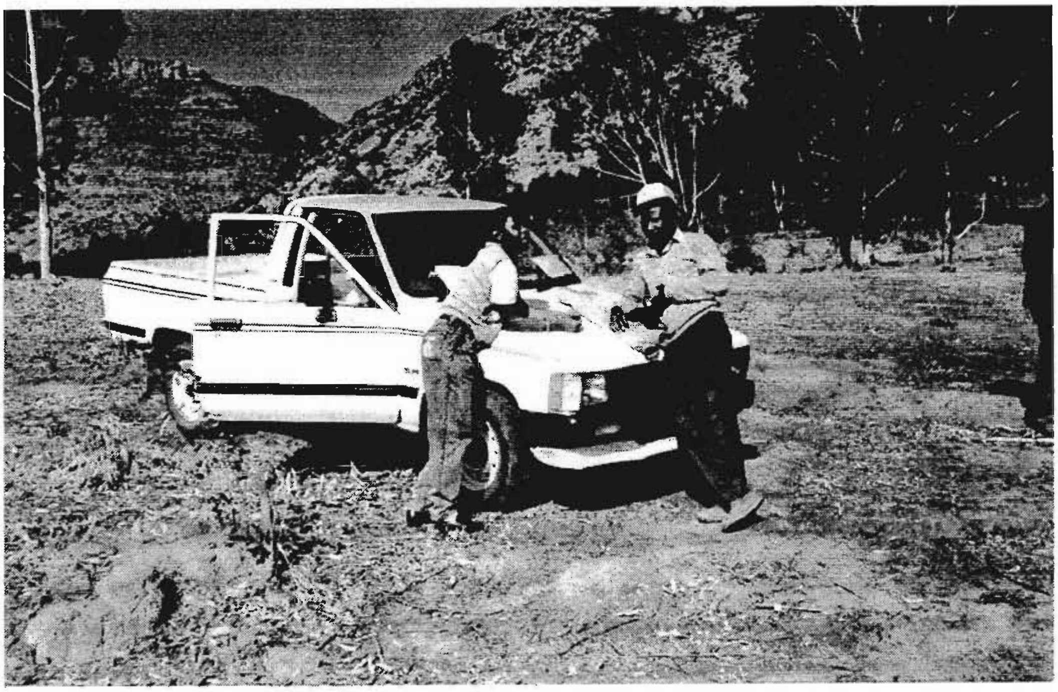

Figure 1: Permanent sample plot (EM/1006/1) in the lowlands

The objectives of the project were stipulated as follows:

(i) determine a rational afforestation policy for Lesotho in terms of its economic and ecological needs;

(ii) create a relevant and well-balanced administrative and technical infrastructure for the support and implementation of a continuing afforestation programme;

(iii) establish woodlots throughout Lesotho for the provision of fuel and building materials;

(iv) provide trees for the planting in catchment areas for their stabilisation;

(v) train Basotho nationals at all levels to assume complete responsibility for the continuing implementation of a soundly based afforestation policy.

The project was phased-out in 1987 and the same year the Forestry Division was formed and the Poles and Fuelwood Project started in the same year and still remains under the umbrella of the Forestry Division. During this period, many gazetted forest reserves were established with total area of 11801 ha which broke down to the distribution of: 2979 ha of eucalypts, 2783 ha of pines and 371 ha committed to other species (Figure 3). The most commonly grown forest tree species were pines and eucalypts. For instance, *Eucalyptus rubida and Pinus radiata* still remain the dominant tree species in forest stands of Lesotho.

Figure 2: Permanent sample plots (ER/1021/1 and PR/1021/1) in the foothills

In 1989, the Community Forestry Programme was initiated as part of the forestry programme by the Lesotho Government together with Overseas Development Administration. This was initiated to meet the demands for forest products such as fuelwood and building poles. The initial estimate of the area of forest required was in the region of 20000 ha. The target groups were schools and the communities attempting to establish woodlots and nurseries. After some time, the woodlots proved more successful so that the nurseries and the Poles and Fuelwood Project ended in 1992 (Figure 2).

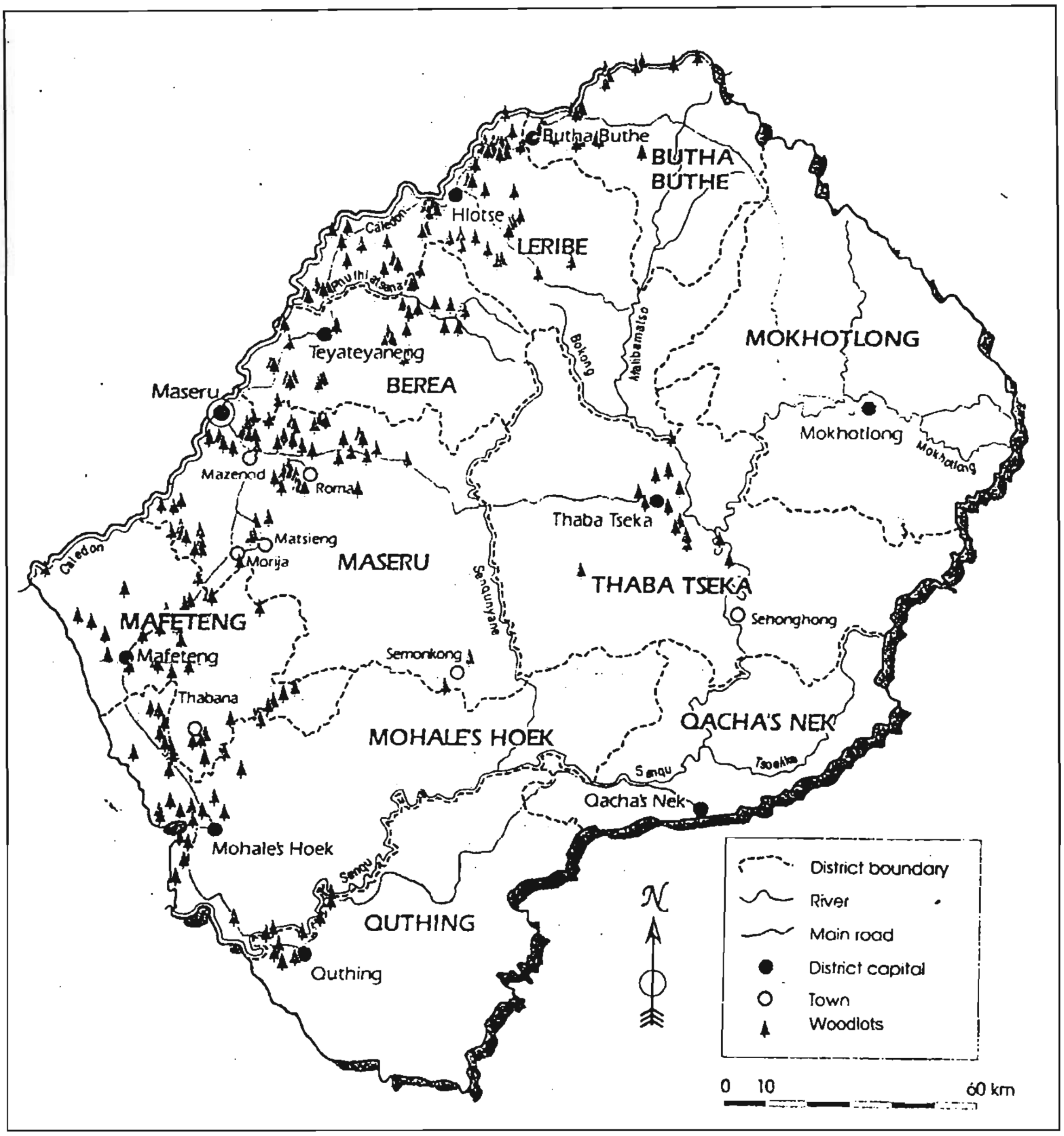

Figure 3: Physical location of woodlots/forest plantations in Lesotho (Chakela, 1997)

Following the termination of the Poles and Fuelwood Project in 1992, a Social Forestry Programme funded by the Germans (GTZ) was started in the Maseru and Mafeteng districts as pilot studies, which have been continued, by individuals, groups, communities, schools and non-governmental organisations. During the pilot studies forest tree seedlings were offered free to the farmers and the concept of fruit tree production was introduced. As a result of these efforts, there are now many farmers who have established forest and fruit tree nurseries. To date, there are some 32 private nurseries fully operational in the country which produced 520 000 forest tree seedlings (Financial Year 2000/2001) but the total benefits have not been fully determined as the area under private forests has not yet been surveyed. To redress this shortfall, the Forestry Planning Section proposes to undertake an inventory of private forests in Lesotho possibly commencing in 2005. In March 2002 the Social Forestry Project was phased out and currently the Forestry Programme is implementing the state policy of decentralisation, privatisation and local governance. In April 2003, the Ministry of Forestry and Land Reclamation was officially declared open.

1.2 **Aims And Objectives Of The Study**

This study is a demand driven initiative, focusing on the forest plantations, woodlots and high altitude forest remnants of Lesotho. The research aim is to identify the forestry best practices for commercial timber production and to help address the energy deficits experienced in the mountainous areas of the country.

The objectives of the study are to:
(i) describe the performance (survival, growth and timber volume) of tree species grown in Lesotho,
(ii) design growth models of *P. radiata* and *E. rubida* cultivated in Lesotho,
(iii) analyse site conditions to enhance site/species matching,
(iv) evaluate various silvicultural practices and their impact on tree performance.

1.3 **Research Hypotheses Of The Study**

The Hypotheses are listed in this manner:
(a) H_0: survival and growth of various species on select sites are equal,
(b) H_0: growth and timber production is not dependent on site factors,
(c) H_0: tree performance, survival and growth are unaffected by various silvicultural practices/procedures.

1.4 **Thesis Outline**

In support of the above aims and objectives, chapters are presented which provide a background in terms of a literature review and biophysical account of the study area. A subsequent methodology with supporting results, culminating in a discussion and recommendations for future study completes this document.

CHAPTER TWO

LITERATURE REVIEW

2.1 **Introduction**

Due to their fast growth and the quality of the timber, a number of pines and eucalypts species have become very important in Lesotho. This chapter therefore, presents the most important information on both genera, particularly as it pertains to their performance in Lesotho.

2.2 **An Overview Of *Eucalyptus spp.***

2.2.1 **Occurrence**

The genus *Eucalyptus* L. Heriter, is one of great complexity, comprising roughly 400 species and more than 200 subspecies, varieties and named hybrids (Johnston and Marryatt, 1965: in Blakely 1965; Pryor and Johnson, 1971; Chippendale, 1976; Poynton, 1979). With a few exceptions, these taxa are all endemic to Australia and Tasmania, the majority occurring south of the tropic of Capricorn. Several however, are indigenous to New Guinea or to certain islands in the Indonesian Archipelago, including Timor, Wetar, Flores and a small number is found in Sundra Islands (Poynton, 1979).

Poynton (1979) states that eucalypts occur naturally from latitude 7° to 43° 39' S, at sea level to about 1800 m, over a wide range of climates. Thus, different members of the genus are encountered from the tropics to the snowline; from regions where rain falls only during the warmer months, to those in areas with uniform rain distribution or rains confined to cooler seasons of the year. They are found occurring from humid forested areas where precipitation averages 3000 mm or more per annum, to semi-desert regions where there is less than 300 mm of rain.

Over the greater part of Australia and Tasmania, eucalypts form the most characteristic and striking element in the native flora, governing 95% of the forest area and accounting for about 75% of the biomass (Penfold and Willis, 1961; Streets, 1962; Poynton, 1979).

The wet sclerophyllous forests of Tasmania are dominated by *E. delegatensis, E. globulus, E. obliqua* and *E. regnans,* in Victoria these are replaced by *E. bicostata, E. dalrympleana, E. fastigata, E. nitens* and *E.viminalis* in Southern Australia and New South Wales *E. acmeniodes, E. grandis, E. maculata, E. microcorys, E. paniculata, E. saligna* and *E. pilulari* predominate and finally, in Western Australia *E. calophylla, E. diversicolor, E. marginata* and *E. patens* are most common (Robertson, 1926; F.T.B., 1951; Poynton, 1979). Of these species, the largest is *E. regnans* sometimes grows to a height of more than 100 m and a diameter over 6 m, though others such as *E. diversicolor* and *E. grandis* may also reach 70 m (Pryor, 1976).

2.2.2 **Physiognomy, anatomy and morphology**

The eucalypts are monoecious, ligneous, sclerophyllous, evergreen or semi-ever green plants ranging in stature and habitat from lofty, erect, forest trees with slender, clean boles to low, occasionally scrambling, branchy shrubs. Sometimes referred to in Australia as Mallees or Marlocks, these species have a swollen or ramifying underground rootstock and a variable number of rather spindly stems, which are often arranged more or less in a circle (Maiden, 1903-1929) but which may be irregularly distributed occasionally over an area of as much as 75 m^2 the size of the crowns (Mullette, 1978; Poynton, 1979). Poynton (1979) declared that these shrubby species can under favourable circumstances develop into small trees that are well adapted to severe climates and have the capacity to sprout from the base if their aerial parts are destroyed by fire or other constraints.

Jacobs (1955; 1979) pointed out that many of the young eucalypts, in particular the mallees, produce an efficient, subterranean storage and protective organ known as lignotuber. This woody outgrowth, which has its origins in the regions of meristematic tissue present in the axils of the cotyledons or first new pairs of leaves formed by the seedling. Subsequently, this gradually increases in size, and coalesce round the stem to form a single, rugose, tuberous mass, which, during the course of a few months, grows downwards into the soil and envelops the upper part of the root. This process is often vital to the survival of the young plant under harsh conditions as it contains reserves of food and is capable of producing new shoots in response to injury or dieback being suffered by the original stem.

The foliage which succeeds the cotyledons, is in most species of eucalypt, markedly heteroblastic, the seedling plant passing through three successive stages during which juvenile (primordial), intermediate and adult (mature) leaves are produced (Maiden, 1903-1929; Blakely, 1965). On other hand, Pryor (1976) highlighted that; the juvenile stage varies greatly in its duration from one species to another, usually lasting beyond the development of the twentieth to thirtieth node.

Poynton (1979) notes that when the leaves are first differentiated by the growing tip, the leaves of all eucalypts are arranged in opposite or sub opposite, decussate pairs. Furthermore with regard to the juvenile leaves, these in the genus *Eucalyptus* may be opposite, subopposite, or alternate, amplexicual, sessile or petiolate, orbicular, ovate, oblong, lanceolate or linear, cordate or cuneate at the base and retuse, obtuse or acute at the apex. The mature leaves, on other hand, are invariably alternate, petiolate, ovate-lanceolate, lanceolate or linear, cuneate or acute.

Jacobs (1955; 1979) implied that eucalypts do not develop dormant or resting buds, but have "indefinite shoots" of which the delicate growing tips are able to produce an unlimited number of leaf pairs with little intermission. He further stressed that, in the axial, of every leaf, at the end of slender shoot, a naked, lateral bud is formed capable of almost immediate, rapid and sustained development. This lateral bud can either give rise to a branch of the next lower order or, should some accident befall the mother shoot, take over it in a matter of days. In addition to the naked bud from which one or more accessory buds develop from a meristematic region in the event of the primary lateral being destroyed.

Penfold and Willis (1961), Pryor and Johnson (1971) recognised that flowers are produced in umbel-like, dichasial or (by suppression of some or all the lateral branches) monochasial cymes, in which the axes have become so reduced that the floral bracteoles from a false whorl at the apex of the peduncle. On the one hand, it was reported by Bentham (1866) and Blakely (1965) that the flowers of *Eucalyptus* species are polyandrous, bear, on the rim of the receptacle just inside the calcyine ring, two or more irregular rows of stamens, the filaments of which may be free or, occasionally, united at the extreme base into four bundles.

Bentham (1866), Blakely (1965), Penfold and Willis (1961) noted that in the fruit, there is somewhat enlarged, thin, hard, receptacle which encloses a woody capsule, to which it is adnate. The outer rim of the fruit is formed by the calcyine ring. At maturity the capsule opens at its apex by as many valves as there are locules.

Hodgson (1976) stated that usually numerous fertile seeds contained in the capsule are mixed with chaff, which consists mainly of the infertile ovulodes but may include some unfertilised ovules. Moreover, he alleged that the seeds of most species are minute, but those of others notably 'the Blood woods', which possess well defined wings measure up to 16 mm in overall length.

The number of fertile seeds (before cleaning) varies in Australia from about 11 000/kg in case of *E. calophylla* to 440 000/kg or more in that of *E. deglupta, E. melliodora, E. microcorys, E. propinqua, E. sideroxylon* (Jacobs, 1955; 1979). On the one hand, Pryor (1976) noticed that, in some species it may even be as high as 700 000/kg, still larger totals have in other instances been noted in South Africa, the number of seedlings raised from seed plus chaff of *E. melliodora,* for example amounting to 113 300 /kg.

Jacobs (1979) noted that the bark (rind) of the various eucalypt species differs much in degree of persistence, in texture and in colour. For taxonomic purposes, the bark present on the middle bole of a vigorous, adult tree is taken to be characteristic of the species. The following bark classification is based on the mature rind covering the bole a few metres above ground were noted:

A. bark deciduous, i.e. gum type, smooth, colour varying somewhat with age;
(i) peeling off in long strips, as in *E. globulus*;
(ii) peeling off in relatively broad plates, as in *E. camaldulensis* or *E. saligna.*
(iii) peeling off in very small flakes or scales as in *E. citriodora*;

B. bark persistent, rough;
(i) iron bark type, hard, very short fibred or non-fibrous with deep, longitudinal furrows; usually dark in colour, sometimes containing kino capsules;
(ii) box type, short fibred, finely furrowed or obliquely reticulated on the surface; pale grey in colour;
(iii) stringy bark and other fibrous bark types, long fibred, thick deeply furrowed longitudinally; dark brown in colour;

(iv) peppermint and blood types, hard with shallow, irregular furrows in two directions giving rise to more or less oblong scales, dull grey to black in colour.

Penfold and Willis (1961) recognised that the wood produced by the eucalypts varies considerably in its physical, mechanical properties and includes some of the densest, strongest, toughest and hardiest timbers known, as well as others which are lighter, softer and more generally useful. Among the heaviest eucalypts timbers found in Australia are those yielded by certain of the boxes and ironbarks, notably *E. fibrosa, E. microtheca, E. moluccana.* Several of these weighing as much as 2 g/cm^3 air-dry. The lightest woods are those obtained from members of the Ash Group, including *E. nitens, E. delegatensis* and *E. fraxinoides.* These species weigh approximately 0,67 g/cm^3 air dry. In Southern Africa, *E. grandis* grown in a rotation of up to 30 years also produces a comparatively light timber, this having an average density of 0,69 g/cm^3 air dry (Schoeman, *et al.,* 1973). They further pointed out that, among the strongest timbers are these species namely *E. bosistoana and E. moluccana,* while the iron barks are *E. fibrosa* and *E. sideroxylon* tree species. In Australia, only about sixty out of approximately four hundred species of eucalypts are classed as being economically significant producers of timbers, though many yield useful woods. Most of the eucalypts that have been planted on a large scale or which show definite promise in Southern Africa, also rank among the major timber trees. The sapwood of most species is colourless or pinkish, but the heartwood ranges from whitish to brown or deep red in hue (Penfold and Willis, 1961). On the other hand, Taylor (1973) reported that an investigation into differences in specific gravity (a property associated with strength of timber and yield of pulp) and fibre length (a property associated with quality paper products). These were examined throughout most of the planted range of *E. grandis,* from Transkei to Northern Transvaal. It was detected that average specific gravity varies greatly from 0,40 to 0,53 g/cm^3 from plot to plot.

2.2.3 **Classification of eucalypts**

Bentham (1866) and Poynton (1979) observed that early attempts to group eucalypts according to such criteria as leaf arrangement, bark features and length of the receptacle relative to that the operculum proved, as the number increased, to be futile. Bentham and Poynton, 113 years apart, further stressed that a more satisfactory basis of classification had to be found. Bentham (1866) did not conduct any field work when he described the genus in his monumental treatise "Flora Australiensis". Instead, he arranged the 135 species which he recognised into five series (the last of which he divided further into nine subseries). As a result he was compelled to establish groups based upon characters supplied by the (herbarium) specimens, particularly on the form of the anthers, secondly upon fruit, and in some cases on the inflorescence or the calyx.

Later, Blakely (1965) made a valuable contribution to the taxonomy of the genus, which identified 605 taxa, which he recognised in most natural position to each other, and kindred genera. He established eight sections and eighteen subsections based on anther morphology, these being sub-divided into one hundred and twenty three series and sub-series using subsidiary criteria as leaf, flower bud and fruit characters. In contrast, Pryor and Johnston (1971) introduced a broader based and hence taxonomically more satisfactory classification of the eucalypts. They arrived at a total of a little over 350 species, drawn upon the disciplines of ecology, genetics and anatomy.

2.2.4 **Uses of eucalypts**

The eucalypts are of immense significance both in Australia and in the many of the countries into which they have been successfully introduced where they represent a major timber resource. In addition, they lend themselves to commercial exploitation for wood distillates, tannins, essential oils, nectar, pollen and sundry minor products such as kino and rutin. Furthermore, they have proved to be useful for the provision of shelter and shade, for ornamental planting, for drifts and reclamation and for the prevention and control of soil erosion (Poynton, 1979).

The area planted to eucalypt species in all parts of the world amounts to about 17 860 000 ha in 2000 (FAO, 2001). This total is distributed over 70 countries.

2.2.5 Silvicultural characteristics of eucalypts

Eucalypts are regarded as having exceptional vigour, a remarkable capacity to survive under adverse conditions and an extraordinary speed of recovery after experiencing a setback in growth. Metabolic considerations aside, the sustained and vigorous growth of the eucalypts as a genus can be ascribed largely to their shoots being capable of rapid and more or less continuous development as long as circumstances permit (Jacobs, 1955; 1979). Further, the tenacity with which the trees cling to life in a harsh environment and the capacity with which they show for sprouting again from the base after being destroyed by climatic, fire or biotic agencies is largely attributable to their possession of a lignotuber. It has been stressed that, eucalypts seed freely, and those that do not form a lignotuber often reproduce themselves in extra-ordinary abundance if the parent trees are killed by fire (Pryor, 1976). Jacobs (1955) highlighted that, in Australia, heavy seeding takes place in cycles of two, three or more years according to species.

In southern Africa, no marked rhythmic periodicity in annual seed production has been found, except in the case of *E. nitens* and to a much lesser extent of *E. maculata* and *E. torquata,* where moderately good to heavy seed crops are borne annually from the age of about five years (Poynton, 1979). Poynton (1979) further states that natural regeneration will sometimes persist on sites with 1/10 of the full sunlight, though young plants grow more vigorously if exposed to higher intensities of illumination. In addition, he also implies that, in southern Africa, seedlings are seldom able to complete successfully with the parent crop under plantation conditions as long as the stand remains well stocked, though they frequently invade adjacent pine compartments and colonise temporarily unplanted or denuded areas.

Most eucalypts coppice strongly, but in Australia certain lignotuber thin-barked species, notably *E. astrigens, E. fraxinoides, E. nitens* and *E. regnans* are considered as weak coppicers. Also, badly scorched *E. deglupta, E. diversicolor* and *E. grandis* often fail to recover after a severe fire (Jacobs, 1955). Similarly, Poynton (1979) noted that under southern African conditions, *E. obliqua, E. oreades* and *E. fastigata* also tend to coppice in Australia. Lane-Poole (1936) found that the coppice shoots of most species develop more rapidly than seedling plants.

Poynton (1979) notified that, in southern Africa, the majority of eucalypts are considered to be highly intolerant of competition, and stands have to be thinned heavily from an early age unless coppiced in a short rotation. He indicated that, failure to thin timeously, results in the stems of the trees becoming "whippy" (excessively slender) and in the crowns "running up" (shedding their lower branches prematurely) as a consequence of low light intensities.

In Australia, dense clumps of even-aged regeneration thin out naturally as the dominants begin to assert themselves, suppressed individuals gradually losing their primary crowns, "feathering" (i.e. putting out epicormic shoots) and eventually become whippy, bending over and dying (Jacobs, 1955; 1979). Lane-Poole (1936) found that defoliation by insects and crown damage by fire are also frequent causes of feathering in Australia.

The roots of large eucalypt trees have been traced horizontally for distances of more than 21 m in clayey soil and 31 m in sand. By far the greatest concentration of roots is to be found within 1 m of the soil surface, though individual roots may penetrate to a depth of well over 30 m, *E. grandis* and *E. pilularis* have comparatively shallow root systems, while *E. microcorys, E. paniculata* and *E. propinqua* tend to be deep rooted (Jacobs, 1955; 1979). Eucalypts have proved to be more wind-firm than pines. In southern Africa, root penetration in sandy soils may amount to be between 30 and 40% of tree height at the age of four or five years (W.R.I., 1972).

Poynton (1968) recognised that different species of eucalypts vary considerably in their resistance to frost and drought. The following are those species, which are more frost hardy members of the genus commonly grown in southern Africa: *E. bridgesiana, E. macarthurii, E. rubida, E. nitens*. He further denoted that species which withstand drought better than others are such as *E. sideroxylon, E. camaldulensis, E. citriodora, E.melliodora* and *E. moluccana.*

The eucalypts, although less accommodating with respect to edaphic conditions than many of the pines, nevertheless adapt themselves to a wide range of sites and a greater diversity of soils, including those derived from such diverse parent materials as granite, basalt, dolerite, slate, dolomite, sandstone and quartzite (Poynton, 1968).

Eucalypts differ a great deal in their resistance to scorching by fire. Species such as *E. regnans* and *E. deglupta,* which have a thin bark, are susceptible to injury, whereas thick barked species like *E. maculata* withstands fire particularly well (Jacobs, 1955; 1979)

Poynton (1955) found that the bark of *E. fastigata* could not be set alight by deliberately burning brushwood at the foot of an adult tree, and it was concluded that these species could be planted in firebelts with complete safety. Furthermore, he stressed that the festoons of decorticated bark, which hang from the lower branches of *E. viminalis* and *E. oreades*, constitute somewhat of a fire hazard.

2.2.6 **Insect pests**

In Australia, eucalypts are subject to infestation by many insects, most of which feed upon the naked buds and leaves with deleterious effects upon rate of growth and timber production (Jacobs, 1955; 1979). Several fungi and higher animals also attack or devour the foliage of eucalypts. On the other hand, Wingfield (2003) stated that in terms of South African plantation forestry health, there have been two major negative forces challenging productivity during the last few years. There are rapid and unexpected movement of *Sirex noctilio*, better known to us as sirex wood wasp and the impact of the pitch canker fungus in nurseries and in plantation establishment. He further indicated that ironically these problems both include insects and fungal pathogens. The sirex wood wasp lives in an obligate symbiosis with a fungus (*Amylostereum areolatum*) and the impact of the pitch canker fungus appears to be closely related to the feeding activities of a wide range of insects.

Tooke (1955) stipulated that, by far the most important introduced insect pest of eucalypts in Southern Africa is *Eucalyptus* snout-beetle (*Gonipterus scutellatus)* which reached South Africa from Australia (possibly as a stowaway in cases of apples) in early years of the previous century. He further stated that this curculionid spread rapidly throughout the country and hence to other parts of Southern Africa. Both the larval and adult forms of the insect feed upon the leaves and tender young shoots of most eucalypt species.

The other major pest is the longhorn beetle (*Phoracantha semipunctata*). It was introduced to the Cape Province from Australia in infested railway sleepers round the beginning of the nineteenth century. This insect seldom attacks healthy trees but it usually attacks weak, drought stricken or dead specimens and newly felled, unbarked logs and branch wood.

2.3 **Description Of *Eucalyptus rubida:***

2.3.1 **Natural distribution and occurrence**

The latitudinal distribution of *E. rubida* is from 28½ to 43½ °S. The elevation is between 300 and 1500 m above sea level on the mainland, whereas in Tasmania its altitudinal range is from 75 to 600 m (Curtis, 1956). The primary occurrence of *E. rubida* is at the intermediate altitudes in the Australian Alps and on the tablelands of New South Wales, while its range extends to the plateau country of south-eastern Queensland. It was also discovered that, in southern Australia *E. rubida* is more or less narrowed to the Mt. Lofty Range. It is found in widespread on the lower and intermediate slopes of the central plateau in Tasmania. It seemed to perform well in great abundance on exposed sites in the rain shadow of the mountains (Boland *et al.*, 1997; Jacobs, 1979).

The tree is detected principally in hilly or mountainous country and on elevated tablelands. Moreover, it was noted that, the tree is reaching its best pith in moist valleys and on gentle slopes. It often grows on a broad range of soils originating from the parent materials such as slates, mudstone, quartz porphyry and granites but it performs best on moist and well-drained, fertile loams with a clayey subsoil. As a species the tree establishes open, savannah-like forest, rather than making pure stands, but is frequently detected in mixture with one or more other eucalypts, including *E. stellulata, E. viminalis, E. tenuiramis, E. dalrympleana, E. aggregata, E. pauciflora, E. ovata and E. fraxinoides* (Boland *et al.*, 1997).

Jacobs (1979) indicated that, the climate of the native environment of *E. rubida* is cool temperate, with mild summers and cool to cold winters. He further noticed that the mean maximum and minimum temperatures for the warmest and coldest months range from 26 to 28 °C and from 0 to 1 °C respectively. Boland *et al.*, (1997) recorded well-performing trees in areas subject to moderately heavy to severe frosts occurring from 15 to 70 nights a year, where light snow is not infrequent.

2.3.2 **Silvicultural characteristics and uses of the tree species**

Under typical conditions *E. rubida* grows moderately fast in early life, and it is tolerant of frost and cold winds, though not to heat or drought (Penfold and Willis, 1961). It makes a good windbreak and is planted for shade and ornament. Its more attractive features include its smooth, white, deciduous bark and its glaucous, juvenile leaves, which change from different shades of red, purple or pink before being shed. Silviculturally, the tree exhibits a great variation, but to what extent this can be related to site quality has not yet been discovered.

E. rubida appears to have been closely associated with both *E. viminalis* and *E. dalrympleana*, the three species not always being readily separable at maturity. Curtis (1956) connoted that *E. rubida* is a medium-size tree which in Tasmania rarely grows more than 30 m tall or 45 cm to 75 cm in stem diameter. On the other hand, Robertson (1926) found that *E. rubida* grows to a height of 35 m and can have a diameter of 180 cm. Moreover, he stressed that under favourable conditions, it produces a fairly well formed bole, though on poor sites its performance is not encouraging as it tends to develop a stunted habit.

Blakely (1965) described the leaves of the tree as having a very low oil content and being favoured by koala bears. The flowers are produced during January and February. He further noted that they produced a reasonable supply of pollen as well as nectar, and honey obtained from them is the same to the one derived from *E. viminalis*.

Penfold and Willis (1961) found that the tree produces a second class timber inferior to that of *E. dalrympleana*. They also studied that the timber is pale pink or pale brown in colour, it is of medium density (0,83 g/cm^3 air-dry) and moderately tough, but comparatively soft and lacking in durability. It is used primarily for pulpwood and fuel.

2.4 *Eucalyptus rubida:* In Southern Africa

2.4.1 Afforestation and field experiments

Poynton (1979) stipulated that this species is normally planted for shelter in cold localities but not for timber. In South Africa a stand was first claimed to have been established (feasibly under the name of *E. gunnii*) at the Katberg plantation in 1883, though the botanical authencity of this record cannot be vouched for (Poynton, 1979). Later, seed was imported from Australia in 1906 and *E. rubida* was planted on the farm Buckland Downs in the Harrismith District of the Orange Free State (Keet,1929; Poynton, 1979). Between 1906 and 1938, six seed stocks with a total mass of over 45 kg were brought from Australia from the Batlow, Goulburn and Marulan districts of New South Wales and Canberra. It was further clarified that, in 1958, a cold tolerant strain of the species was introduced (seemingly from New South Wales) for the purpose of establishing further experimental plantings on the south-eastern Transvaal highveld (Beard, 1958; Poynton, 1979).

Poynton (1979) emphasises that where experiments were established, as in the eastern Highveld, stands were not for timber, but planted out for rough building and fencing materials, fuel and shelter due to its resistance to frost. He further records that at the Harrismith Plantation and at Buckland Downs, the species demonstrated a strong, healthy performance. In the Eastern Orange Free State, from Frankfort and Reitz to the Drakensberg, *E. rubida* tolerated the cold well, better than any other eucalypt, under droughty as well as moist conditions. Furthermore, it seemed to accept all types of soil including sands, loams, black peats to heavy clays covered by overlying gravel. However, the preferred medium were deep, loose textured loams.

Despite a certain robustness, response to apparently similar sites can vary. For example on a very wet site in the arboretum at Lottering Plantation in the Southern Cape the performance of the species was different to the one of the Eastern Orange Free State. Thus under the drier conditions at the Keurbooms River Plantation the performance was better than most of the other eucalypts, though the form of the trees was inferior to those at the Lottering Plantation (Poynton, 1979).

Other instances of site variation (Poynton, 1979) (realised that, at the Pan Plantation where losses were caused by drought, while at Jessievale the trees escaped injury from insufficient rains. Similarly, on the Spring Valley Estate in the Iswepe district the species indicated a resistance to both drought and frost while at the Belfast Plantation the saplings were killed outright by subzero temperatures, though at Ermelo Plantation edge trees were only "scorched" by cold winds.

Elsewhere in Africa, *E. rubida* was pioneered at Malawi where it was introduced from South Africa in 1951. Under the temperate, sub humid conditions the species performs moderately for the production of timber, poles and fuel (M.F.R.I., 1976; Poynton, 1979). In 1969, *E. rubida* seed was imported from Victoria and trees were planted in an arboretum at Chongoni Forest Reserve. Mortality was high up to the age of three years, and the surviving trees lack vigour and are of poor form. The species proved itself of low value in Malawi and no other experiments were considered to be introduced, apart from the northern province where it could be introduced for use in shelterbelts under dry conditions (M.F.R.I., 1976; Poynton, 1979).

2.4.2 **Silviculture**

E. rubida can be regenerated without difficulty in the nursery from seed, of which 1 kg produces approximately 670 000 viable seeds. It has been further connoted that growth, specifically on moist, deep, friable, loamy soils, is moderately fast, and the mean annual height increment over the first decade frequently amounts to between 1 and 2 m. However, the performance of the species is poorer than that of *E. viminalis*. The tallest tree so far measured in South Africa had a height of 32 m. Regeneration by coppicing is good (Poynton, 1966a).

E. rubida tolerates a great deal of exposure to frost and cold winds, being in this respect slightly hardier than *E. viminalis*, and it has survived at Mokhotlong in Lesotho as well as the coldest parts of the Eastern Transvaal Highveld (Mpumalanga). While fairly drought-resistant, under subhumid conditions stress has been recorded during prolonged dry periods, particularly when planted on shallow soils (Poynton, 1966a). Thus, at the Hartebeespoort Experimental Station, near Brits in the central Transvaal (Mpumalanga), *E. rubida* failed completely over a period of years, presumably, as a result of drought and relatively high temperatures. Moreover, while fairly tolerant of waterlogging, trees succeed on dry, shallow soils overlying hardpan where the rainfall was adequate. However, in sub humid localities establishment should be restricted to relatively deep, moist soils. Finally, though not subject to snow break, under very rigorous conditions it may be attacked to some extent by the *Eucalyptus* snout beetle, *Gonipterus scutellatus* (Tooke, 1955).

The form displayed by the species is favourable to that of *E. dalrympleana,* while normally stems are clean to a fair height, the boles of the trees sometimes show a tendency to lean and are apt to be crooked or, at best, slightly sinuous, specifically near the butt. Branching is comparatively light except in the case of trees exposed to full illumination from the side, and the dead stubs rarely persist. Under suitable conditions the species, when grown in stand form, yields a fairly dense crown of modest spread (Poynton, 1966a).

2.4.3 **Utilisation**

It was noted that the wood that comes from Jessievale has a pale reddish-brown, brownish, or pinkish colour with creamy white sapwood, which is straight grained. The timber cut from the immature trees is weak not heavy. The mature trees do usually yield a higher density wood (about 0,83 g/cm^3), which is tough, hard, stiff and moderately strong. The timber has a fine finish, it is appropriate for a number of uses, particularly for making handles of the tools and can be used for low quality transmission and telephone poles due to its form (Poynton, 1979).

E. rubida is selected to be described in such detail but not *E. nitens* or *E. macarthurii* that are also main species in this thesis because *E. rubida* is the dominant species planted in forest plantations in Lesotho. It should be noted that there are 33 plots of *E. rubida*, 4 of *E.*

macarthurii and 1 of *E. nitens*. It can also be noted that there are few plantations of *E. macarthurii* and *E. nitens* respectively.

2.5 **An Overview Of *Pinus spp.***

2.5.1 **Occurrence**

Pines have a broad distribution in the northern hemisphere, whereas in the south they are more fragmented. Thus pines have been reported to have been well represented from Artic circle to the subtropics in Asia, Asia Minor, Malaysia, Oceania, North and Central America (Dallimore and Jackson, 1966; Mirov, 1967; Poynton, 1977). Conversely, Critchfield and Little (1966) indicate that *P. merkusii* occupies the tropics and crosses the equator at the southern extremity of its range in Indonesia. In addition, they stated that, *P. caribaea* and other species encroach south of the Caribbean region, whereas *P. pinaster* and *P. halepensis* colonised North Africa particularly Sahara region (Mirov, 1967; Poynton, 1977). Species regarded as real pines, consisted of about one hundred taxonomically obvious species (Martinez, 1945; Loock, 1950; Dallimore and Jackson, 1966; Poynton, 1977).

2.5.2 **Physiognomy, anatomy and morphology**

Poynton (1977) stated that the pines are resinous, monoecious, evergreen plants ranging in stature from lofty, forest trees to dwarfed shrubs. They tend to develop cone-shaped and symmetrical crowns when immature, being reinforced by short branches classified in false whorls. Furthermore, pines when mature tend to branch haphazardly frequently developing flat topped heads in isolated individuals. In general, apical dominance is chiefly developed in the majority of species up to the close of the pole stage, when the growth rate in height starts to be reduced. Regarding the bark of immature trees, it is thin, smooth, and scaly or flaky and sometimes might have a reddish cast; conversely the bark of mature tree tends to be lamellar in structure, furrowed and thick.

Norskov-Lauritsen (1963) indicated that winter buds, enclosed by frequent resinous scales are yielded by all species in areas where growth occurs seasonal and also followed by a distinct resting period. He further reported that in mild climates suitable to growth throughout the year, the primary role of the winter bud is seldom taken over by an over wintering shoot in a late stage of elongation. Contrarily, Shaw (1914) noted that proventitious or dormant buds sometimes do thrive at the nodes, and are available at the apex of the dwarf shoots, which produce needle fascicles. Moreover, he clarified that the buds that are present at the nodes give rise to the epicormic or coppice shoots yielded under certain instances by some species when the physiological balance between the roots and the crown is disturbed by excessive felling or pruning. The buds of the dwarf shoots have the capacity for developing into long shoots if the branchlet on which they occur is being injured by mistake.

Shaw (1914), Dallimore and Jackson (1966), and Poynton (1977) noticed that in pines, every internode consists of a short base without foliage and a longer, leaf section culminating in a node surrounded by a false whorl of lateral buds. Finally, in mature trees a spirally arranged cluster of male catkins is yielded round the base of the branch let or long shoot in spring, while the female spikes may be either sub terminal or lateral, and occur at the nodes. Shaw (1914) stressed that male and female parts of a plant or tree are usually borne separately on a single tree. On the other hand, Hagedoorn (1975) implied that hermaphrodite inflorescence might probably be produced by specific trees or clones of particular species. The male catkins are sub-cylindrical in the form and consist of a central axis, bearing numerous spirally arranged sessile anthers, each provided with two pollen-sacs (Shaw, 1914; Poynton, 1977). It was further detected that the female spikes, which replace one or more sub-terminal or lateral (long shoots) buds and which may either be solitary or pseudo verticillate, consists of paired scales of two types organised spirally about a central axis, the lower scale in each pair being sterile and developing marginally in the cone, but upper scale bearing two pendulous ovules and expanding to many times its former size at maturity (Dallimore and Jackson, 1966). Furthermore, they stated that on pollination, the scales of the female spike are usually closed to form cone let, the process of fertilisation of the ovules is taking place only a year or so later. After fertilisation, the cones grow rapidly in size, becoming woody and maturing at the end of the second or third year.

Shaw (1914), Loock (1950), and Poynton (1977) pointed out that the mature cones differ much in colour, size form, symmetry and the mode of placement to the branch on a number of species. They even indicated that these characteristics, in addition to the physical appearances of the cone scales (specifically the form, size and colour of the apophysis and umbo presence or absence of a persistent mucro or prickle) are of prime taxonomic significance. In a number of species, the cone opens when old to shed off its seeds, although in others it stays closed for many years unless exposed to heat of fire or mutilated by squirrels and other animals in search of food. It was emphasised that characteristically, in the closed cone or seritinous pines the cone is not shed on when getting old but it remains fixed to the tree for a number of years, after which it falls to the ground and eventually breaks (Shaw, 1914; Poynton, 1977).

Research conducted into the wood yielded by the pines showed tracheids interspersed with resin canals and fine medullary rays, the latter composed of parenchyma ray tracheids and sometimes one resin canal. It was found that the growth rings, composed of concentric bands of early (spring) and late (summer) wood are easily seen. The tracheids of the former wood normally tend to have larger lumens and thinner walls than those of the latter. It is known characteristically that pine timbers are resinous, long fibred, of low medium density, strong and elastic in association to their mass but uniformly soft and easily worked. In a number of species, the pale brownish or yellowish heartwood containing tyloses and infiltrates is easily distinguished from the creamy-white or sometimes pinkish sapwood (Shaw, 1914; Poynton, 1977).

2.5.3 **Classification of pines**

Pines are categorised taxonomically into two sections, Haploxylon (Soft or White Pines) and Diploxylon (Hard Pines). These two sections are based initially on the majority of vascular bundles showing up in a transverse sections of the secondary needle. The haploxylon pines have the following features: (i) fascicle sheath deciduous (ii) ray tracheid cells with smooth internal walls, (iii) secondary leaf containing only a vascular bundle, (iv) umbo (boss) of the cone scale dorsal, (iv) ray tracheid cells with dentate internal walls, (v) base of the primary leaf decurrent on branch let. It also detected that the Soft Pines produce a softer, paler wood having a lower proportion of dense latewood than the Hard Pines. Many pine species perform well in Southern Africa includes non-commercial species: *P. wallinchiana, P. strobes, P. cembroides, P. ayacahute* and *P. flexilis* (Shaw, 1914; Poynton, 1977).

2.5.4 **Uses of pines**

Poynton (1977) indicated that the genus *Pinus* is of great significance, mainly on account of serviceable wood produced by majority of species. Pines form an essential element of commerce and lend themselves to a number of uses including bridge construction and building, joinery, the interior finish of dwellings, turnery, crafting, utility furniture, mouldings, carving, boxes, distillation and impregnation with a preservative, paving blocks, harbour piles, fence posts scaffolding, telephone and transmission poles. Because pines produce resin, it makes them a preferred firewood species. It is also used extensively in South Africa as a pulpwood in thermo-mechanical and chemical and mechanical pulping process for the production of unbleached newsprint papers.

In addition to the uses listed above, pine-leaf oil, found from distilling leaves of particular species, has pharmaceutical applications, while a fibre organised from the needles can be utilised to stuff mattresses and pillows, tannins which are present in the bark can be exploited (Mirov, 1967; Poynton, 1977). Loock (1950) and Streets (1962) emphasised that the nuts and seeds of many species can be eaten e.g. *P. pinea* and *P. cembroides*. Moreover, they stressed that in times of famine the sapwood and inner bark of *P. ponderosa* have been used by North American Indians for sustenance. Finally, selected Asian species and *P. pinaster* are tapped on a large scale for resin, from which turpentine is obtained by distillation. This is supported by Dallimoore and Jackson (1966) who listed many products found from distillation of pine wood namely: tar, oils, turpentine, pitch, pyroligneous acid, lampblack and rosin.

Earlier, Hiley (1930) reported that large natural forests found in the northern hemisphere were heavily exploited and brought under scientific management with objectives of guaranteeing future supplies of timber and minor forest products as well as of protecting mountain catchments, coastal drift sands and other areas susceptible to erosion. Conversely, Troup (1932) and Streets (1962) indicated that in southern hemisphere, where the extent of natural coniferous forest is less prevalent, species such as *P. radiata* have been established on a large scale to increase the provision of softwoods from local sources and that these activities have been focused mainly in Australia, New Zealand, parts of South America and Southern Africa.

In Southern Africa, pines have been established to provide shelter from sun and wind for crops and animals, to prevent and control soil erosion, to stabilise the drift sands, for ornamental and amenity purposes (Poynton, 1966a; 1971; 1972; 1977). The primary species of pines planted for timber in Southern Africa are *P. taeda, P. patula, P. elliottii* and *P. kesiya* in the summer rainfall region, while *P. radiata* and *P. pinaster* are usually planted in the uniform and winter rainfall regions. The other pine species of actual or potential economic significance in the summer rainfall region are *P. michoacana, P. merkusii, P. cubensis* and *P. caribaea* (Poynton, 1975; 1977). *P. serotina* has indicated some promise in the uniform rainfall region, whereas *P. muricata* and *P. canariensis* showed good performance in the winter rainfall region. The species that are broadly established for shade and shelter are *P. pinaster, P. halepensis, P. patula, P. roxburghii* and *P. radiata. P. montezumae, P. canariensis, P. halepensis, P. radiata, P. patula, P. roxburghii* and *P. pinea* are used for ornamental purposes in the summer, uniform and winter rainfall region. *P. sabiniana, P. engelmannii* and *P. cembroides* were reported to have been successfully introduced in Southern Africa, but they are rarely seen in gardens, parks and avenues plantings.

2.5.5 **Silvicultural characteristics of pines**

The majority of pines regenerate freely from seed, particularly after clear felling (Troup, 1932; Boland *et al*, 1997; Poynton, 1977). Hutchins (1904) and Poynton (1977) found that some species, particularly *P. pinaster,* have a marked tendency in Southern Africa to invade undisturbed, natural grassland or “fynbos”. Boland *et al* (1997) and Poynton (1977) emphasised that the seedlings of many pines tolerate shade for a number of years but normally demand full sunlight for their best development. They indicated that the serotinous pines could flourish when the canopy has been destroyed by fire.

Dallimore and Jackson (1966) pointed out that old trees of the majority of pine species are light demanding and in pure even-aged stands dominance is asserted during early pole stage. In contrast, Poynton (1960) found that in South Africa, stands of *P. elliottii, P. radiata, P. roxburghii* and *P. pinaster,* planted experimentally at a stocking of 3000 stems/ha started to thin out naturally at ages of about 7, 10, 11, 14 and 17 years respectively. Craib (1939) stipulated that all pines when established at wide initial espacements, need pruning if quality saw timber is to be yielded.

It was noticed that a number of pine species prefer moderately acid soils. They can be successfully cultivated under a wide range of edaphic conditions provided that root penetration is satisfactory and the drainage is adequate or deep enough. It was further indicated that *P. halepensis* performs well in the presence of free lime, whereas *P. radiata* thrives well on soils which are not excessively acidic and not waterlogged. It is usually infected with the fungus *Sphaeropsis sapinea* on heavy, wet, badly aerated soils. Contrarily, *P. elliottii* and *P. serotina* have shown to be strongly resistant to periodic water logging. A number of species such as *P. pinaster, P. caribaea, P. elliottii* can be grown on sand dunes fairly close to the sea (Poynton, 1960; 1977).

Poynton (1972; 1977) also indicated that most species of pines tolerate severe frost as well as exposure to cold winds. It was further discovered that species such as: *P. cemroides, P. halepensis, P. roxburghii* and *P. pinea* are more tolerant to drought whereas *P. taeda* and *P. palustris* are less tolerant to drought (Poynton, 1966b; 1968; 1972; 1977).

2.5.6 **Insect pests and diseases of pines**

Boyce (1948), Pearce (1962) and Poynton (1977) implied that the pines are liable to attack by a number of fungi and insects both in their natural environment and in establishment as exotics. Similarly, Donald (1968) recognised that damping off and other diseases may be troublesome in the nursery. Other symptoms of disease were root disturbances; saplings root collars, while older trees are sometimes affected by various fungi including in Europe *Fomes annosus* as well as *Armillaria mellea, Helicobasidium compacrtum, Polyporus balldonii* and

*Rhizina inflata (*syn. *R. undulata*) in Southern Africa. In addition, it was also determined that a degeneration in the bark and cambium could be attributed in the northern hemisphere to *Cronartium flaccidum, C. ribicola, Peridermium pini* and other fungi (Moore, 1959; Poynton, 1977).

Finally, it was also discovered that both in Southern Africa and Europe wood rot may result from the entry of *Seretum sanguinolentum* through bad pruning wounds and branch stubs. It was further discovered that in Southern Africa, diseases of the terminal shoot and needles of pines could be ascribed to *Sphaeropsis sapinea, Dothistroma pini* and *Lophodermium pinastri* (Poynton, 1977). Further, Streets (1962) stipulated that larvae of the wasp Sirex noctilio in New Zealand have caused the great mortality of *P. radiata* in dense stands and this species spread recently to South Africa. Bennet (1961) described several insects, which infest on the pines. Tree pathology cooperative programme (TPCP) (2003) mentioned that *Dothistroma septospora* is one of the most important pathogens of plantation grown *Pinus* species in the world. *Dothistroma* disease or red band needle blight occurs in South Africa but the damage caused by this pathogen has been restricted to *P. radiata* in Eastern Cape.

2.6 **Description Of *P. radiata*:**

2.6.1 **Natural occurrence and distribution of *P. radiata***

Dallimore and Jackson (1966) recognised that *P. radiata* is a native of Monterey County, California, where its distribution is limited to a very small region of hilly ground in the Island of Guadalupe (Streets, 1962; Mirov, 1967; Poynton, 1977). It was further indicated that the species is located in the latitudes of approximately 35 to 37° N, while the variety of Guadalupe is found at 29° N. *P. radiata* is found at the elevations ranging between 300 m to 1160 m a.s.l (Critchfield and Little, 1966).

P. radiata has two and three needled varieties. They occur at three separate localities found within an overall distance of about 200 km from one another and extending on this inland for less than 10 km (Scott, 1960; Roy, 1966; Poynton, 1977). The biggest of these occurrences, which occupies the region of approximately 3000 to 5000 ha and is located on and immediately to the south of the Monterey Peninsula. The second biggest occurrence covers a region of about 1000 ha in the Cambria district. The least and northern most occurrences, which probably are less than 400 ha in the extent, exist in the vicinity of Swanton. It was noticed that a two needled form of the species, (variety binata) is located on the Island of Guadalupe, situated in the Pacific Ocean about 250 km off the Coast of Baja California (Poynton, 1977).

Poynton (1977) reported that the climate throughout the natural range of the species is temperate, and more or less of the Mediterranean type. It differs specifically from summer months by the occurrence of clouds or sea fog and prevalence of high humidities. The MAT ranges from 9 to 17 °C and sometimes with extremes ranging between –4 to 37 °C. The winters are relatively mild, hard frosts are known to occur over a period of 2 to 3 months. Mean annual rainfall differs from region to region, from 380 to 890 mm per year. The minimum and maximum precipitation researched for any one year was 145 mm and 1270 mm respectively. Scott (1960) expressed that this climate is a special type of Mediterranean climate.

2.6.2 **Physiognomy, anatomy and morphology**

P. radiata flowers in late winter or very early spring. The female flowers occur in whorls of 3 to 5, often both sub-terminal and lateral, both on the main stem and side branches. The male flowers are normally on the side branches only. The tree is likely to bear fertile cones at 7 to 8 years of age, but normally does not bear heavily until 15 to 20 years old if it is grown openly. The cones ripen in the autumn season of the year and normally open in the first warm days of the year. The cones remain on the trees for many years, opening and closing repeatedly with changes of temperature and humidity. The seedlings perform well in a moist mineral soil; initially consist of a whorl of 5 to 9 cotyledons, which are succeeded by primary needles borne singly. The secondary needles appear after a few months since germination. Both the primary and secondary needles occur until the plant is about 3 years old (Scott, 1960).

In California, the species grows on a variety of soils derived from various parent materials. *P. radiata* grows most common on strongly acid, permeable, coarse-textured, siliceous soils, but it attains its biggest size on deep, well-drained, often calcareous, fine sandy loams. It also grows on almost pure sea sand on littoral dunes (Roy, 1966; Poynton, 1977). Isolated or open grown trees develop a wide spreading and relatively flat-topped crown, while in closely grown trees is narrow. *P. radiata* is usually found growing in pure stands, generally with an under storey of *Quercus agrifolia,* and other shrubby species. It can be found growing in mixture with *Cupressus goveniana, Cupressus macrocarpa* and *P. muricata.*

In old trees, bark is deep red or dark brown, and 3 cm or more thick (Scott, 1960). Deep furrows separate broad bridges. The spring shoots are multinodal. The resting bud, usually forms in the autumn, expands in the spring into one or more internodes each of which may produce branches or female flowers. *P. radiata* seems to be a more shade tolerant species than any other pine in the west of the United States. Growth begins at the end of January and goes until October after which tree rests. The species is relatively short-lived, averaging not more than 80 to 90 years in its origin and infrequently extending to 150 years.

2.6.3 **Classification of *P. radiata***

P. radiata is classified as the hard pine of the Diploxylon, which has a serotinous cone which cannot fall off from a branch, and has some of the following characteristics: (i) base of the primary leaf decurrent on branch let (ii) ray tracheid cells with dentate internal walls (Shaw, 1914; Dallimore and Jackson, 1966; Poynton, 1977).

2.6.4 **Silvicultural characteristics of *P. radiata***

The authors discovered that *P. radiata* is an exceptionally vigorous and moderately big tree which sometimes grows to a height of 37 m and a diameter of 180 cm, but in unfavourable conditions it may rarely overtake half of this size (Scott, 1960; Streets, 1962; Roy, 1966; Poynton, 1977). In well-stocked stands, it yields an erect moderately well defined cylindrical bole, even though defects such as forks and sporadic large limbs are normally common (Dallimore and Jackson, 1966). The tree can be distinguished from other pines by its superior long internodes with separate whorls of branches, especially those developed between the fifth and the fifteenth years. These normally measure 1 to 2 m in length and yield entirely knot-free wood. In close stands, the trunks of the big trees may be clean to a height of 10 or 15 m. Up to the age of 40 years, trees in dense stands tend to have spear-like crowns and normally conical, but with increasing maturity, their heads usually become flattened or rounded at the top. The trees which are singly standing tend to form twisted or leaning boles and coarsely branched wide spreading rather flat topped heads, particularly when fully established in exposed regions near the sea.

In its native country *P. radiata* is considered of little economic and commercial importance as its timber is regarded as inferior to other natural conifers. The timber usually has a purplish or pale brown colour with a pale yellow or whitish sapwood which is associated with knots and has a wide annual rings measuring up to 4 cm in breadth. Although comparatively light (density 0,40 to 0,45 g/cm^3), its wood is relatively strong and durable. *P. radiata* is a prolific and sometimes precocious seeder. The seed is easy to collect, germinates well and can be kept for long periods without much loss of viability. Natural regeneration is sparse under close canopy, but abundant in cutover places. When it is young, the tree resists shade better than most other original pines. It can show much vigour, starting growth earlier in spring while temperatures are still low. Tree height growth reaches its final point just after 15 years on poor sites, but under suitable conditions, the tree grows rapidly up to the age of 30 or 40 years. The tree has an apparent root system, which rarely extends to a depth of more than 0,6 m and is occupying primarily the uppermost 0,3 m of soil. Taproot development tends to end at an early age, overtaken by the growth of strong lateral roots. These can grow out radially to a distance of 10 to 12 m and are reinforced at their point of placement to the root collar. They interlock and often anastomose with the roots of other individuals in the stand rendering the tree relatively wind-firm (Scott, 1960; Roy, 1966; Poynton, 1977).

2.6.5 **Uses**

Scott (1960), Streets (1962) and Mirov (1967) stipulated that *P. radiata* is unique among its allies, although it is of little economic significance in the country of origin. It has been established more broadly as an exotic than feasibly as other species. Moreover, it was denoted that in USA it is established mainly for amenity purposes. The species has been used extensively for afforestation in countries like New Zealand, Australia, South Africa and Chile. The primary factors which have led to select *P. radiata* when appropriate climatic and soil conditions exist are (i) freedom from serious diseases and pests, (ii) superb fast growth, (iii) amenability to planting in pure, even-aged forests, (iv) ease of establishment. Overall the species is used extensively for commercial purposes such as sawn timber, furniture and building materials.

2.6.6 **Insect pests and diseases**

The species is liable to attack by several fungi and a great many insects in its native habitat. (Roy, 1966; Poynton, 1977). Scott (1960) listed the following insects on younger trees: (i) *Lyda* spp. – a pine sawfly affecting a large percentage of trees of five to ten years of age (destroying foliage and stunting or killing trees attacked) (ii) *Aprophora angulata* – a spittle insect, causing the foliage to fall off, (iii) *Pissodes radiata* – the Monterey pine weevil, (iv) *Dendroctonus valens* – the red turpentine beetle. He also connoted that some 30 fungi have been reported to affect pine in its native home, including *Fomes annosus, Armillaria mellea, Cronartium cerebrium* and *Coltricia schweinitzii.*

In South Africa, Kirsten *et al* (2000) denoted that the main trees attacked by insects are *P. radiata* and *P. patula* in plantations. The pine woolly aphid – *Pineus boerneri* known before as *Pineus pini* in Europe, North America, Asia, and the Mediterranean arrived in South Africa in 1978. The pine woolly aphid is a small sucking insect, which destroys many pine plantations. The obvious symptoms on *P. radiata* include few and short, thick needles, multiple resin pockets visible in the annual growth rings and arrested root development. Wingfield and Roux (2000) stated that a number of new diseases have been observed, and some of them have caused considerable losses in nurseries and plantations. They further mentioned that *Sphaeropsis sapinea* is one of the most common pathogens attacking pines in South Africa. The fungus is related to many different disease symptoms including shoot blight of seedlings and trees (die-back), blue stain of timber, root diseases and stem cankers.

2.7 ***P. radiata*: In Southern Africa**

2.7.1 **Afforestation and field experiments**

P. radiata was possibly introduced into South Africa during the second quarter of the nineteenth century even though the precise situations surrounding its introduction can no longer be traced (King, 1951). In contrast Legat (1930) denoted that the first published information on the species was found in the report of colonial Botanist, Cape of Good Hope, for the year 1865, where trees were reported to have been planted in the Cape Peninsula. Similarly, Lister (1957) discovered that 250 plants were timely produced in the nursery at Tokai plantation at Cape Peninsula in Western Cape. The seed from which these were raised had been collected from a tree of unknown origin standing in the Botanic Gardens in Cape Town. Furthermore, it was stressed that fertile seeds seem to have been borne as early as 1857 by trees of the species growing in the Caledon district. Poynton (1977) emphasised that *P. radiata* has been planted and experimented on different zones of the winter, uniform and summer rainfall regions. It is only the humid, cooler-temperate areas of the Eastern Cape Province, the species is utilised for afforestation outside the winter and uniform rainfall regions. Trial plantings on the coasts and Zululand for all practical reasons entirely failed. The species was reported to show good performance on a number of sites in the Western Cape, on Table Mountain, lower slopes of Outeniqua and Tsitsikama mountains, humid parts of Orange Free State, on steep slopes of Harrismith and Imperani plantation. According to Poynton (1968), the tree is liable to attack by *Sphaeropsis sapinea* throughout Transvaal.

In Lesotho *P. radiata* grows well on all types of soil, including montmorillonitic clay loam to which Drakensberg basalt gives rise after weathering. The species has been broadly introduced at high altitudes in Lesotho, where it indicates better growth in most localities than any other conifer introduced so far. It has proved exceedingly tolerant to frost and indicates a good performance even at Mokhotlong, found at an altitude of 2375 m above sea level where individual trees have obtained a height of 12 m at a juvenile stage of growth. It has also been recognised that the species does not perform well on warm and dry sites like the ones in Mohale's Hoek, where it shows a rather unthrifty appearance. The tree is one of the chief species utilised for soil rehabilitation where it has been broadly introduced on eroded slopes in catchments areas of gullies and dongas. Promising results were obtained on severely eroded, often dry sites, and the tree has succeeded to a remarkable degree on completely denuded ground (Poynton 1966a; 1977)

In Malawi, Streets (1962) and Poynton (1977) stipulated that *P. radiata* has been introduced experimentally on a number of sites where it is grown for timber on a minor scale at elevations from 1400 to 2400 m and in places where rainfall exceeds 1000 mm a year. On Dedza Forest reserve, two stands were established on loam soil composed of many loose boulders and trees have performed well. The trees in the older stands indicate signs of needle cast which resulted in a rather thin crowns and poor performance altogether.

It was reported that species has not been introduced to any great extent in Angola. It was further highlighted that, in Poligono Florestal de Humpata above Sa' da Brandeira, species performance has been poor and uneven on infertile, sandy soil, the trees differing in height from 1 to 14 m at the age of 13 years (Poynton, 1977).

In Mozambique, the species that was introduced in Parque Florestal at Namaacha on a rather shallow, litholic clay-loam derived from rhyolite, failed completely (Poynton, 1977). The few trees, which managed to thrive, indicated poor performance.

In Zimbabwe, it was reported that *P. radiata* was firstly pioneered probably from South Africa in 1902 (Poynton, 1977; Barret and Mullin, 1968; S.R.F.C., 1957). It was indicated that many small plantations of the species existed in1920, which indicated good performance. It was again reported that a big scale of afforestation started in 1928, and seed was imported initially from South Africa but later from New Zealand. Early results indicated good performance, and the species was planted more extensively than other pines. The small quantities of seed were used from four different places in Swanton and Cambria areas of California in 1960. Local collections from open pollinated trees and two stocks from South Africa were utilised to set up 27 unreplicated experimental plots at different elevations at the John Meike Research Station. The locusts, birds, fungal diseases such as *Dothistroma pini* were reported to be major threats to the cultivation of *P. radiata* in Zimbabwe.

2.7.2 **Silviculture**

King (1951) and Legat (1930) mentioned that sowing seed in situ under appropriate conditions can regenerate *P. radiata*, but more common method of afforestation is to make use of transplants raised in the nursery. The quantity of seed per kg differs from about 3000 to 55 000 and averages 41 000 seeds per kg. Contrarily, Donald (1968) connoted that the average number of viable seeds is 27 500/kg. It was stressed further that germination starts after about 10 days and normally completes after about 30 days. The seed is recommended to undergo wet stratification at a temperature of 2 to 3 °C for a period of 40 days. The production of 25 000 usable plants/kg can be attained in the nursery if appropriate precautionary measures are applied. The seedlings and young plants are subject to attack by damping off if sowing is conducted in summer. Birds and mice are also pests in nurseries. Sherry (1942) showed that *P. radiata* could be regenerated at ease by means of cutting when trees were up to 8 years old.

2.7.3 **Utilisation**

Scott (1953) stipulated that the logs of this species are generally of good form and saw at ease and may rarely be spirally grained. If the wood is properly stacked it seasons quickly. If lumber is intended to be used for joinery or other finished work, great caution should be taken to treat the timber in a kiln for 2 or 3 days after air drying, in order to remove stress. Similarly, Scott and Stephens (1947) implied that the wood seasons well if correct methods of seasoning are practised. In addition, timber from these species of pine can be used for roofing timbers, beams, wall plates, flooring, panelling, shelving, joinery and laminated railway sleepers. In South Africa the species has been used to produce resin too (Poynton, 1977)

2.7.4 **Other potentials**

The Monterey pine tree proved itself to be used in shelterbelts, rehabilitation of degraded lands or sites, on roadside or avenues. It can also be selected for good landscaping and amenity purposes on large estates (Poynton, 1977).

2.8 **Information About Site Conditions**

The knowledge of site quality and its influence on tree growth, wood and fibre properties is of strategic importance to forest industry in South Africa (Du Plessis, 2002). Zwolinski, *et al.* (1998) connoted that the knowledge of soil water storage, rainfall, as well as air temperature, soil bulk density and carbon content of the soils was useful to comprehend and predict growth of trees.

Zwolinski (2001) stressed that the traditional definition of site utilised in this context needs some clarification as the word is utilised normally in its common meaning ("place") or confused with other ecological terms such as environment. He further implied that, a site is defined as a relatively stable complex of the physical environment, which determines the type of vegetation and associated herbivores. Louw (1999) defined the forest site as an integrated complex of a range of "environmental factors" within a prescribed area. Similarly, Grey (1987) utilised "environmental factors" in a context of site characteristics and classification. Furthermore, (Pojar, *et al.,* 1985; Herbert, 1993) elaborated on this theme adding that, a combination of vegetation, animals and physical habitat is called an ecosystem or biogeocoenosis (terrestrial ecosystem). A terrestrial ecosystem consists of organisms (biocoenosis) and the physical (abiotic) elements of a habitat. Trees often control a forestry ecosystem.

Woodward (1986) explained site as a holistic biophysical unit where special vegetation will manage to succeed if, within a particular plant's life requirements, conducive climatic, hydrological and nutritional processes permit a complete physiological cycle of survival, biomass production and reproduction. Site conditions influence in one or another way the following: growth rates, timber production, operational costs and economic returns, wood properties, forest hygiene and species suitability.

Avery and Burkhart (1994) defined site as an area considered in terms of its environment, particularly where this determines the type and quality of vegetation the area can carry. If required, site may be classified qualitatively into site types by their climate, soil, and vegetation, or quantitatively into site classes, by their potential to produce primary wood products. It should be feasible to measure site directly by analysing many factors inducing the productivity of forests, such as soil nutrients and moisture, temperature regimes, available light, topography and so on.

Site studies assist the forester to comprehend which of the soil, topographic or climatic factors are related to tree growth and thus determine amelioration strategies, which are likely to succeed (Schonau and Grey, 1987). Similarly, Herbert (2000) strongly contended that there are three main criteria for consideration when examining the site's ability to support tree growth, viz climatic, edaphic and biotic factors. The most important climatic factor is ambient air temperature, as each genotype has a particular optimum range of physiological activity for fast and continuous growth, as well as resistance to frost, snow and diseases.

Schutz (1990) pointed out that a better knowledge of site-tree relationships would facilitate site classification for yield prediction, site-specific silviculture, species choice, nutrient cycling problems and nutrition programmes. Theron (2000) showed that significant site-relevant selection criteria comprises of mean annual precipitation (MAP), mean annual temperature (MAT), occurrence of frost, and soil depth. Disregarding the tolerance of a species will influence its growth performance and susceptibility to pests.

Grey (1983a) highlighted that site factor studies are described by the use of mathematical and statistical techniques for model building, the screening of environmental factors, the reduction of the dimensionality of data sets, the testing of hypotheses and estimation of parameters for the establishment of functional relationships to tree growth.

Bazill (1985) and Moshoeshoe (1987) classified site types for forestry in Lesotho based on landforms. Their contention was that proper planning incorporates decision on the following:

site selection, type of species to be planted, stands prescriptions, which includes weeding, pruning, thinning etc. They further pointed out, that there are eight landforms identified so far, these are: (i) basaltic slopes, (ii) structural sandstone plateau, (top), (iii) debris slope, (iv) lowland hill crest and upper slopes, (v) lowland hill, (vi) lower slopes and plains, (vii) plains alluvial terraces, (viii) dolerite hills and Senqu gorge.

Zwolinski (2001) commented that, while determining or discussing site conditions to enhance site species matching, the other site variables to report on will be: temperature, altitude, rainfall, aspect, geology, soils, exposure, longitude, latitude, vegetation and topography. He strongly elaborated that height growth has been accepted as the most reliable reflection of site quality. It became the responsibility of researchers not only to match species with sites but also to benchmark operational performance of stands and optimisation of silvicultural investments. Improved allocation of species, hybrids and clones to sites is based on site related growth variation predicted with site growth models. In this regard, geocentric classification of forests in Russia were defined by Morozov (1904), while on the one hand, forest floor flora was utilised to differentiate forest sites in Finland (Cajander, 1909).

The three primary types of site classification can be determined from the literature and previous systems of implementation:
(a) phytocentric – based on a composition of plant communities (or their performance, like e.g. site index of trees),
(b) geocentric – including climate, soil factors, topography, parent material and geomorphology into a system providing for specific type and production of forests.
(c) mixed – inclusive of both abiotic and biotic components.
The phytocentric system is infrequently utilised where afforestation of non – forestland is intended or where vegetation is changed beyond its natural cover.

In Lesotho, the highlands experience considerably lower temperatures than the lowlands. In winter in the highlands it is common for temperatures to be below freezing point. Snow falls during the coldest months. The lowest temperature ever of –20 ^{0}C was recorded in 1967 (Vilakati, 1986)

The amount of rainfall received in Lesotho is variable. In the lowlands, mean annual precipitation (MAP) is between 700 and 800 mm from Maseru to the northern part of the country. MAP also ranges from 400 to 600 mm in the southern part of the country. Greater amounts of precipitation are received in the highlands. MAP is between 800 and 1000 mm when rainy conditions are favourable. The rainy season starts in October and ends in May (Vilakati, 1986).

The climatic zones are classified according to four elements in Lesotho, which are:
(a) temperatures from October to March,
(b) elevation range in metres,
(c) estimated length of growing period in days,
(d) rainfall probabilities from October to March.

Contrarily to the above method, the utilization of the geocentric methods usually demands sophisticated knowledge of factors which are difficult or costly to investigate (e.g. climatic information) and their interpretation for exotics based plantation forestry (Cajander, 1909; Zwolinski, 2001).

A great deal of research has been undertaken worldwide to obtain a better understanding of relationship between site and tree growth. Less attention, however, has been given to wood properties. Recent studies have shown that site cannot be ignored when considering variation in wood properties and causes of certain defects of timber (Schutz *et al.*, 1991). Thus, it was determined that the genetic variation in the wood properties of pine species grown in Southern Africa is high so that there is a strong relationship between soil drainage and stem deformities in *Pinus patula,* heart shake in *Pinus elliottii* and abnormal wood in *Pinus taeda* (Schutz, *et al.*, 1991).

2.9 **Conclusion**

An overview of *Eucalyptus* spp and *Pinus* spp and other related information was dealt with, by a number of authors and researchers all over the world. Quite a number of detailed studies were done. It can be concluded that quite a useful amount of secondary information was given in this chapter which could also be helpful in the formation of this study and interpretation of its results.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1 Introduction

Akin (1991) indicated that the climate is recognised as a major factor in the distribution of vegetation, and he used vegetation types as an indicator of major climatic gradations. He highlighted that Koppen climatic classification fitted known vegetation patterns with observed average temperature and rainfall, and their seasonality. Moreover, he stressed that the modified Koppen's system of climatic classification is as follows:

(a) humid tropical climates,
(b) dry climates,
(c) humid mesothermal climates,
(d) humid micothermal climates,
(e) polar climates,
(f) undifferentiated highlands.

Woodward (1986) supports the contention that climate exercises a strong controlling influence on, the geographical distribution of plants and that climate changes in response to latitude. As a result of this strong association, the general descriptions of vegetation zones such as boreal, temperate and rain forest embody climatic connotation. In summary this means that variations in climate can affect the constitution of vegetation, and therefore control plant distribution.

An alternative perspective is that of Monin (1986) that climate is determined by three groups of factors: (a) external astronomical factors such as the irradiance of the sun, the position and the motion of the earth in the solar system, the inclination of its axis etc.; (b) external (relative to the atmosphere-ocean-land system) geophysical factors such as the size and mass of the earth, its axial rotation etc.; (c) internal geophysical factors (properties of the atmosphere-ocean-land system) such as the mass and composition of the atmosphere. He further stated that it is not known whether the climate is determined uniquely by all these factors or whether for given fixed values of all the climatogenic factors, different climates are feasible.

Another approach is that of Schrimper (1890) in: Schulze, 1997) who recognised that climatic impact on plant distribution and survival is influenced by physiological processes. This is an approach that favours for thousands of years by communities who have successfully understood the relationship between biotic and abiotic land features. Similarly, Woodward (1986) found that, early records confirming these relationships date back to Theophrastus (370 – 285 BC), a pupil of Plato and Aristotle, who realised the significance of climate plant relationship between the life of plants and cycle of the seasons.

In other work, Schulze (1997) and Akin (1991) concluded that of the three great natural patterns that control the earth's environment, (climate, plant distribution and soil), climate is inevitably considered to be the principal dynamic component, the independent variable shaping the other two on both the meso and regional scales. As a part of this pattern, they suggest that higher altitudes are the primary influence on lowering temperatures, although the lapse rate of temperature varies with region and the season.

Finally, Schonau and Schulze (1984) recognised that the availability of precipitation and solar energy, (the latter characterised by temperature) are the limiting factors in determining the presence and success of all crops. It is the interaction of precipitation and temperature, with given soil properties that determines the potential productivity of a given area. In addition, altitude is included in any strategic delineation for determining areas of optimal tree growth i.e. areas where commercial afforestation can be undertaken successfully (irrespective of market and other limitations).

3.2 **Location**

The Kingdom of Lesotho is outside the tropics located approximately between 28^0 and 31^0 latitude south and between 27^0 and 30^0 longitude east. With an estimated total surface area of 30351.641 km^2 this landlocked country is completely surrounded by the Republic of South Africa, bordered to the west by the province of Orange Free State, KwaZulu-Natal to the east and north east and the Eastern Cape Province to the south east and the south west (Vilakati, 1986).

The mountain Kingdom of Lesotho is the only country in the world with its entire altitude above 1000 m a.s.l and it is divided into two distinct regions: firstly the lowlands and valleys known as the "lowlands," and secondly the foothills and mountains which are collectively referred to as the "highlands". The lowlands occupy a quarter of the country predominantly in the west, while the highlands consisting of the Thaba Putsoa Range in the south, the Central Range, the Maluti Mountains and the Drakensberg occupy the rest of the country. The highest point is Thabana Ntlenyana (3482 m) in the Drakensberg, which makes it the highest mountain in Southern Africa (Vilakati, 1986).

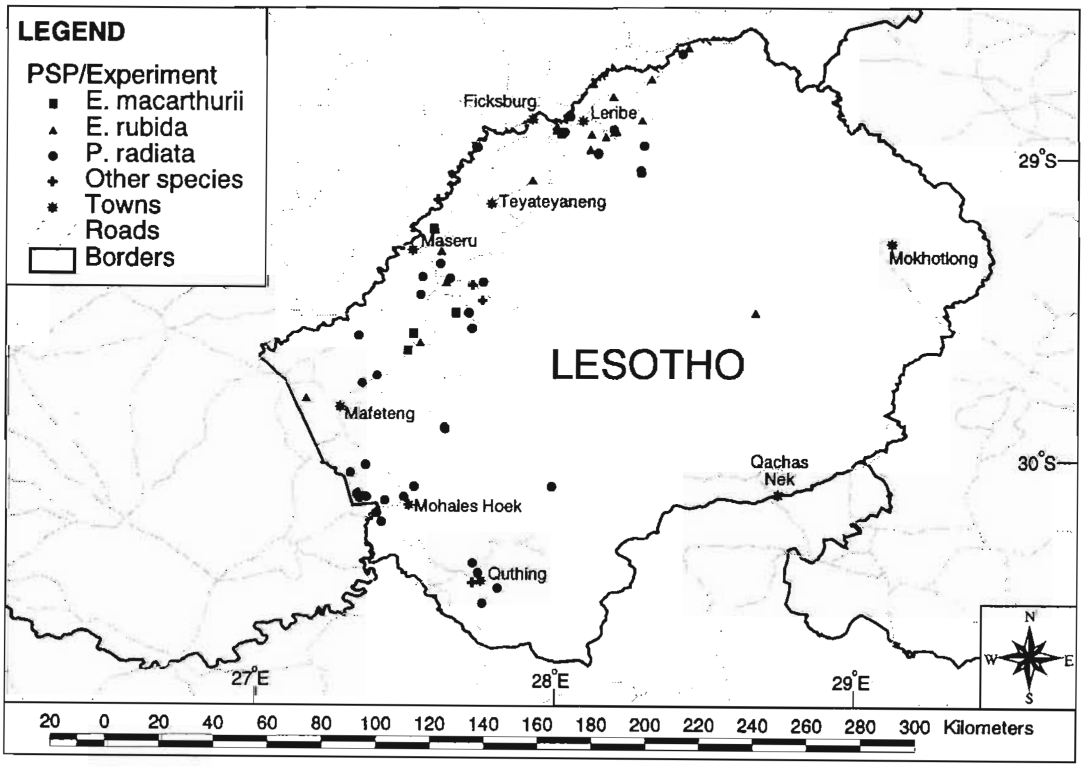

Figure 4: Location map of permanent sample plots and experiments in the study area in Lesotho

3.3 **Climate**

Lesotho has four distinct seasons, spring, summer, autumn and winter. Climatically, Lesotho is dominated by a temperate environment of warm summers and cold winters. The rains start in the spring during August and September and end the following autumn between February and March, snow is frequent over the highlands. The hottest months of the year are in summer during the months of November, December and January. The coldest months of the year are in winter, namely June and July.

Overall, the weather conditions are warm and cool and favour crops and tree production throughout much of the year in the lowlands (Figures 5 and 6). Thus, in the lowlands, temperatures generally vary from a maximum of 30 ^{0}C in summer to a minimum of –7 ^{0}C in winter. Maseru has an average monthly temperature of 24 ^{0}C in January and an average monthly temperature of 8 ^{0}C in June and July. Altitude has a big influence on temperature: an increase in every 1000 metres results in a decrease in temperature by 6,5 ^{0}C (Vilakati, 1986). Thus, there is an estimated growing period of 170 to 190 frost-free days within an elevation ranging from 1750 m to 2000 m and rainfall of between 350 mm and 500 mm occurring from October to March (Berding, 1984; Moshoeshoe, 1987; Vilakati, 1986; Russell, 1979; Jayamaha, 1980; Bureau of Statistics, 2003).

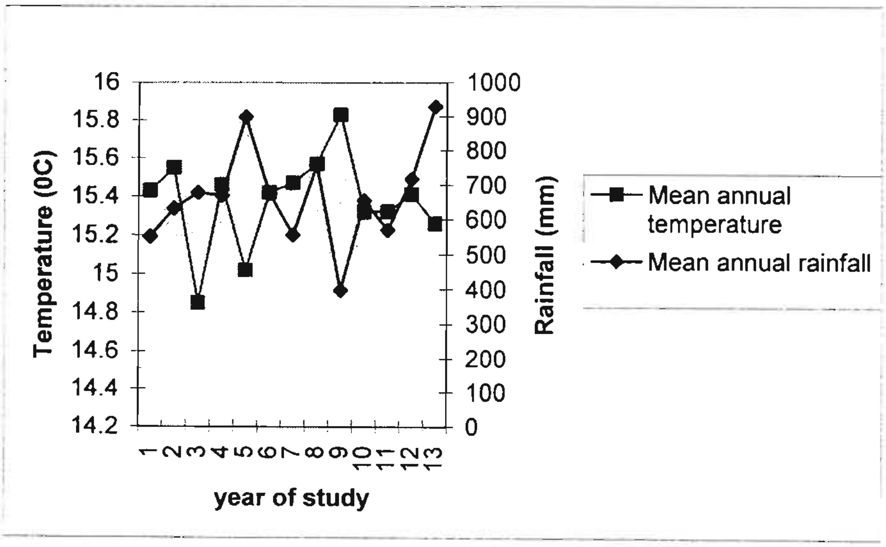

Figure 5: Climatic conditions in *E. rubida* study areas between 1984 and 1996

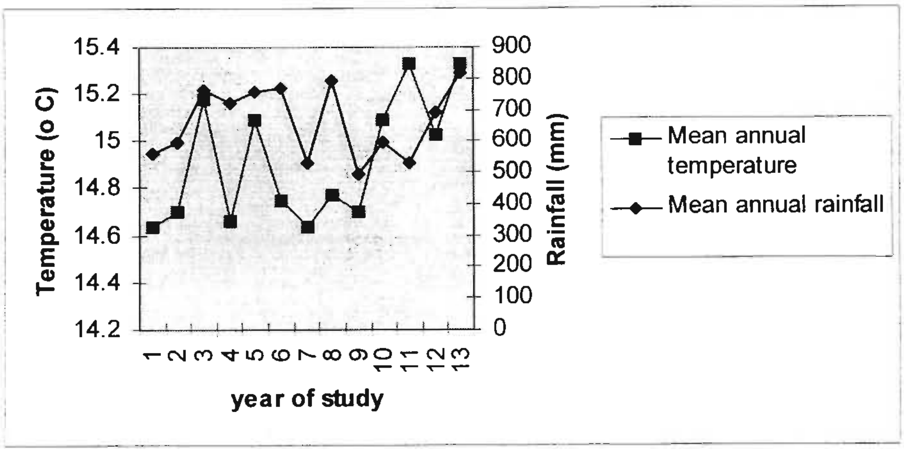

Figure 6: Climatic conditions in *P. radiata* study areas between 1984 and 1996

3.4 Agro-Ecological Zones

3.4.1 Geomorphic landforms and crop production

Lesotho has four agro-ecological zones, which are lowlands, foothills, highlands and valleys. The lowlands elevation ranges from 1400 and 1680 m a.s.l. The main cereal crops produced are maize, sorghum, wheat, beans and peas. Vegetables, which are primarily grown, are cabbage, carrots, spinach, beetroot, onion, tomatoes, pumpkins and potatoes. The foothills altitude starts from 1680 to 2300 m a.s.l. The primary cereal crops are maize, sorghum, wheat, beans and peas. Vegetables, which are commonly planted, are cabbage, spinach, tomatoes, beetroot, onion, carrots and potatoes.

The altitudinal range of mountains is above 2300 m a.s.l whereas the elevation of the valleys is not distinct as they are in the lowlands and mountains (Figure 7). The chief staple food is wheat, beans, peas, maize and sorghum. This region is mostly famous on fodder production chiefly rye, barley and so on. The fundamental vegetables grown are cabbage, carrots, potatoes, pumpkins, beetroot, tomatoes and spinach.

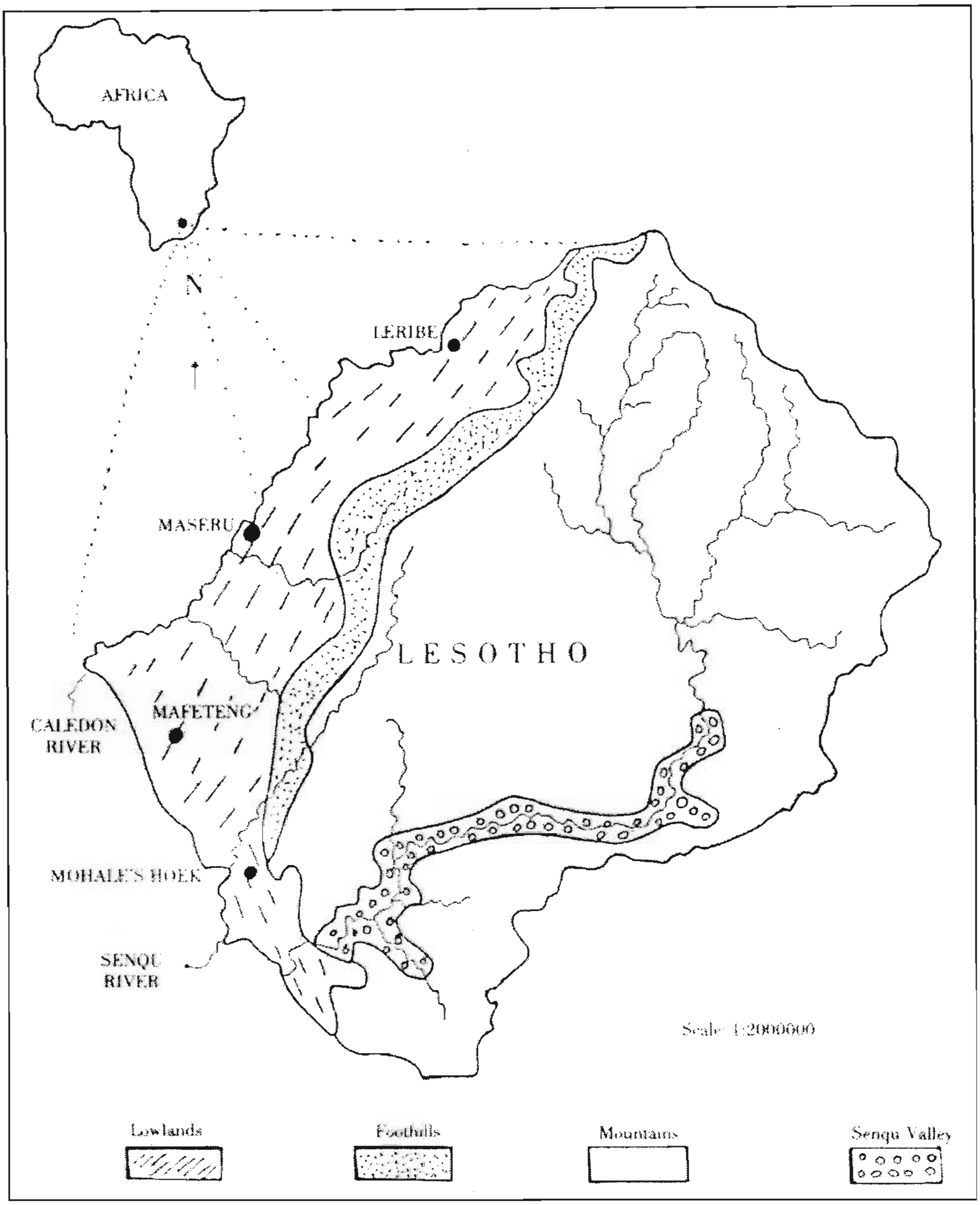

Figure 7: Agro-ecological zones in Lesotho (Rooyani and Badamichian, 1986)

According to the study undertaken by Ruicon (1998), it was detected that every year, yields in agriculture are deteriorating mainly on both livestock and crops due to many contributing factors such as poor condition of the rangelands and farmers not having access to credits. The average yield per hectare for maize and sorghum in the whole country are 1,210 and 1,166 tons respectively. The average production per hectare of beans and peas nationally is 1,025 and 0,959 tons respectively. Lastly, but not the least, the average yield of wheat is 0,982 tons. A recent study undertaken by Ruicon (1998), indicates a yearly decrease in both livestock and crops due to a number of factors such as the poor condition of the rangelands and farmers not having access to credits. The average yield per hectare for maize and sorghum in the whole country is 1,210 and 1,166 tons respectively. However when these results are compared with those from nearby South Africa the results are poor. Thus, under the same climatic conditions the average yield per hectare for maize in the Ficksburg-Fouriesburg area is between 1,7 and 2,65 tons per ha., while that in the Leribe District of Lesotho is a mere 0,868 tons.

Schulze (1997) and Smith (1994) projected that the average potential yield per hectare of dry beans in Lesotho is from 1 to 1,25 tons in the lowlands and from 0,75 to 1 ton in foothills. Furthermore, they estimated that the average potential yield per hectare of sorghum and maize both ranges from 3 to 4 tons.

On the one hand, Bazill (1992) stated that some measurements have been made on thickets of grey poplar, coming up with estimated MAI's of between 8 and 18 m^3/ha/yr. Zwolinski *et al.*, (1998) indicated that the growth and yield data can proved clearly that pines can produce a good volume of timber (over 20 m^3/ha/yr) in the region if site species matching is correct. Similarly, Schulze (1997) indicated that the MAI of *P. patula* is estimated as less than (<) 10 tonnes per hectare ($t.ha^{-1}$) and in the highlands and between 14 and 16 $t.ha^{-1}$ in the lowlands of Lesotho. Meanwhile, the MAIs of *P. elliotii* and *P. taeda* were projected to < 14 $t.ha^{-1}$ and < 16 $t.ha^{-1}$ respectively.

3.4.2 **River systems**

Lesotho is well drained with river systems running through deep and narrow valleys of the rugged mountains. The main river systems are the Senqu (Orange), Senqunyane, Maliba-Matso, Makhaleng, and Mohokare (the Caledon). Unlike most rivers, which are in Southern Africa, these rivers flow westward (Figure 3). They are in fact tributaries of the Orange River, which drain into the Atlantic Ocean. The source of the Orange River is in the mountains of Lesotho, which are also an important watershed in Southern Africa. The Maliba-Matso River has now been turned into a watershed known as Katse Catchment, which transports water to the factories and big farms of South Africa through tunnels (Vilakati, 1986).

3.5 **Geology**

The geological formations of Lesotho are the oldest formations of the Upper Beaufort Beds. Beaufort series occur only in the valley of Little Caledon River. The Upper Beaufort Beds are made up of buff sandstones with purple and red shales and mudstones. Completely surrounding them are the molteno beds, coarse-grained white sandstones and grits with shales and mudstones (Caroll and Bascomb, 1979).

This formation also crops out in southern part of the country. Most of the lowland region is occupied by Red Beds, buff and red sandstones alternating with red and purple shales and mudstones. Overlying this formation is the conspicuous Cave Sandstone formation. This massive, fine to very fine grained, buff sandstone forms Berea and Qeme plateaus and the winding persistent escarpment which runs along the eastern edge of the lowlands. Farther east, the Cave Sandstone of the foothill region is capped by Drakensberg Beds. A series of lava flows covers about two thirds of Lesotho's surface area. The lowest flows, along the Pitsaneng stream sometimes contain two or three thin sandstone layers. The bulk of the formation is made up of compact and amyloidal basalts. They are several peaks, which were formed by piling up of layers of this lava.

The six formations were laid down successively during the Triassic and Lower Jurassic Ages. The lava flows, which occurred last, were accompanied by igneous intrusions into older sedimentary rocks. The dolerite dykes formed characteristically long, slightly curving ridges by increasing the resistance to erosion of the Red Beds into which they cut, conversely, the dolerite weathers faster than the massive Cave Sandstone. As a result, the dykes erode away and the hardened sandstone is left standing. A chute like Lancers's Gap is formed and kimberlite intrusions are of uncertain age but of great interest in Lesotho. A small kimberlite dyke cuts the Cave Sandstone of the Berea plateau (Conservation Division, 1977; Caroll and Bascomb, 1979).

The lowlands are covered by a few to many feet of erosion products called "pedisediments". These pedisediments may have accumulated under strongly eroding conditions during wet cycles in an interglacial period. Presently, these pediments are undergoing an erosion cycle in which the landscape is becoming truncated so that earlier deposited sediments are becoming exposed or lost through erosion. Because the pediments are largely "creep", "colluvium" or local alluvial" sediments, it can be stressed that soil characteristics in the lowlands are governed more by the nature of this underlying accumulative layer than by nature of the bedrock. The lowland region occupies mostly the broad generally level to sloping, dissected and often severely eroded pedisediments between the Caledon River to the west and the Cave Sandstone escarpment to the north, east and south. Outliers of the higher foothill plateaus mark the landform. The pedisediments rest on or are often eroded to reveal Red Bed sandstones and shales, with isolated areas of Molteno and Upper Beaufort sandstone and/or shales. Alluvial terraces occupy the valleys marginal to major streams and often widen into extensive flood plains (Caroll and Bascomb, 1979).

The mountain region is entirely underlain by basaltic bedrock. The landform consists of moderately steep to very steep mountain slopes that are deeply incised and shaped by swift flowing, intermittent and perennial mountain streams. Contrarily, the foothill region occupies the mostly undulating to steeply rolling land area between the Cave Sandstone escarpment and the slopes of the mountain region. It is underlain by Cave Sandstone bedrock that is thinly mantled in places, by strongly weathered basaltic bedrock or its early residuum. This plateau land is marked by broad slopes that are broken sharply, in places, by moderately to deeply incised valleys (Caroll and Bascomb, 1979)

The entire mountain zone consists of basaltic rocks, which are igneous and were formed during volcanic activity around 180 million years ago. Basalt in general consists of minerals such as calcium feldspar, mica, and olivine (or other Ferro magnesium silicates such as pyroxene). Sandstone is sedimentary rock formed from consolidation of sand grains by binding minerals such as carbonates and iron oxides (Rooyani and Badamichian, 1986).

The mineralogy of sandstone is quartz. in Lesotho, the sandstone layers are made up of sedimentary materials, about 200 million years old. In the foothills and lowlands, the layers of sandstone alternate with layers of shale. Shale is a sedimentary rock formed from cementation of clay materials (Rooyani and Badamichian, 1986).

The volcanic dykes are the main complication to the rather uniform sedimentary formations of the foothills and lowlands. Dolerite is an igneous rock similar to basalt. Dolerite dykes intercept the horizontal sedimentary layers. In fresh, they are dark reddish in colour (Rooyani and Badamichian, 1986).

Geology is defined as the science of the earth's crust and the strata which constitutes it, and their mutual relations and the consecutive changes to which their current conditions and status are due (Ellis, 2000a). To a practical forester, such a unique definition is not significant, but the influence of geological materials on tree growth is fundamental. The influence primarily stems from the effect of soils, which evolved on a certain parent material, might have on tree growth. If the origin of the parent material is well recognised more accurate predictions regarding characteristics and land use will be feasible (Ellis, 2000a).

3.6. **Soils**

3.6.1 **Introduction**

Soil is defined as the collection of natural bodies made of earthy materials containing living matter and capable of supporting plants out-of-doors. Its upper boundary is atmosphere or shallow water and the lower limit may be underlying geological materials, ice or water (Rooyani and Badamichian, 1986). Soil is the product of the interaction of soil forming factors. These factors are climate, vegetation, parent material, topography and time. Soils are different in properties because of differences in soil forming factors and the rate at which they interact to produce a soil (Rooyani and Badamichian, 1986).

Advancement in comprehending the nature, properties and processes of soils on forestry land has been slow. When land was readily available at economic prices, it may have been a prudent policy to expand the country's timber reserves by "blanket" planting large areas (Ellis, 2000b).

Soil hydrology is of crucial significance in South Africa where lack of water limits crop production and increasing areas of land irrigated from a limited water supply. A knowledge of the energy status of soil water in relation to water content, usually portrayed as a retentively curve, aids in estimating water storage capacities of soil profiles, solution of soil water problems and simulation of hydrological processes by means of mathematical models (Hutson, 1986). Most soil data include clay content while more detailed work includes complete particle size distribution and bulk density. In this work retentively data for South African soils were obtained from several sources and combined to form a data set representing a wide range of South African soils. Regression equations were developed using different combinations of parameters (Hutson, 1986).

3.6.2 **Soil formation**

The process of soil evolution follows the weathering process of geologic materials. Climate affects the rate of weathering of geologic materials, and then the vegetation cover incorporates organic matter into weathered material or parent material. Topography affects the stability of the landform by controlling the erosion and deposition processes and finally time involved determines the rate at which they interact to produce a soil (Rooyani and Badamichian, 1986).

The properties of the soils in Lesotho reflect the influence of soil forming factors. Although Lesotho is a small country, variability among the soils is substantial. This is probably due to the variability in topography and parent materials rather than to vegetation and climate. The vegetation of the country is predominantly tall grass. The influence of this factor is evident in dark A horizon of many mountain soils such as Popa and Ralebese which is of the order Mollisols which are mostly black soils (Rooyani and Badamichian, 1986). These soils originated from basaltic bedrocks. Under moderate weathering basalt tends to weather to clay. In Lesotho, most of mountain soils have significant amounts of clay, which are rich in calcium and other basic cations. The mountain soils have either formed directly on basaltic slopes or on the basaltic colluvium at the toe of basaltic slopes (Rooyani and Badamichian, 1986).

Some of the soils of the upper foothill formed from sandstone. Sandstone weathers into sand and thus forms sandy soil. Depending on the binding material, some sandstone are buff yellowish in colour and some are red. Leribe soil, a red soil of the order of the alfisols, are used extensively for cropping. These soils are found in the foothills and presumably formed on red sandstone (Rooyani and Badamichian, 1986).

Certain soils (mainly in the lowlands) have formed on shale. Shale weathers into clay. The shales of Lesotho, similar to sandstone layers are bluish green and grey (Rooyani and Badamichian, 1986).

3.6.3 **Soil classification**

Soil classification is defined as the technique of categorically grouping soils based on similarities and differences in properties (Rooyani and Badamichian, 1986). Morphological, physical, chemical, and mineralogical properties of the soils that are important in the genesis of the soils or influence the plant growth or the use and management of the soils, usually are used as criteria to classify the soils. The nomenclature offered to a soil classification serves as a technical language for easier and effective communication among the people who are working on soils (Rooyani and Badamichian, 1986).

Hunt (1972) classified forest soils into five groups such as: (i) podzol soils – light soils, conspicuous light leached layer, vegetation is mostly spruce and pine forest, climate is cold humid; (ii) gray - brown podzolic soils – dark soils; brown to grey-brown leached layer, vegetation is mostly deciduous broadleaf forest, climate is temperate humid; (iii) brown forest soils – dark soils without a noticeable leached layer, vegetation is mostly northern hardwood forest and some mixed broadleaf and conifer forest, climate is cool temperate; (iv) red and yellow podzolic soils – red and yellow clayey soils, vegetation is South-Eastern pine forest, climate is warm temperate and tropical humid; (v) ground water podzol soils – sandy soils over shallow water table, vegetation is mostly south eastern pine forest, climate is cool to tropical, humid.

The soil classification of Lesotho had been undertaken (Caroll and Bascomb, 1979). The detailed soil surveys of Lesotho were cross-referenced to many systems of soil taxonomy, which have an international link or standard. For an example, Macvicar *et al.,* (1977) developed the soil classification called a binomial system for South Africa and also used in Swaziland. The FAO/UNESCO system is used and adopted in Botswana. Caroll and Bascomb provided valuable information on soils of Lesotho. These soils were published under the direction of the United States Department of Agriculture (USDA) Soil classification system (Caroll and Bascomb, 1979; Rooyani and Badamichian, 1986).

Because soil taxonomy has been adopted as the official soil classification system of Lesotho, there are six categories namely: (a) order, (b) suborder, (c) great group, (d) subgroup, (e) families, (f) soil series. Soil taxonomy is fundamental to soil classification (Rooyani and Badamichian, 1986).

Currently, there are no soil classification systems, which were developed primarily for forestry in Lesotho. According to Rooyani and Badamichian (1986), there are eight land capability classes (LCC) developed in Lesotho and applicable to soils of Lesotho such as: (i) class I – Intensive cropping: irrigated vegetable production and management; (ii) class II – Intensive cropping – irrigated on more gentle slopes (sprinkler) and rainfed on more steep slopes; (iii) class III – rainfed cropping: irrigation may be allowed on well constructed and well maintained broad bench terraces only; (iv) class IV – improved pasture: rainfed cropping may be allowed on well constructed and well maintained broad bench terraces only; (v) class V – natural grazing land or woodlot - pasture improvement allowed provided minimum disturbance of land; (vi) class VI – natural grazing land or woodlot; (vii) Class VII – natural grazing land, woodlot and wildlife; (viii) Class VIII – wildlife habitats, natural parks, and protected watersheds – minimal disturbance required.

Land capability classification may be defined in two broad terms such as land evaluation and land suitability classification (LSC). Land evaluation is the process of assessment of land performance when used for specific purposes. Meanwhile, LSC is the evaluation of a land system for a specific defined agricultural use and rating the suitability of the land for that use. Suitability is defined in terms of the highest output-input ratio and lowest environmental damage (FAO, 1976; Rooyani and Badamichian, 1986)

In the process of land evaluation, soils and land qualities such slope and climate, and any other relevant factor are assessed in order to: (i) identify the major limitations, (ii) identify the capability or suitability of the land use system, (iii) recognise the most promising kinds of land use (Rooyani and Badamichian, 1986). The LSC and LCC systems therefore have the similar objective that is to make predictions as to what is the best agricultural use for a soil (Rooyani and Badamichian, 1986)

With the above-mentioned background, it has been clearly recognised that forestry is given the least priority in the country according the LCC developed by the Ministry of Agriculture. Class V, VI and VII are the ones recommended for forestry practices in Lesotho. Therefore, there is a good challenge for the author to undertake this study in order to come up with some findings and techniques, which might be more appropriate and applicable to Lesotho.

3.6.4 **Soil conditions**

There are a number of soil physical properties, which are significant to plant or tree growth when soil studies are conducted. Physical properties of soils are those properties that are related to size, shape and colour of materials, particles as well as aggregates (Rooyani and Badamichian, 1986). The soil water relationship and aeration (both related to movement of water and air through the soil) are largely influenced by the physical properties. Soil management and tillage practices, soil conservation, irrigation and drainage of soils are measures, which are implemented according to physical properties of soils (Rooyani and Badamichian, 1986). On the other hand, Smith (1992; 1995) stipulated that trees differ from the main agronomic crops in that they possess complex and deep rooting strategies which vary temporally, spatially and from species to species. Moreover, he indicated that although it is very difficult to establish with any effects of soil compaction on "long term site productivity", research carried out at ICFR and else where has so far indicated that only excessive compaction caused by "excessive traffic" has caused significant short term decrease in tree growth for a range of species and the effects of soil compaction will reduce future site productivity.

3.6.5 **Soil texture**

Rooyani and Badamichian (1986) defined the soil texture as the relative proportions of the different soil separates clay, silt, and sand in the soil material. Soil separates are soil materials with different sizes. The clay particles are particles having a diameter of less than 0,002 mm (2 microns). Silt has a diameter of 0,002 to 0,05 mm and finer than 2 mm are sands. Coarser fragments, such as gravels, cobbles and stones having a diameter of more than 2 millimetres are not considered as soil particles. The clay particles, because of their fineness and large surface area, take part in chemical reactions in the soil system. The sand particles however are not chemically active, but they have a primary function in determining the physical properties of the soil (Rooyani and Badamichian, 1986).

This term refers to the textural parameters, for example textural layering (stratification) or type of sand, gravel or stones (including stoneliness) that change significantly with depth. Any pronounced textural change with depth has detrimental effect on water movement and air and root penetration. Such effects on usable soil depth can be quantified (Ellis, 2000b).

The term "texture" commonly refers to the sizes of the particles that make up a surface deposit or soil. But the term also refers to the size and shapes of the particles and their arrangement, or packing. The three features determine the porosity of a surface deposit or soil (Hunt, 1972).

3.6.6 **Soil structure**

The term soil structure is used to refer to the forms assumed by aggregates of particles, whether in soils or surface deposits, and to the partings that separate aggregates (Hunt, 1972). The various natural structural forms are intermediate between two non-structural extremes that are loose, single grains, without any cohesiveness, and massiveness due to uniform cohesion of particles. Soil structure is to a considerable degree controlled by the kind and amount of clay and its moisture content. There are eight principal kinds of soil structure and some terms are burrowed from agriculturists (U.S.D.A.) soil survey manual (195). These are such as: (i) loose single grains without cohesiveness, (ii) crumb, (iii) platy, (iv) prismatic or columnar, (v) blocky, (vi) granular, (vii) nodular, (viii) tabular (Hunt, 1972).

Macvicar *et al.,* (1977) denoted that structure refers to the natural aggregation of primary soil particles into compound units or peds, which are separated from one another by planes of weakness.

3.6.7 **Soil depth**

Ellis (2000b) proposed that trees need a minimum usable depth (also known as effective rooting depth or ERD) of the soil in which roots can develop to take up sufficient water and nutrients for good tree growth. Many soils, however, have some limitation, e.g. wetness, a dense clay layer, an indurated pan or hard rock that limits the usable soil depth. The nature and extent of such limitations can only be determined by a soil survey. Effective soil depth is a difficult and controversial issue to deal with in soil and land evaluation. Depth must be rated on a continual basis and other physical and chemical limitations must be ranked to decide what utilisable soil depth is.

It has been discovered that, ERD is the most influential variable in predicting growth potential of black wattle. It occurs in all the models relating soil factors to site index (SI). Other soil factors showing apparent direct casual relationship with SI are phosphorus P, potassium K, and carbon contents of the top soil (Schonau and Aldworth, 1991; Louw, 1991; Noble *et al*, 1991).

3.6.8 **Soil colour**

The study of soil colour is important because it shows some of the features of the soil. Soil colour may be influenced by the presence or lack of organic matter, by minerals such as iron oxides and carbonates, by the stage of soil development, and by water logging and poor aeration conditions. Soil colour is determined by using the standard colour charts known as "Munsell colour chart" (Rooyani and Badamichian, 1986).

Smith (1995) and Du Plessis (2002) stressed that the principles in the identification or interpretation of soils by using their colour are: (i) soils are usually darker than sub soils due to organic matter enrichment, (dark colours may also be the indication of a dry climate such as in case of base rich melanic or vertic top soils), (ii) grey top soils indicate poor drainage in the sub soil, sub soil colour changes from red through yellow to grey, blue and green (gleyed) when the top soils get more saturated with water, less aerobic and often more reduced in iron element.

Erasmus and Maclennan (1998) stated that forestry industry soils database normally utilises general soil colour with the option to determine the degree of colour intensity. Colour is one of the most obvious physical properties of soils and surface deposits. Many black soils contain little organic matter, some yellow and brown soils contain little hydroxide, the colouring can be caused by organic compounds (Hunt, 1972).

3.6.9 **Wetness**

Ellis (2000b) stipulated that wetness is defined as the presence of free water occurring for some periods within normal reach of tree roots in soils. The limitation wetness places on the growing of pines, wattle and eucalypts has not been successfully realised in South Africa. He indicated that wetness causes low oxygen and increased carbon dioxide in soils with active root respiration. Another negative effect is the reduction (and thereby mobilization) of iron compounds. Where there is lateral flow (i.e. perched water tables), the iron can be leached from the soil, with or without clay, causing a bleached soil.

Jacobs *et al.,* (1989) defined wetness as the presence of free water occurring during prolonged periods of the year within reach of the tree roots. Primarily, two kinds of wetness hazards that are caused by a perched water table, mostly due to poor drainage in the sub-soil and those caused by permanent water bodies in the area such as pans, vleis and rivers.

3.6.10 **Soil fertility**

(Rooyani and Badamichian, 1986) noted that, the world's arable lands are limited, therefore there is a need for necessary measures to increase production. On the other hand, Noble *et al.,* (1991) and Herbert (1991) and Wilde *et al.*, (1964) observed that, plant nutrients and soil reaction to chemical processes all influence tree growth, specifically the development of the root system. Du Toit and Carlson (2000) detected that, the inherent nutrient supplying capacity of sites differ because of differences in soil parent materials and organic matter content, climate and silvicultural management practices in order to boost the rate of mineralization of organic matter.

Herbert (1991) emphasized that, although foliar analysis is commonly used to diagnose the nutritional status of trees and their ability to respond to fertilising, it is also a measure of site type and quality. In his study, he discovered that, soil factors strongly influence the foliar nutrient content of *Eucalyptus grandis*, and in a way that is consistent with the current understanding of soils. Foliar analysis is thus confirmed as an important tool for determining the nutritional status of sites and predicting where nutritional problems are likely to occur. Climatic factors, although successfully explaining variations in concentration for some of the foliar nutrients, failed to yield additional information to soil analysis. However, temperature and rainfall are closely related to soil organic matter content.

3.6.11 **Available soil water**

For healthy growth, plants require water. Good agricultural soil should contain (by volume) about one-half solid material, one fourth to one third water, and one fourth to one-sixth air (Hunt, 1972). Plants cannot survive without water. Plants need water because water is a major constituent of plant tissue. About 90% of the protoplasm is water. The most important plant process, photosynthesis, cannot take place without water (Rooyani and Badamichian, 1986).

Bowden (1991) alleged that water is undoubtedly the primary factor limiting tree growth in Southern Africa. *E. grandis* is no exception and, being highly intolerant of adverse conditions, indicates substantial declines in growth when planted on shallow soils and/or on dry sites. Furthermore, the numerous reports of yields declining during some second or subsequent rotations of *E. grandis* may well be due to insufficient available water once initial soil water reserves have been utilised. It is clear therefore that the influence of site and particularly soil water availability.

In areas where soil water is a crucial factor, the modern day silviculturist might find it necessary and economical to resort to the choice of tree species, which use less water. The use of site preparation methods, which conserve the water on site and imposition of fallow periods between successive rotations (Bowden, 1991)

3.6.12 **Organic carbon content**

Organic matter affects many of the physical properties of the ground. At the surface, the layer forms an insulating mat that helps retain moisture and protects the ground against compaction and washing. The surface layers are made porous by the burrows of insects and larger animals and by the decay of roots (Hunt, 1972). Rooyani and Badamichian (1986) declared that organic materials are added to soils naturally or artificially. The major component of organic matter is carbon.

According to Walkley (1947), there are many ways of detecting the organic matter content of the soil. The classic approach is by a wet-oxidation technique known as the Walkley-Black method. This is commonly the method against which all other determinations of soil organic carbon content are compared. In a number of laboratories, it is the only recognisable tool to be used when organic carbon contents are low (< 4%).

Contrarily, Jackson (1962) defined soil organic matter as the readily oxidisable organic matter present in a soil known as humus, as well as highly condensed, nearly elemental organic carbon such as charcoal, graphite or coal. Moreover, he indicated that the soil organic carbon content is calculated as a proportion of soil organic matter. The conventional conversion factor of converting carbon to organic matter factor is 1,724.

Donkin *et al.*, (1993) broadly detected that forestry top soils from Zululand, Kwa Zulu-Natal, south Africa, have an organic carbon content of less than 1%, while those from the other forestry regions frequently have carbon contents greater than 2%. On the one hand, Zahner (1962) observed that site quality for loblolly pine on well-developed zonal soils increases with clay content of the sub-soil to a level of about 35% clay, thereafter decreases with further increases in clay. Trees on light and heavy sub soils could be expected similarly to differ in root development and underground competition.

3.6.13 **Soil particle density**

Soil particle density is the ratio between the mass of the solid phase of the soil and the volume of the solid phase, that is, the volume occupied by pore space is excluded. The minerals forming the solid phase of the soils are predominantly quartz, feldspar, mica and silicate clays. Because the density of such minerals is more or less close to 2,65 g/cm^3. The average particle density of the most soil minerals is considered to be 2,65 g/cm^3. It should be noted that, soils with large amounts of iron and aluminium oxides have a particle density of more than 2,65 g/cm^3 (Rooyani and Badamichian, 1986).

3.6.14 **Soil bulk density**

Bulk density of the soil is the ratio between dry mass of soil solids and the total volume of the soil including pore space. Because, the total volume of the soil is larger than the volume of the only solid phase, it drives that, the bulk density of a soil is smaller than particle density; that is smaller than 2,65 g/cm^3. The higher the percentage of the pore space, the lower will be the bulk density. Soils rich in organic matter and soils with large amounts of fine particles have a lower bulk density compared to the soils poor in organic matter and rich in sand particles (Rooyani and Badamichian, 1986).

3.6.15 **Soil pore space**

The fraction of soil volume occupied by air and water is considered the pore space of soil. That is the proportion of soil not occupied by soil solids (particles) and soil organic matter. The shape of the particles, their size, and soil aggregation determine the amount and size of pore space. In a fine texture soil, the pores are small; and therefore the movement of water is very slow. However, in a coarse texture soil, the pores are large and water moves rapidly through soil profile. A medium texture soil, rich in organic matter, and aggregation, provides ideal amount and size of pore space. The pore space of the soil is calculated as (Equation 1):
Pore space (%) = 100 - (bulk density/particle density) *100 ....**Equation 1**
(Rooyani and Badamichian, 1986).

3.6.16 **Soil consistency**

Soil consistency is a term used to describe the behaviour of soil under different conditions. Soil consistency has a highly practical significance. Some soils lack aggregation and are loose when dry and moist (sandy soils). Other soils become very sticky when wet and form hard clods when dry. It is very important for a farmer, agriculturists, engineers, foresters and planners to know about the behaviour his/her soil under different moisture conditions (Rooyani and Badamichian, 1986).

Cultivation practices and farming operations should be executed when an optimal soil moisture status exists. Clayey soils should be ploughed and worked with when wet. The same soils become extremely hard when dry, and the condition makes it difficult to work such soils. Soil consistency is therefore a property that determines the workability of soils. Consistency is described under three moisture conditions: (i) dry – loose, soft, hard, very hard and extremely hard. (ii) moist – loose, very friable, friable, very firm, and extremely firm. (iii) wet –

stickiness and plasticity. A description of soil consistency is made by working the soil sample between the thumb and fingers (Rooyani and Badamichian, 1986).

3.7 **Native Vegetation**

3.7.1 **General information on vegetation**

Vegetation types reflect changes in climate and soils. They can best be described by reference to three major geomorphic landforms: lowlands, foothills and mountains. The lowlands below the elevation of 1680 m a.s.l have a MAP of 600 to 800 mm. Most of the land that is suitable for farming is being used for the production of maize, wheat, sorghum, sunflower, potatoes, beans, peas, asparagus, lucerne and other crops. Only rough lands have remnants of native vegetation, in small-protected areas, there are good patches of thatching grass (*Hyparrhenia spp.)* (Conservation Division, 1977).

On the one hand, Acocks (1975) compared vegetation of Lesotho in A.D. 1400 as being dominated by sweet grassveld in the highlands and mixed grassveld in the lowlands. Furthermore, he indicated that vegetation of Lesotho in A.D. 1950 was primarily occupied by scrubby mixed grassveld and mixed grassveld in the highlands. The mixed grassveld and a small portion of sour grassveld cover the lowlands.

3.7.2 **Native grasses, shrubs, bushes and trees**

Most of the native vegetation in the lowlands is considered increasers, and the condition of the range is fair or poor. The more common grass species (increasers) are *Eragrostis spp., Digitaria spp., Aristida spp., Andropogon spp., Heteropogon contortus, and Themeda triandra.* Invaders include all annual grasses and forbs. The more common species are *Chloris virgata, Eragrostis teff, Poa anna, Seteria verticiliata, Schismas barbatus, and Sporoblus discosporus.* The common unpalatable scrub species are (sehalahala): *Chrysocoma tenuifolia, Leucosidea serecia* (chechebush), *Celtis kraussiana* (stinkwood), and *Olea verrucosa* (wild olive). These scrubs rapidly invade overgrazed and other disturbed areas and reduce the more palatable forage of the range (Conservation Division, 1977).

The foothills areas have elevations of 1680 to 2300 m. The MAP is different from the lowlands. Most of the native grassland is heavily overgrazed and many of the climax species are lacking. Occasionally there are a few small-protected areas where dominant vegetation is composed of key decreaser plants such as *Cymbopogon spp., Digitaria eriantha, Harpechloa falx, Hyparrhenia spp., Panicum maximum, Pennisetum spp., Phalaris arandinacea* and *Trachypogon spicatus.* Most of the rangeland in the foothill area is in fair to poor condition and nearly all decreaser plants are lacking. The current vegetation is made up of mostly increaser and invader plants. The key increaser plants are *Aristida spp., Brachiaria serrata, Cynodon dactylon, Digitaria spp., Eragrostis spp., Heteropogon contortus, Merxmullera spp. (Danthonia), Paspalum spp., Seteria spp., Sporobolus fimbriatus and Themeda triandra.* Invader plants include all annual grasses and forbs as well as unpalatable scrubs. The more common invaders are *Bromus japanicus, Chloris virgata, Digitaria spp., Eragrostis teff, Lolium spp., Panicum laevifolium, Pentachistis airoides, Phalaris canariensis, Poa annua, Seteria spp., Sporoblus discosporus* and *Tragus racemous.* The more common unpalatable scrubs include *Chrysocoma tenuifolia, Leucosidea serecia, Celtis kraussiana and Olea verrucosa.* These plants rapidly invade overgrazed or disturbed areas and rduce the more palatable forage of the range (Conservation Division, 1977).

In the mountain areas, generally above 2300 m, MAP ranges from 600 to 1200 mm. Only small patches are suitable for farming. Most of the native grassland is heavily overgrazed and many climax species are lacking. Occasionally, in small-protected areas, there are a number of key decreaser plants such as *Bromus leptoclados, Bromus speciosus, Poa binata* and *Seteria nigrirostris.* At higher elevation many of the taller growing species such as *Harpechloa falx* and *Hyparrhenia spp.,* or lacking. For most part, the current vegetation is made up of increasers or invaders. The key increasers are *Festuca spp.,* some *Eragrostis spp., Merxmullera spp. (Danthonia), Pentashittis spp., Sporobolus centrifuges, Themeda triandra* and *Trichoneura gradiglumis.* The invader plants include all annual grasses and forbs as well as unpalatable scrubs such as *Chrysocoma tenuifolia, Leucosidea serecia, Celtis kraussiana, Olea verrucosa, Erica cafforum* and *Pentzia cooperi.* There are a number of annual forbs and grasses that are also invaders, which occupy heavily overgrazed and disturbed areas. The species composition changes with elevation (Caroll and Bascomb,1979; Conservation Division, 1977).

CHAPTER FOUR

MATERIALS AND METHODS

4.1 **Materials**

Materials included: woodlot maps, woodlot registers, hypsometer, suunto clinometer, suunto compass, soil auger, shovel, tapes, paint, brush, squared grid paper, maps, protractor, GPS, fence standard pole, fence standard drive, munsell soil colour chart book, water, 1,3 m stick. The function and operation of the above mentioned materials are explained in section 4.2.2.

4.2 **Methods**

4.2.1 **Permanent sample plot (PSP) procedures**

Information was collected on all woodlots surveyed recently from woodlot registers, related master files and reports from District Forest Offices and Head Forest Office. Woodlots were then grouped or classified according to different climatic zones and stratified according to site type.

After determining the woodlot and compartment within which a PSP is to be located, a plot was randomly positioned. New positions were located if insufficient number of thus existed in a random location. A squared grid paper was laid over compartment of interest to select random location of a plot. A prominent object such as woodlot corner or boundary was identified on the map. This served as an access point to the plot centre after which the bearing (grid bearing) and distance to the plot centre were recorded on the map.

4.2.2 **Field procedure**

After identifying the access point on the ground, the plot centre was determined using the suunto compass for magnetic bearing. A global positioning system (GPS) was used to measure the grid coordinates of the plot centre. A thirty-metre tape was used to measure distance where the plot centre had been located. The plot centre was permanently marked by driving in fence standard pole halfway in the ground and painted white to make it visible for subsequent visits to the plot.

A circular plot of 11,28 m radius was established. Diameter at breast height (DBH) of all trees lying within a plot were measured with a diameter tape, starting with the tree nearest to magnetic north and moving in a clockwise direction. Heights (HTs) of four trees with the largest DBHs were measured using the hypsometer or the height rod. The plot area was 400 m² (0.04 ha). A white band was painted on all trees measured. The distance and bearing of each tree from the plot centre was also recorded using the 30-metre tape and Suunto compass respectively.

A soil sample was taken within the plots using a shovel or soil auger. The soil horizons were identified, their colour, texture, consistency were recorded. The munsell soil colour chart book was used. The soil depth was recorded and classified (Table 1).

Table 1: Classification of soil samples by depth class and soil depth

Depth class	**Soil depth (cm)**
A	0 to 50
B	50 to 100
C	Greater than 100

The under storey vegetation was identified by recording botanical and common names of the dominant species. The angle of slope was then measured by using a Suunto clinometer and 1,3 m stick. The plot aspect was recorded.

The permanent sample plots were visited after every two years to carry out periodic assessments. At rotation age, final assessments were carried out, and then trees were felled and used as pre-felling tariff tables. All trees within plots were subjected to exactly the same silvicultural treatments carried out within compartments.

Maintenance work was executed every year. This involved repainting white bands on trees within the plots. The access point and plot centre were also repainted. This exercise was conducted to ensure that every plot location could be easily spotted out and to improve the work output and quality.

4.3 **Uses Of Permanent Sample Plots**

A permanent sample plot is defined as a system whereby a plot centre is marked permanently on the ground in the forest stand or plantation of two years or above, in order to enable periodic measurements to be conducted up to rotation age (Moshoeshoe, 1987).

The permanent sample plots are required for different reasons: (i) in national inventories they serve as essential components of continuous forest inventories, (ii) in growth and yield modelling, they are indispensable to supply stand data being used for models construction (Van Laar, 1997); and moreover, they have the main objective of establishing a system of permanent sample plots in African plantations to construct reliable growth and yield models for plantation forestry. The models are designed to estimate either growth or yield per unit area from stand variables, which are usually age, site index and stand density. Further, the construction of yield tables is one way to numerically express the relationship between yield and age, for different site index categories and stand density variables.

In a parallel vein Shiver and Borders (1996) connoted that permanent sample plots are invaluable for obtaining information on changes that occur in a forest. Most permanent sample inventories are based on a continuous forest inventory (CFI) system developed by U.S. Forest Service at the beginning of the mid 1930s. This system originated as a method of recording growth and mortality as a basis for encouraging sustained timber operations on large industrial and public land holdings. The CFI system of permanent sample plots were originally laid out systematically over property on a rectangular grid, one-fifth per acre in size and circular on each plot with a separate record maintained for each tree in the plot.

Similarly, Avery and Burkhart (1976; 1994) indicated that the periodic remeasurement of permanent sample plots is considered statistically superior to successive independent inventories for assessing changes in forest conditions. Moreover, they highlighted that when the same sample trees were reassessed, sampling errors associated with the variations are appropriate to be lower and the precision of change estimates is improved.

In another argument, (Bird, 1984; Bazill, 1985; Moshoeshoe, 1987) stressed that permanent sample plots data is utilised to study or assess: (i) the behaviour of tree stands at different sites and treatments, (ii) tree forms, tree volumes, basal area, top heights and tree diameter at varying densities, for each and every individual tree species, (iii) growth rate at different density regimes.

In summary PSP information is therefore normally utilised for the following objectives:
(i) to determine the pre-felling tariff tables, volume tables prior to harvesting of mature forest stands/plantations (Avery and Burkhart, 1976, 1994; Clutter *et al.,* 1983; Van Laar and Akca, 1997);
(ii) for the preparation of a forest management to ensure the proper sustenance of the growing stock and forest resources (Husch *et al.,* 1992, 1993; Chiswell and Pienaar, 1999; Du Plessis, *et al.,* 1997);
(iii) for the construction of growth and yield models which are essential for planning, implementation, controlling and prediction of current and future operations (Husch *et al.,* 1992, 1993; Kotze, 2000; Vanclay, 1994).

It was further concluded by a number of authors that while constructing PSPs, the following principles or practices should be followed or applied:
(i) all the trees within the plot should be given the same silvicultural practices for the entire compartment (Moshoeshoe, 1987; Avery and Burkhart, 1976, 1994; Husch *et al.,* 1992, 1993; Vanclay *et al.,* 1995) and (Figure 8);
(ii) The field plots must cover the forest region for which inferences are made.

Figure 8: Silvicultural treatments applied to permanent sample plot (ER/1021/1)

4.4 **Sampling Design**

Shiver and Borders (1996) defined sampling as the process of obtaining information by examining only a portion of the whole. Furthermore, they emphasised that because of time and financial limitations, sampling, rather than 100% inventories will be a necessity in most forestry situations when information is needed. The various structures of forests and stands to be inventoried, and various objectives for various inventories, led to the development of various sampling techniques.

Adding to the debate Husch *et al.*, (1993) denoted that the sampling design is based on the type of sampling units employed, and the way that the sampling units are selected and how they are distributed over the forest area, as well as the means of taking measurements and analysing the results. The specifications for each of these elements can be altered to produce the needed precision at a minimum specified cost. Moreover, they indicated that basic inventory designs broadly fall into the following categories:

A Probability sampling

(i) simple random sampling, (ii) stratified random sampling, (iii) multistage sampling, (iv) multiphase sampling (v) sampling with varying probabilities;

B. Non-random sampling

(i) selective sampling, (ii) systematic sampling.

Some of the following guidelines are significant when sampling design and data collection is undertaken:

(i) various stand factors such, as parameter stand density per hectare must be highly taken into consideration. Poor stocked areas must be eliminated because they might yield unreliable results, which are not useful for the study;

(ii) the sample must be the representative of the site conditions of the study site;

(iii) the PSPs must cover the geographical spread of the study area (Du Plessis, 2002).

4.4.1 **Plot area and shape**

There are some major guidelines followed when selecting the plot and its layout:

(i) all the plots have the same area of 0,04 ha;

(ii) the plot size must remain constant for the whole life of the compartment;

(iii) a global positioning system (GPS) was utilised to assess the location (grid references) of the plot centre;

(iv) every plot was allocated a code number in order to allow the other assessments of the similar tree in order to increase the efficiency and accuracy of the data (Moshoeshoe, 1987).

4.4.2 **Measurement of the plot**

Recording must be undertaken by skilled, reliable persons in order to ensure the collection of meaningful data. There are some hints to be followed for the assessment of trees:

(i) the diameter of every tree at breast height (1,3 m) from ground level was assessed;

(ii) the heights of the four trees with largest DBHs were assessed;

(iii) the assessment rule and direction of the trees were uniform for every assessment, the last records as well as the plot map were utilised as a field guide (Moshoeshoe, 1987; Du Plessis, 2002);

(iv) the state of every tree and its stem form were measured (Table 2);

(v) tree assessments were executed periodically and sometimes yearly (Moshoeshoe,1987; Chiswell and Pienaar, 1999; Du Plessis, 2002).

Table 2: Tree characteristics of permanent sample plots in Lesotho

Characteristics	**Classes**
Condition	1 = live, 0 = dead
Stem form	0 = straight, 1 = crooked
Stem number	0 = single, 1 = multiple
branching	0 = light, 1 = heavy

The tree and plot level parameters assessed and noted are provided in tables 3 and 4.

Table 3: Tree level parameters assessed and noted.

Parameter	**Procedure**	**Unit**	**Accuracy**
Tree number	Note every tree position within a plot	number	Should be uniform in each assessment
DBH	Diameter at breast height (1,3 m)	cm	To the nearest 0.1 cm
Height	Tree height to the growing tip – measured with a height rod.	m	To the nearest 1 cm
Stem number	Mark every stem at each tree location	number	Should be uniform in each assessment.

Table 4: Plot level parameters assessed and noted

Parameter	**Procedure**
Plot co-ordinates (grid references)	Use a GPS to measure in (degrees, min, sec)
Plot number	Code number
Woodlot	Woodlot name
Compartment	Compartment number
Species	Tree species name
Soil factors	Soil depth, texture, colour etc.
Planting date	Planting date of the compartment
Assessment date	Assessment date of the plot
Silvicultural and management operations	Note what activities were done in the plot.
altitude	Distance from sea-level (m)
Aspect	Dominant facing aspect (degrees)
Slope, topographical position of the plot	Assess the slope in the direction of the steepest gradient (degrees/ percentage)
Plot size and shape	Measure the plot radius with a tape (m)
Stand parameters	Define spacing of the trees (m)
Vegetation	Note vegetation within the plot

4.4.3 **The assessment of trees**

The primary growth parameters utilised in this study:

(a) Diameter at breast height (DBH) was assessed in cm, over the outside bark to the nearest decimal place, with a caliper or tape placed around the stem at 1,3 m height from the ground level. The information utilised for the study mainly refers to the mean DBH of a stand which is normally the arithmetic mean DBH of a sample n, and is defined by the following equation (Equation 2):

$$\text{DBH} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad \text{-- } \textbf{Equation 2}$$

This formula gives an unbiased estimate of the population mean based on the point that random sampling is contented (Snedecor and Cochran, 1980; Du Plessis, 2002). This is restricted to particular types of trial investigations, mainly fertiliser experiments small genetic variation testing.

Rollinson (1988) and Bredenkamp (2000a) described the mean DBH of a stand which is also called the quadratic mean DBH and calculated in this manner (Equation 3):

$$D_q = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}}$$ .... **Equation 3**

(b) Height – The top height (HTOP) of a stand is defined as the average of the total heights of a number of trees in the stand of largest dbh. This is not necessarily the tallest tree (Rollinson, 1988). The HTOP can also be described as the regression height of the 20% biggest diameter trees (Bredenkamp, 2000a).

The height of tree (HT) is normally needed to obtain or find the site index (SI) of the PSP and height or diameter and age relationship to estimate the growth of trees, their volume. The HTOP is generally considered as the significant parameter for immediate suggestions, analysis and pre-conclusions on tree growth in many field experiments. It has been detected that the mean height at a certain reference age, and is a good measure of the site quality. Height is also not affected by silvicultural practices such as thinning (Husch *et al,* 1992; 1993).

The total tree height was used to estimate the following parameters: tree volume, SI etc. This formula was used to estimate the individual tree height of *Eucalyptus rubida* PSPs (Equation 4). It was detected that R^2 is very low and the second one (Equation 5) was preferred:

$\text{Ln HT} = b_0 + b_1 * \text{DBH}^{-1}$ .... **Equation 4**

$\text{HT} = b_0 + b_1 * \text{DBH} + b_2\text{Age}$ .... **Equation 5**

Where:

HT = Tree height in m

DBH = Diameter at breast height in cm over-bark (1,3 m) from ground level.

Age = years from planting

b_0, b_1, b_2 = coefficients

In the same manner, equation 5 was used for predicting individual tree heights for *P. radiata* and it was found that R^2 is not high enough and it is not a good fit model and it was left out and another HT- DBH regression equation (Equation 6) was preferred as shown below.

$HT = b_0 + b_1*DBH + b_2*DBH^2 + b_3*(Age/12)$.. **Equation 6**

(c) Age - is described as the elapsed time since germination of the seed or time since the budding of the sprout or cutting from which the tree evolved (Avery and Burkhart, 1976; 1994). Data about age of the forest was obtained from woodlot registers and forest management plans.

(d) Stems per hectare (SPH) was estimated for every PSP by simply measuring the area at the time of plot assessment. SPH was calculated by a simple equation (Equation 7). SPH is normally associated with stand density (Bredenkamp, 2000b).

SPH =(number of stems per plot/plot size (m^2))*10000............................ **Equation 7**

(e) Trees per hectare (TPH) - was also found for every plot by finding the number of trees on a certain plot area at the date of measurement. It can be calculated in a similar manner like SPH.

(f) Basal area per hectare (BAH) - the tree basal area is the cross-sectional area of the tree stem normally estimated at breast height (1,3 m) from ground surface (Rollinson, 1988; Clutter *et al*, 1983). All the measurements were taken from circular plots of every PSP.

(g) Volume (VPH) - the individual tree volume was estimated using different formulas based on the Schumacher and Hall model (Schumacher, 1939; Bredenkamp, 2000b). *Eucalyptus rubida* was not among the species that were commercially researched by the South African Research Institutes recently, therefore the equation of *Eucalyptus maidenii* was used (Equation 8).

$Ln\ Vol = b_0 + b_1 * Ln\ (DBH) + b_2 * Ln\ (HT)$ .... **Equation 8**

Where:

Ln = natural logarithm to the base e

Vol = stem volume under-bark (m^3), usually to 75 mm tip diameter

DBH = over-bark breast height diameter (cm)

HT= tree height (m)

Authors of original volume equations of different commercial species in South Africa are as follows: *E. nitens* (Bredenkamp, 1994) *E. macarthurii* (Schonau, 1982; Pienaar, 1996), *P. pinaster, P. radiata* (Loveday, 1984).

Stand volume represents the total of the individual tree volume; the best prediction is through the mean tree volume, the number of trees, form of trees, mean height and basal area (Bredenkamp, 2000b; Clutter *et al,* 1983). This can be estimated as stem or tree volume, total or merchantable volume, over or under bark volume. The volume of the stand can be estimated from HTOP and mean DBH parameters.

(h). Site Index (SI) - information of the growth responses of the forest trees to the conditions of the environment is significant to forest management. The forester can utilize this information to recommend the growth of desirable species. SI is explained as the relationship of tree HT to age (Husch *et al,* 1993; Van Laar and Atkca, 1997). SI also quantifies the combined effect of soil factors and climatic variables and expressed in terms of dominant height at a fixed reference age (Van Laar, 1997).

4.5 **Permanent Sample Plots Data Sets And Preliminary Analysis**

4.5.1 **Data from tree measurements**

There were 86 permanent sample plots used for this study. There are 33 PSPs of *Eucalyptus rubida,* 44 of *Pinus radiata,* 4 of *E. macarthurii,* 3 of *Pinus halepensis,* 1 of *Eucalyptus nitens* and 1 of *Pinus pinaster.*

The allocation of plots to the agro-ecological zones is also shown in (Table 5). The PSPs code numbers and their location in different parts of Lesotho, as well as the number of assessments are provided in Table 7, 8, 9, 10, 11 and 12. In total, 33 plots of *E. rubida* were assessed 123 times and there were 7771 individual tree measurements. The 44 PSPs of *P. radiata* were measured 180 times and individual tree measurements made a sum of 8305. Meanwhile, there are 111 individual tree assessments for *P. pinaster* with 4 measurements conducted. There are 786 individual tree measurements of *E. macarthurii* with 3 assessments carried out. *E. nitens* had 270 individual tree assessments with 4 measurements executed. There are also 541 individual tree measurements and 5 assessments done for *P. halepensis*.

Eight site types were found in the agro-ecological regions where PSPs had been established (Table 5 and 6).

Table 5: Number, species and location of permanent sample plots by agro-ecological zones

Species	**lowlands**	**Foothills**	**Total**
E. rubida	11	22	33
P. radiata	26	18	44
E. macarthurii	2	2	4
P. halepensis	-	3	3
E. nitens	-	1	1
P. pinaster	-	1	1
Total	39	47	86

Table 6: Number, species and location of permanent sample plots by landforms (site types)

Landform	***E. rubida***	***P. radiata***	***E. macarthurii***	***P. halepensis***	***E. nitens***	***P. pinaster***
Basaltic slopes	3	8	-	3	1	1
Structural sandstone plateau (top)	17	2	1	-	-	-
Debris slope	3	11	2	-	-	-
Lowland hill crest	2	4	-	-	-	-
Lowland hill lower slopes	6	8	-	-	-	-
Alluvial terraces	1	5	-	-	-	-
Dolerite hills	1	5	1	-	-	-
Senqu gorge	-	1	-	-	-	-
Total	33	44	4	3	1	1

Table 7: Plot code numbers, location and assessment dates of *E. rubida* permanent sample plots

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
ER/5002/1	28°52'23"	28°17'07"	Butha-Buthe	4b	11/84, 11/86,11/88, 11/90
ER/1021/1	29°30'35"	28°40'03"	Ha Khoeli	2	4/86, 4/88, 4/90
ER/1007/1	29°18'25"	27°37'01"	Ha Tonki	1	6/84, 6/86, 6/88
ER/1007/1a	29°18'25"	27°37'25"	Ha Tonki	1	10/90
ER/1007/2	29°18'26"	27°37'01"	Ha Tonki	1	6/84, 6/86, 6/88
ER/4011/2	29°04'09"	27°55'15"	Hlajoane	2b	10/84, 10/86, 10/88
ER/2013/1	28°47'47"	28°11'23"	Koenaneng A	1b	7/84, 7/86,
ER/2013/1a	28°47'47"	28°11'23	Koenaneng A	1b	12/88, 12/90, 12/92
ER/4001/1	29°14'05"	27°35'49"	Leshoboro Plateau	3b	5/84, 5/86
ER/4001/2	29°14'03"	27°35'46"	Leshoboro Plateau	2f	5/84
ER/4001/2a	29°14'03"	27°35'46"	Leshoboro Plateau	2f	9/86, 9/88
ER/4001/2b	29°14'03"	27°35'46"	Leshoboro Plateau	2f	10/90, 10/92

Table 7 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
ER/4001/4	29°13'58"	27°35'38"	Leshoboro Plateau	7i	5/84, 5/86, 5/88, 5/90, 5/92
ER/4001/4a	29°13'58"	27°35'38"	Leshoboro Plateau	7i	9/94
ER/4001/5	29°13'58"	27°35'35"	Leshoboro Plateau	2c	9/84, 9/86, 9/88
ER/4001/6	29°14'03"	27°35'34"	Leshoboro Plateau	7i	9/84, 9/86
ER/2023/1	29°47'30"	27°10'06"	Levi's Nek	6	11/84, 11/86, 11/88, 11/90
ER/2007/1	28°55'38"	28°09'56"	Mahobong	2c	12/84, 12/86, 12/88
ER/2016/1	28°58'13"	28°06'52"	Makhoa II	1f	7/84, 7/86, 7/88 7/90, 7/92
ER/2016/2	28°58'06"	28°06'49"	Makhoa II	1f	7/84, 7/86, 7/88, 7/90, 7/92
ER/5010/1	28°38'05"	28°26'27"	Makhunoane	1b	11/84, 11/86, 12/87
ER/5010/1a	28°38'05"	28°26'27"	Makhunoane	1b	12/89
ER/1005/1	29°36'26"	27°32'49"	Matsieng	1h	9/84, 9/86, 9/88

Table 7 Cont.

Plot number	Latitude (south)	Longitude (east)	Woodlot name	Compartment	Assessment dates
ER/1005/1a	29°36'26"	27°32'49"	Matsieng	1h	11/90, 11/92, 11/94
ER/1005/2	29°36'23"	27°32'50"	Matsieng	1h	9/84, 9/86, 9/88, 1/90
ER/5006/1	28°44'18"	28°19'01"	Manamela	1h	7/84, 7/86,
ER/5006/1a	28°44'18"	28°19'01"	Manamela	1h	10/88
ER/1026/1	29°23'40"	27°38'26"	Ntlo-kholo	1f	6/84, 6/86
ER/1026/1a	29°23'40"	27°38'26"	Ntlo-kholo	1f	6/88, 6/90
ER/2019/1	28°55'10"	28°07'00"	Qokolo	1b	7/84, 7/86, 7/88, 7/90, 7/92, 2/93
ER/2019/2	28°45'10"	28°07'20"	Qokolo	1b	7/84, 7/86, 7/88, 7/90, 7/92, 2/93
ER/2006/1	28°53'59"	28°11'40"	Seetsa	1g	11/84, 1/86, 11/88
ER/2006/1a	28°53'59"	28°11'40"	Seetsa	1g	11/90
ER/2009/1	28°54'34"	28°12'02"	Serupane Plateau	7a	10/84, 9/85
ER/2009/2	28°54'46"	28°11'49"	Serupane Plateau	8a	10/84, 9/85
ER/2009/3	28°54'39"	28°11'41"	Serupane Plateau	8b	10/84, 9/85
ER/1028/1	29°24'35"	27°38'00"	Thaba-khupa	1b	10/84, 1/87
ER/1028/1a	29°24'35"	27°38'00"	Thaba-khupa	1b	1/89, 1/91

Table 7 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
ER/2012/1	28°54'12"	28°00'06"	Tsikoane Plateau	3a	6/84, 6/86
ER/2012/3	28°54'20"	28°00'20"	Tsikoane Plateau	5	6/84, 8/85
ER/2012/4	28°54'22"	28°00'24"	Tsikoane Plateau	6a	6/84, 8/85
ER/2012/5	28°54'22"	28°00'28"	Tsikoane Plateau	6a	6/84, 8/85
ER/2012/9	28°54'49"	28°01'03"	Tsikoane Plateau	17b	7/84, 7/86, 7/88, 7/90, 7/92
ER/2012/10	28°55'04"	28°00'56"	Tsikoane Plateau	19	7/84, 7/86, 7/88, 7/90, 7/92

Table 8: Plot code numbers, location and assessment dates of *P. radiata* permanent sample plots

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PR/1031/1	29°20'58"	27°36'50"	Boqate rock	2	9/84, 9/86, 9/88, 9/90, 9/92
PR/1011/1	29°27'05"	27°32'51"	Fika le Mohala	1	11/84, 11/86, 11/88, 11/90, 11/92
PR/6008/1	29°43'03"	27°24'13"	Boleka I	3	8/94, 8/96

Table 8 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PR/3033/1	30°07'53"	27°25'51"	Ha Bolokoe	2	9/87, 9/89, 9/91, 9/93
PR/1021/1	29°30'45"	27°39'59"	Ha Khoeli	5	4/86, 4/88, 4/90, 4/92, 4/94
PR/1080/1	29°30'39"	27°42'32"	Ha Khoarai	15a	8/88, 8/90, 8/92, 8/94
PR/Makoae I/1	30°22'17"	27°44'29"	Ha Makoae I	1	11/88, 11/90
PR/Makoae II/2	30°25'18"	27°48'27"	Ha Makoae II	4	1/90, 1/92, 1/94
PR/3037/1	30°06'37"	27°20'18"	Ha Mokhatla	2a	1/90, 1/92, 1/94
PR/2021/1	28°57'49"	27°43'59"	Ha 'Musi	1	8/87, 8/89, 8/91, 8/93, 8/95
PR/2021/2	28°57'48"	27°44'17"	Ha 'Musi	1	8/87, 8/89, 8/91, 8/93, 8/95
PR/3029/1	30°12'06"	27°25'13"	Ha Molefi	1	9/87, 9/89
PR/4022/1	30°05'09"	27°59'15"	Ha Posholi	4	8/88, 8/90
PR/3027/1	30°07'12"	27°29'37"	Ha Potsane	2	8/86, 8/88, 8/90
PR/1066/1	29°24'38"	27°45'27"	Ha Ramotsoane	1	8/88, 8/90, 8/92, 8/94
PR/1025/1	29°23'51"	27°38'47"	Khokhotsaneng	4	4/86, 4/88, 4/90, 4/92, 4/94

Table 8 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compart ment**	**Assessment dates**
PR/1063/1	29°35'08"	27°20'32"	Kolo Ha Ntsie	8	8/87,8/89, 8/91, 8/93, 8/95
PR/1052/1	29°34'45"	27°31'31"	Lekhoareng	1	4/86, 4/88, 4/90,4/92, 4/94
PR/2038/1	28°54'47"	28°01'41"	Lenyakoane	2	9/87, 9/89, 9/91, 9/93, 9/95
PR/2038/2	28°51'42"	28°02'45"	Lenyakoane	2	9/87, 9/89, 9/91, 9/93, 9/95
PR/4001/1	29°14'09"	27°35'36"	Leshoboro plateau	5r	9/84,9/86, 9/88,9/90, 9/92, 9/94
PR/3040/1	30°20'18"	27°43'28"	Letlapeng	1a	9/87,9/89, 9/91,9/93, 9/95
PR/3003/1	30°07'25"	27°20'48"	Liphiring	2a	9/87,9/89, 9/91, 9/93, 9/95
PR/3036/1	30°07'10"	27°22'13"	Makhineng	1	9/87, 9/89, 9/91
PR/3036/2	30°07'11"	27°22'05"	Makhineng	2	9/87, 9/89, 9/91
PR/3026/1	29°53'49"	27°37'53"	Masemouse	1	9/86, 9/88
PR/3026/2	29°53'33"	27°37'47"	Masemouse	1	9/86, 9/88

Table 8 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PR/1001/1	29°23'33"	27°33'16"	Masianokeng West	1d	9/84,9/86, 9/88, 9/90, 9/92, 9/94
PR/2026/1	28°54'20"	28°11'29"	Mokhubu	2	9/87, 9/89
PR/2026/2	28°57'26"	28°17'35"	Mokhubu	2	9/87, 9/89
PR/1048/1	29°33'42"	27°43'15"	Phomolong	2	8/88,8/90, 8/92, 8/94
PR/2014/1	29°02'50"	28°17'01"	Pontseng	1d	9/86,9/88, 9/90, 9/92, 9/94, 9/96
PR/2014/2	29°02'25"	28°16'55"	Pontseng	1a	9/86,9/88, 9/90, 9/92, 9/94
PR/5016/1	28°39'22"	28°25'15"	Qholaqhoe	2	9/86, 9/88, 9/90, 9/92, 9/94, 9/96
PR/Pulane Spring/1	30°28'20"	27°45'25"	Pulane spring	4	11/88,11/90, 11/92, 11/94
PR/3016/1	30°02'26"	27°19'00"	Ramonate	2	9/86,9/88, 9/90, 9/92, 9/94, 9/96
PR/6015/2	29°44'33"	27°21'15"	Ramokoatsi	5	11/89,11/91, 11/93
PR/Sankatana II/1	30°10'21"	27°24'15"	Sankatana II	1	1/90, 1/92, 1/94,
PR/Sankatana II/2	30°10'22"	27°24'18"	Sankatana II	2	1/90,1/92, 1/94, 1/96

Table 8 Cont.

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PR/2029/1	28°58'54"	28°08'26"	Thaba-Phatso'a	2	9/86,9/88, 9/90, 9/92, 9/94, 9/96
PR/2029/2	28°59'04"	28°08'22"	Thaba-Phatso'a	2	9/86,9/88, 9/90, 9/92, 9/94
PR/3012/1	30°00'51"	27°22'01"	Tsoloane I	2	10/84,10/86, 10/88,10/90,
PR/3012/2	30°00'56"	27°21'57"	Tsoloane I	2	10/84,10/86, 10/88, 10/90, 10/92
PR/3023/1	30°05'09"	27°31'41"	Tri-Hoek	3	5/90, 5/92, 5/94

Table 9: Plot code numbers, location, and assessment dates of *E. macarthurii* permanent sample plots

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
EM/1021/1	29°30'35"	27°40'03"	Ha Khoeli	7	4/86, 4/88, 4/90, 4/92
EM/1052/1	29°34'44"	27°31'31"	Lekhoareng	2	4/86, 4/88, 4/90, 4/92
EM/4001/1	29°13'59"	27°35'32"	Leshoboro Plateau	11	3/86, 3/88
EM/1006/1	29°38'04"	27°30'26"	Morija south	1q	4/86, 4/88, 4/90

Table 10: Plot code numbers, location and assessment dates of *P. halepensis* permanent sample plots

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PH/3026/1	29°53'33"	27°37'47"	Masemouse	2	9/86, 9/88
PH/MakoaeII/1	30°24'18"	27°43'27"	Ha Makoae II	4	1/90, 1/92, 1/94
PH/3023/1	29°08'12"	27°36'20"	Tri-Hoek	1	9//87,9/89, 9/91, 9/93, 9/95

Table 11: Plot code numbers, location and assessment dates of *E. nitens* permanent sample plot

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
EN/1080/1	29°30'39"	27°42'32"	Ha Khoarai	5	8/88, 8/90, 8/92, 8/94

Table 12: Plot code numbers, location and assessment dates of *P. pinaster* permanent sample plot

Plot number	**Latitude (south)**	**Longitude (east)**	**Woodlot name**	**Compartment**	**Assessment dates**
PP/1048/1	29°33'46"	27°43'16"	Phomolong	1	9/88, 9/90, 9/92, 9/94

Table 13: Species, number and 2 nd assessments of all *Eucalyptus* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
E. rubida	33	1727	169
E. macarthurii	4	359	6
E. nitens	1	55	0
Total	38	2141	175

Table 14: Species, number and last assessments of all *Eucalyptus* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
E. rubida	33	1608	288
E. macarthurii	4	339	26
E. nitens	1	39	16
Total	38	1986	330

Table 15: Species, number and 2 nd assessments of all *Pinus* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
P. radiata	44	1995	46
P. halepensis	3	167	3
P. pinaster	1	25	2
Total	48	2187	51

Table 16: Species, number and last assessments of all *Pinus* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
P. radiata	44	1641	400
P. halepensis	3	166	4
P. pinaster	1	22	5
Total	48	1829	409

Table 17: Species, number and 2nd assessments of *E. rubida* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
E. rubida	33	1727	169

Table 18: Species, number and last assessments of *E. rubida* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
E. rubida	33	1608	288

Table 19: Species, number and 2 nd assessments of *P. radiata* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
P. radiata	44	1995	46

Table 20: Species, number and last assessments of *P. radiata* permanent sample plots

Species	**Number of plots**	**Live**	**Dead**
P. radiata	44	1641	400

Table 21: Site types (landforms), number and 2 nd assessments of *E. rubida* permanent sample plots

Landform	**Number of plots**	**Live**	**Dead**
Basaltic slopes	3	90	10
Sandstone plateau (top)	17	843	121
Debris slope	3	95	9
Lowland hill crest	2	72	7
Lowland hill lower slopes	6	558	15
Alluvial terraces	1	33	4
Dolerite hills	1	36	3
Senqu gorge	-	-	-
Total	33	1727	169

Table 22: Site types (landforms), number and last assessments of *E. rubida* permanent sample plots

Landform	**Number of plots**	**Live**	**Dead**
Basaltic slopes	3	88	12
Sandstone plateau top	17	740	224
Debris slope	3	93	11
Lowland hill crest	2	70	9
Lowland hill lower slopes	6	550	23
Alluvial terraces	1	32	5
Dolerite hills	1	35	4
Senqu gorge	-	-	-
Total	33	1608	288

Table 23: Site types (landforms), number and 2 nd assessments of *P. radiata* permanent sample plots

Landform	**Number of plots**	**Live**	**Dead**
Basaltic slopes	5	202	0
Structural sandstone plateau (top)	1	27	0
Debris slope	11	402	12
Lowland hill crest	4	296	1
Lowland hill lower slopes	13	567	18
Alluvial terraces	5	301	2
Dolerite hills	4	163	13
Senqu gorge	1	37	0
Total	44	1995	46

Table 24: Site types (landforms), number and last assessments of *P. radiata* permanent sample plots

Landform	**Number of plots**	**Live**	**Dead**
Basaltic slopes	5	200	1
Structural sandstone plateau (top)	1	21	6
Debris slope	11	348	54
Lowland hill crest	4	260	38
Lowland hill lower slopes	13	466	147
Alluvial terraces	5	200	100
Dolerite hills	4	110	53
Senqu gorge	1	36	1
Total	44	1641	400

Table 25: A summary of site conditions/variables for *E. rubida* permanent sample plots

Plot number	**Altitude**	**Slope**	**Aspect**	**Geological/ Parent material**	**MAT**	**MAP**	**Exposure**	**Soil depth**	**Soil texture**
ER/5002/1	1868	4°	365°	Sedimentary	14	902	2	> 1m	Sandy loam
ER/1021/1	1887	5°	271°	Arenite	14	597	2	> 1 m	Clay loam
ER/1007/1	1665	10°	239°	Arenite	13	792	2	> 1 m	Sandy loam
ER/1007/2	1665	9°	231°	Arenite	13	792	2	> 1 m	Sandy loam
ER/4011/2	1645	5°	205°	Sandstone	14	724	2	> 1 m	Sand
ER/2013/1	1723	15°	294°	Arenite	14	814	1	± 1 m	Loam
ER/4001/1	1777	0°	360°	Limestone	14	743	2	> 1 m	Sand
ER/4001/2	1775	8°	276°	Limestone	14	743	2	< 1 m	Sandy loam
ER/4001/4	1792	6°	189°	Sandstone	14	743	2	> 1 m	Sand
ER/4001/5	1792	6°	91°	Arenite	14	743	2	> 1 m	Sandy loam
ER/4001/6	1802	4°	300°	Silcrete	14	743	2	< 1 m	Sandy loam
ER/2023/1	1764	25°	230°	Siltstone	14	639	2	>1 m	Clay loam

Table 25 Cont.

Plot number	**Altitude**	**Slope**	**Aspect**	**Geological/ Parent material**	**MAT**	**MAP**	**Exposure**	**Soil depth**	**Soil texture**
ER/2007/1	1676	9°	59°	Limestone	14	841	1	> 1 m	Sand
ER/2016/1	1657	11°	55°	Arenite	14	835	1	> 1 m	Loamy sand
ER/2016/2	1657	8°	75°	Conglomerate	14	835	1	> 1 m	Sand
ER/5010/1	1894	12°	110°	Conglomerate	13	834	2	± 1 m	Clay loam
ER/1005/1	1667	3°	170°	Limestone	14	741	1	> 1 m	Clay
ER/1005/2	1664	5°	148°	Arenite	14	741	1	> 1 m	Clay
ER/5006/1	1788	11°	158°	Pyroclastic Breccia	14	710	1	> 1 m	Loamy sand
ER/1026/1	1654	21°	263°	Siltstone	14	710	1	±1 m	Clay loam
ER/2019/1	1617	27°	245°	Mudstone	14	786	1	±1 m	Sandy loam
ER/2019/2	1614	24°	31°	Rhyolite	14	763	1	± 1 m	Sandy loam
ER/2006/1	1743	15°	90°	Dolerite	14	810	2	< 1 m	Clay loam
ER/2009/1	1808	4°	15°	Basalt	14	827	2	± 1 m	Sandy loam
ER/2009/2	1798	9°	60°	Conglomerate	14	827	2	> 1 m	Sandy loam
ER/2009/3	1799	4°	65°	Rhyolite	14	827	2	±1 m	Loam
ER/1028/1	1687	8°	37°	Basalt	14	686	1	± 1 m	Clay loam
ER/2012/1	1840	3°	174°	Basalt	14	803	2	> 1 m	Clay loam
ER/2012/3	1837	2°	325°	Pyroclastic Breccia	14	803	2	> 1 m	Clay loam
ER/2012/4	1846	2°	340°	Basalt	14	803	2	> 1 m	Clay loam
ER/2012/5	1848	7°	70°	Granophyre	14	803	2	> 1 m	Sandy loam
ER/2012/9	1849	7°	30°	Mudstone	14	803	2	> 1 m	Sandy loam
ER/2012/10	1864	2°	120°	Arenite	14	808	2	> 1 m	Loamy sand

Table 26: A summary of site conditions /variables for *P. radiata* permanent sample plots

Plot number	**Altitude**	**Slope**	**Aspect**	**Geological parent material**	**MAT**	**MAP**	**Exposure**	**Soil depth**	**Soil texture**
PR/1031/1	1544	8°	140°	Shale	14	744	1	> 1 m	Clay loam
PR/1011/1	1606	10°	110°	Mudstone	14	722	1	> 1 m	Sandy loam
PR/6008/1	1704	5°	73°	Mudstone	14	693	1	±1 m	Sandy loam
PR/3033/1	1513	4°	54°	Arenite	14	626	1	> 1 m	Sand
PR/1021/1	1896	10°	338°	Shale	13	777	2	±1 m	Clay
PR/1080/1	1890	11°	112°	Mudstone	13	772	2	±1 m	Loamy sand
PR/Makoae I/1	2234	25°	348°	Shale	13	673	2	> 1 m	Clay loam
PR/Makoae II/2	2231	20°	349°	Shale	12	533	2	> 1 m	Clay loam
PR/3037/1	1515	15°	97°	Arenite	14	646	1	> 1 m	Clay loam
PR/2021/1	1547	21°	175°	Arenite	15	674	1	> 1 m	Sandy loam
PR/2021/2	1542	24°	178°	Arenite	15	674	1	> 1 m	Sandy loam
PR/3029/1	1607	16°	182°	Arenite	14	613	2	± 1 m	Sandy loam
PR/4022/1	1673	12°	179°	Arenite	14	660	2	± 1 m	Clay loam
PR/3027/1	1597	22°	216°	Arenite	13	662	1	±1 m	clay loam
PR/1066/1	1811	14°	284°	Shale	13	714	1	± 1 m	Clay loam
PR/1035/1	1689	20°	279°	Shale	13	712	1	± 1 m	Sandy loam
PR/1063/1	1622	10°	51°	Shale	15	684	1	±1 m	Sandy loam
PR/1052/1	1715	17°	162°	Arenite	14	705	1	± 1 m	Clay loam
PR/2038/1	1589	16°	304°	Arenite	15	805	1	±1 m	Sandy loam
PR/2038/2	1582	11°	258°	Arenite	14	778	1	± 1 m	Sandy loam
PR/4001/1	1812	4°	141°	Arenite	14	743	2	> 1 m	Clay loam
PR/3040/1	1728	16°	93°	Arenite	14	770	2	±1 m	Clay loam

Table 26 Cont.

Plot number	**Altitude**	**Slope**	**Aspect**	**Geological parent material**	**MAT**	**MAP**	**Exposure**	**Soil depth**	**Soil texture**
PR/3003/1	1512	6°	191°	Shale	14	657	1	> 1 m	Sand
PR/3036/1	1482	4°	119°	Shale	15	661	1	> 1 m	Sand
PR/3036/2	1486	4°	214°	Ecca sandstone	15	661	1	> 1 m	Sand
PR/3026/1	1604	20°	317°	Shale	13	671	2	±1 m	Loam
PR/3026/2	1610	5°	321°	Arenite	13	671	2	±1 m	Clay loam
PR/1001/1	1563	5°	340°	Arenite	14	688	1	> 1 m	Sand
PR/2026/1	1801	6°	322°	Arenite	15	845	2	±1 m	Clay loam
PR/2026/2	1809	7°	329°	Arenite	12	1071	2	± 1 m	Clay loam
PR/1048/1	1982	10°	353°	Arenite	12	769	2	±1 m	Clay loam
PR/2014/1	1952	12°	344°	Shale	12	1023	2	> 1 m	Clay loam
PR/2014/2	1897	13°	342°	Shale	13	789	2	±1 m	Clay loam
PR/5016/1	1933	10°	357°	Arenite	13	801	2	± 1 m	Sandy loam
PR/Pulane Spring/1	2235	12°	352°	Tilite	11	817	2	±1 m	Sandy loam
PR/3016/1	1578	6°	121°	Shale	14	715	1	± 1 m	Sand
PR/6015/2	1635	5°	124°	Shale	14	697	1	± 1 m	Clay loam
PR/Sankatana II/1	1507	15°	104°	Shale	15	609	1	± 1 m	Clay loam
PR/Sankatana II/2	1515	12°	229°	Shale	15	609	1	± 1 m	Clay loam
PR/2029/1	1638	19°	172°	Shale	14	878	1	> 1 m	Clay loam
PR/2029/2	1659	12°	194°	Shale	14	878	1	> 1 m	Clay loam
PR/3012/1	1551	10°	190°	Arenite	15	694	1	± 1 m	Sandy loam
PR/3012/2	1556	15°	20°	Arenite	15	694	1	> 1 m	Sand
PR/3023/1	1672	16°	287°	Arenite	13	645	2	> 1 m	Clay loam

Table 27: A summary of site conditions/ variables for *E. macarthurii* permanent sample plots

Plot number	Altitude	Slope	Aspect	Geological parent material	MAT	MAP	Exposure	Soil depth	Soil texture
EM/1021/1	1890	2°	217°	Mudstone	13	777	2	± 1 m	Sandy loam
EM/1052/1	1716	3°	112°	Shale	14	705	1	±1 m	Loamy sand
EM/4001/1	1797	5°	355°	Mudstone	14	743	2	± 1 m	Sand
EM/1006/1	1746	10°	226°	Shale	14	756	2	± 1 m	Sandy loam

Table 28: A summary of site conditions/variables for *P. halepensis* permanent sample plots

Plot number	Altitude	Slope	Aspect	Geological parent material	MAT	MAP	Exposure	Soil depth	Soil texture
PH/3026/1	1606	20°	341°	Arenite	13	671	2	> 1 m	Clay loam
PH/Makoae II/1	12231	2°	286°	Arenite	14	676	2	> 1 m	Clay loam
PH/3023/1	1672	3°	174°	Arenite	15	719	2	± 1 m	Clay loam

Table 29: A summary of site conditions/variables for *E. nitens* permanent sample plot

Plot number	Altitude	Slope	Aspect	Geological parent material	MAT	MAP	Exposure	Soil depth	Soil texture
EN/1080/1	1890	3°	264°	Mudstone	13	772	2	± 1 m	Sandy loam

Table 30: A summary of site conditions/variables for *P. pinaster* permanent sample plot

Plot number	Altitude	Slope	Aspect	Geological parent material	MAT	MAP	Exposure	Soil depth	Soil texture
PP/1048/1	1983	8°	207°	Mudstone	12	769	2	> 1 m	Clay loam

4.6 **Conclusion**

From tables 25 to 30 it can be deduced that the critical factors relating to exposure at the study sites or PSP is that of frost, wind, hail and so forth.

It can be noted from table 13 that the survival of *E. rubida* is 91%, while the percentage of dead trees is 9. The survival of *E. macarthurii* is 98% whereas its mortality rate is 2% for the 2nd assessment. The survival of *E. nitens* is 100% for 2nd measurement. The survival percentage of all *Eucalyptus* species for the 2nd assessments is 92% while their mortality was 8%. The survival percentage of *E. rubida* for the last assessment was 85%, while its mortality was 15%. *E. macarthurii* has a survival of 93%, while the percentage of dead trees is 7%. *E. nitens* has a survival of 71%, while mortality rate was 29%. The survival of all *Eucalyptus* tree species for the last assessments was 86%, while the percentage of dead trees is 14% (table 14).

P. radiata and *P. halepensis* have 98% survival and 2% for dead trees for the 2nd assessments. Contrarily, *P. pinaster* has 93% survival, while the percentage of dead trees is 7. The survival of all pine trees is 98% whereas the percentage of dead is 2% for the 2*nd* assessments (Table 15). The survival of *P. radiata* is 80%, whereas 20% trees dead. *P. halepensis* has 98% survival and 2% for dead trees. On the other hand, *P. pinaster* has 81% survival and its mortality rate was 19%. The survival of pine trees is 82%, whereas their mortality was 18% for the last assessments (Table16).

CHAPTER FIVE

DATA MANAGEMENT AND ANALYSIS OF PERMANENT SAMPLE PLOTS

5.1 **Introduction**

There are 44 PSPs of *P. radiata,* 33 of *E. rubida,* four of *P. halepensis*, three of *E. macarthurii,* one of *E. nitens* and one of *P. pinaster*. In total, there are 86 PSPs which were studied. There are two data sets, which were created as PSP and experiment data sets respectively. The objectives of the study are summarised under sub-chapter 1.2. It should be noted that the following work was anticipated: (a) define HT and DBH relationships for all species of the 86 PSPs; (b) calculate HTs for all DBHs of trees of 86 PSPs of all species; (c) calculate the volume of all trees; (d) regress HT, DBH, volume and BAH etc. against age or all species; (e) define growth curves per species and site (location); (f) investigate DBH distribution against SD; (g) determine the number of live and dead trees. It was stipulated that the objectives of the study were to describe performance (survival, growth, and timber volume) of tree species grown in Lesotho and to look at the growth rate of various species cultivated in Lesotho. PSPs information was used as a source of reference for this study.

The HT and DBH relationships for both *E. rubida* and *P. radiata* PSPs were determined in order to determine the regression equations which were used for interpolating and extrapolating whenever necessary. Growth curves per species per location were investigated in order to study the growth rates of different species per location such as mean annual increment (MAI), current annual increment (CAI) as well as detecting the age, which certain species can be able to produce the maximum volume annual increment. The number of lives and dead trees were determined in order to be in a good picture at the time of harvesting how many trees could be utilised and reach the maturity stage.

The HT and DBH relationships for both *E. rubida* and *P. radiata* plots were determined by a simple linear regression. The HTs were predicted for all DBHs of trees of 77 PSPs by looking at a highest R^2. The predicted HTs of all trees were fed into the computer and stored under either *E.* rubida or *P. radiata* PSPs data sets file under the Microsoft Excel 2000 (Microsoft Excel, 2000). The volumes of all trees of *E. rubida* and *P. radiata* were calculated by using the different volume equations of commercial tree species studied in South Africa, as developed by Schumacher and Hall (Schumacher, 1939; Bredenkamp, 2000b) and taper equations by (Demaerschalk, 1972; Bredenkamp, 2000b) were compared with the ones of Lesotho (Moshoeshoe, 1987). Then, the South African volume equations were chosen to be used (Dr. D. Wilson, pers. comm. Forestry Programme, UKZN, 2004). The volume equations are as written and explained under sub-chapter 4.4.3. The HT, DBH, DBH^2 relationship with age of *E. rubida* and *P. radiata* species were executed with simple linear regression, selected based on highest R^2. Growth curves for each species and location were carried out by plotting several dependent variables such as DBH, HT, VPH and BAH against age with the use of Genstat 7th edition (Genstat, 2003). Growth site factors relationships of all studied species were analysed with multiple linear regression analysis. The number of live and dead trees of all the species was determined by categorical analysis. The DBH, HT, TPH, VPH, MAI etc, for these species namely *P. halepensis*, *E. macarthurii*, *E. nitens* and *P. pinaster* were determined (Appendix 40-43).

Regressions are presented as graphs or corresponding mathematical expressions indicating the relationship between a variable of interest and one or more other independent variables. Further research was aimed to: (i) explore the relationship between stand volume and stand age, site index and stand density, (ii) make estimations of future DBH based on past DBH (iii) make predictions of parameters of merchantable volume of a timber utilizing DBH and tree HT. It was also explored that correlation is concerned with the strength of the association between two variables. An association between two or more variables might exist and be shown by a regression analysis, however, if it has to be utilized to make predictions, it has to be strong enough so that estimates are sensible. Therefore, a measure of the degree of correlation lying between the parameters is normally included in a statement based on regression (Johnson, 2000). On the same line, regression analysis is used to observe if there is relationship between the dependent and independent variables, to investigate the form or shape of the curve of the relationship, and to estimate the dependent variable from the independent one (s) by using such a relationship (Kassab, 1989).
Kassab (1989) showed that residuals are quite helpful for studying how good the fitted regression model is, if the selected operational form is suitable and if the assumptions of the model are satisfied.

Similarly, Freeze (1984) stated that coefficient of determination (R^2) is a measure of the degree of linear relationship between variables, and it is free of the impacts of the scale of measurement. It may differ from –1 to +1. A coefficient of 0 shows that there is no linear relationship; there might be a very strong non-linear relationship. A coefficient of +1 or –1 indicates a perfect linear relationship.

5.2 **Data Analysis And Results**

The number of trees/plot and individual tree assessments for the following species: *E. rubida*, *P. radiata*, *E. macarthurii*, *E. nitens*, *P. halepensis* and *P. pinaster* are as described from sub-chapter 4.5.1. It should be noted that age, number and frequent assessments are also as shown from table 7–12. All the six species mentioned above were included in the assessments. For HT/DBH relationship and other analysis only *E. rubida* and *P. radiata* species were included as they are the dominant species planted in forest plantations of Lesotho.

There are many steps that were followed before data could be analysed. Firstly, the data was fed into the computer and stored under the Microsoft Excel 2000. The data sets were created by species e.g. *E. rubida* PSPs data sets. Once the data sets creation was finalised, they were properly stored in the computer. Then, the preliminary analysis was started. The DBHs and HTs of *E. rubida* and *P. radiata* species were regressed. The regression equations for estimating HTs for all DBHs of the above mentioned species are as written and explained under 4.4.3. It should be noted that age in months was used for *E. rubida* regression equation, unlike *P. radiata* whereby, age in years was used. It was detected that R^2 for *E. rubida* was very low and the relationship between DBH and HT was linear (Figure 9). Then the two explanatory variables such as DBH and age against HT were used to get a better R^2 of 0,72. Then, the predicted HT residuals for *E. rubida* are as indicated from figure 10. The R^2 of *P. radiata* was 0,90 after utilizing the three predictor variables while it was 0,75 before (Figure 11). The predicted HT residuals for *P. radiata* and *E. rubida* are as shown below (Figures 10 and 12). The regression summary statistics for *E. rubida* and *P. radiata* species are shown in tables 31-34.

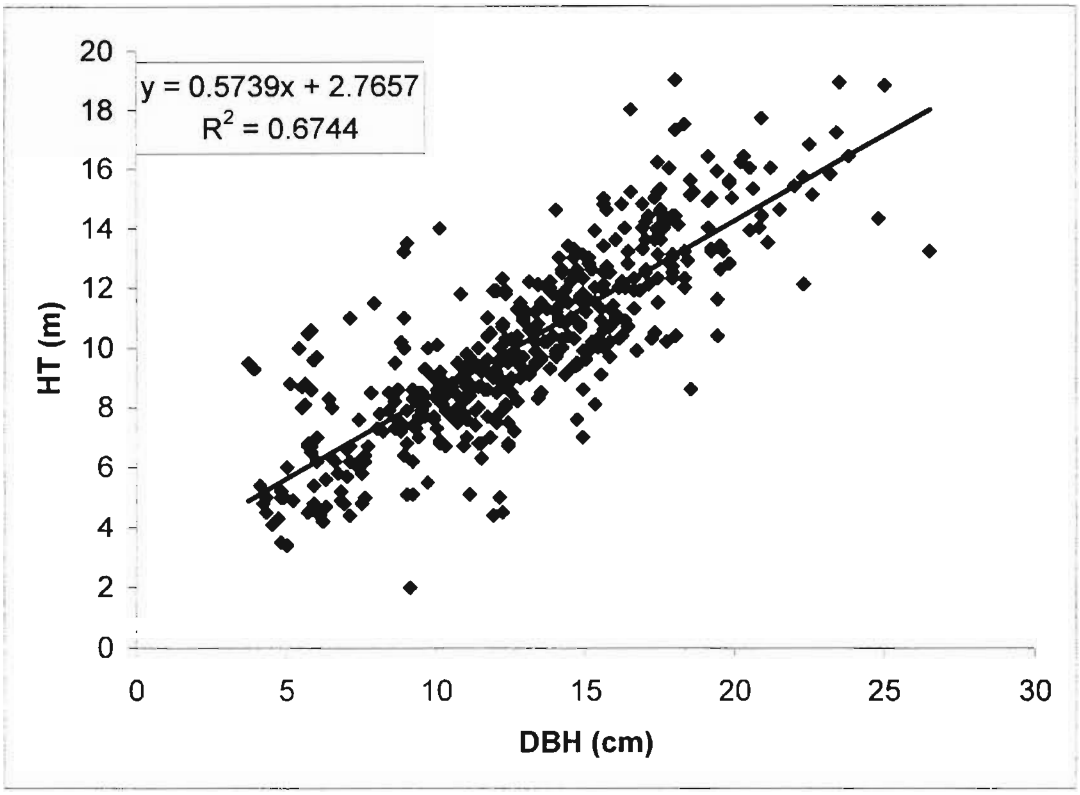

Figure 9: The simple linear relationship between mean diameter at breast height and mean height for *E. rubida* based on permanent sample plots data for Lesotho. Each point is the mean values for a single permanent sample plot measurement.

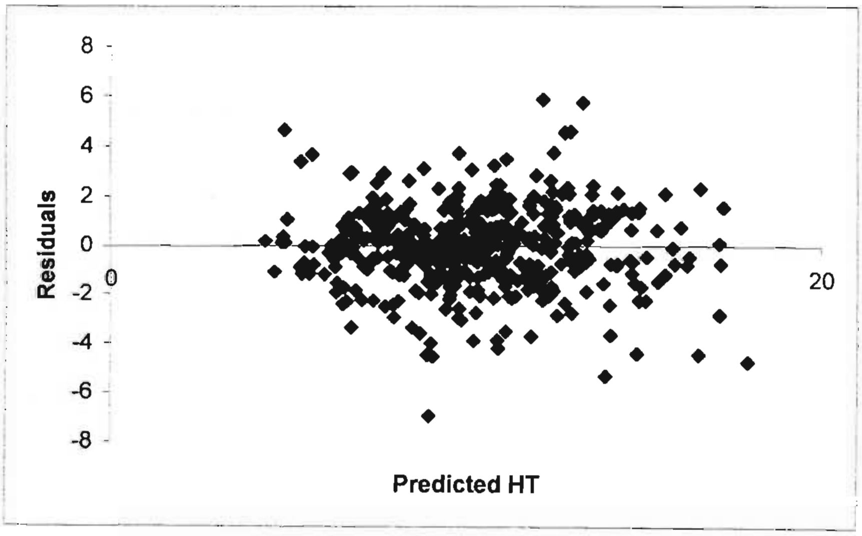

Figure 10: Predicted height vs. residuals for *E. rubida* permanent sample plots

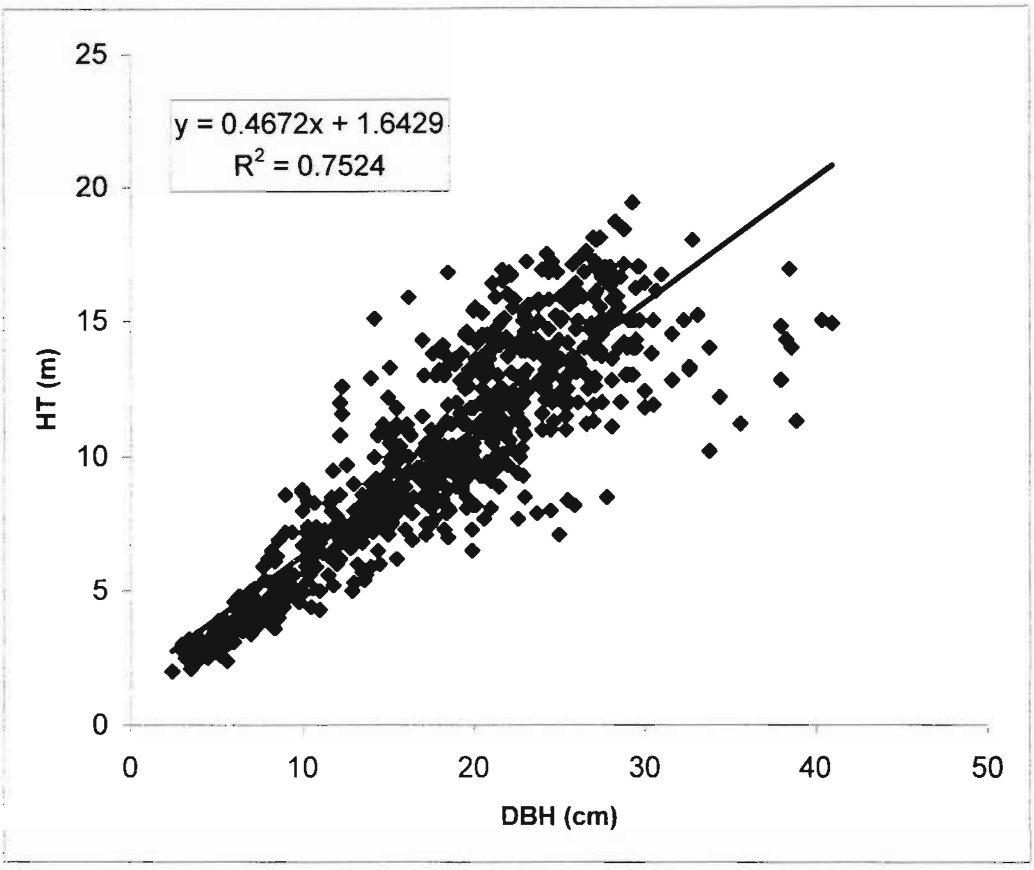

Figure 11: The simple linear relationship between mean diameter at breast height and mean height for *P. radiata* based on permanent sample plots data for Lesotho. Each point is the mean values for a single permanent sample plot measurement.

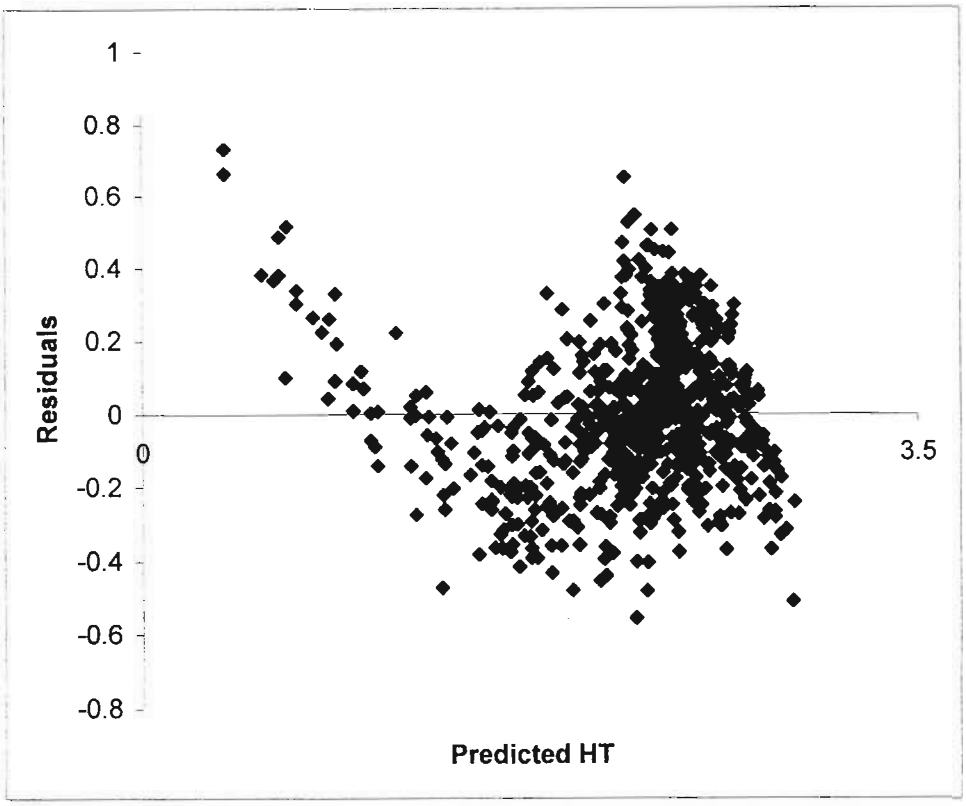

Figure 12: Predicted height vs. residuals for *P. radiata* permanent sample plots

Table 31: Summary statistics of the regression analysis of diameter at breast height and height for *E. rubida* plots. (d.f. = degrees of freedom, ss = sum of squares, f = f value, P = probability)

	df	**ss**	**ss**	**f**	**P≤0,05**
Regression	2	3183,8	1591,9	602,4	<0,0001
Residual	464	1226,1	2,64		
Total	466	4409,9			

Table 32: Summary statistics of the regression analysis of diameter at breast height, age and height for *E. rubida* plots. (Coeff. = coefficients, se = standard error, P-value = probability)

Independent variable	**Coeff.**	**se**	**T-stat**	**P≤0,05**
intercept	1,5610	0,2705	5,77	<0,0001
DBH	0,5296	0,0178	29,72	<0,0001
age	0,0171	0,0019	8,09	<0,0001

Table 33: Summary statistics of the regression analysis of diameter at breast height and height for *P. radiata* plots (d.f. = degrees of freedom, ss = sum of squares, ms = mean squares , P = probability)

Source	**df**	**ss**	**ms**	**f value**	**P≤0,05**
Model	3	67,84197429	22,61	2097,77	<0,0001
Error	731	7,88017756	0,11		
Corrected Total	734	75,72215185			

Table 34: Summary statistics of the regression analysis of diameter at breast height, diameter at breast height squared, age and height for *P. radiata* plots (se = standard error, P = probability).

Parameter	**Estimate**	**se**	**T value**	**P≤0,05**
Intercept	0,1024	0,1362	0,75	0,45
DBH	0,5641	0,0259	21,76	<0,0001
DBH*DBH	-0,0041	0,0009	-4,65	<0,0001
age	0,1571	0,0309	5,08	<0,0001

The PSPs were analysed with the use of the statistical packages called Genstat 7th edition (Genstat, 2003) and Microsoft Excel 2000 (Microsoft excel, 2000). The following variables were calculated: HT, DBH, VPH etc. of both *P. radiata* and *E. rubida* PSPs at reference age (Appendix 32 and 33). The plot volumes were determined by summing up individual tree volumes. The similar procedure was followed for the basal area per plot (BA/plt). The number of trees per plot and plot volume were multiplied by twenty-five to get TPH, BPH and VPH respectively because the PSP area is just 400 m^2. The linear regression was utilised to study the relationship between HT and DBH of both species. The Categorical analysis was carried out to detect the number of live and dead trees (Table 13–24).

5.2.1 **Growth curves of *P. radiata* plots in Lesotho**

Husch *et al.* (1992; 1993) connoted that when the size of a living thing such as DBH, HT, volume and BA for a tree is plotted against its age, the curve is usually explained as the growth curve. They emphasised that such curves tend to develop S or sigmoid shape, they also indicate the cumulative size at any age. These curves are named as cumulative growth curves. It was also declared that the pattern of growth for short growing periods tend to follow the sigmoid shape curve. It was once elaborated that during youth the growth rate increases rapidly to maximum at the point of inflection, and during maturity and senescence, the growth rate decreases with related changes in acceleration in the cumulative growth curve (Figures 13, 14, 22 and 23). The current annual increment (CAI), periodic annual increment (PAI) and mean annual increment (MAI) curves can also be obtained from a cumulative growth curve (Husch *et al.*, 1992; 1993; Hetherington, 1990 and Phillip, 1998).

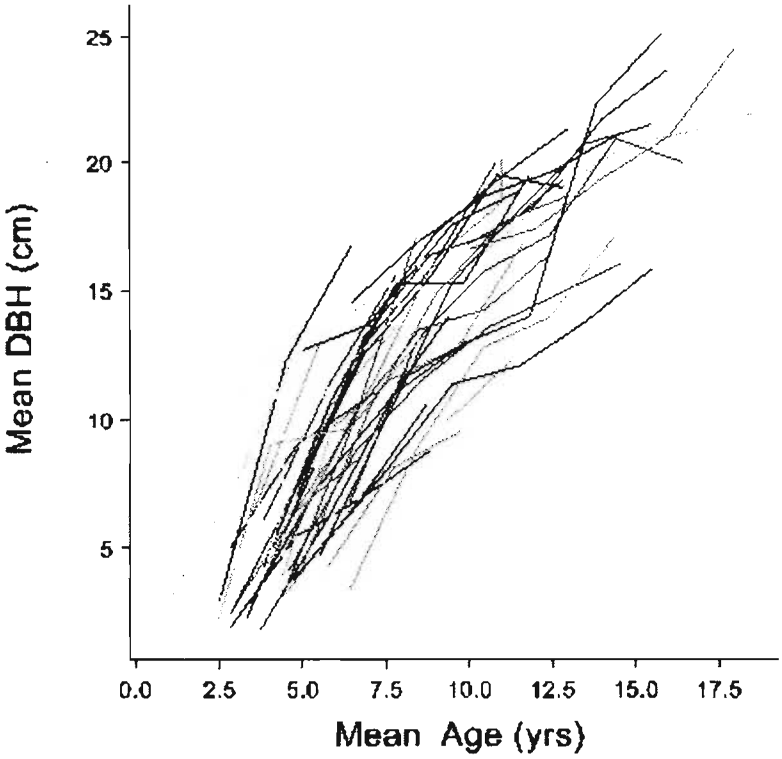

Figure 13: Diameter at breast height vs. age relationship for *P. radiata* plots

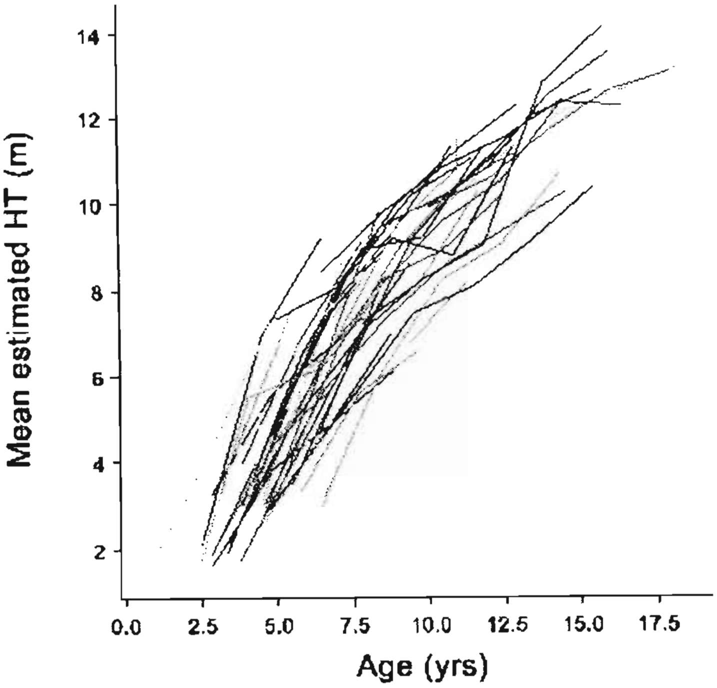

Figure 14: Mean estimated height vs. age relationship for *P. radiata* plots

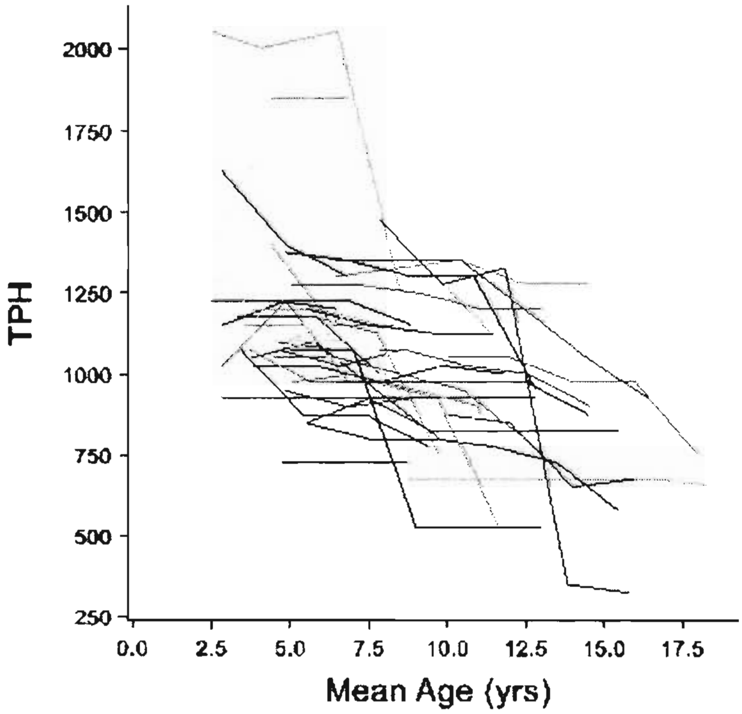

Figure 15: Trees per hectare vs. age relationship for *P. radiata* plots

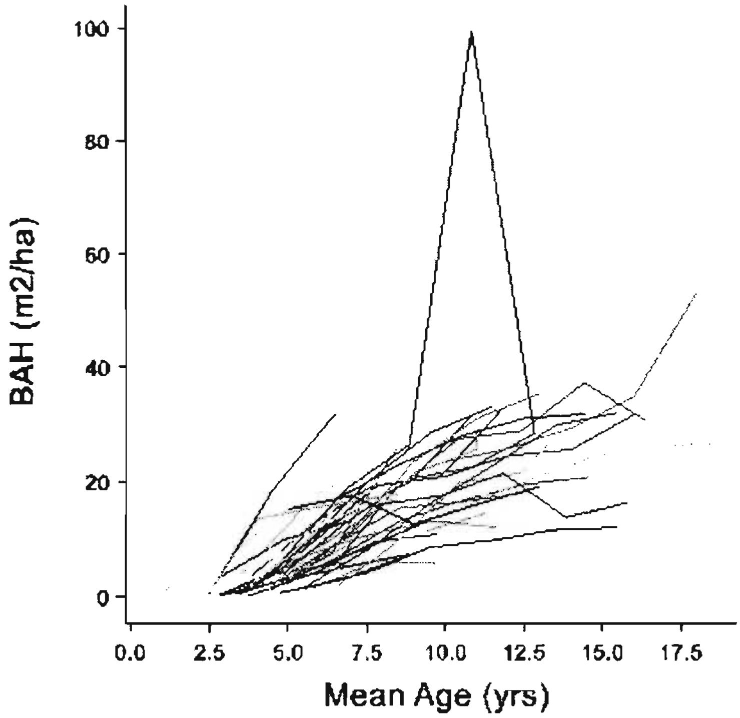

Figure 16: Basal area per hectare vs. age relationship for *P. radiata* plots

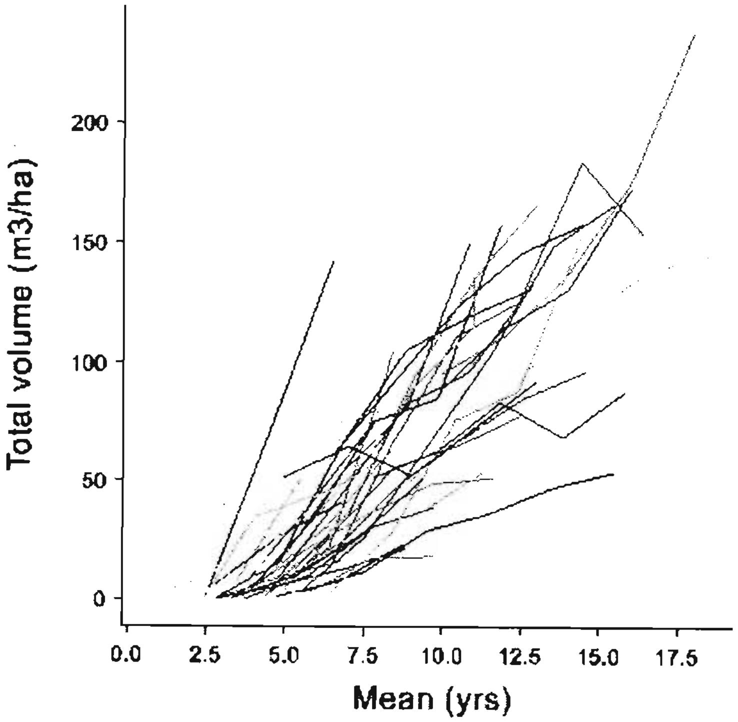

Figure 17: Total standing volume vs. age relationship for *P. radiata* plots

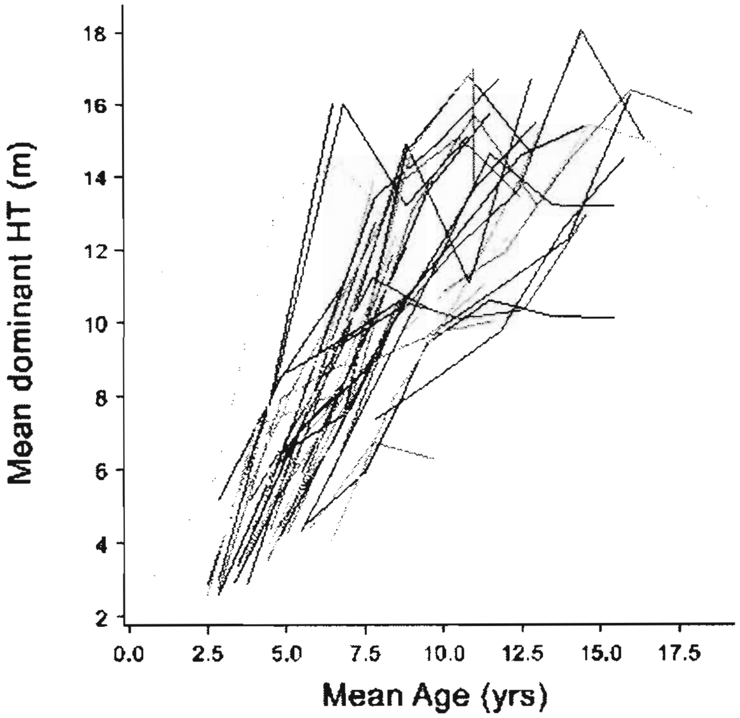

Figure 18: Mean dominant height vs. age relationship for *P. radiata* plots

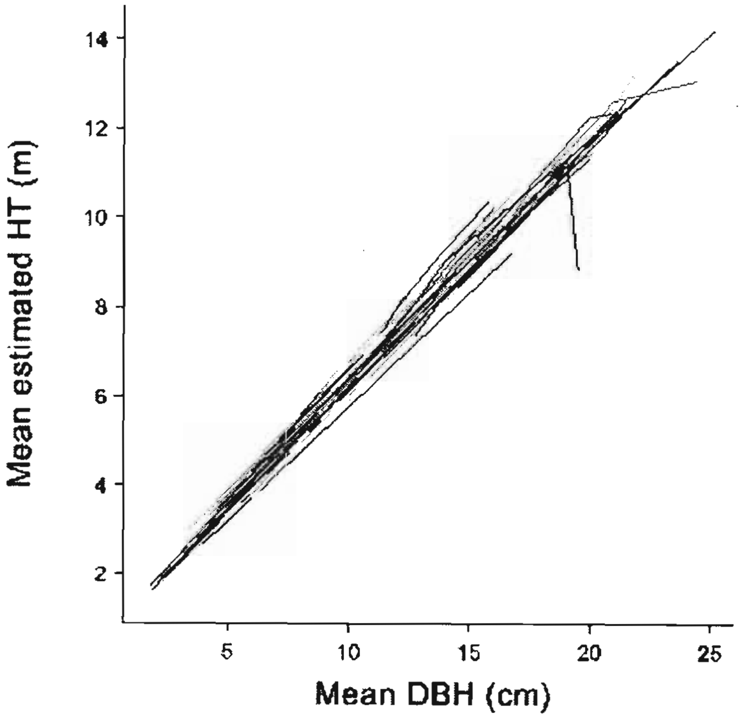

Figure 19: Mean estimated height vs diameter at breast height relationship for *P. radiata* plots

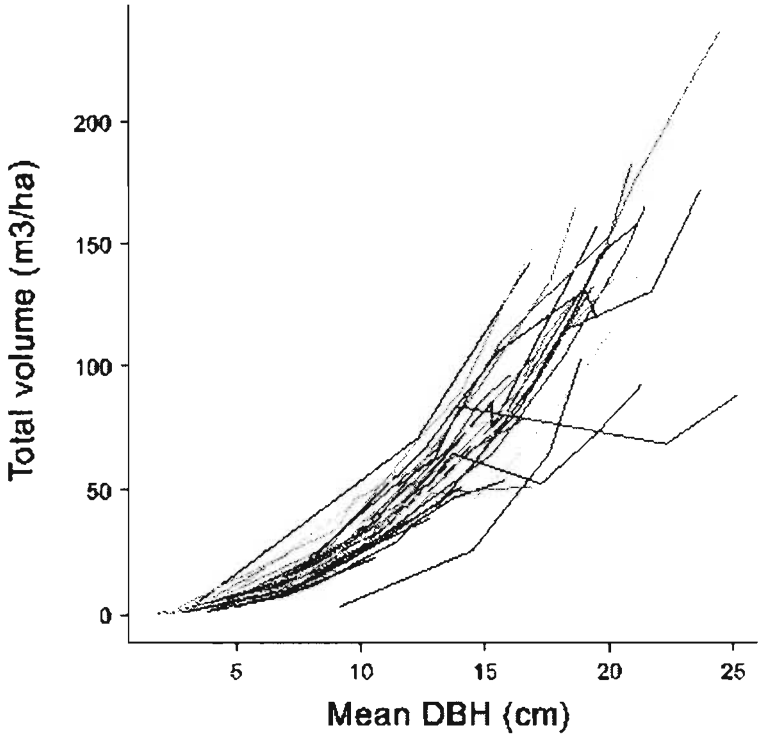

Figure 20: Total standing volume vs. diameter at breast height relationship for *P. radiata* plots

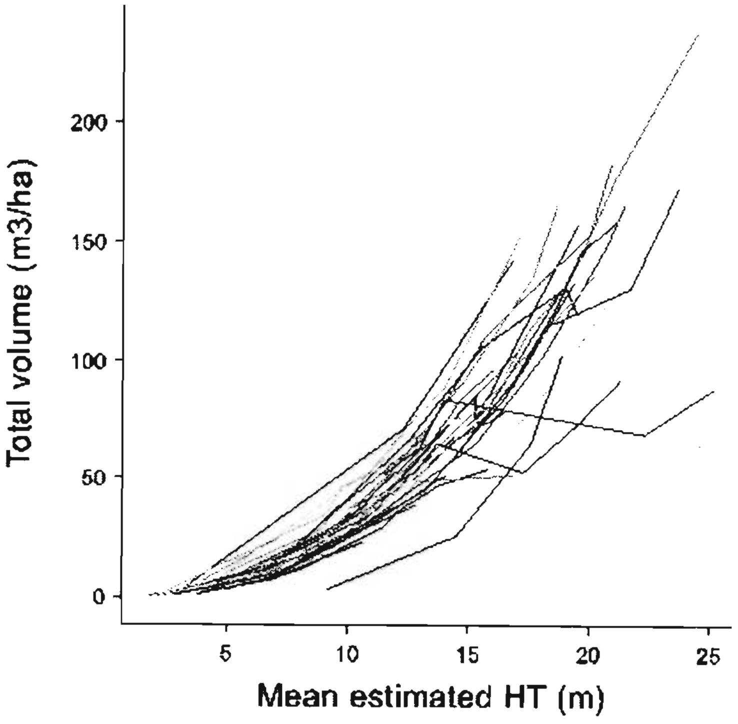

Figure 21: Total standing volume vs. height relationship for *P. radiata* plots

5.2.2 **Growth curves of *E. rubida* plots in Lesotho**

The growth curves of *E. rubida* PSPs tend to follow the S- shaped form. The relationship of growth of DBH and HT is somehow linear. The relationships of tree growth parameters with age are given (Figure 22, 23).

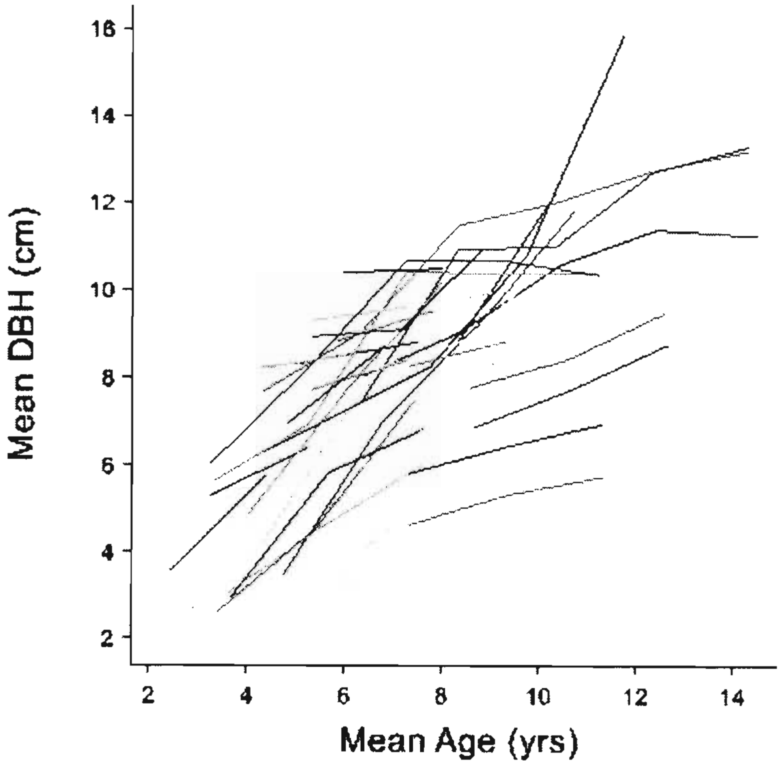

Figure 22: Diameter at breast height vs. age relationship for *E. rubida* plots

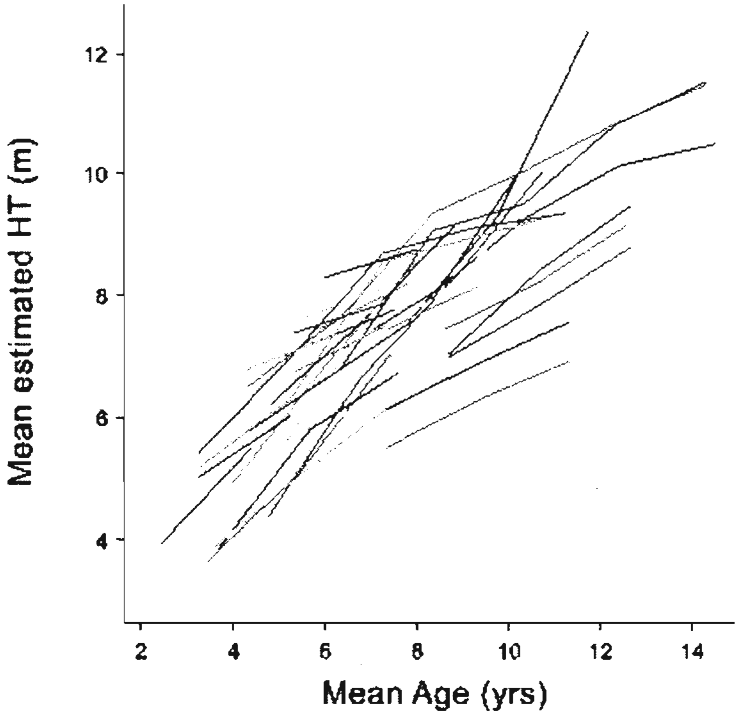

Figure 23: Estimated height vs. age relationship for *E. rubida* plots

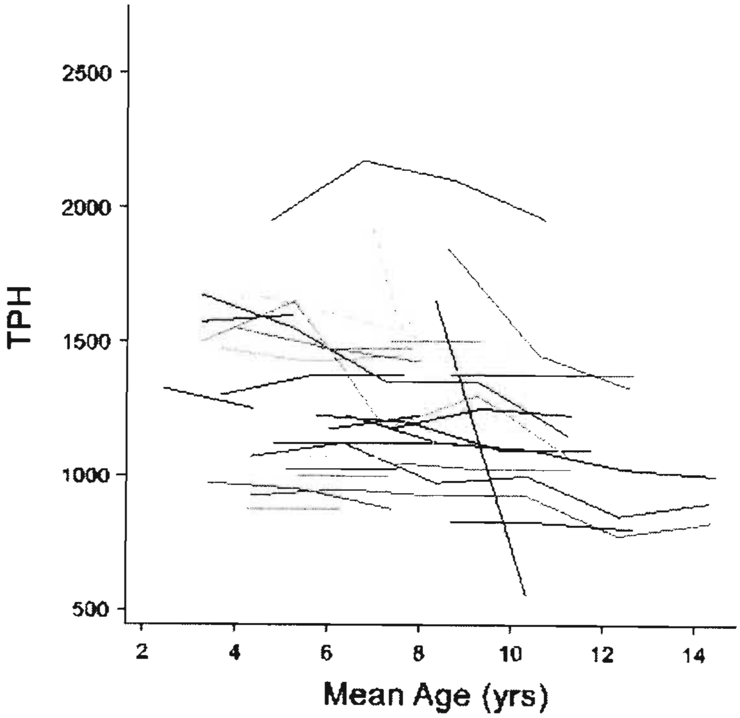

Figure 24: Trees per hectare vs. age relationship for *E. rubida* plots

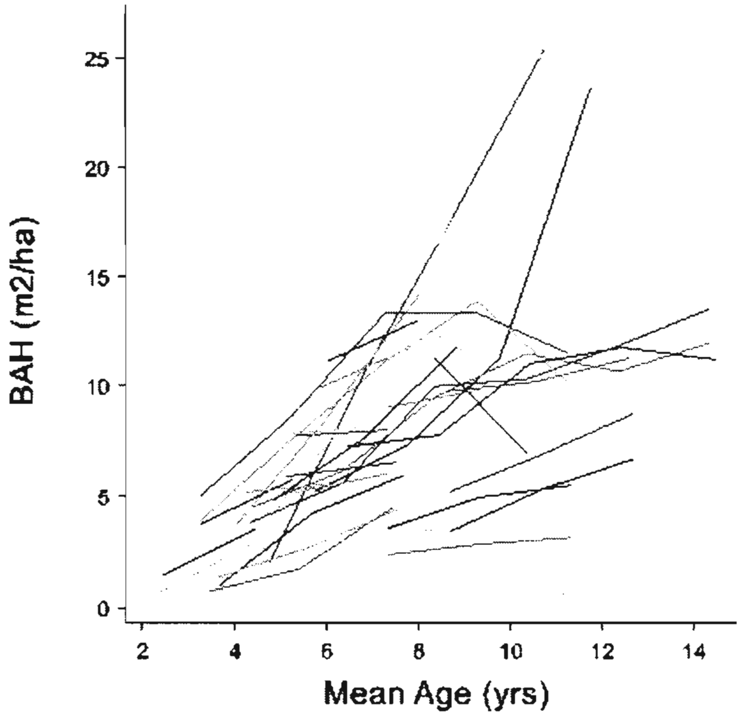

Figure 25: Basal area per hectare vs. age relationship for *E. rubida* plots

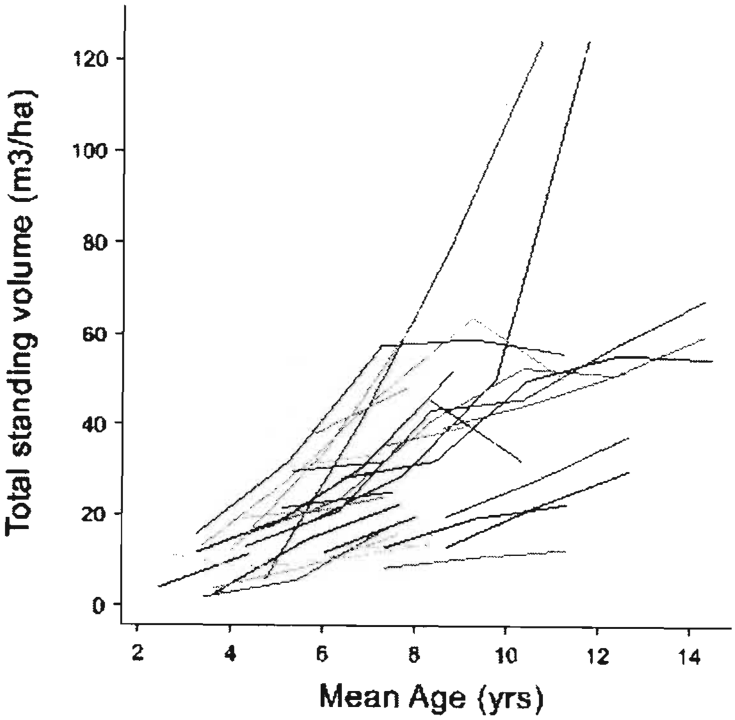

Figure 26: Total standing volume vs. age relationship for *E. rubida* plots

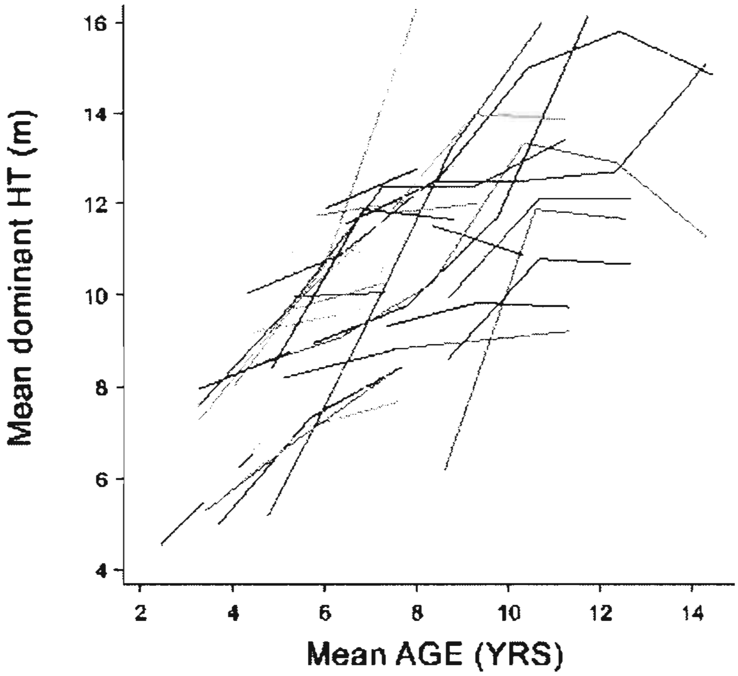

Figure 27: Dominant height vs. age relationship for *E. rubida* plots

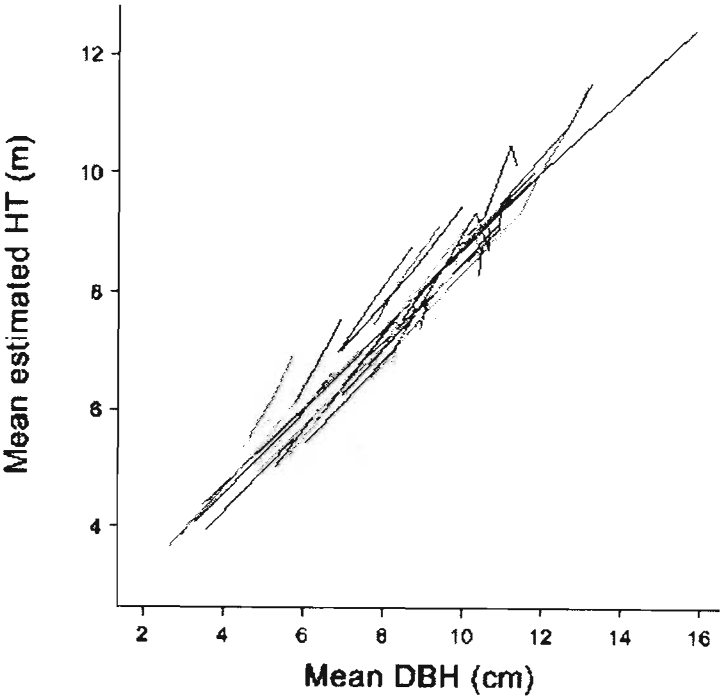

Figure 28: Mean estimated height vs. diameter at breast height relationship for *E. rubida* plots

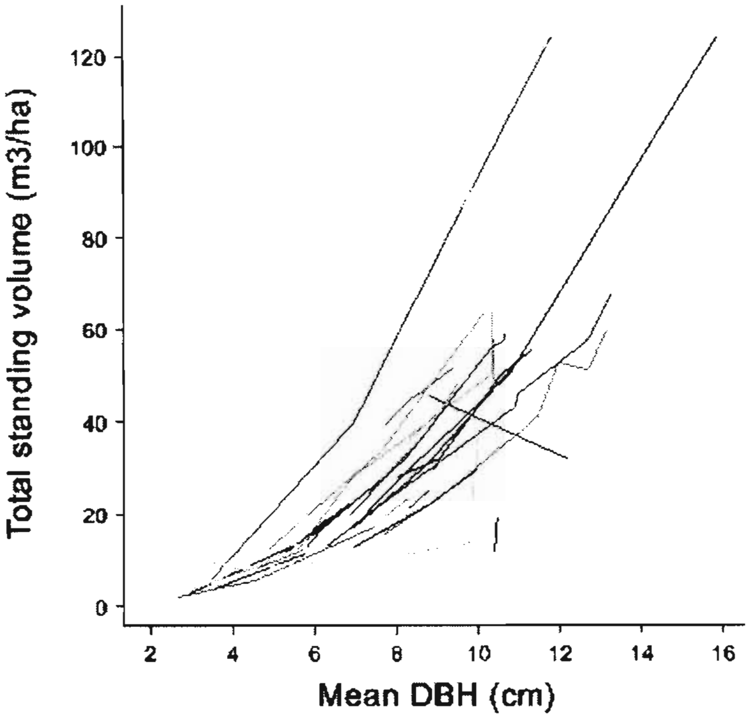

Figure 29: Total standing volume vs. diameter at breast height relationship for *E. rubida* plots

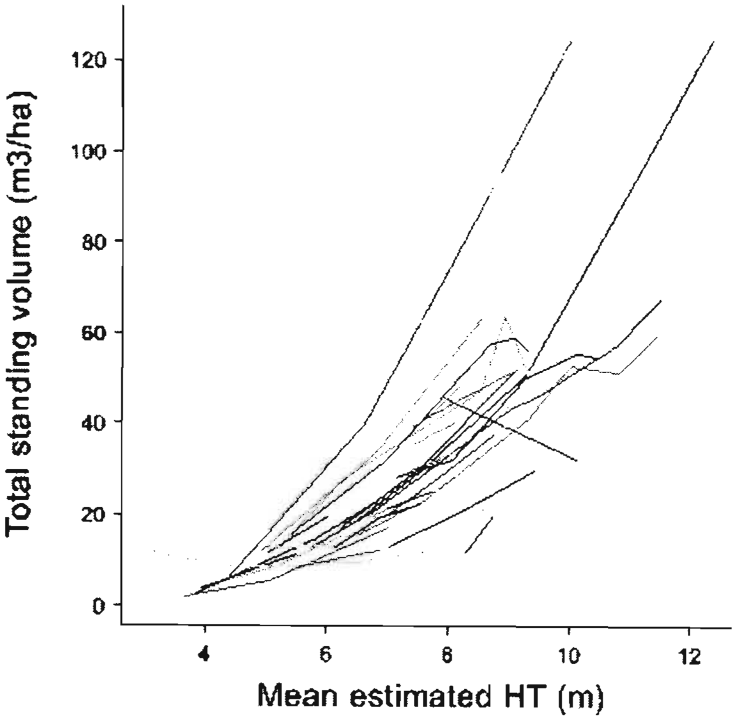

Figure 30: Total standing volume relationship vs. height for *E. rubida* plots

5.3 **Discussion Of Results**

There is a lot of changes that took place on some of E. *rubida* PSPs which were affected including: ER/1005/1, ER/1005/2, ER/1007/1, ER/1026/1, ER/1028/1, ER/2006/1, ER/2013/1, ER/4001/2, ER/4001/4, ER/5006/1, ER/5010/1. There were eleven PSPs of *E. rubida, which* were either felled illegally or felled according to forest management plans (Appendix 38). This made the other PSPs to be given new names and define age, for an instance, PSP ER/4001/2 was assessed six times. It was discovered that, there was only one measurement for the original (1st rotation crop). Then, there were two measurements for the 1st coppice (2nd rotation) crop and other two assessments for the 2nd coppice, which is a 3rd rotation crop (Appendix 38). It should be noted that PSP ER/4001/2 was named three times, like ER/4001/1a to indicate 1st coppice measurement, and ER/4001/ 1b for 2nd coppice assessment. This means that PSP is still the same but it was done to assess the growth of original, 1st coppice and 2nd coppice crop separately.

All the silvicultural practices that were applied in these PSPs have influenced the means of the plots such as DBH, BAH, TPH and MAI. This is approved by the fact that when the two variables (Age and BAH) were plotted their figures or graphs appear not to follow as expected growth curve. It can also be viewed that MAI ranges from 1,446 to 10,8123 m³/ha/yr for the 1st rotation crop. It ranges also from 0,5833 to 16,8936 m³/ha/yr for the 1st coppice assessment and from 6,5424 to 10,8827 m³/ha/yr for the 2nd coppice assessment for *E. rubida* plots. It should also be realised that the mean volumes and plot volumes of *E. rubida* PSPs are different because the mean volume is calculated mainly from actual tree stem, while plot volumes include everything e.g. coppice (Appendix 33). The other major contributing factor to the volume value decline of PSPs is drought. The trees were heavily stricken by drought.

The *P. radiata* PSPs were also affected. This has influenced the number of measurements to some PSPs. They were as follows: PR/1001/1, PR/1011/1, PR/1031/1, PR/2014/2, PR/3012/1, PR/3012/2, PR/3033/1 and PR/Sankatana II/1. There were 8 plots which were influenced. The two plots were thinned namely PR/1001 and PR/1011/1. The measurements of the thinned PSPs were not included, so as to treat the crop in all the PSPs as a non-thin regime and to make analysis much easier. Illegal felling was noticed in these plots, even though some of the trees were already dead, this enticed the rural community to cut the trees. Mean volume and plot appeared to be the same. MAI was from 0,0770 to 21,9103 m³/ha/yr. The MAI was 0,25 to 9,99 m³/ha/yr for *E. macarthurii.* It also ranges from 1,59 to 7,54 m³/ha/yr for *E. nitens.* The MAIs start from 0,010 to 3,52 and from 0,073 to 2,70 m³/ha/yr for *P. halepensis* and *P. pinaster* respectively. The mean dominant HT and estimated HT seem not to have been induced by any silvicultural practices, unlike BAH, VPH and TPH which were affected by silvicultural treatments (Appendix 32).

The relationship of age with other dependent variables is discussed briefly. And prints have been shown in figures 13 to 30. The relationship of age with HT or DBH is curvilinear for both species (Figure 13, 14, 23 and 24). They also tend to follow a sigmoid shape. The relationship of TPH and age is that, at younger stage, there are many TPH; at a bigger age there are few trees (Figure 15 and 24). This curve tends to move from up left downwards. The relationship of HT, DBH and volume is curvilinear (figures 14, 15, 23 and 24). The minimum DBH ranges from 2,04 cm to 15,87 cm for the 1st rotation crop, and from 3 to 9,05 cm for the 1st coppice measurement, which is the 2nd rotation crop. It could be noticed that for the 2nd coppice assessment, which is the 3rd rotation crop, the minimum DBH is found between 4,87 to 8,63 cm. It was also investigated that the growth rate of coppice crop is faster than that of the original crop for *E. rubida* plots (Appendix33).

This is similar to what Causton (1983) described as the curve of the relative growth rate, which normally declined throughout growth in a reverse sigmoid manner. This matches well with Evans statement in 1971 when he stipulated that the relationship between HT and volume is strongly curve linear. He strongly highlighted that in order to compare linear regressions between these variables the data was transformed. He expressed further that for the median and lower percentile trees, a logarithmic transformation was used to volume figures, while for upper percentiles trees a square transformation was applied. This growth curve tends to follow what Causton (1983) used to call a logistic growth function. Bredenkamp (1977) studied that the relationship between stand density and volume changes rapidly with age in that the rate of volume growth with increasing stand density increases with age. He emphasised that the relationship between mean DBH and stand density was researched at different ages. He observed that at the youngest age tested, the relationship was clearly linear and the regressions coefficient was detected to be highly significant. For the mature trees the function explained the relationship satisfactorily. However, in both studies he found out that the term was not significant at 5% level of significance but the residual sum of squares was positively correlated with age. The equation he used is written as follows (Equation 9):

$Y = b_0 + b_1 \text{ Ln } X + b_2X$ ....**Equation 9**

Freeze (1964) and Evans (1971) explored that the dangers of utilising the approach without due consideration of the assumptions made in the building of regression models. The assumptions concern the nature of the sample data and were reported as follows: (i) there is a linear relationship between parameters over the range of values explored though the regression line need to go through zero, (ii) the assessed values of Y, dependent parameter for set values of x, the independent parameter, are normally distributed, that there has been no bias sampling in assessing y for certain values of x, (iii) that the values of x variables are assessed as accurately as possible, (iv) that the variances of the values of y for each value of x are homogenous. They further expressed that it is not wise to extrapolate the regression relationship beyond the range of values sampled. Even though the overall distribution of y need not be normal for computing the regression, the application of significance tests such as "t" and "f" needs to confirm that it is so. It was also indicated that if data have been completed without due regard to the significance of these assumptions and limitations, the computed regressions may become meaningless.

Evans (1971) investigated that before any computations was performed the relationship between HT and DBH were explored by the values on a graph. This exploration meet three functions and all obvious and therefore important relationships were quickly shown up, the existence of curve linear relationship was demonstrated. He connoted that the preliminary inspection of the data, through the use of scatter diagrams, help considerably in meeting demands of other assumptions made in regression analysis (Figures 9-12). He expressed that the importance of the second role of scatter diagrams was stressed that, for most biological relationships there exists a non-linear association when the whole range of a relationship between two variables is considered.

The overall performance of different species of pines and eucalypts based in terms of survival is as described below. *E. nitens* showed good performance by having 100% survival better than all the other *Eucalyptus* species for the 2nd assessments. It is followed by *E. macarthurii* with 98% for live trees and 2% for dead trees, and lastly it is *E. rubida* which still indicated good performance of 86% survival and 14% mortality. It can be realised that *E. macarthurii* performed better than the other *Eucalyptus* species by having 93% survival and 7% mortality for the last assessments. It is followed by *E. rubida* with 85% survival and 15% for dead trees. Lastly, *E. nitens* has the survival of 71% and 29% for dead trees. The performance of eucalypts is 92% survival and 8% for dead trees, and 86% survival and 14% for dead trees for the 2nd and last assessments respectively.

P. halepensis and *P. radiata* showed good performance of 98% for live trees and the mortality rate of 2%. Meanwhile, *P. pinaster* indicates promising performance of 93% for survived trees and 7% for dead ones for the 2nd assessment which is more related to growth of trees because it is believed that at this point the trees have already managed to establish themselves (Prof. J. Zwolinski, pers. comm. Forestry Programme, UKZN, 2004). It can be noted that for the last measurements *P. halepensis* once again outbids its candidate species by having 98% for live trees and the mortality rate of 2%. It is once again followed by *P. pinaster* with 81% survival and 19% for dead trees. *P. radiata* seems to be the last with 80% survival and the mortality rate of 20%. In general, pines had 98% for live trees while the mortality rate was 2%, and they also indicated the performance of 82% for live trees while the mortality rate was 18% for the 2nd and last measurements respectively.

In comparison of the performance of eucalypts and pines species investigated in this study, is rather interesting and challenging for one to make note of. Pines performed better than the eucalypts for the 2nd measurement, they out-classed eucalypts by the margin of 6% while having few dead trees. It should be realised that for the last assessments eucalypts seemed to have performed better than pines. There is a margin of 4% for both live and dead trees between eucalypts and pines. The performance in regard to volume, DBH and HT is detected for only two species such as *E. rubida* and *P. radiata*. In general *P. radiata* seems to perform better than *E. rubida* in terms of continuous and discrete variables such as mean DBH, mean dominant HT, volume/ha and MAIs (Appendix 32; 33). It should be noticed that another hypothesis connotes that survival and growth of various species on select sites is equal. The study proves this to be incorrect because there are differences between performance of species as explained above and shown from table 31-34. Therefore H_0 is rejected while H_1 is accepted.

5.4 **Conclusion**

The performance of both eucalypts and pine species is fairly good in terms of survival but not in DBH and HT. It is very important when it is being looked at by species. It can be concluded that *P. halepensis* showed better performance than for all the other species explored in this study. It is followed by *E. macarthurii*. Pines indicated better performance than eucalypts for the 2nd measurement, hence eucalypts performed well than pines for the last measurements. It should be noted that *P. radiata* seemed to have higher values of continuous and discrete variables such as mean DBH, HT, volume/ha and MAIs than *E. rubida*. Growth curves of *E. rubida* and *P. radiata* species were drawn and they indicate a sigmoid shape, with an asymptote.

CHAPTER SIX

CLIMATE

6.1 Introduction And Objectives

6.1.1 Importance of climate to tree growth

Climate plays a major role in the development of plants. The primary contributing factors to climate are: temperature, precipitation and solar radiation. Temperature has a direct effect on all forms of life on earth, affecting a wide range of processes and activities ranging from human comfort and consequent energy supply and demand for heating and cooling, to crops and domestic animals, the incidence of pests and diseases as well as rates of evaporation. Plants use visible part of solar radiation to produce carbohydrates (dry matter, or yield) out of water and carbon dioxide in the form of starch, sugar and cellulose. Photosynthesis takes place during the daytime in the green parts of the plants mainly leaf, which are exposed to sunlight (Schulze, 1997).

The MAP (mm) characterises the long-term quantity of water available to a region. It has been detected that under non-irrigated systems it gives an upper limit to a region's sustainable agricultural potential in regard to biomass production if other factors (e.g. light, temperature, topography, soils) are not limiting. In Southern African agro-hydrological studies, MAP-derived parameters include a number of rain or crop production days, monthly rainfall distribution, and flood prediction. Limitations in water availability are often a restrictive condition in plant development. Water is significant for the maintenance of bio-chemical and physiological processes within the plant, performing as an energy exchanger and carrier of nutrient food supply in solution (Dent *et al,* 1989; Schulze, 1983; Schmidt and Schulze, 1987).

Herbert (1997) stated that ambient air temperature should be considered first when selecting species for sites. This is due to the strong influence of temperature on physiological activity i.e. growth rate, vigour and resistance to pests. He further expressed that snow may occur in most areas of where MAT is approximately 16 °C or less. Damage from snowfalls involves the bending of stems, the snapping off of branches and crowns. Wind damage is concerned mainly with the stripping of branch lets, loss of main branches and even leaders and the whole crown. Frost damage is primarily dangerous in immature trees, and results from the breaking of cell walls during thawing following freezing.

The thorough knowledge of climate will lead and enable a forester, agriculturist and a farmer to make appropriate and concrete decisions on the following:
(i) which tree species or crop is suitable to plant or grow?
(ii) when to plant or grow the crop?
(iii) for how long will it take before harvesting?
(iv) what kind of harmful agents are likely to attack the crop?

The above-mentioned information can lead to making good plans of forest production and development in any country.

The objectives of this chapter are listed as follows: (i) to describe the importance of climate to tree growth, (ii) to learn or explore which methods or techniques to be used to predict the climatic variables such as MAT and MAP which are significant to tree growth, (iii) to show the role of weather stations, (iv) to get a good estimate of many climatic factors of experimental sites.

The climate of Lesotho is temperate dominated mainly by warm summers and cold winters. Lesotho has four distinct seasons such as spring, summer, autumn and winter. The rains start to fall primarily from the spring to the end of the autumn. Snow is received especially in the highlands in winter. The hottest months of the year are in summer months: November, December and January. The coldest months of the year are in winter namely June and July. The spring months are August, September and October while autumn months are such as February, March and April. The weather conditions are warm and cool during these months and still favourable for crop or tree production (Vilakati, 1986).

In the lowlands, temperatures generally vary from a maximum of 30 °C in summer to a minimum of –7 °C in winter. Maseru has an average monthly temperature of 24 °C in January and an average monthly temperature of 8 °C in June and July. Altitude has a big influence on temperature in Lesotho. It is a well-known fact for every 1000 m rise in altitude; mean temperature drops by 6.5 °C (Vilakati, 1986). The amount of precipitation received in Lesotho is variable. In the lowlands, MAP is between 700 and 800 mm from Maseru to the northern part of the country. MAP ranges from 400 to 600 mm in the southern part of the country. Greater amounts of precipitation are received in the highlands. MAP is between 800 and 1000 mm when rainy conditions are favourable. The rainy season starts in October and ends in May (Vilakati, 1986).

6.1.2 **Study area and methods**

In order to get a good estimate of many climatic factors of experimental sites, the climatic information offered by Schulze (1997) was utilised. The electronic data points for grid coordinates of the experimental sites (PSPs) were found from the Computing Centre for Water Research (CCWR), Department of Agricultural Engineering (DAE), in collaboration with ICFR, University of Kwazulu-Natal Pietermaritzburg campus. The climatic average conditions for the study sites are as given from tables 41-43 and appendix 2-30. The importance of climate to tree growth is as discussed under sub-chapter 6.1.1 and by referring to relevant literature. The climatic variables are as described under sub-chapter 6.2. The role being played by weather stations in showing the climate of a site in relation to tree growth are explained below.

There are many weather stations that are operational in Lesotho, which are very close to the experimental areas. Lesotho is divided into ten administrative districts. In each district, there is more than one weather station. The weather stations are set up to take measurements of rainfall, temperature etc. Many weather stations, however measure only rainfall and there are no measurements taken other than climatic factors like wind speed. Many of these weather stations have been functioning for about 100 years. For an example, the weather stations of Butha-Buthe and Leribe have been functioning for more than 97 and 116 years, respectively. These stations are very near to some of the experimental sites (Appendix 36 and 37).

In 2003, a Water Research Commission (WRC) funded a project, which was finalised aimed at revising the MAP values developed for the Southern African region. The original MAP statistics are widely used by the forest industry to classify sites (MAP is utilised as an indicator of site potential) and for site-species matching. One of the outputs of the project was a daily rainfall database of more than 300 million rainfall values from a total of 11269 stations. This information came from various organisations and individuals in South Africa, including municipalities and private companies as well as from Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe. The three primary custodians of rainfall data in South Africa include South African Sugar Association (SASA), Institute for Soil, Climate and Water (ISCW) and the South African Weather Service (SAWS). In order to utilise this information kept in the database efficiently, the Institute For Commercial Forestry Research (ICFR), in collaboration with the School of Bio Resources Engineering and Environmental Hydrology (SBEEH) of the University of KwaZulu-Natal (UKZN), Pietermaritzburg Campus (Kunz, 2004), formulated a daily rainfall extraction tool.

In addition to this, a number of studies were carried out for compiling information on climatic factors measured from the existing weather stations. As a result climatic zones were developed (Schulze, 1997). This was used to estimate the MAP, MAT and other climatic factors for the experimental sites once these location (grid references) were determined.

6.2 Climatic Variables

6.2.1 Precipitation

Herbert (1997) stated that, in the Drakensberg Mountains, the precipitation tends to increase with altitude. But also it decreases with distance from the coast and from the leading southern crest of the escarpment. These phenomena are associated with moist air which tends to be channelled inland primarily from the south and southeast. It is presumably intercepted as orographic rainfall and mists by escarpments facing into the air mass direction of movement.

Distinct differences in regional productivity occurred mainly due to differences in precipitation (low vs. high) and the type of parent material (sandstone vs. mudstone and dolerite). Soil depth, texture and OC affect some water holding capacity, which may moderate temporarily deficiency of rain. In principle, low topsoil OC indicates regular periods of poor water availability. The minimum MAP for commercial forestry is set at 815 mm at lower elevations (1280 m a.s.l) (Herbert, 1997; Gardener *et al.*, 2001).

6.2.2 Other factors

It was also discovered that plants require certain limits of temperature for their growth depending on individual species (Schulze, 1997). He further indicated that temperature has been used as a fungicide to determine the suitability of a location for certain agricultural, horticultural and exotic tree species or pasture varieties. Examples that temperature has been specified in atlas as a variable include descriptions of optimum production areas of: *Eucalyptus grandis* – 16 °C to 22 °C, *Accacia mearnsii* – 15 °C to 20 °C, *Pinus elliottii* - > 14 °C, *Pinus patula* – 13 °C to 18 °C, cotton - > 16 °C, *Eragrostis curvula* – 13 °C to 16 °C. Heat units are expressed in terms of degree-days at a base of 10 °C from October to March, and April to September respectively. Schulze (1997) connoted that generally, the lower the temperature the slower the rate of growth of plants.

Solar radiation plays major part for processes like photosynthesis to take place. On the same line, potential evaporation is another factor of importance to plant growth. Contrarily, high relative humidities lower the rate of transpiration and also reduce the amount of water needed by crops. It was also detected by a number of researchers that, broadly speaking photosynthesis is positively related to humidity. It was also studied that combinations of high humidity and temperature could have damaging effects in agriculture and forestry because of fast development of weeds and parasites on such sites (Schulze, 1997).

Lang's climatic index (LCI) is defined as the ratio of MAP to MAT (Herbert, 1997; Lang, 1926; Du Plessis, 2002). It is also described as the effective precipitation and water balance. LCI is explained further by this equation (Equation 10).

(LCI mm/°C) = MAP (mm)/MAT (°C)... **Equation 10**

It was detected that there is a good association between LCI and SI for black wattle, and in the same manner 50 mm/°C was confirmed to be minimum for a commercial forestry (Schonau, 1969; Lang, 1926; Herbert, 1997; Du Plessis, 2002). Herbert (1997) stated that there is an association between altitude and MAT, and this has been approved statistically with the significance level of $P \leq 0,01$ (Equation 11).

MAT (°C) = 55,43287 – 5,592502 (Ln Altitude (m)) (n =108; $R^2 = 0,96$). ...... **Equation 11**

It was clarified that this equation was adjusted by 0,60 °C downwards, and it emanated equation (Equation 12).

MAT (°C) = 54,83287 – 5,592502 (Ln Altitude (m)). .... **Equation 12**

6.3 **Results And Discussion**

It can be noted from tables 35-37 that the minimum MAP is 533, 597 and 705 for the experimental areas of *P. radiata, E. rubida* and *E. macarthurii*. These PSPs were established in lowlands and foothills at elevations from 1400 to 2300 a.s.l. Britz (1998), Monnik and Bonnardot (1998) stipulated that the association between the independent factors such as altitude, latitude and longitude indicated a good correlation. It is quite obvious that the rainfall tends to be high during the months of September to March, and declines from May to August. The monthly rainfall patterns for *E. rubida* and *P. radiata* are shown in figures 31 and 32.

Temperature tends to follow the same pattern like rainfall: it is low during the winter months and high during the summer (Figures 31 and 32). The coldest month is July with a minimum and maximum temperature of 11 and 16 °C respectively (Tables 35-37).

The monthly solar radiation is as indicated in appendices 26-28. The minimum, maximum and mean monthly solar radiation and mean heat units for *E. rubida, P. radiata* and *E. macarthurii* are also shown in tables 35-37. Hence, the minimum, maximum and mean monthly potential evaporation for the sites of *E. rubida*, *P. radiata* and *E. macarthurii* are tabulated in tables 35-37 and also in appendices 23-25. The DAE's A-pan evaporation model at the UKZN seemed to be precise and preferable for a number of sites (Herbert, 1997; Schulze, 1997; Du Plessis, 2002). The monthly relative humidity distribution patterns for the sites of three species are shown in appendices 29-31. The minimum and maximum relative humidity of *P. radiata* are 53 and 68 mm respectively (Table 36).

The LCI of the three species can be noted from tables 35-37. It was realised that the maximum growth of plants occurred when LCI = 65 per annum whereas minimum growth occurred when LCI is approximated to be 50 mm/°C or less (Du Plessis, 2002).

Table 35: Climatic average conditions for the 33 *Eucalyptus rubida* permanent sample plots

Precipitation (mm)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	Mean annul (MAP)	777	597	902	61,34
	Driest month (Jun)	5	1	6	31,12
	Wettest month (January)	122	83	146	50,88
	20th Percentile	877	687	1045	71,08
	80th percentile	625	490	731	55,62
	Median annual rainfall	694			
	Hail frequency	6	4	6	0,52
Temperature (°C)	Mean annual (MAT)	14	13	14	0,29
	Mean max. hottest month (January)	27	24	28	4,21
	Mean max. coldest month (June & July)	15	14	16	3,62
	Mean min. hottest month (January)	12	11	14	4,50
	Mean min. coldest month (July)	0	-1	1	4,36
Heat units (°C)	Heat units April-Sept.	248	135	307	31,19
	Heat units Oct.-Mar	1508	1293	1593	101,99
Solar radiation (°C)	Monthly solar radiation	24,4	13,8 (June)	34,4 (Dec)	52,11

Table 35 Cont.

Frost (°C)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	Frost start	136	119	147	6,54
	Frost end	262	253	276	5,17
	Frost duration	131	107	158	11,28
	Frost days	47	24	68	10,53
Evaporation (mm)	Mean monthly A-pan	150	83 (June)	251 (December)	48,99
	Mean annual A-pan	1833	1692,2	1956,2	55,98
Relative humidity (mm)	Mean Monthly relative humidity	61	54 (Jul&Aug)	66 (Feb-Apr)	2,89
Lang's climatic index (mm/ °C)	Lang's climatic index	55,5	45,9	64,4	

Table 36: Climatic average conditions for the 44 *Pinus radiata* permanent sample plots

Precipitation (mm)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	MAP	726	533	878	102,06
	Driest month (July)	7	3	7	26,63
	Wettest month (January)	137	71	172	64,35
	20 th percentile	851	622	1238	112,49
	80 th percentile	605	428	872	90,17
	Median annual rainfall	694			
	Hail frequency	6	4	6	0,42
Temperature (°C)	MAT	14	12	15	0,99
	Mean max. hottest month (January)	26	23	29	4,55
	Mean max. coldest month (July)	14	11	16	3,42
	Mean min. hottest month (January)	12	10	13	4,67
	Mean min. coldest month (June&July)	0	-2	1	4,39
Heat units (°C)	Heat units April - Sept	231	54	325	68,01
	Heat units Oct. - March	1480	811	1711	189,52

Table 36 Cont.

Solar radiation (°C)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	Mean monthly solar radiation	24,7	12,6 (June)	34,6 (Dec)	6,48
Frost (°C)	Frost start	128	112	137	4,53
	Frost end	265	256	286	6,21
	Frost duration	138	120	173	10,62
	Frost days	53	35	83	7,93
Evaporation (mm)	Mean Monthly A-pan	148	81 (June)	255 (Jan)	51,33
	Mean annual A-pan	1825,6	1744	2045,7	90,08
Relative humidity (mm)	Mean monthly relative humidity	61	53 (Jul, Aug&Sept)	68 (Feb&Apr)	1,93
Lang's Climatic index (mm/°C)	Lang's Climatic index	51,9	44,4	58,5	

Table 37: Climatic average conditions for the 4 *Eucalyptus macarthurii* permanent sample plots

Precipitation (mm)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	MAP	745	705	777	30,27
	Driest month (June & July)	5	5	6	36,85
	Wettest month (January)	104	97	108	40,67
	20 th percentile	872	829	908	23,39
	80 th percentile	586	554	609	23,39
	Median annual rainfall	743			
	Hail frequency	6	4	6	0
Temperature (°C)	MAT	13	14	14	0,50
	Mean max. hottest month (January)	27	26	27	4,36
	Mean max. coldest month (July)	14	14	14	38,85
	Mean min. hottest month (January)	12	12	13	4,93
	Mean min. coldest month (June & July)	-1	-1	0	4,99

Table 37 Cont.

Heat units (°C)	**Variable**	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
	Heat units April – Sept.	207	178	240	25,99
	Heat units Oct - March	1453	1369	1524	63,72
Solar radiation (°C)	Mean monthly solar radiation	24,9	14,9 (June)	33,4 (Dec)	6,55
Frost (°C)	Frost start	127	123	130	3,51
	Frost end	267	263	271	3,50
	Frost duration	142	134	149	6,95
	Frost days	56	50	62	6,38
Evaporation (mm)	Mean monthly A-pan	157	83 (June)	239 (Dec)	55,91
	Mean annual A-pan	1896,4	1847,2	1956,2	44,93
Relative humidity (mm)	Mean monthly relative humidity	60	55 (June&July)	64 (Feb&Apr)	2,84
Lang's climatic index (mm/°C)	Lang's climatic index	57,3	50,4	55,5	

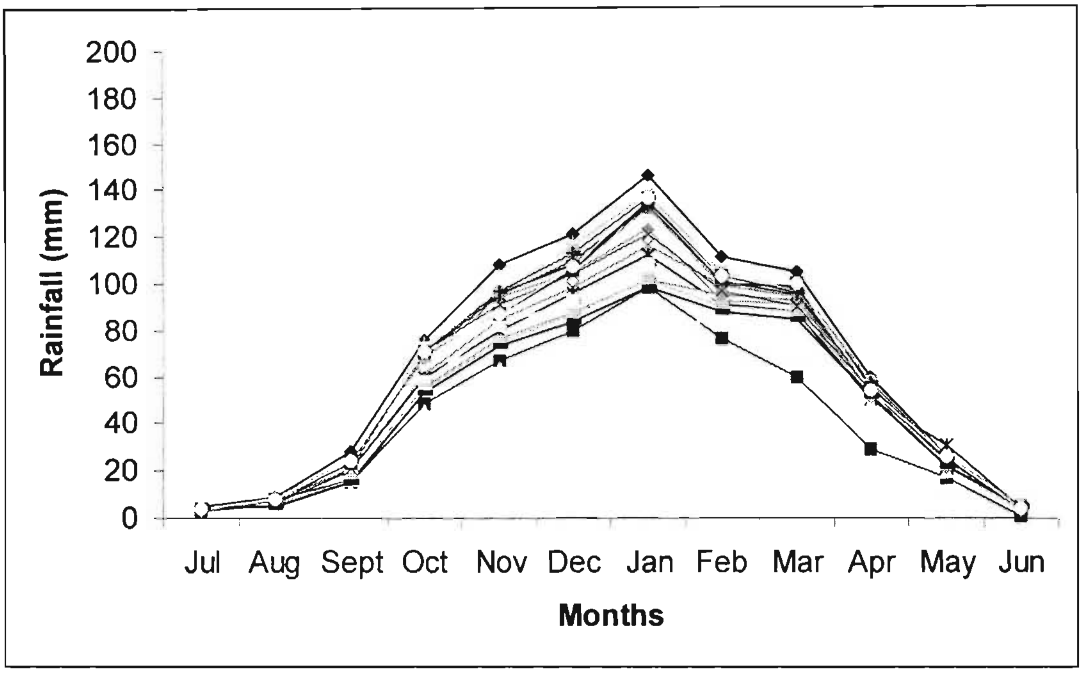

Figure 31: Mean monthly rainfall for *E. rubida* permanent sample plots

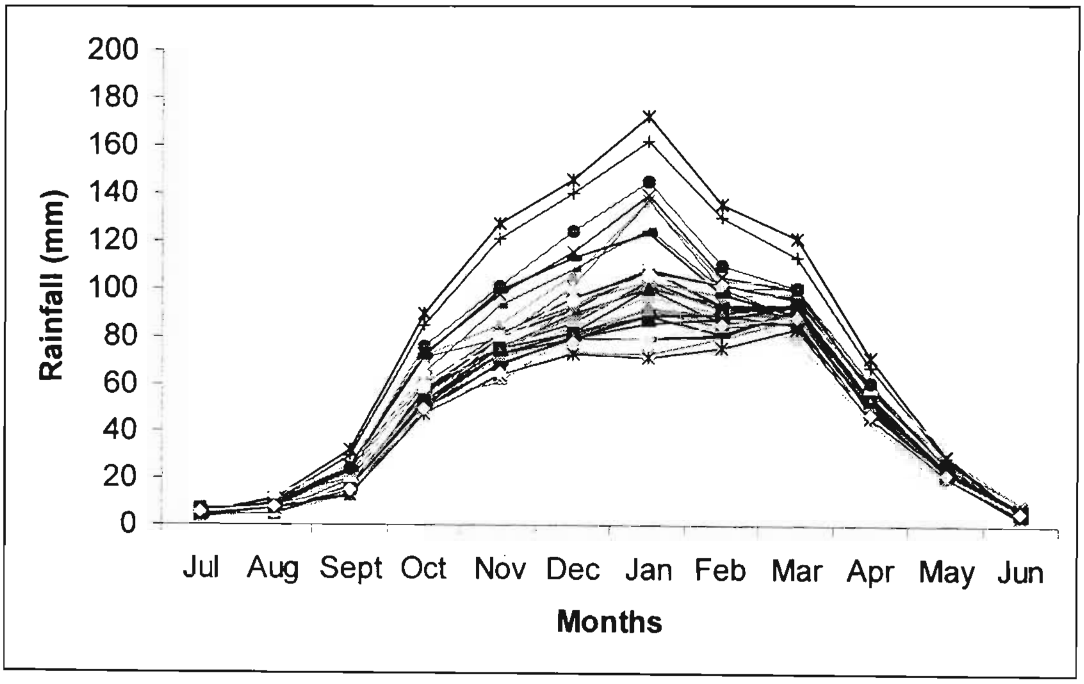

Figure 32: Mean monthly rainfall for *P. radiata* permanent sample plots

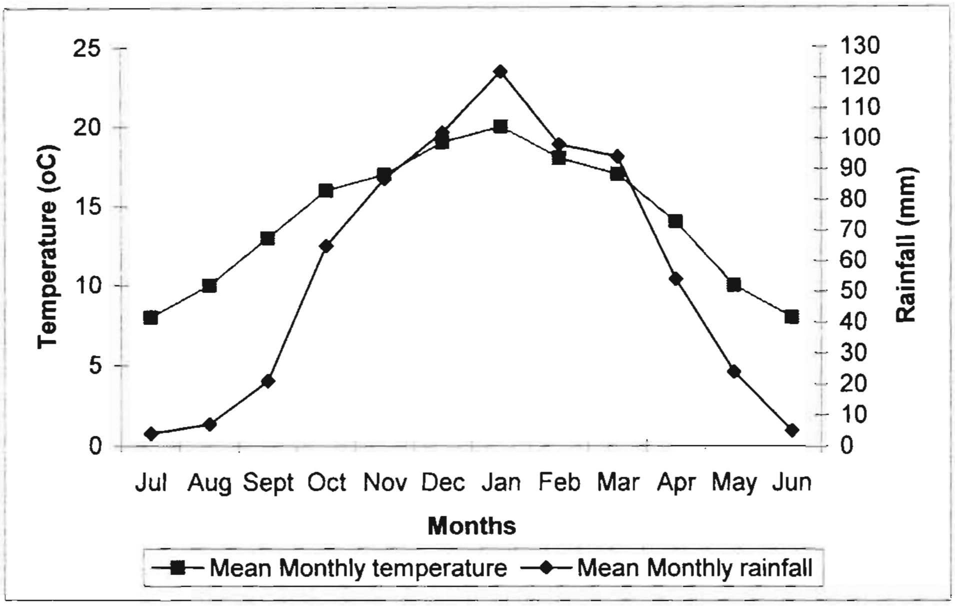

Figure 33: Gausen Walter climatic diagrams for *E. rubida* permanent sample plots in Lesotho

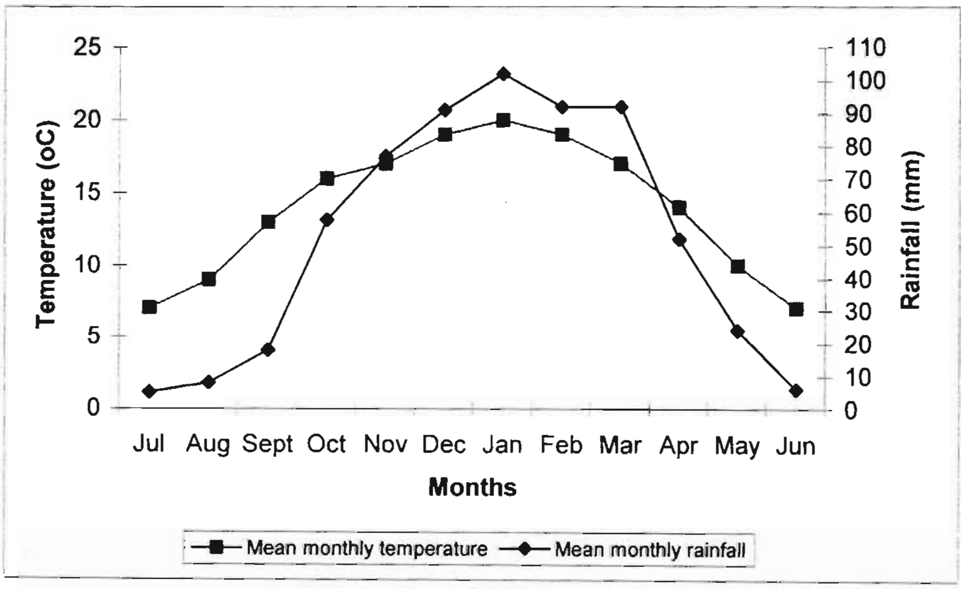

Figure 34: Gausen Walter climatic diagrams for *P. radiata* permanent sample plots in Lesotho

6.4 Conclusion

The importance of climate to tree growth was highlighted. It was indicated that temperature plays major role for many processes like photosynthesis to function. The climatic variables were briefly explained. The rainfall extraction tool was developed by ICFR in collaboration with DAE UKZN, to estimate mainly MAP from the weather stations in the SADC region, because original MAP values are broadly utilised by the forestry industry and other companies to classify sites. They can also be used as indicators of site potential and for site-species matching. The role played by weather stations in line with plant growth was given to take up measurements of climatic variables MAT, MAP and so forth. With the basis of climatic variables, growth of certain crops can be predicted easier.

CHAPTER SEVEN

THE RELATIONSHIP BETWEEN SITE CONDITIONS AND SITE INDEX OF *E. RUBIDA* AND *P. RADIATA* IN LESOTHO

7.1 **Introduction And Objectives**

There have been a number of studies, which were carried out worldwide for investigating site conditions or requirements for different species in relation to their growth (Louw, 1991; Grey, 1983b). Many researchers used multiple regression analysis to investigate site-species relationships on various sites, but this type of analysis failed in a number of cases (Louw, 1991; Grey, 1983b). The site requirements for *E. rubida* and *P. radiata* are shown in table 38 and table 39, respectively.

Table 38: Site requirements for *E. rubida* (Boland *et al,* 1997; Poynton, 1979; Jacobs, 1979; Curtis, 1956; Louw, 1997; Schonau, 1969).

Factor	**Conditions**
Latitude	28 to 43° south
Altitude	75 to 1500 m a.s.l
Precipitation	600 to 1270 mm
Temperature	-4 to 30 °C
Soil types	Moderately fertile, well-drained loams with clay sub-soil
Frost risk	Moderately susceptible
Snow risk	Susceptible

Table 39: Site requirements for *P. radiata* (Poynton, 1977; Pallet and Morris, 2000; Grey, 1983b; Cricthfield and Little, 1966; Streets, 1962; Mirov, 1967; Scott, 1960)

Factor	**Conditions**
Latitude	45° south to 45° north
Altitude	0 to 2375 m a.s.l
Precipitation	> 600 mm
Temperature	-4 to 37 °C
Soil types	Deep, sandy loam, acidic, well-drained, humus content
Frost risk	Moderately susceptible
Snow risk	Susceptible

Boland *et al*., (1997), Poynton (1979), Jacobs (1979), Curtis (1956) reported that *E. rubida* is found in latitudinal range of between 28° - 43° S, while altitude differs from 75 to 750 m in Tasmania and up to 1400 m in the Snowy Mountains. It prefers the climate, which is cool to warm, sub-humid to humid, with mean maximum temperature of the hottest month in the range 20–30 °C and mean minimum of the coldest month between –4 to 4 °C. However, they connoted that frosts are common throughout the range occurring from 15 to more than 100 times each winter. Heavy snowfalls are common at higher altitudes. Snow remains on the ground for weeks in some areas. It is primarily a species of tablelands, mountain slopes and hills occurring on a wide range of soil types including those which are rather dry, shallow and almost skeletal. Best development is on moderately fertile, well-drained loams with clay sub-soil (Table 38).

In California, *P. radiata* is found on the headlands and in hilly country close to the sea, but avoiding hot, dry, southerly aspects except in the Swanton area, where conditions tend to be cooler and more humid. It grows on a great variety of soils such as acidic, deep, well-drained soils with high humus content in the A horizon, permeable, coarse-textured, siliceous soils, often calcareous, finely sandy loams, gravely clays. In South Africa good yields are obtained on Hutton, Clovelly, Fern wood; Lamotte and Oak leaf soils provided the organic C content is relatively high (>1.50). Louw (1991) stipulated that certain of the deeper wet duplex soils, typical of the Tsitsikamma plateau in South Africa, may be successfully planted with the aid of phosphate fertilisers. Grey (1987) stated that to associate site and soil characteristics with tree growth; SI was used extensively as a measure of site productivity and yielded better results than any other growth criterion. Similarly, Louw (1991) pinpointed that in the past, efforts to model growth of *P. radiata* were carried out with varying success, primarily because the research areas included a complex range of variables, thus hampering the growth modelling of a highly sensitive species. Phillips (1992) connoted that the assessment of the productive capacity of the land for a given crop is a significant component of any growth or yield model. It was discovered that the most widely accepted assessment of productive capacity is SI, defined as the average dominant HT of trees at a given age. This age is normally also referred to as the base age (Phillips, 1992; Clutter *et al*, 1983; Hagguland, 1981; Tesch, 1981).

Herbert (1997) stated that the Maclear District of the Eastern Cape comprises rather different geological, climatic and edaphic conditions to other forestry regions of South Africa. He stressed further that precipitation is only locally high, and early growth studies on plantation – grown pines and eucalypts by the North East Cape Forests had indicated mixed results, from good to poor, and even stand failure. He declared that there is a need for greater understanding of growing conditions, and how these may best be exploited through the development of optimum site-specific silvicultural operations.

Norris (2000) emphasised that eucalypts are grown commercially mainly for pulp and not much for saw timber and poles. He expressed further that for pulpwood the prime objective is to maximise volume production per hectare. Volume production goes hand in hand with good site preparation methods like complete surface cultivation, weeding, etc as well as spacing and rotation age.

It was also reported that the climate of species in general is temperate, fairly equable and more or less of the Mediterranean type. Although it is greatly changed, especially during summer months, by regular occurrence of sea fogs or cloud and high humidities. MAT differs between 9 to 17 °C in California; while MAP ranges from 380 to 890 mm. Frosts occur in California coasts, while snow and frosts are noticed in Guadalupe. Its altitudinal range is from 300 to 1160 m and from 0 to 300 m (Grey, 1983b; Poynton, 1977; Pallet and Morris, 2000) (Table 39).

In Lesotho site factor studies were undertaken for species such as *P. greggii*, *P. taeda* and *P. patula* (Richardson, 1982; 1983; 1984a; 1985a; Leslie, 1991). However, the SIs for *P. radiata* and *E. rubida* are not yet determined even though they are the main plantation species in Lesotho. Therefore, it is very difficult to match the species to sites. The conclusion made so far was that the eucalypts were detected to perform well in the northern districts such as Butha-Buthe, Leribe, Berea and the northern part of the Maseru districts. This is because there are good rains ranging from 600 to 800 mm per year. Eucalypts tend to perform well on the south facing slopes because they are usually cool and moist. They do not grow well on the north facing slopes, as they are always dry and warm. It was noted also that the pines were found to perform well in the southern part of Maseru, Mafeteng, Mohale's Hoek and Quthing districts. These districts are considered as dry zones since the MAP is between 450 to 500 mm per year (Lesotho Forestry Operations Manual, 1973; 1989; Green, 1987; 1988).

The objectives of the study are as follows: (i) define site conditions for the experimental sites, (ii) determine SI, (iii) use correlation analysis in order to study associations between variables, (iv) define relationships between site variables and SI by using multiple regression analysis.

7.2 **Study Area And Methods**

This study involves data sets, which were obtained in Lesotho. The number, species and location of PSPs by agro-ecological zones and landforms is explained in tables 6 and 7. The location map of PSPs in the study area is shown in figure 4. Site conditions for the above mentioned species were defined by making a thorough literature review and surveys. Equations were used to start the analysis of PSPs. Equations 15 and 16 were used to get SIs for *P. radiata* and *E. rubida* plots respectively (Appendices 34 and 35). SI has been already provided in chapter 4.4.3. The SIs for both species of *E. rubida* and *P. radiata* were calculated (Appendix 34 and 35) at ages 6 yr and 15 yr, respectively. The SI ranged from 6,72 m to 14,40 m and from 12,05 m to 18,43 m for *E. rubida* and *P. radiata*, respectively. Van Laar (1997) stipulated that foresters are aware of the fact that a set of SI curves may be *anamorphic* or *polymorphic*. Furthermore, he explained that anamorphy refers to the individual curves, which are located above one another with the similar relative distance between the curves. Polymorphic curves imply that the relative distance between the curves either increases or decreases with age.

The statistical analysis used was mainly correlation and multiple regression analysis. The association between variables was done with the use of correlation analysis. Correlation analysis was conducted to find out which factors are significantly associated with SI and other site variables and such variables were chosen for further analysis. This was used to pre-select variables, which could explain growth. The relationships between the select site variables and SIs were analysed with multiple regression analysis. Genstat was used to draw the correlation between two variables. The Pearson correlation coefficient (r) was utilised to estimate the association between the variables (Du Plessis, 2002; Du Plessis and Zwolinski, 2003; Genstat, 2003).

The transformation of the aspect and slope values for sites was carried out in this manner (Equations 13 and 14):

New_slope = square root (slope)..**Equation 13**
New_aspect = square root (slope)*Cos (aspect)..**Equation 14**

The numbers were transformed because e.g. 0° and 360° are both two different numbers but they reflect the northern aspect and in a linear scale they are different. The slope and aspect were transformed to improve the outcome of the analysis (Dr. D. Wilson, pers. com. Forestry Programme, UKZN, 2004).

7.3 Results

7.3.1 Correlation analysis between the site variables and site index

Results of the correlation analysis between all the tested variables are shown in tables 40 and 41. This analysis indicates how strong the linear association between two variables is. The primary objective of this analysis is to find those variables, which usually associate with tree growth to be used for further analysis and formulation of regression models (Du Plessis, 2002; Van Laar, 1991; Freeze, 1984).

A subjective rule has been set that (i) a strong correlation is referred to when $r \geq 0,7$, (ii) moderate correlation is shown when $0,5 \leq r < 0,7$, and (iii) a weak association occurs at r <

0,5 (Dr. D. Wilson, pers. com., Forestry Programme, UKZN, 2004). The following observations have been made based on the correlation analysis Table 40 and 41:

Slope - appears to have a weak association with aspect, MAT and solar radiation (SR). It also has a strong relationship with heat units (October to March) (HUOM) for *E. rubida* plots. However, it has only a weak relationship with altitude, aspect and SI for *P. radiata* sites.

Altitude - has a weak correlation with SI, heat units (April to September) (HUAS) and MAP for *E. rubida* plots. It has a weak association with slope, MAP and aspect for *P. radiata* sites.

Heat units (October to March) – correlated with solar radiation and showed a strong association with MAT and HUOM for *P. radiata* plots. On the one hand, they were weakly correlated with MAP, MAT and SR for *E. rubida* plots.

Heat units (April to September) – were weakly correlated with SR and MAT and had a stronger association with slope for *E. rubida* plots. They were also strongly correlated with MAT and SR for *P. radiata* sites.

Aspect – has a very weak association with SI, SR and slope with both species sites.

Solar radiation – was correlated weakly with aspect but it was strongly correlated with HUAS and MAT. It was also strongly associated with HUOM for *P. radiata* plots. A strong correlation was observed with HUOM for *P. radiata* plots, and weak correlation with aspect, HUAS, HUOM and MAT for *E. rubida* sites.

MAT – was strongly related with HUAS and HUOM for *P. radiata* sites. It was weakly correlated with both HUOM and HUAS for *E. rubida* plots.

SI - has a weak association with aspect, slope and solar radiation for *P. radiata* and *E. rubida* plots. SI is also correlated weakly with altitude, aspect, heat units (April to September) and MAP.

Table 40: Symmetric matrix indicating Pearson's correlation coefficients and significance (* for P≤ 0,25) for site attributes and site index for *P. radiata*. HUAS – Heat units (April – Sept.), HUOM – Heat units (Oct – March), MAP – Mean annual precipitation, MAT – Mean annual temperature, SI – Site index, SR – Solar radiation.

	Altitude	**Aspect**	**HUAS**	**HUOM**	**MAP**	**MAT**	**SI**	**SR**	**Slope**
Altitude	**1**								
Aspect	0,18 *	**1**							
HUAS	-0,69 *	-0,02	**1**						
HUOM	-0,79 *	-0,02	**0,95** *	**1**					
MAP	0.,30 *	-0,12	-0,26 *	-0,37 *	**1**				
MAT	-0,70 *	-0,05	**0,92** *	**0,95** *	-0,36 *	**1**			
SI	-0,15	**0,09**	-0,09	-0,08	0,06	-0,04	**1**		
SR	-0,74	0,01	0,78 *	**0,87** *	-0,30 *	0,84 *	-0,00	**1**	
Slope	0,23	0,07	-0,09	-0,13	-0,10	-0,14	0,12	-0,04	**1**

Table 41: Symmetric matrix indicating Pearson's correlation coefficients and significance (* for P≤ 0.25) for site attributes and site index for *E. rubida* (HUAS – Heat units (April – Sept.), HUOM – Heat units (Oct – March), MAP – Mean annual precipitation, MAT – Mean annual temperature, SI – Site Index, SR – Solar radiation)

	Altitude	**Aspect**	**HUAS**	**HUOM**	**MAP**	**MAT**	**SI**	**SR**	**Slope**
Altitude	**1**								
Aspect	-0,07 *	**1**							
HUAS	0,00	-0,07	**1**						
HUOM	-0,58 *	-0,04	0,45 *	**1**					
MAP	0,25 *	-0,02	0,38 *	-0,28 *	**1**				
MAT	-0,67 *	-0,00	0,00	0,09	-0,01	**1**			
SI	0,26 *	0,30	0,14	-0,18	0,19	-0,19	**1**		
SR	-0,72 *	0,04	0,30	0,39 *	-0,24 *	0,31	-0,03 *	**1**	
Slope	-0,49 *	0,01	-0,14 *	0,75 *	-0,48 *	0,20 *	-0,25	0,32 *	**1**

7.3.2 Multiple regression analysis between site variables and site index

Firstly, all the predictor variables were plotted against SI as a response variable, for each species, to observe the dispersion of the data, before further analysis was carried out. The normality of the data was tested visually by plotting the residuals (Figure 37 and 38), before the data was analysed (Dr. D.Wilson, pers. com., Forestry Programme, UKZN, 2004). Whitaker (1990) and Snedecor and Cochran (1980) clarified that the observed data is taken to find the histogram of it and visually check normality. Then, a significance test could be used and based on the concept of getting the expected number of data between two class limits and the expected number of data between the same limits. The expected number is being calculated under the hypothesis of the data that is normally distributed. It was realised that the residuals showed the normal distribution curves, which are the bell shapes for both species. And, there was no need to transform the data. The response variables chosen for this research are MAI_i ($m^3/ha/yr$) and SI_i (m) and SI_{15} (m), with ages i = 6 yrs for *E. rubida* and i = 15 yrs for *P. radiata* (Appendices 32-35).

The multiple regression analysis was used to analyse the relationship between growth of trees with site factors, of all the plots, of both species, with a statistical package Genstat 7th edition (Genstat, 2003). HTOP and SI were standardised at reference age by regressing HT of the 20% largest diameter trees (Du Plessis and Zwolinski, 2003; Bredenkamp 1993). The Kotze and Puumalainen (1995) formula was used to fit the original HT assessments data for each of the 44 plots of *P. radiata* species. The coefficients were as follows: (i) COEF a = 3,99454, (ii) COEF b = -6,86812, (iii) COEF c = -3,59407. Then the HT was predicted against age using the equation (Equation 15). The formula was tested to determine if it functions properly by plotting predicted HT against difference. The residuals indicate that the majority of the points lie between 2 and –2 m from the mean (Figure 35).

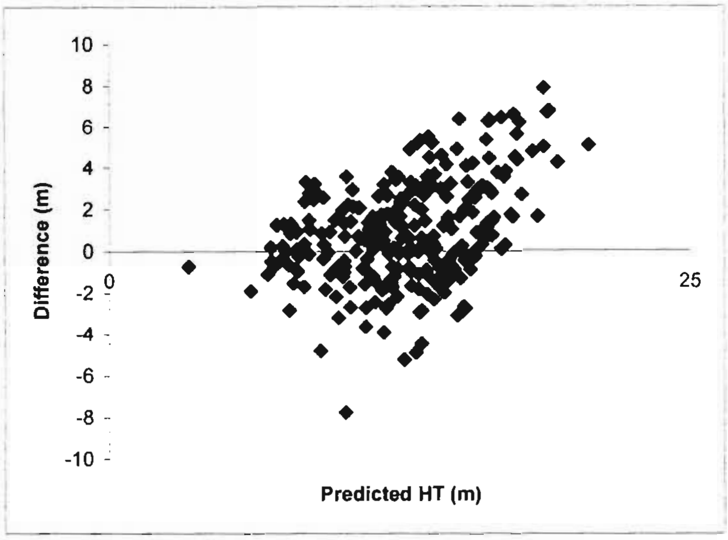

Figure 35: Predicted height vs height difference for the 44 plots of *P. radiata* (Kotze and Puumalainen, 1995)

HD2=exp(((((Ln(HD1))-(COEF2/AGE1)+COEF3)/(exp(COEF1*((1/AGE1)-(1/AGE2)))))+(COEF2/AGE 2)-COEF 3).. ....**Equation 15**

HD2 = predicted HT at age 2

HD1 = observed HT at age 1

Age2 = future age (could be previous also)

Age 1 = current age

Similarly, Phillips (1992) developed a formula, which was also used to fit the original tree HT assessments data for each of the 33 plots of *E. rubida* (Equation 16). The equation was tested. The predicted HT was plotted against the HT difference. It can be noted that most of the residuals are found between –2 and + 2 m (Figure 36)

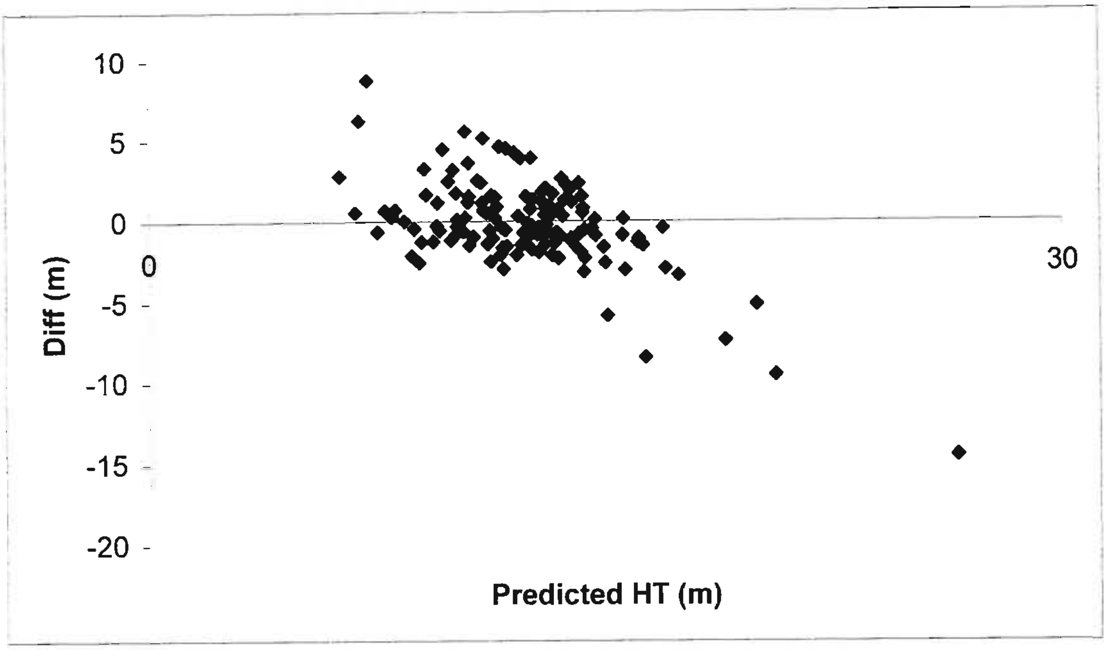

Figure 36: Predicted height vs height difference for the 33 plots of *E. rubida* (Phillips, 1992).

HD2=exp(Ln(HD1)+(-3,6*(Age2^(-1,2)-Age1^(-1,2))))......................**Equation 16**

HD2 = predicted HT at age 2

HD1= observed HT at age 1

Age 2 = future age (could be previous age also)

Age 1 = current age

The summarised statistics information after having analysed SI against all site variables for *E. rubida* and *P. radiata* species are as given from table 40-41.

A correlation analysis was utilised to choose first the appropriate variables for further investigations and for model development (Du Plessis and Zwolinski 2003; Du Plessis, 2002). When including all the variables, the multiple regression analysis indicated low coefficient of determination of 20,4% and 37,0 % for *E. rubida* and *P. radiata* respectively. Then, the variables that indicated best correlation were selected. The multiple regression analysis was run again with variables included $P \leq 0,25$. It was found that after selecting the variables that correlate best, R^2 for both species was very low and it was only 10,9% and 2,6% for *P. radiata* and *E. rubida* species. The final models for both species defined with the multiple regression analysis are as shown equations 17 and 18. The summary statistics for the models are shown in tables 42-45. The residual plots are provided in figures 37 and 38.

The regression equation for SI_{15} of *P. radiata*:

SI = 27,70 + –0,00608*ALT + 0,958*MAT + 0,0589*Slope................ **Equation 17**

SI= Site index at 15 m at base age 15 years.

Alt = Altitude (m)

MAT = Mean annual temperature (°C)

The regression equation for SI_6 of *E. rubida*:

SI = -2,17 + 0,00689*HUAS + 0,00585*Alt................................. **Equation 18**

SI = Site index at base age 6 years

HUAS = Heat units from April to September at base 10 °C

Table 42: Summarised statistics of multiple regression analysis of *P. radiata* site index and site variables. (d.f. = degrees of freedom, s.s = sums of squares, m.s. = mean squares, v.r. = variance ratio (F value), p = probability)

	d.f.	**s.s.**	**m.s.**	**v.r.**	**P≤0,25**
Regression	4	24,2	6,061	2,32	0,074
Residual	39	101,8	2,611		
Total	43	126,1	2,932		

Table 43: Multiple regression analysis on estimated parameters of summarised statistics for *P. radiata* (s.e. = standard error, p = probability)

	estimate	**s.e.**	**T(39)**	**P≤0,25**
Constant	27,70	7,11	3,90	<0,001
ALT	-0,00608	0,00214	-2,84	0,007
MAT	0,958	0,776	1,23	0,224
SLOPE	0,0589	0,0416	1,42	0,165

Table 44: Summarised statistics of multiple regression analysis of *E. rubida* site index and site variables. (d.f. = degrees of freedom, s.s = sums of squares, m.s. = mean squares, v.r. = variance ratio (F value), p = probability)

	d.f.	**s.s**	**m.s.**	**v.r.**	**P≤0,25**
Regression	2	10,6	5,294	1,42	0,257
Residual	30	111,6	3,720		
Total	32	122,2	3,819		

Table 45: Multiple regression analysis on estimated parameters of summarised statistics for *E. rubida* (s.e. = standard error, p = probability)

	estimate	**s.e.**	**T (30)**	**P≤0,25**
Constant	-2,17	7,21	-0,30	0,766
HUAS	0,00689	0,00883	0,78	0,441
ALT	0,00585	0,00392	1,49	0,145

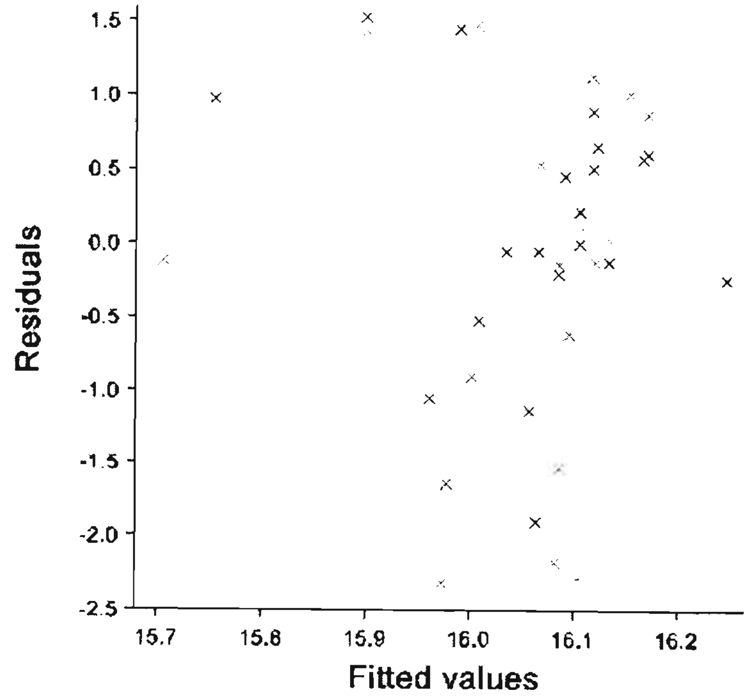

Figure 37: The residual plots of site index of *P. radiata* regressed against heat units (October –March), altitude, mean annual temperature and slope of sites in Lesotho

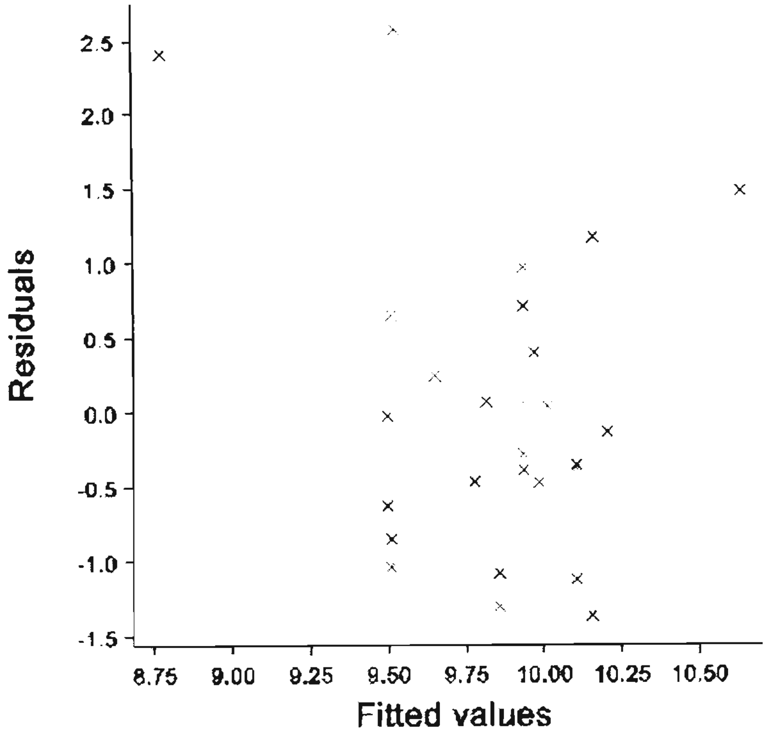

Figure 38: The residual plots of site index of *E. rubida* regressed against heat units (April – September) and altitude of sites in Lesotho

7.4 Classification Of *E. rubida* And *P. radiata* Study Sites

7.4.1 Classification of *E. rubida* study sites

Thirty-three study sites of *E. rubida* were arbitrarily classified by SI, starting from the class of 6 m to 8 m up to the last class of 14 m to 16 m. The class midpoints are of two metres interval. There were five classes made. The two explanatory variable SI model heat units (April to September) and altitude were calculated for each class as shown in table 46. MAP was decided to be added in the matrix. It should be noted that minimum, mean and maximum HUAS, altitude and SI were calculated for each class based on the number of PSPs found in that class. The other classification was conducted according to the agro-ecological zones (Table 47).

Table 46: Classification of *E. rubida* study sites based on site index classes

Class SI (m)	**PSP number**	**No. of plots**	**Heat units (Apr–Sep)**	**Altitude (m)**	**MAP (mm)**	**Site Index (m)**
6 – 8	ER/1028/1,ER/1007/1 ER/1007/2,ER/1026/1 ER/2009/2,ER/4001/5 ER/4001/6,ER/5010/1, ER/4011/1	9	Min Huas = 192 Mean Huas = 231 Max Huas = 302	Min alt = 1645 Mean alt = 1734 Max alt = 1894	Min = 686 Mean = 761 Max = 834	Min SI = 6,72 Mean SI = 7,51 Max SI = 7,97
8–10	ER/1005/1,ER/1005/2 ER/2006/1,ER/2007/1 ER/2009/1, ER/2009/3 ER/2012/4, ER/2019/1 ER/5006/1	10	Min Huas = 199 Mean Huas = 259 Max Huas = 307	Min alt = 1617 Mean alt = 1746 Max alt = 1848	Min = 710 Mean = 789 Max = 841	Min SI = 8,31 Mean SI = 9,30 Max SI = 9,95
10–12	ER/2012/1,ER/2012/10 ER/2012/3,ER/2012/9 ER/2013/1,ER/2019/2 ER/4001/1,ER/4001/2 ER/4001/4,ER/2012/1	9	Min Huas = 240 Mean Huas = 261 Max Huas = 307	Min alt = 1614 Mean alt = 1786 Max alt = 1864	Min = 743 Mean = 780 Max = 814	Min SI = 10,06 Mean SI= 10,72 Max SI = 11,77
12–14	ER/2016/1, ER/2016/2 ER/2023/1, ER/5002/1	4	Min Huas = 243 Mean Huas = 254 Max Huas = 261	Min alt = 1657 Mean alt = 1737 Max alt = 1868	Min = 639 Mean = 803 Max = 902	Min SI = 12,36 MeanSI= 12,82 Max SI = 12,93
14–16	ER/1021/1	1	Min Huas = 265 Mean Huas = 265 Max Huas = 265	Min alt = 1887 Mean alt = 1887 Max alt = 1887	Min = 597 Mean = 597 Max = 597	Min SI = 14,40 Mean SI= 14,40 Max SI = 14,40

Table 47: Classification of *E. rubida* study areas by agro-ecological zones

Agro-ecological zones	**PSP number**	**Frequency of plots**	**Site Index (m)**
Lowlands (1400 –1680 m a.s.l)	ER/1007/1,ER/1007/2, ER/4011/1 ER/2007/1,ER/2016/1,ER/2016/2 ER/1005/1, ER/1005/2, ER/1026/1 ER/2019/1, ER/2019/2, ER/1028/1	12	Min = 6,72 Mean = 9,36 Max = 12,93 SD = 2,18
Foothills (1681 – 2300 m a.s.l)	ER/5002/1, ER/1021/1, ER/2013/1 ER/4001/1, ER/4001/2, ER/4001/5 ER/4001/6, ER/2023/1, ER/5010/1 ER/5006/1, ER/2006/1, ER/2009/1 ER/2009/2, ER/2009/3, ER/2012/1 ER/2012/4, ER/2012/5, ER/2012/9 ER/2012/10, ER/4001/4, ER/2012/3	21	Min = 7,54 Mean = 10,12 Max = 14,40 SD = 1,88

7.4.2 **Classification of *P. radiata* study sites**

Forty-four study areas of *P. radiata* were also arbitrarily classified by SI beginning from class of 12 m to 14 m up to 18 m to 20 m. The class midpoints were also of two metre interval. There were four classes that were established. The two variable SI models included MAT and altitude were utilised instead of using four. It was decided that HUOM and slope must be taken out of the model, especially HUOM and MAT mean the same thing and it is not advisable to have both in the same model. In addition, The MAP was decided to be put into the matrix. The minimum, mean and maximum MAT, altitude and SI were determined for each class based on the number of plots found in that class (Table 48). Moreover, a classification of the study areas was done by agro-ecological zones (Table 49).

Table 48: Classification of *P. radiata* study sites based on site index classes

Class mid-points	PSP number	Frequency	MAT (°C)	Altitude (m)	MAP (mm)	Site Index (m)
12–14	PR/2038/1,PR/3016/1 PR/5016/1,PR/6008/1 PR/6015/2	5	Min temp = 13 Mean temp = 14 Max temp = 15	Min alt = 1589 Mean alt = 1689 Max alt = 1933	Min = 693 Mean = 742 Max = 805	Min SI = 12,35 Mean SI = 12,77 Max SI = 13,45
14–16	PR/1011/1,PR/1021/1 PR/1031/1,PR/1063/1 PR/1066/1,PR2026/2 PR/2038/2,PR3012/1 PR/3012/2,PR/3037/1 PR/3040/1,PR/4001/1 PR/4022/1,PR/Makoae I/1, PR/Makoae II/2, PR/Pulane Spring/1	16	Min temp = 11 Mean temp = 13 Max temp = 15	Min alt = 1515 Mean alt = 1775 Max alt = 2235	Min = 533 Mean = 733 Max = 1071	Min SI = 14,07 MeanSI= 15,22 Max SI = 15,91
16–18	PR/1001/1,PR/1052/1 PR/1080/1,PR/2014/1 PR/2021/1,PR/2021/2 PR/2026/1,PR/3023/1 PR/3026/2,PR/3029/1 PR/3033/1,PR/3036/1 PR/3036/2,PR/Sankatana II/1, PR/Sankatana II/2, PR/1035/1, PR/1048/1,PR/3003/1	18	Min temp = 12 Mean temp = 14 Max temp = 15	Min alt = 1507 Mean = 1644 Max alt = 1982	Min = 609 Mean = 699 Max = 1023	Min SI = 14,44 MeanSI= 16,78 Max SI = 17,84
18–20	PR/2014/2,PR/2029/2 PR/3026/1,PR/3027/1 PR/2029/1	5	Min temp = 13 Mean temp = 13 Max temp = 14	Min alt = 1597 Mean alt = 1679 Max alt = 1897	Min = 622 Mean = 768 Max = 878	Min SI = 18,01 MeanSI= 18,26 Max SI = 18,43

Table 49: Classification of *P. radiata* study areas by agro-ecological zones

Agro-ecological zones	**PSP number**	**Frequency of plots**	**Site index (m)**
Lowlands (1400 – 1680 m a.s.l)	PR/1031/1,PR/1011/1, PR/3033/1, PR/3037/1,PR/2021/1,PR/2021/2, PR/3029/1,PR/4022/1,PR/3027/1, PR/1035/1,PR/1063/1,PR/2038/1, PR/2038/2,PR/3003/1,PR/3036/1, PR/3036/2,PR/3026/1,PR/3026/2, PR/1001/1,PR/3016/1,PR/6015/2, PR/Sankatana II/1,PR/Sankatana II/2, PR/2029/1, PR/2029/2, PR/3012/1, PR/3012/2, PR/3023/1	28	Min = 12,05 Mean =16,10 Max = 18,43 SD = 1,70
Foothills (1681 – 2300 m a.s.l)	PR/6008/1, PR/1021/1,PR/1080/1 PR/1066/1,PR/1052/1,PR/4001/1,PR/3040/1 PR/2026/1,PR/2026/2,PR/1048/1, PR/2014/1, PR/2014/2, PR/5016/1	13	Min = 13,18 Mean =15,78 Max = 18,43 SD = 1,52
Mountains (> 2300 m a.s.l)	PR/Makoae I/1, PR/Makoae II/2, Pulane Spring/1	3	Min = 14,18 Mean =14,79 Max. = 15,83 SD = 0,90

7.5 **Discussion**

There was a significant relationship between SI and site variables in *P. radiata* plots. All the three variables, (ALT, MAT and slope) included in the SI model were significant at $P \leq 0{,}25$. It was also realised that two significant ($P \leq 0{,}25$) variables were included in the model for *E. rubida*. In this model altitude was significant even though it was a very weak relationship. HUAS was another variable included in the model. It was noted that when plotting SI against altitude of *P. radiata* plots, there was a decreasing trend. This indicates that *P. radiata* was more affected by lower temperature and less by lower MAP. Contrarily, when SI was plotted against altitude for the *E. rubida* sites then there was an increasing trend. This could mean that the higher the rain, the better the growth of trees irrespective of temperature within the study range.

It can be observed that there are three and two site classes of *P. radiata* and *E. rubida*. The first class is based on forest site productivity, whereas the second one is by agro-ecological zones. Agro-ecological zones is as defined in sub-chapter 3.4.1. On the one hand, there are five and four site classes by SI and other variables for *E. rubida* and *P. radiata* respectively (Table 46-49). For the forest site productivity classes, there is an overlap of certain variables like MAT, ALT etc. and there is no distinct class. On the other hand, the classes of plots by agro-ecological zones seem to have a well-defined classes and there is not that much overlap of site variables. It should be noted that what was expected out of the two models of the two above-mentioned species, MAP should be part of each model. But it is not part of any model probably because the MAP figures that were used were estimates. However, the results are in line with the findings of the other researchers and they can be more widely applicable on analysing site conditions to enhance site/species matching. They can also be applied on classifying sites. One of the hypotheses of the study is that growth and timber production are not dependent on site factors. This is not true when running the correlation and multiple regression analysis. It was detected that there are differences for site factors required by *E. rubida* and *P. radiata*. *E. rubida* is significantly affected by ALT and HUAS in regression models, while *P. radiata* is significantly affected by ALT, HUOM, MAT and slope. Therefore, H_0 is rejected while H_1 is accepted.

7.6 **Conclusion**

It can be concluded that the site requirements for *E. rubida* and *P. radiata* were defined. The SI for the above mentioned species were determined. The association between site variables of plots were executed with the help of correlation analysis. The SI models for *P. radiata* and *E. rubida* plots were calculated. The study areas were classified by SI and other variables and also by agro-ecological zones. The analysis of SI relationships was done by correlation and multiple regression analysis.

The multiple regression analysis of site index against the site variables explained very little of the variation. It is possible that some of the errors resulted in inaccurate estimation of site conditions especially where climatic variables were interpolated from general climatic models in this geomorphologically complex study area. It is possible that a variety of genetic plant material was used in the study experiments while different quality of plant stock and methods, as well as various plants were added to the varied response.

Despite all these adverse factors, some site factors were found as significant in the SI models.

CHAPTER EIGHT

PERFORMANCE AND GROWTH OF TREES IN SPECIES AND PROVENANCE TRIALS IN LESOTHO

8.1 Introduction

In the past, trees were introduced and planted in Lesotho by missionaries and government officials on trial and error basis. Due to huge demand of forest products and the energy crisis, it was felt that there has to be intensive research on fast growing species in order to address the scarcity of fuel wood and building materials. In 1979, the Forestry Research Section of the Lesotho Woodlot Project introduced many trials countrywide to assess the performance of various species of eucalypts and pines due to the quality timber they provide.

8.2 Study Area And Methods

Four species trials have been introduced in the various parts of the country. These experiments have been established on different sites and land types such as mountains, foothills and lowlands. The objectives of the trials were to: (i) quantify growth differences between species, (ii) quantify growth differences between provenances within species, (iii) observe frost and snow tolerance of the species and provenances, (iv) determine the relative performance of different species, (v) determine the relative performance of different provenances within species, (vi) measure differences in survival, frost, drought hardiness and height growth of various species and provenances. Variables such as diameter at root collar and breast height, height, survival were assessed at each enumeration. The data was transformed in order to attend the normal distribution and Log base 10 was used to transform survival, DBH and HT data to normal distribution. Jayaraman (2000) denoted that the log transformation is particularly effective in normalising positively skewed distributions. It is also used to achieve addivity of effects in certain cases. The least significance difference was used to define the significance between various means of species in terms of survival, HT and DBH.

The location and growth conditions of four species trials established at various parts of the country are provided in table 50.

Table 50: Location and growth conditions of four species trials

	Experiment number			
Characterisation	**L25/27**	**L25/6**	**L25/10**	**L25/9**
Latitude	29°25'11"	29°28'14"	30°06'33"	28°54'13"
Longitude	27°43'18"	27°45'19"	27°20'34"	28°00'14"
Woodlot name	Thaba-Putsoa	Thaba-Putsoa	Majapereng	Tsikoane plateau
Trial types	*Eucalyptus* species trial	*Eucalyptus* species provenance trial	*Eucalyptus* species provenance trial	*Eucalyptus* species provenance trial
Altitude (m)	2200	2200	1511	1840
Mean annual precipitation (mm)	1000	1000	800	1000
Geology	basalt	basalt	shale/mudstone	sandstone
Soil texture	clay loam	clay loam	sandy/clay	sandy loam
Min. soil depth (cm)	80	80	100	80
Topography	convex	convex	concave/flat plains	flat
Slope (°)	17	25	2	2-3
Geomorphology	Basaltic slope	Basaltic slope	Lowland hill lower slopes	Structural plateau top
Exposure to wind	high	high	low	high
Aspect	east	east	north	South west

8.2.1 **Experiment number L25/27**

The trial was established on 22 February 1979. The ground preparation was by the digging of the planting pits which were 100 cm*100 cm*25 cm deep. The planting was done manually. The field site was predominantly covered by grass. The trial was assessed once every year at the same month except in the first year, when it was assessed twice. The total number of measurements conducted was six when trial was just established to reduce the competition. Weeding was repeated when necessary until the stage when trees were fully established. The experimental design was split plot with the species allocated to main plots and provenances within the species allocated to sub-plots. Each provenance was planted in a 10 double tree line sub-plot. This experiment was unreplicated. Trees were planted at 3 m in lines and 3 m between lines. The area of each subplot was 180 m^2. The treatments were 16 species and 32 provenances (Table 51). The total area of the trial was 0,576 ha.

Table 51: Species and provenances in the Thaba-Putsoa woodlot trial L25/27

Species	**Provenance numbers**
E. rubida	Ex M/Hoek
E. gunnii	11977
E. macarthurii	11821, 12023
E. nova-anglica	10717
E. camphora	11938, 9839
E. dalrympleana	S9537,12097,11721
E. pauciflora	12009
E. debeuzevillei	9829
E. badjensis	12090
E. stellulata	11287,10443
E. deanei	11245
E. sideroxylon	12017, 11844
E. nitens	12102, 11861, 12107, 12155, 11814
E. viminalis	10073, 11175, 12282, 10811, 11743
E. blakelyi	11835, 11819
E. glaucescens	10841, 11253

8.2.2 **Experiment number L25/6**

The experiment was planted on 14 February 1980. The land preparation was the establishment of planting pits of 100 cm long and 100 cm wide. The planting was deeper with root collars placed about 20 cm below soil surface. The experimental site was dominated by grass. The number of assessments executed was six. The experiment was measured twice in the first year and three times in the third year. Weeding was done manually and when necessary until canopy closure. In April 1982, aphids infested heavily juvenile leaves of *E. nitens*, while rodents damage was noticed primarily on foliage and bark of *E. macarthurii* and *E. viminalis*. Heavy snow had fallen on the 17 and 18 April 1982, and it had affected almost every tree except *E. stellulata, E. glaucescens, E. macarthurii* and *E. nova-anglica*.

The experimental design was a complete randomised block with 10 replications. The treatments were 14 species and 28 provenances (Table 52). The experiment was demarcated by stone cairns, block corners and plot centres along block boundaries. The spacing was 3 m between lines and 3 m between trees. The total plot and block sizes were 45 m^2 and 1260 m^2 respectively. Each plot was planted with 5 trees. The total size of this trial was 12600 m^2 (1,26 ha).

Table 52: Species and provenances in the Thaba-Putsoa woodlot trial L26/6

Species	**Provenance numbers**
E. camphora	12448, 11938
E. chapmaniana	12304
E. bridgesiana	Ex Mohale's Hoek
E. glaucescens	10841, 11253
E. gunnii	12583, 12864
E. laevopinea	C747, 11653
E. largiflorens	8646
E. neglecta	7339
E. nitens	11861, 12102, 12107
E. nova-anglica	11667, 10717
E. macarthurii	10942, 30946, 11821, 12023
E. pauciflora	10808, 12009
E. rubida	11866, 12438
E. stellulata	12293, 11287, 10443

8.2.3 **Experiment number L25/9**

The experiment was planted on 10 March 1980. The fertilizer (2:3:0 (26)) was applied at a rate of 100 g per tree around each plant. The ground preparation was double pass with a nardi plough. The experimental site was primarily covered with grass. The trial was assessed once every year at the same time, apart from 1980 when it assessed twice. In 1982, the experiment was measured three times. The trial was closed in 1985 when it was stricken heavily by drought. The snout beetle damage was assessed after every three to four months. It was discovered that seven blocks were badly affected by the past in August 1982. Weeding was done manually and executed when necessary. The number of trial measurements executed was seven. The frost assessments were carried out by counting and observing the discolouration of leaves of the trees.

The experimental design was complete randomised block with ten replications. The treatments were 13 species and 32 provenances (Table 53). The spacing was 2,5 m in lines and 4 m between lines. Total plot and block sizes were 50 m^2 and 1600 m^2 respectively.

Table 53: Species and provenances in the Tsikoane Plateau woodlot trial L25/9

Species	**Provenance numbers**
E. blakelyi	11819, 11835
E. blaxlandii	10336
E. camaldulensis	11403, 12182, 12186, 12355, 12359
E. dalrympleana	S9537, 10810, 11721, 12097, 12473, 12512, 12517
E. deanei	10340, 12170, 11245
E. elata	25740
E. parvifolia	11725
E. punctata	10863
E. radiata	20425
E. rummeryi	11740
E. sideroxylon	11844, 12017
E. viminalis	10073, 10811, 10934, 11175, 11743, 12282
E. bridgesiana	Ex Mohale 's Hoek

8.2.4 **Experiment number L25/10**

The experiment was established on the 28 March 1980. The land preparation was double pass with a nardi plough. The experimental site was mainly dominated by grass and broadleaves. The trial was assessed once every year at the similar time, except in the first year when it was assessed twice. The number of measurements was six. The experiment was fertilized with 2:3:0 (26) at a fertilizer application rate of 100 g per tree. Weeding was done manually and frequently as required.

The experimental design was a complete randomised block with 5 replications. The treatments were 23 species and 25 provenances (Table 54). The area was not fenced at the time of planting. The spacing was 2,5 m in lines by 4 m between lines. Each plot included 5 trees in a line. Total plot size and block sizes were 50 m^2 and 1250 m^2 respectively. Total experimental size was 6250 m^2.

Table 54: Species and provenances in the Majapereng woodlot trial L25/10

Species	**Provenance numbers**
E. acmeniodes	11250
E. argillacea	11670
E. argophloia	9372
E. campanulata	C747
E. dunnii	C683, 10411, 11241, 11705
E. exserta	11022
E. globulus	11677, 12130, 12321, 12459
E. maculata	C940
E. melliodora	28784
E. microtheca	12496
E. ochrophloia	12507
E. tereticornis	10245, 10816, 10837, 11239, 11357, 11946, 12377
E. trachyphloia	10997

8.3 Results

8.3.1 Results of experiment number L25/27 at Thaba-Putsoa woodlot

The results of this experiment are shown in table 55.

Table 55: Survival, height and diameter at breast height means of the species and provenance trial of L25/27 at age 63 months in the Thaba-Putsoa woodlot.

Species	**Provenance**	**Survival (%)**	**Height (m)**	**Diameter at breast height (mm)**
E. rubida	Ex M/Hoek	60	1,17	0,10
E. gunnii	11977	60	4,20	6,30
E. macarthurii	11821, 12023	70	1,42	3,80
E. nova-anglica	10717	85	1,49	3,40
E. camphora	11938, 9839	70	2,27	1,60
E. dalrympleana	S9537, 12097, 11721	55	4,78	6,90
E. pauciflora	12009	75	1,52	0,40
E. debeuzevillei	9829	25	1,02	0,10
E. badjensis	12090	20	4,05	5,40
E. stellulata	11287, 10443	85	3,96	6,00
E. deanei	11245	5	1,30	4,80
E. sideroxylon	12017, 11844	48	3,28	4,80
E. nitens	12102, 11861, 12107, 12155, 11814	11	4,84	6,50
E. viminalis	10073, 11175, 12282, 10811, 11743	46	4,38	6,00
E. blakelyi	11835, 11819	28	0,26	0,10
E. glaucescens	10841, 11253	73	3,62	6,00

The survival means of different species of L25/27 are shown in table 55. It can be noted that the species, which have shown the best survival, were *E. nova-anglica* and *E. stellulata* with 85% survival. The least surviving species was *E. deanei* with 5% survival. It was found that the best performing species in terms of mean HT of 4,84 m was *E. nitens,* and then followed by *E. dalrympleana* with a mean HT of 4,78 m at age 63 months. *E. blakelyi* shows poor mean height of 0,26 m. The other species, which showed the reasonable HT, were namely *E.* viminalis, *E. gunnii*, *E. badjensis*, *E. stellulata* and *E. glaucescens*.

The species, which indicated best performance in terms of diameter, was *E. dalrympleana* with a mean DBH of 6,9 mm, and then followed by *E. nitens* with a diameter of 6,5 mm. The least performing species in terms of diameter growth were *E. rubida* and *E. debeuzevillei* with mean DBH of 0,10 mm respectively. The other species, which showed good performance, were, *E. glaucescens*, *E. viminalis* and *E. gunnii*.

Since the experiment was unreplicated there was no need to carry out further analysis. The least sigficance difference (LSD) was not done because the analysis of variance was not conducted.

8.3.2 Results of experiment number L25/6 at Thaba Putsoa woodlot

The results of this trial are indicated in table 56.

Table 56: Survival, height and diameter at breast height means of the species and provenance trial of L25/6 at age 55 months in the Thaba-Putsoa woodlot.

Species	**Provenance**	**Survival (%)**	**Height (m)**	**Diameter at breast height (mm)**
E. camphora	12448, 11938	85a	1,47cb	8,70c
E. chapmaniana	12304	26c	1,88ba	11,70b
E. bridgesiana	Ex Mohale's Hoek	70b	0,75c	3,10c
E. glaucescens	10841, 11253	67b	3,06a	31,40a
E. gunnii	12583, 12864	63b	2,42ab	18,30a
E. laevopinea	C747, 11653	35c	1,27cb	11,0a
E. largiflorens	8646	62b	2,30ba	20,50a
E. neglecta	7339	60b	0,89c	1,00c
E. nitens	11861, 12102, 12107	33c	3,12ab	33,40a
E. nova-anglica	11667, 10717	92a	3,49a	39,50a
E. macarthurii	10942, 30946, 11821, 12023	63b	1,72ba	12,20b
E. pauciflora	10808, 12009	57b	1,68ba	11,50b
E. rubida	11866, 12438	63b	2,88a	25,20a
E. stellulata	12293, 11287, 10443	79a	3,27a	32,20a

The best surviving species was again *E. nova-anglica* with 92%. It was followed by *E. camphora* with 85%. The other species, which showed good survival, were *E. stellulata*, *E. neglecta*, *E. bridgesiana*, E. *gunnii* and *E. glaucescens*. The poor surviving species was

E. chapmaniana with 26%. It was explored that the species, which indicated best performance in terms of HT growth, was *E. nova-anglica* with 3,49 m. It was followed by *E. stellulata* with HT of 3,27 m. The least performing species was *E. bridgesiana* with 0,75 m. The other species, which showed good performance, were *E. nitens*, *E. glaucescens* and *E. rubida*. It was investigated that the species, which performed well in terms of diameter than others, was *E. nova-anglica* with 39,50 mm diameter. The species, which showed better performance, were *E. nitens* and *E. stellulata*. The poor performing species was *E. neglecta* with a diameter of 1,00 mm. It should be noted that survival, HT and DBH measurements were carried out at age of 55 months.

It can be noticed from table 57 that there is significant difference between survival means of different species. It can be realised that there are also significant difference between HT and DBH of various species (Tables 58 and 59).

Table 57: Summarised results of analysis of variance for survival (%) at age 55 months in experiment number L25/6. (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability).

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	9	1,32103	0,14678	4,74	
Species	12(1)	6,79230	0,56602	18,26	<0,001
Residual	204 (53)	6,32329	0,03100		
Total	225 (54)	11,26618			

Table 58. Summarised results of analysis of variance for height at age 55 months in experiment L25/6 (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability)

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	9	4,31620	0,47958	5,58	
Species	12 (1)	8,87914	0,73993	8,61	<0,001
Residual	205 (52)	17,61047	0,8590		
Total	226 (53)	28,87156			

Table 59. Summarised results of analysis of variance for diameter at breast height at age 55 months in experiment L25/6 (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability)

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	9	13,1970	0,3552	2,65	
Species	12 (1)	15,6810	1,3068	9,76	<0,001
Residual	144 (113)	19,2886	0,1339		
Total	165 (114)	29,2121			

8.3.3 **Results of experiment number L25/9 at Tsikoane Plateau woodlot**

The results are shown in table 60.

Table 60: survival, height and diameter at breast height means of species and provenance trial of L25/9 at age 53 months in Tsikoane Plateau woodlot.

Species	**Provenance**	**Survival (%)**	**Height (m)**	**DBH (mm)**
E. blakelyi	11819, 11835	94b	4,10d	22,10a
E. blaxlandii	10336	72a	8,16a	7,00b
E. camaldulensis	11403, 12182, 12186, 12355, 12359	68ab	3,56d	22,30ab
E. dalrympleana	S9537, 10810, 11721, 12097, 12473, 12512, 12517	85ba	6,40b	16,70ab
E. deanei	10340, 12170, 11245	79ba	5,31c	20,80ab
E. elata	25740	79ab	7,68a	9,60b
E. parvifolia	11725	83ab	5,42c	21,00ab
E. punctata	10863	82ab	5,05c	19,30ab
E. radiata	20425	82ab	8,22a	15,60ab
E. rummeryi	11740	39c	3,86d	9,40c
E. sideroxylon	11844, 12017	92ba	2,80e	12,60b
E. viminalis	10073, 10811, 10934, 11175, 11743, 12282	93b	4,23d	23,40a
E. bridgesiana	Ex Mohale 's Hoek	87ba	4,21d	22,30ab

The species which showed best survival was *E. blakelyi* with 94% and followed by *E. viminalis* with 93%. The other species, which indicated good survival, were *E. sideroxylon* and *E. bridgesiana*. The species which indicated poor survival was *E. rummeryi* with 39%. It was discovered that the species which showed the best performance in terms of HT growth was *E. radiata* with HT of 8,22 m. Seconded was *E. blaxlandii* with HT of 8,16 m. The species which performed poorly was *E. sideroxylon* with HT of 2,80 m. The other species which indicated good performance were *E. elata* and *E. dalrympleana*. *E. viminalis* performed better than the other species in terms of diameter with a diameter of 23,4 mm. The species which performed second but in terms of diameter growth were *E. bridgesiana* and *E. camaldulensis* with a diameter of 22,3 mm respectively. The species which performed poorly was *E. blaxlandii* with a diameter of 7,00 mm. The other species which indicated good performance were *E. elata* and *E. radiata*. It must be noticed that DBH, HT and survival were measured at age of 53 months.

It was discovered that there is significant difference between survival, HT and DBH means of species (Tables 61-63).

Table 61: Summarised results of analysis of variance for survival at age 53 months in experiment L25/9. (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability)

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	9	0,17600	0,01956	0,51	
Species	12	2,81898	0,23491	6,16	<0,001
Residual	298	11,36905	0,03815		
Total	319	14,36403			

Table 62: Summarised results of analysis of variance for height at age 53 months in experiment L25/9 (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability).

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	9	0,02564	0,00285	0,27	
Species	12	5,12544	0,42712	41,20	<0,001
Residual	289 (9)	2,99629	0,01037		
Total	310 (9)	8,05753			

Table 63: Summarised results of analysis of variance for diameter at breast height at age 53 months in experiment L25/9 (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability).

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0.05**
Blocks stratum	9	2,2358	0,2484	1,20	
Species	12	14,7446	1,2287	5,95	<0,001
Residual	298	61,5616	0,2066		
Total	319	78,5420			

8.3.4 **Results of experiment number L25/10 at Majapereng woodlot**

The results of this trial are shown in table 64.

Table 64: Survival, height and diameter at breast height means of the species and provenance trial of L25/10 at age 63 months in the Majapereng woodlot

Species	**Provenance**	**Survival (%)**	**Height (m)**	**Diameter at breast height (mm)**
E. acmeniodes	11250	44ba	1,58b	9,50b
E. argillacea	11670	36bc	0,34c	0b
E. argophloia	9372	64a	0,55c	0c
E. campanulata	C747	18c	0,87a	0a
E. dunnii	C683, 10411, 11241, 11705	46ba	1,62b	11,2a
E. exserta	11022	34bc	1,36c	7,00b
E. globulus	11677, 12130, 12321, 12459	27cb	1,82a	8,30b
E. maculata	C940	37bc	2,14a	8,90a
E. melliodora	28784	64a	1,39b	7,50b
E. microtheca	12496	68a	1,42b	10,70b
E. ochrophloia	12507	55ab	1,45b	12,60a
E. tereticornis	10245, 10816, 10837, 11239, 11357, 11946, 12377	48ba	1,95a	10,20a
E. trachyphloia	10997	44ba	1,58b	9,50b

It can be noted that the species, which showed best survival, was *E. microtheca* with 68%. The species, which indicated good survival, were *E. melliodora* and *E. argophloia*. The species, which showed poor survival, was *E. campanulata* with 18%. *E. ochrophloia* performed well in terms of diameter than other species with a diameter of 12,60 mm. The species, which showed second performance in terms of diameter growth, was *E. dunnii* with a diameter of 11,20 mm. The least performing species were *E. argophloia*, *E. argillacea* and *E. campanulata* with 0 mm diameter. The species, which indicated good performance, are *E. microtheca* and *E. tereticornis*. The species, which performed well in terms of HT, is *E. maculata* with a HT growth of 2,14 m. The other species, which indicated good performance, are *E. tereticornis*, *E. globulus*, *E. dunnii* and *E. trachyphloia*. The least performing species is *E. argillacea* with a HT growth of 0,34 m.

It was connoted that there is significant difference between survival, HT and DBH means for the species; therefore H_0 is rejected while H_1 is accepted (Tables 65-68).

Table 65: Summarised results of analysis of variance for

Table 67: Summarised results of analysis of variance for diameter at breast height at age 63 months in experiment L25/10. (d.f. = degrees of freedom, s.s. = sums of squares, m.s = mean squares, v.r. = variance ratio (F value), P = probability).

Source of variation	**d.f. (m.v.)**	**s.s.**	**m.s.**	**v.r.**	**P≤0,05**
Blocks stratum	4	2,21764	0,55441	12,44	
Species	10 (2)	1,60318	0,16032	3,60	<0,001
Residual	66 (42)	2,94222	0,04458		
Total	80 (44)	5,68354			

8.4 Discussion

It must be realised that from the results that are obtained from the four trials under sub-chapter 8.3, the following species indicated good performance in terms of growth (HT, DBH) and survival: *E. nova-anglica*, *E. stellulata*, *E. gunnii*, *E. dalrympleana*, *E. glaucescens*, *E. nitens*, *E. viminalis*, *E. camphora*, *E. blakelyi*, *E. bridgesiana*, *E. elata*, *E. radiata*, *E. microtheca*, *E. melliodora*, *E. argophloia* and *E. dunnii*. These results are in line with other researchers obtained because Richardson (1985b) stipulated that he undertook the study for species and provenance trials with cold resistant eucalypts in Lesotho. These were about 118 provenances of 46 species, which were imported from Australia in 1978 and 1979. Twenty-six sources of 14 species were selected for potentially high cold hardiness and were planted in experiments at lowland and mountain sites.

It was detected that after five years, provenances of new species were identified for wood fuel production at both altitudes and a new provenance of Lesotho's primary hardwood, *Eucalyptus rubida*, was recommended for use in both zones. It was reported that additionally, *Eucalyptus stellulata* proved most suitable especially in colder, wetter areas. Similarly, *Eucalyptus macarthurii* and *Eucalyptus nitens* are now being planted at lower altitude. It was recommended that further research should be undertaken for these species namely *Eucalyptus glaucescens*, *Eucalyptus nova-anglica* and *Eucalyptus gunnii*. On the other hand, Maile and Nieuwenhuis (1996) stipulated that the *genus Eucalyptus* is playing a significant role in Lesotho as it provides 60% of fuel wood for domestic use and clearly eucalypts will remain an essential component in future afforestation programmes in Lesotho.

It must be noted that one of the hypothesis of the study connotes that tree performance is unaffected by various silvicultural practices/procedures. The results indicated that this is true because there is significance difference between performance of different species (Table 57-67). It must also be noted that the species were analysed for the last assessment in terms of survival, HT and DBH (Tables 56, 60 and 64). It should also be noted that if the mean DBH – LSD is less than the second species mean DBH then the two species are statistically similar (Tables 56, 60 and 64).

8.5 **Conclusion**

It can be concluded that the relative performance of different species was determined. The differences in survival and height growth of various species were measured. The growth differences between species were quantified. It can be realised from the study that good silvicultural practices applied in trials, like weeding, good land preparation methods like complete ploughing and using advanced planting pits, can be able to absorb a large amount of water. The best timing of planting a tree and a planting technique applied confirm a successful woodlot or plantation forestry in Lesotho. The study justifies that the best performance of tree species in terms of survival and growth can be achieved easily if the above mentioned factors are highly considered and matching of species to site.

The study results support the remarks made by (Pryor, 1973; Richardson, 1985b) that further research of cold- hardy eucalypts was justified in Lesotho, and gave especially valuable results by identifying several little known species which have potential for fuel wood production. In particular, a better provenance of *E. rubida* was identified in other research and an excellent provenance of *E. stellulata* is now being planted in Lesotho. It was emphasised that additionally three other species (*E. glaucescens*, *E. gunnii* and *E. nova-anglica*) were shown to have promise and more provenance work should be executed. Two species commonly planted on the South African Highveld (*E. macarthurii* and *E. nitens*) performed well in the lower altitude experiment and they are now used on appropriate sites in Lesotho.

CHAPTER NINE

SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS

It can be learnt from the other chapters, the new findings (results) were thoroughly explained and conclusions were made. In brief, this chapter will highlight the summary, general conclusions and draw recommendations for further investigations.

It can be reported that the objectives of the study were:
(i) describe performance (survival, growth, and timber volume) of tree species grown in Lesotho,
(ii) design the growth models of *P. radiata* and *E. rubida* cultivated in Lesotho,
(iii) analyse site conditions to enhance site/species matching,
(iv) evaluate various silvicultural practices and their impact on tree performance.

It can also be emphasised that the hypotheses of the study were:
(a) H_0: survival and growth of various species on select sites is equal,
(b) H_0: growth and timber production is not dependent on site factors,
(c) H_0: tree performance, survival and growth are unaffected by various silvicultural practices/procedures.

It can be emphasised that the research study clearly stipulated that it would bring out the major findings on important aspects of timber production for commercial use and in this way it will address the major energy crisis in harsh mountain areas of Lesotho. It can be noted that in the case of timber production for commercial use, the PSPs and experiments networks developed by Forestry Research Section were used as a source of information for this study. It can be realised that the findings (results) from two data sets, indicated that *E. macarthurii*, *E. rubida* and *P. radiata* can be used to produce a viable commercial forestry timber under the site conditions in Lesotho. Such conditions and their relationship with timber production require more studies as their results failed to explain much variation in tree performance. The limiting factors for a viable commercial forestry in Lesotho could be unfavourable climatic conditions such as cold winters, drought periods, etc. It is thought that even more species tested in the trials could still be used in a viable commercial forestry. However, specific analysis of this nature was not undertaken in this research. Factors complicate the outcomes ot this study include different objectives for establishment of the woodlots apart from the one for the timber production. Also, for the seedling stock that was used, might not be of a good quality. However, the MAIs and SIs of different species justify that a viable commercial forestry can be implemented in Lesotho in particular in the mist belt districts like Qacha's Nek which has the highest amount of MAP (Appendix 37).

In the case of fuel wood scarcity in order to address the energy crisis, there are many species, which were detected to perform well in terms of survival and growth. They were such as: *E. rubida*, *E. nitens*, *E. stellulata*, *E. nova-anglica*, *E. gunnii*, *E. glaucescens*, *E. dalrympleana*, *E. elata*, *E. melliodora*, *E. macarthurii*, *E. radiata* and *E. microtheca* etc. These species were tested in different regions in Lesotho. Therefore, the problem of energy crisis is addressed by promoting tree planting either individually, groups, community, schools, clubs and societies. The other factor would be increasing the survival percentage of the species eucalypts afforestation. It was found out that eucalypts contribute about 60% of fuel wood for domestic use in Lesotho, as they are easy to propagate and coppice.

(Cawse, 1979; Denison, 1981; Richardson, 1984b, Richardson, 1985b) stressed that successful tree planting depend on many factors. Winter planting could become common practice especially as its greater cost would probably be offset by reduced blanking requirements. The technique of using deep planting and progressive soil firming was tested. The use of more versatile trained labour would allow the combination of planting and fertilising operations with a resultant cost saving. The other skills that can be adopted and applied are such as: (i) a suitable method of soil preparation, (ii) protection of the plantings from desiccating winds and invading weeds, (iii) acquisition of abundant soil moisture in the ground by removal of most of the competition for this moisture, (iv) the practice of a high quality planting skill.

In this study the site conditions to enhance site-species matching have been analysed by utilising mainly environmental variables with the help of correlation analysis first. Climatic variables were mainly utilised for site-species matching for PSPs and there is not much information on soils that is why it was not included in the analysis. Then, correlation analysis was used to select variables, which indicated good correlation for further investigations of development of model. Multiple regression analysis was used to analyse the SI and variables, which indicated best correlation and come up with the SI models for *P. radiata* and *E. rubida*. The SIs for 44 *P. radiata* and 33 *E. rubida* were calculated. The SI models for *P. radiata* and *E. rubida* were finally developed. The soil variables were not used in the further analysis of SI model. There was not much information collected, which could be of much help for this study. The *P. radiata* and *E. rubida* sites were classified by site productivity and agro-ecological zones.

It was noted that the site conditions have a large influence on the tree performance. It was detected that four species/provenance trials that were planted at different altitudes and agro-ecological zones indicated that the good analysis of site conditions, could have a large impact on tree performance. The environmental variables like MAP, soil texture, soil depth, slope and altitude play a major role on tree performance. It should also be realised that the trials L25/27 and L25/6 were established on basaltic parent material with a texture of clay loam which is considered to be good for holding enough moisture for tree growth. Moreover, these black soils are regarded as fertile soils and they contain certain minerals like calcium and others, which are essential for tree growth. MAP is around 1000 mm for these trials, which is more than enough for developing a viable commercial forestry.

Various silvicultural practices and their impact on tree importance were evaluated. It was noticed that silvicultural practices like good land preparation methods, weed control and management, the practice of high planting technique and deep planting can have a large impact on successful tree planting. This can have a large influence on the performance of a tree.

It is highly recommended that a viable commercial forestry be implemented in Lesotho. This can be undertaken in mist belt districts like Qacha's Nek where conditions are favourable for tree planting. The MAIs range up to 21.91 m^3/ha/yr and up to 10.81 m^3/ha/yr for 15-yr-old *P. radiata* and 6-yr-old *E. rubida* plots respectively. There are good prospects for commercial introduction of *E. nitens*, *E. macarthurii*, *P. halepensis* and *P. pinaster*. It is anticipated that these production numbers could be improved by advanced selection of genetic material, improved silviculture and good site species matching.

It is also recommended that further research be undertaken on cold tolerant species for High altitude sites. Species that showed very promising results are such as *E. stellulata*, *E. nitens*, *E. glaucescens*, *E. nova-anglica*, *E. gunnii* and *E. dalrympleana*. These species can be used to address the problem of fuel wood scarcity in the mountains by having a large afforestation programmes. It is recommended that bio-energy project be executed especially to address the problem of energy in mountain areas. The other research, which is recommended to be undertaken, is on dry zone (low altitude research) in order to have trials on drought resistant species, which is another marginal area in Lesotho, which is not fully utilised.

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APPENDICES

Appendix 1: The Lesotho climatic zones distribution pattern (Berding, 1984)

October – March rainfall probabilities					**October – March temperatures**			**Estimated Length of growing period (days)**		**Elevation**
Number	>350mm	>400mm	>450mm	>500mm	Mean max °C	Mean min °C	Max+ Min/2	70% frost free	90% frost free	Elevation Range (m)
I 1.1	>80	>80	>80	>80	25 - 26	11 - 12	18 - 19	180 - 200	150 - 180	1550 -1750
I 1.2	>80	>80	>80	>80	23 - 25	10 - 11	16 - 18	170 - 190	140 - 160	1750 -2000
I 1.3	>80	>80	>80	>80	19 - 23	7 -10	13 - 16	140 - 180	100 - 150	2000-2500
I 1.4	>80	>80	>80	>80	15 - 19	4 - 7	10 - 13	50 - 140	40 -100	2500-3000
I 1.5	>80	>80	>80	>80	13 - 15	1 - 4	7 - 10	<50	<40	3000-3300
I 2.1	>80	>80	>60	60 - 80	25 - 27	11 - 13	18 - 20	180 - 200	150 - 180	1400-1750
I 2.2	>80	>80	>80	60 - 80	23 - 25	10 - 11	16 - 18	170 - 190	140 - 160	1750-2000
I 2.3	>80	>80	>80	60 - 80	19 - 23	7 - 10	13 - 16	140 - 180	140 - 160	2000-2500
I 2.4	>80	>80	>80	>80	15 - 19	4 - 7	10 - 13	50 - 140	40 -100	2500-3000
I 3.1	>80	>60	60 - 80	40 - 60	25 - 27	11 - 13	18 - 20	180 - 200	150 - 180	1400-1750
I 3.2	>80	>60	60 - 80	40 - 60	23 - 25	10 - 11	16 - 18	170 - 190	140 - 160	1750-2000
I 4.1	>80	60 - 80	40 - 60	<40	25 - 27	11 - 13	18 - 20	180 - 200	150 - 180	1400-1750

Appendix 1 Cont

October – March rainfall probabilities					**October – March temperatures**			**Estimated Length of growing period (days)**		**Elevation**
II 1.1	60 - 80	40 - 80	40 - 60	<40	25 - 27	11 - 13	18 - 20	140 - 180	130 - 170	1400-1750
II 2.1	60 - 80	60 - 80	60 - 80	40 - 60	25 - 26	11 - 12	18 - 19	170 - 190	140 - 160	1500-1750
II 2.2	>80	60 - 80	60 - 80	40 - 60	23 - 25	10 - 11	16 - 18	170 - 190	140 - 160	1750-2000
II 3.1	>80	>80	>80	60 - 80	23 - 25	10 - 11	16 - 18	170 - 190	140 - 160	1750-2000
II 3.2	>80	>80	>80	60 - 80	19 - 23	7 - 10	13 - 16	140 - 180	100 - 150	2000-2500
II 4.1	>80	>80	>80	>80	15 - 19	4 - 7	10 - 13	50 - 140	40 - 100	2500-3000
III 1.1	60 - 80	40 - 60	<60	<40	23 - 26	10 - 12	16 - 19	140 - 180	130 - 170	1550-2000
III 1.2	>80	60 - 80	40 - 60	<60	21/20 - 23	8/7 - 10	14 - 16	160/150-180	120/110-150	2000-2250/2400
III 2.1	>80	>80	40 - 80	40 - 60	19/18 – 21/20	6/5 – 8/7	12 - 14	130/140-160/150	90/100-120/110	2250/2400-2500/2650
III 3.1	>80	>80	>80	>60	19 - 23	7 - 10	13 - 16	140 - 180	100 - 150	2000-2500
III 3.2	>80	>80	>80	>60	15 – 17/18	4 – 6/5	10 - 12	50-130/140	40 - 90/100	2500/2650-3000
III 3.3	>80	>80	>60	>60	11 - 17	1 - 4	6 - 10	<50	<40	3000-3482
III 4.1	>80	>80	>80	>80	19 -24	7- 11	13 - 17	140 - 180	100 - 150	3482-3600

Appendix 2: Monthly mean maximum temperature for *E. rubida* permanent sample plots (degrees Celsius)

PSP number	**Lat**	**Long.**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	26	25	24	21	18	15	15	18	21	23	24	25
ER/1021/1	293035	284003	24	23	21	19	16	14	14	16	19	20	24	23
ER/1007/1	291825	273701	26	25	23	20	17	14	14	17	20	22	24	26
ER/1007/2	291826	273701	26	25	23	20	17	14	14	17	20	22	24	26
ER/4011/2	290409	275515	28	27	25	22	19	16	16	19	22	24	25	27
ER/2013/1	284747	281123	27	26	24	21	18	15	16	18	21	23	24	26
ER/4001/1	291405	273549	27	26	24	21	18	15	15	18	21	23	24	26
ER/4001/2	291403	273546	27	26	24	21	18	15	15	18	21	23	24	26
ER/4001/4	291358	273538	27	26	24	21	18	15	15	18	21	23	24	26
ER/4001/5	291358	273535	27	26	24	21	18	15	15	18	21	23	24	26
ER/4001/6	291403	273534	27	26	24	21	18	15	15	18	21	23	24	26
ER/2023/1	294730	271006	28	27	25	21	18	15	15	18	21	24	25	27
ER/2007/1	285538	280956	27	26	24	21	18	15	16	18	21	23	24	26
ER/2016/1	285813	280652	27	26	24	21	18	15	16	18	21	23	24	26
ER/2016/2	285806	280649	27	26	24	21	18	15	16	18	21	23	24	26
ER/5010/1	283805	282627	25	24	22	20	17	14	14	17	20	22	22	24
ER/1005/1	293626	273249	27	26	24	21	17	14	15	17	20	23	24	26
ER/1005/2	293623	273250	27	26	24	21	17	14	15	17	20	23	24	26
ER/5006/1	284418	281901	26	25	23	20	18	14	15	17	20	22	23	25

Appendix 2 Cont.

PSP number	**Lat**	**Long.**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/1026/1	292340	273826	27	26	24	21	18	15	15	18	21	23	24	26
ER/2019/1	285510	280700	27	26	25	22	19	16	16	19	22	24	25	27
ER/2019/2	284510	280720	27	26	25	22	19	16	16	19	22	24	25	27
ER/2006/1	285359	281140	27	26	24	21	19	16	16	19	22	23	24	26
ER/2009/1	285434	281202	26	25	23	21	18	15	15	18	21	22	24	25
ER/2009/2	285446	281149	26	25	23	21	18	15	15	18	21	22	24	25
ER/2009/3	285439	281141	26	25	23	21	18	15	15	18	21	22	24	25
ER/1028/1	292435	273800	27	26	24	21	18	15	15	18	21	23	25	26
ER/2012/1	285420	280006	26	25	23	20	17	14	15	17	21	22	24	25
ER/2012/3	285420	280020	26	25	23	20	17	14	15	17	21	22	24	25
ER/2012/4	285423	280024	26	25	23	20	17	14	15	17	21	22	24	25
ER/2012/5	285422	280028	26	25	23	20	17	14	15	17	21	22	24	25
ER/2012/9	285449	280103	26	25	23	20	17	14	14	17	20	22	23	25
ER/2012/10	285504	280056	26	25	23	20	17	14	14	17	20	22	23	25

Appendix 3: Monthly mean maximum temperature for *P. radiata* permanent sample plots (degrees Celsius)

PSP number	**Lat.**	**Long.**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug.**	**Sep**	**Oct**	**Nov**	**Dec**
PR/1031/1	292058	273650	27	26	24	21	18	15	15	18	21	23	25	27
PR/1011/1	292705	273251	27	27	25	22	19	16	16	19	22	23	25	27
PR/6008/1	294303	272413	27	26	24	21	17	14	15	17	20	24	24	26

Appendix 3 Cont.

PSP number	**Lat.**	**Long.**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug.**	**Sep**	**Oct**	**Nov**	**Dec**
PR/3033/1	300753	272551	28	26	25	21	18	15	16	18	21	23	25	27
PR/1021/1	293045	273959	26	25	23	20	17	14	14	17	20	23	23	25
PR/1080/1	293039	274232	26	24	23	19	16	13	14	16	20	21	23	25
PR/Makoae I/1	302217	274429	27	26	24	21	18	15	15	18	20	22	24	26
PR/Makoae II/2	302518	274827	24	23	21	18	15	12	13	15	18	19	21	23
PR/3037/1	300637	272018	28	27	25	21	18	14	15	18	21	23	25	27
PR/2021/1	285749	2743159	28	27	25	22	19	16	16	19	22	24	26	28
PR/2021/2	285748	274417	28	27	25	22	19	16	16	19	22	24	26	28
PR/3029/1	301206	272513	27	26	24	21	18	15	15	18	21	23	24	26
PR/4022/1	300509	275915	27	26	25	22	19	16	16	19	21	23	24	26
PR/3027/1	300712	272937	26	25	23	20	17	14	14	17	20	22	23	25
PR/1066/1	292438	274527	26	25	23	20	17	14	14	17	20	22	23	25
PR/1035/1	292351	273847	26	25	23	20	17	14	14	17	20	22	23	25
PR/1063/1	293508	272032	29	27	26	22	19	16	16	19	22	24	26	28
PR/1052/1	293445	273131	27	26	24	20	17	14	15	17	20	23	24	26
PR/2038/1	285447	280141	28	27	25	22	19	16	16	19	22	24	25	27
PR/2038/2	285142	280245	27	26	24	21	19	15	16	18	22	23	25	26
PR/4001/1	291409	273536	27	26	24	21	19	15	15	18	21	23	24	26
PR/3040/1	302018	274328	27	26	24	21	19	16	16	18	21	23	24	26
PR/3003/1	300725	272048	28	27	25	22	19	15	16	18	21	23	25	27

Appendix 3 Cont.

PSP number	Lat.	Long.	Jan	Feb	Mar	April	May	June	July	Aug.	Sep	Oct	Nov	Dec
PR3036/1	300710	272213	28	27	24	22	19	16	16	19	22	24	25	27
PR/3036/2	300711	272205	26	27	24	22	19	16	16	19	22	24	25	27
PR/3026/1	295349	273753	26	25	24	20	17	14	15	17	20	22	24	27
PR/3026/2	295333	273747	26	25	24	20	17	14	15	17	20	22	24	26
PR/1001/1	292333	273316	27	26	24	21	18	15	15	18	21	23	25	27
PR/2026/1	285420	281129	27	26	25	22	19	16	16	19	22	24	25	27
PR/2026/2	285726	281735	24	23	22	19	16	16	13	16	19	21	25	23
PR/1048/1	293342	274315	24	23	21	18	15	13	12	15	18	20	22	23
PR/2014/1	290250	281701	25	24	22	19	17	14	14	16	20	21	22	24
PR/2014/2	290225	281655	25	24	23	20	17	14	14	17	20	22	23	24
PR/5016/1	283922	282515	25	24	23	20	17	15	14	17	20	22	23	25
PR/Pulane Spring/1	302820	274525	23	22	20	17	14	12	11	14	17	19	20	22
PR/3016/1	300226	271900	28	26	24	21	18	15	15	18	21	23	25	27
PR/6015/2	294433	272115	27	26	24	21	18	15	15	18	21	23	24	26
PR/Sankatana II/1	301021	272415	28	27	25	22	19	16	16	19	21	24	25	27
PR/Sankatana II/2	301022	272418	28	27	25	22	19	16	16	19	21	24	25	27
PR/2029/1	285854	280826	27	26	24	21	18	16	15	18	21	23	24	26
PR/2029/2	285904	280822	27	26	24	21	18	16	15	18	21	23	24	26

Appendix 3 Cont.

PSP number	**Lat.**	**Long.**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug.**	**Sep**	**Oct**	**Nov**	**Dec**
PR/3012/1	300051	272201	28	27	25	22	18	16	16	19	22	24	25	28
PR/3012/2	300056	272157	28	27	25	22	19	16	16	19	22	24	25	28
PR/3023/1	300509	273141	27	25	24	20	17	15	14	17	20	22	24	26

Appendix 4: Monthly mean maximum temperature for *E. macarthurii* permanent sample plots (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
EM/1021/1	293035	274003	26	25	23	20	17	14	14	17	20	21	23	25
EM/1052/1	293444	273131	27	26	24	20	17	15	14	17	20	22	24	26
EM/4001/1	291359	273532	27	26	24	21	18	15	14	18	21	23	24	26
EM/1006/1	293804	273026	27	26	24	21	18	15	14	17	20	23	24	26

Appendix 5: Monthly mean maximum temperature for *P. halepensis* permanent sample plots (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
PH/3026/1	295333	273747	26	25	24	20	17	15	14	17	20	22	24	26
PH/Makoae II/1	302418	274327	27	26	24	21	18	16	15	18	21	22	24	26
PH/3023/1	290812	273620	28	27	25	22	19	16	16	19	22	24	26	27

Appendix 6: Monthly mean maximum temperature for *E. nitens* permanent sample plot (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**August**	**Sep**	**Oct**	**Nov**	**Dec**
EN/1080/1	293039	274232	26	24	23	19	16	14	13	16	20	21	23	25

Appendix 7: Monthly mean maximum temperature for *P. pinaster* permanent sample plot (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**August**	**Sep**	**Oct**	**Nov**	**Dec**
PP/1048/1	293346	274316	24	23	21	18	15	13	12	15	18	20	22	23

Appendix 8: Monthly mean maximum temperature for experiment site (degrees Celsius)

Experiment number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L/25/9	285413	280014	26	25	23	20	17	14	15	17	21	22	24	25
L/25/10	300633	272034	28	27	25	22	19	15	16	18	21	23	25	27
L/25/27	292511	274318	26	25	23	20	17	14	15	17	20	22	24	25
L/25/6	292814	274519	26	25	23	20	17	14	14	17	20	22	23	25

Appendix 9: Monthly mean minimum temperature for *E. rubida* permanent sample plots (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	12	12	10	7	2	0	0	2	5	8	10	11
ER/1021/1	293035	284003	11	10	9	5	2	0	0	1	4	6	8	10
ER/1007/1	291825	273701	12	10	10	6	2	0	0	1	4	7	9	11
ER/1007/2	291826	273701	12	12	10	6	2	0	0	1	4	7	9	11
ER/4011/2	290409	275515	13	12	11	7	2	0	0	1	5	8	10	12
ER/2013/1	284747	281123	12	12	10	6	2	0	0	1	5	8	10	12
ER/4001/1	291405	273549	13	12	10	7	2	0	0	1	5	8	10	11
ER/4001/2	291403	273546	13	12	10	7	2	0	0	1	5	8	10	11
ER/4001/4	291358	273538	13	12	10	7	2	0	0	1	5	8	10	11
ER/4001/5	291358	273535	14	12	10	7	2	0	0	1	5	8	10	11
ER/4001/6	291403	273534	13	12	10	7	2	0	0	1	5	8	10	11
ER/2023/1	294730	271006	13	13	11	6	2	0	-1	1	5	8	10	12
ER/2007/1	285538	280956	12	12	10	7	2	0	0	1	5	8	10	11
ER/2016/1	285813	280652	12	12	10	6	2	0	0	1	5	8	10	11
ER/2016/2	285806	280649	12	12	10	6	2	0	0	1	5	8	10	11
ER/5010/1	283805	282627	12	11	10	7	3	0	0	2	5	8	9	11
ER/1005/1	293626	273249	12	12	10	6	2	0	-1	1	4	7	9	11
ER/1005/2	293623	273250	12	12	10	6	2	0	-1	1	4	7	9	11
ER/5006/1	284418	281901	12	12	10	7	3	1	0	2	5	8	10	11
ER/1026/1	292340	273826	12	12	10	6	2	0	-1	1	5	8	10	11

Appendix 9 Cont.

PSP number	Lat.	Long.	Jan	Feb	Mar	April	May	June	July	Aug.	Sep	Oct	Nov	Dec
ER/2019/1	285510	280700	12	12	11	7	2	0	0	1	5	8	10	12
ER/2019/2	284510	280720	13	12	11	7	2	0	0	2	5	8	10	12
ER/2006/1	285359	281140	13	12	11	7	2	0	0	1	5	8	10	12
ER/2009/1	285434	281202	12	12	10	7	3	0	0	2	5	8	10	11
ER/2009/2	285446	281149	12	12	10	7	3	0	0	2	5	8	10	11
ER/2009/3	285439	281141	12	12	10	7	3	0	0	2	5	8	10	11
ER/1028/1	292435	273800	12	12	10	6	2	-1	-1	1	5	8	10	11
ER/2012/1	285412	280006	12	12	10	7	3	1	1	2	5	8	10	11
ER/2012/3	285420	280020	12	12	10	7	3	1	1	2	5	8	10	11
ER/2012/4	285423	280024	12	12	10	7	3	1	1	2	5	8	10	11
ER/2012/5	285422	280028	12	12	10	7	3	1	1	2	5	8	10	11
ER/2012/9	285449	280103	12	12	10	7	3	2	1	3	5	8	9	11
ER/2012/10	285504	280056	12	12	10	7	4	2	1	3	5	8	9	11

Appendix 10: Monthly mean minimum temperature by *P. radiata* PSPs (degrees Celsius)

PSP Number	Lat	Long	Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
PR/1031/1	292058	273650	12	12	10	6	2	0	-1	1	5	7	10	11
PR/1011/1	292705	273251	13	13	11	7	2	0	0	1	5	8	10	12
PR/6008/1	294303	272413	12	12	10	6	2	0	0	1	5	8	9	11
PR/3033/1	300753	272551	13	13	11	7	3	0	0	2	5	8	10	12
PR/1021/1	293045	273959	12	11	10	6	1	-1	-1	0	4	8	9	11
PR/1080/1	293039	274232	11	11	9	5	1	0	-1	1	4	7	9	10
PR/Makoae I/1	302217	274429	13	12	11	7	3	0	0	2	5	8	10	11
PR/Makoae II/2	302518	274827	11	11	9	6	3	1	1	2	4	6	8	10
PR/3037/1	300637	272018	13	13	11	7	2	0	0	1	5	8	10	12
PR/2021/1	285749	274359	13	13	11	7	2	0	0	1	5	8	10	12
PR/2021/2	285748	274417	13	13	11	7	2	0	0	1	5	8	10	12
PR/3029/1	301206	272513	13	13	11	7	2	0	0	1	5	8	10	12
PR/4022/1	300509	275915	13	13	11	7	3	0	0	2	5	8	10	12
PR/3027/1	300712	272937	12	12	10	6	2	0	0	1	5	7	9	11
PR/1066/1	292438	274527	12	11	10	6	2	0	-1	1	4	7	9	11
PR/1035/1	292351	273847	12	12	10	6	2	0	0	1	4	7	9	11
PR/1063/1	293508	272032	13	13	11	7	2	0	-1	1	5	8	10	12

Appendix 10 Cont.

PSP Number	Lat	Long	Jan	Feb	Mar	April	May	June	July	August	Sept	Oct	Nov	Dec
PR/1052/1	293445	273131	12	12	10	6	2	0	0	1	5	8	10	11
PR/2038/1	285447	280141	13	13	11	7	2	0	0	1	5	8	10	12
PR/2038/2	285142	280245	13	12	11	7	3	0	0	2	5	8	10	12
PR/4001/1	291409	273536	13	12	10	7	2	0	0	1	5	8	10	11
PR/3040/1	302016	274328	13	13	11	7	3	0	0	2	5	8	10	12
PR/3003/1	300725	272048	13	13	11	7	2	0	0	1	5	8	10	12
PR/3036/1	300710	272213	13	13	11	7	2	0	0	1	5	8	9	12
PR/3036/2	295333	273747	12	13	11	6	2	0	0	1	5	8	10	12
PR/3026/1	295349	273753	12	12	10	6	2	0	-1	1	4	7	9	11
PR/3026/2	295333	273747	12	12	10	6	2	0	-1	1	4	7	9	12
PR/1001/1	292333	273316	13	12	11	7	2	0	0	1	5	8	10	12
PR/2026/1	285420	281129	13	12	11	7	2	0	0	1	5	8	10	12
PR/2026/2	285726	281735	11	11	9	6	2	0	0	1	4	7	8	10
PR/1048/1	293342	274315	10	10	8	4	0	-2	-2	0	3	6	8	9
PR/2014/1	290250	281701	11	11	9	5	1	-1	-1	1	4	7	9	10
PR/2014/2	290225	281655	11	11	9	6	2	0	-1	1	4	7	9	10
PR/5016/1	283922	282515	12	12	10	7	3	0	0	2	5	8	10	11
PR/Pulane Spring/1	302820	274525	10	10	8	5	1	0	0	0	3	5	7	9
PR/3016/1	300226	271900	13	12	11	6	1	0	0	1	5	8	10	12
PR/6015/2	294433	272115	12	12	10	6	2	0	-1	1	4	8	10	11

Appendix 10 Cont.

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
PR/Sankatana II/1	301021	272415	13	13	11	7	2	0	0	1	5	8	10	12
PR/Sankatana II/2	301022	272418	13	13	11	7	2	0	0	1	5	8	10	12
PR/2029/1	285854	280826	12	12	10	7	2	0	0	1	5	8	10	11
PR/2029/2	285902	280822	12	12	10	7	2	0	0	1	5	8	10	11
PR/3012/1	300551	272201	13	13	11	7	2	0	0	1	5	8	10	12
PR/3012/2	300056	272157	13	13	11	7	2	0	0	1	5	8	10	12
PR/3023/1	300509	273141	12	12	10	6	2	0	-1	1	4	7	9	11

Appendix 11: Monthly mean minimum temperature for *E. macarthurii* permanent sample plots (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
EM/1021/1	293035	274003	12	11	10	6	1	-1	-1	0	4	7	9	11
EM/1052/1	293444	273131	12	12	10	6	1	-1	-1	0	4	7	9	11
EM/4001/1	291359	273532	13	12	10	7	1	0	0	1	5	8	10	11
EM/1006/1	293804	273026	12	12	10	6	1	0	-1	1	4	8	9	11

Appendix 12: Monthly mean minimum temperature for *P. halepensis* permanent sample plots (degrees Celsius)

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PH/3026/1	295333	273747	12	12	10	6	2	0	-1	1	4	7	9	11
PH/Makoae II/1	302418	274327	13	12	11	7	2	0	0	1	5	8	10	12
PH/3023/1	290812	273620	13	13	10	7	2	0	-1	1	5	8	10	12

Appendix 13: Monthly mean minimum temperature for *E. nitens* permanent sample plot (degrees Celsius)

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
EN/1080/1	293039	274232	11	11	9	5	1	0	-1	1	4	7	9	10

Appendix 14: Monthly mean minimum temperature for *P. pinaster* permanent sample plot (degrees Celsius)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PP/1048/1	293346	274316	10	10	8	4	0	-2	-2	0	3	6	8	9

Appendix 15: Monthly mean minimum temperature for experiment site (degrees Celsius)

Experiment number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L/25/9	285413	280014	12	12	10	7	3	1	1	2	5	8	10	11
L/25/10	300633	272034	13	13	11	7	2	0	0	1	5	8	10	12
L/25/27	292511	274318	12	11	11	7	1	0	-1	0	4	8	9	11
L/25/6	292814	274519	12	11	10	6	1	0	-1	1	4	7	9	11

Appendix 16: Monthly median rainfall for *E. rubida* permanent sample plots (milli-metres)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	146	111	105	60	26	5	5	9	28	76	108	121
ER/1021/1	293035	284003	98	77	60	29	17	1	3	6	15	48	67	80
ER/1007/1	291825	273701	116	99	99	58	26	6	5	6	20	61	85	98
ER/1007/2	291826	273701	116	99	99	58	26	6	5	6	20	61	85	98
ER/4011/2	290409	275515	112	91	88	50	21	4	4	6	20	60	80	96
ER/2013/1	284747	281123	133	100	98	56	24	4	4	6	25	71	96	108
ER/4001/1	291405	273549	108	92	92	53	24	5	5	6	19	58	82	93
ER/4001/2	291403	273546	108	92	92	53	24	5	5	6	19	58	82	93
ER/4001/4	291358	273538	108	92	92	53	24	5	5	6	19	58	82	93
ER/4001/5	291358	273535	108	92	92	53	24	5	5	6	19	58	82	93
ER/4001/6	291403	273534	108	92	92	53	24	5	5	6	19	58	82	93

Appendix 16 Cont.

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/2023/1	294730	271006	83	84	81	48	19	4	5	6	12	45	64	70
ER/2007/1	285538	280956	139	105	97	58	25	5	4	8	24	73	97	116
ER/2016/1	285813	2806582	138	105	97	58	25	5	4	8	24	72	95	116
ER/2016/2	285806	280649	138	105	97	58	25	5	4	8	24	72	95	116
ER/5010/1	283805	282627	127	102	93	52	21	3	3	8	25	75	104	118
ER/1005/1	293626	273249	102	95	93	55	24	6	5	8	16	56	77	88
ER/1005/2	293623	273250	102	95	93	55	24	6	5	6	16	56	77	88
ER/5006/1	284418	281901	123	93	91	51	21	4	3	9	24	68	94	105
ER/1026/1	292340	273826	102	90	88	53	23	6	5	5	16	55	75	87
ER/2019/1	285510	280700	132	99	94	54	24	4	4	8	24	69	88	106
ER/2019/2	284510	280720	121	97	90	54	24	5	4	7	21	71	91	104
ER/2006/1	285359	281140	133	101	95	55	24	4	4	8	24	70	95	110
ER/2009/1	285434	281202	136	103	96	57	25	4	4	8	24	71	97	113
ER/2009/2	285446	281149	136	103	96	57	25	4	4	8	24	71	97	113
ER/2009/3	285439	281141	136	103	96	57	25	4	4	8	24	71	97	113
ER/1028/1	292435	273800	98	88	85	52	22	5	5	5	15	53	73	84
ER/2012/1	285412	280006	135	103	100	54	25	4	4	8	23	71	87	106
ER/2012/3	285420	280020	135	103	100	54	25	4	4	8	23	71	87	106
ER/2012/4	285423	280024	135	103	100	54	25	4	4	8	23	71	87	106
ER/2012/5	285422	280028	135	103	100	54	25	4	4	8	23	71	87	106
ER/2012/9	285449	280103	136	103	100	54	26	4	4	8	24	71	87	107
ER/2012/10	285504	280056	136	103	101	54	26	4	4	8	24	71	87	107

Appendix 17: Monthly median rainfall for *P. radiata* permanent sample plots (milli-metres)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PR/1031/1	292058	273650	108	93	93	55	25	5	6	5	18	57	80	91
PR/1011/1	292705	273251	103	91	91	54	24	5	6	5	16	57	76	86
PR/6008/1	294303	272413	92	88	88	51	22	5	5	7	14	55	72	91
PR/3033/1	300753	272551	73	79	87	47	22	6	6	7	14	51	64	74
PR/1021/1	293045	273959	108	101	96	59	25	6	6	6	17	49	81	95
PR/1080/1	293039	274232	107	102	95	59	25	7	6	6	17	60	81	96
PR/Makoae I/1	302217	274429	91	84	86	50	27	10	5	11	20	54	61	82
PR/Makoae II/2	302518	274827	72	68	67	38	20	7	4	8	16	42	49	65
PR/3037/1	300637	272018	79	79	90	48	24	6	7	6	15	47	68	78
PR/2021/1	285749	274359	101	75	88	45	16	4	3	9	15	59	81	88
PR/2021/2	285748	274417	101	75	88	45	16	4	3	9	15	59	81	88
PR/3029/1	301206	272513	71	76	83	46	22	6	5	7	13	48	63	73
PR/4022/1	300509	275915	91	89	79	43	20	6	4	9	19	50	66	84
PR/3027/1	300712	272937	78	86	92	49	23	7	6	8	16	52	67	79
PR/1066/1	292438	274527	100	94	88	56	23	6	5	5	16	56	75	90
PR/1035/1	292351	273847	102	91	88	54	23	6	5	5	16	55	75	88
PR/1063/1	293508	272032	92	86	88	50	20	5	4	5	13	51	71	80
PR/1052/1	293445	273131	97	90	88	52	22	5	5	6	15	53	73	84
PR/2038/1	285447	280141	137	103	101	54	26	4	4	9	25	72	85	106
PR/2038/2	285142	280245	137	100	100	51	27	4	4	10	26	71	79	101

Table 17 Cont.

PSP number	Lat	Long	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PR/4001/1	291409	273536	108	92	92	53	24	5	5	6	19	58	82	93
PR/3040/1	302018	274328	103	97	98	57	30	10	6	12	22	62	71	94
PR/3003/1	300725	272048	79	80	91	49	24	6	7	7	15	49	69	79
PR/3036/1	300710	272213	79	81	91	50	24	7	6	7	15	50	69	79
PR/3036/2	300711	272205	89	81	91	50	24	7	6	7	15	50	69	79
PR/3026/1	295349	273753	89	89	85	48	22	6	5	8	16	51	68	80
PR/3026/2	295333	273747	89	89	85	48	22	6	5	8	16	51	68	80
PR/1001/1	292333	273316	100	86	86	51	23	5	5	5	15	53	73	82
PR/2026/1	285420	281129	139	105	99	58	25	5	4	9	25	73	98	115
PR/2026/2	285726	281735	172	135	121	71	30	5	5	11	32	90	127	146
PR/1048/1	293342	274315	106	101	94	57	25	6	5	6	18	59	80	95
PR/2014/1	290250	281701	162	130	113	67	29	5	5	10	30	85	121	140
PR/2014/2	290225	281655	125	100	88	52	22	4	4	7	23	65	93	108
PR/5016/1	283922	282515	123	98	89	50	21	3	3	8	24	72	99	113
PR/Pulane Spring/1	302820	274525	110	102	104	60	34	13	7	13	25	65	75	99
PR/3016/1	300226	271900	89	90	94	54	24	6	7	8	15	53	75	82
PR/6015/2	294433	272115	92	89	89	52	21	5	5	7	13	50	73	79
PR/Sankatana II/1	301021	272415	71	75	83	46	22	7	5	7	13	47	64	73
PR/Sankatana II/2	301022	272418	71	75	83	46	22	7	5	7	13	47	64	73

Appendix 17 Cont.

PSP number	Lat	Long	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PR/2029/1	285854	280826	145	110	100	61	26	5	5	8	24	76	101	124
PR/2029/2	285904	280822	145	110	100	61	26	5	5	8	24	76	101	124
PR/3012/1	300051	272201	86	87	93	52	23	6	7	8	15	51	73	79
PR/3012/2	300056	272157	86	87	93	52	23	6	7	8	15	51	73	79
PR/3023/1	300509	273141	79	85	88	47	22	6	6	8	15	50	65	78

Appendix 18: Monthly median rainfall for *E. macarthurii* permanent sample plots (milli-metres)

PSP Number	Lat	Long	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EM/1021/1	293035	274003	108	101	96	59	25	6	6	6	17	60	81	95
EM/1052/1	293444	273131	97	90	88	52	22	5	5	6	15	60	73	84
EM/4001/1	291359	273532	108	92	92	56	24	5	5	6	19	53	82	93
EM/1006/1	293804	273026	103	97	95	56	24	6	5	7	16	58	79	93

Appendix 19: Monthly median rainfall for *P. halepensis* permanent sample plots (milli-metres)

PSP number	Lat	Long	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PH/3026/1	295333	273747	89	89	85	48	22	6	5	8	16	51	68	80
PH/Makoae II/1	302418	274327	93	82	86	51	28	11	5	12	21	56	57	81
PH/3023/1	290812	273620	102	86	89	50	22	4	4	6	18	55	85	90

Appendix 20: Monthly median rainfall for *E. nitens* permanent sample plot (milli-metres)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
EN/1080/1	293039	274232	107	102	95	59	25	7	6	6	17	60	81	96

Appendix 21: Monthly median rainfall for *P. pinaster* permanent sample plot (milli-metres)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PP/1048/1	293346	274316	106	198	94	57	25	6	5	6	18	59	80	95

Appendix 22: Monthly median rainfall for experiment site (milli-metres)

Experiment number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
L/25/9	285413	280014	135	103	100	54	25	4	4	8	23	71	87	106
L/25/10	300633	272034	79	80	91	49	24	6	7	7	15	49	69	79
L/25/27	292511	274318	106	100	94	59	25	7	6	5	17	59	80	95
L/25/6	292814	274519	111	108	100	64	27	8	7	5	17	63	84	102

Appendix 23: Monthly mean apan evaporation for *E. rubida* permanent sample plots (milli-metres)

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	213	172	156	117	98	86	98	134	169	189	195	219
ER/1021/1	293035	284003	191	151	144	115	96	85	96	130	154	158	171	196
ER/1007/1	291825	273701	266	178	161	116	94	84	95	130	172	194	204	229
ER/1007/2	291826	273701	266	178	161	116	94	84	95	130	172	194	204	229
ER/4011/2	290409	275515	232	184	164	119	99	87	98	133	175	199	211	235
ER/2013/1	284747	281123	221	177	160	119	99	87	99	134	173	195	203	227
ER/4001/1	291405	273549	238	187	169	120	96	84	95	132	176	202	212	239
ER/4001/2	291403	273546	238	187	169	120	96	84	95	132	176	202	212	239
ER/4001/4	291358	273538	238	187	169	120	96	84	95	132	176	202	212	239
ER/4001/5	291358	273535	238	187	169	120	96	84	95	132	176	202	212	239
ER/4001/6	291403	273534	238	187	169	120	96	84	95	132	176	202	212	239
ER/2023/1	294730	271006	251	195	173	122	100	83	94	131	175	202	217	251
ER/2007/1	285538	280956	219	176	159	118	98	87	98	134	171	192	201	225
ER/2016/1	285813	280652	221	177	160	118	97	87	98	134	172	193	202	226
ER/2016/2	285806	280649	221	177	160	118	97	87	98	134	172	193	202	226
ER/5010/1	283805	282627	207	165	154	117	99	85	97	132	166	183	188	211
ER/1005/1	293626	273249	225	176	158	115	95	84	95	129	168	189	202	227
ER/1005/2	293623	273250	225	176	158	115	95	84	95	129	168	189	202	227
ER/5006/1	284418	281901	212	169	156	118	99	86	99	134	168	186	195	219
ER/1026/1	292340	273826	232	182	164	118	96	84	95	131	173	195	208	234
ER/2019/1	285510	280700	225	180	163	119	98	87	99	134	174	197	207	230

Appendix 23 Cont.

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ER/2019/2	284510	280720	228	181	164	119	99	87	99	135	175	199	208	232
ER/2006/1	285359	281140	221	178	161	119	98	87	99	134	172	194	202	226
ER/2009/1	285434	281202	214	172	156	117	97	86	98	134	169	188	196	220
ER/2009/2	285446	281149	214	172	156	117	97	86	98	134	169	188	196	220
ER/2009/3	285439	281141	214	172	156	117	97	86	98	134	169	188	196	220
ER/1028/1	292435	273800	235	185	166	119	97	85	96	132	174	197	210	237
ER/2012/1	285412	280006	218	174	157	117	97	86	98	133	171	191	201	224
ER/2012/3	285420	280020	218	174	157	117	97	86	98	133	171	191	201	224
ER/2012/4	285423	280024	218	174	157	117	97	86	98	133	171	191	201	224
ER/2012/5	285422	280028	218	174	157	117	97	86	98	133	171	191	201	224
ER/2012/9	285449	280103	214	170	155	116	97	85	98	133	169	187	198	221
ER/2012/10	285504	280056	214	170	155	116	97	85	98	133	169	187	198	221

Appendix 24: Monthly mean a pan evaporation for *P. radiata* permanent sample plots (millimetres)

PSP number	Lat	Long	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PR/1031/1	292058	273650	236	186	166	119	96	85	96	132	175	192	211	238
PR/1011/1	292705	273251	242	191	170	119	97	85	96	133	177	199	216	245
PR/6008/1	294303	272413	231	181	162	117	96	83	94	128	169	203	204	232
PR/3033/1	300753	272551	229	178	159	115	95	84	94	126	165	191	201	228
PR/1021/1	293045	273959	221	173	155	114	95	84	95	130	167	186	198	223
PR/1080/1	293039	274232	216	167	152	113	94	83	95	129	165	180	193	218
PR/Makoae I/1	302217	274429	215	168	153	114	92	83	93	124	157	173	187	214
PR/Makoae II/2	302518	274827	194	149	140	110	91	81	92	123	147	152	169	195
PR/3037/1	300637	272018	239	185	164	118	94	82	93	127	168	190	206	236
PR/2021/1	285749	274359	245	194	173	124	103	87	99	136	182	210	222	248
PR/2021/2	285748	274417	245	194	173	124	103	87	99	136	182	210	222	248
PR/3029/1	301206	272513	227	176	157	114	94	83	94	125	163	182	198	225
PR/4022/1	300509	275915	219	174	157	116	95	85	95	127	162	179	193	220
PR/3027/1	300712	272937	217	168	151	113	94	82	93	125	160	176	191	217
PR/1066/1	292438	274527	220	172	156	115	95	84	96	131	168	186	199	223
PR/1035/1	292351	273847	226	177	160	116	95	83	94	129	170	191	202	228
PR/1063/1	293508	272032	255	200	177	124	100	84	96	134	180	208	225	257
PR/1052/1	293445	273131	230	180	162	117	95	83	94	129	170	191	204	231
PR/2038/1	285447	280141	229	184	164	120	98	88	99	134	176	201	211	234
PR/2038/2	285142	280245	224	180	162	119	98	87	99	134	174	197	208	231

Appendix 24 Cont.

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PR/4001/1	291409	273536	238	187	169	120	96	84	95	132	176	202	212	239
PR/3040/1	302018	274328	218	172	154	114	92	83	94	125	159	178	191	217
PR/3003/1	300725	272048	233	181	160	115	94	84	94	126	167	189	203	231
PR/3036/1	300710	272213	235	182	162	116	95	84	94	126	168	190	205	232
PR/3036/2	300711	272205	220	182	162	116	95	84	94	126	168	190	205	232
PR/3026/1	295349	273753	220	171	155	115	94	84	95	127	164	181	195	221
PR/3026/2	295333	273747	220	171	155	115	94	84	95	127	164	181	195	221
PR/1001/1	292333	273316	236	186	167	119	97	85	96	132	175	199	212	239
PR/2026/1	285420	281129	223	179	162	119	98	87	99	134	173	196	204	228
PR/2026/2	285726	281735	195	158	145	114	95	84	97	132	161	175	179	203
PR/1048/1	293342	274315	207	160	147	112	93	82	94	128	160	173	186	210
PR/2014/1	290250	281701	200	161	147	114	95	85	97	132	162	177	182	207
PR/2014/2	290225	281655	207	164	152	116	97	85	97	132	164	179	188	212
PR/5016/1	283922	282515	211	169	157	119	100	86	97	133	168	186	193	216
PR/Pulane Spring/1	302820	274525	183	143	132	107	87	78	90	122	143	147	160	186
PR/3016/1	300226	271900	238	185	163	116	94	82	93	127	168	191	206	236
PR/6015/1	294433	272115	235	183	164	117	96	83	94	128	170	193	207	235
PR/Sankatana II/1	301021	272415	234	182	162	116	95	84	94	126	167	189	204	231
PR/Sankatana II/2	301022	272418	234	182	162	116	95	84	94	126	167	189	204	231

Appendix 24 Cont.

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
PR/2029/1	285854	280826	219	176	159	118	97	87	98	133	171	193	200	224
PR/2029/2	285904	280822	219	176	159	118	97	87	98	133	171	193	200	224
PR/3012/1	300051	272201	244	190	168	118	96	83	94	129	171	196	211	243
PR/3012/2	300056	272157	244	190	168	118	96	83	94	129	171	196	211	243
PR/3023/1	300509	273141	221	171	154	114	94	83	94	126	162	179	193	220

Appendix 25: Monthly mean A-pan evaporation for *E. macarthurii* permanent sample plots (milli-metres)

PSP number	**Lat.**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
EM/1021/1	293035	274003	221	173	155	114	95	84	95	130	167	180	198	223
EM/1052/1	293444	273131	230	180	162	117	95	83	94	129	170	186	204	231
EM/4001/1	291359	273532	238	187	169	120	96	84	95	132	176	191	212	239
EM/1006/1	293804	273026	231	181	162	116	95	83	94	129	170	202	204	232

Appendix 26: Monthly mean solar radiation for *E. rubida* permanent sample plots

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	31.7	28.8	25.3	21.3	17.7	15.5	16.6	20.5	25.2	29	31	32.5
ER/1021/1	293035	284003	30.4	27.9	24.5	20.5	17	14.8	15.9	19.7	24.3	27.9	29.5	31.1
ER/1007/1	291825	273701	32.6	29.3	25.4	21.2	17.5	15.2	16.4	20.5	25.2	29.3	31.6	33.1
ER/1007/2	291826	273701	32.6	29.3	25.4	21.2	17.5	15.2	16.4	20.5	25.2	29.3	31.6	33.1

Appendix 26 Cont.

PSP number	Lat	Long	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
ER/4011/2	290409	275515	33.1	29.9	26.1	21.9	18.2	15.9	17.1	21.2	26	30	32.2	33.8
ER/2013/1	284747	281123	32.4	29.3	25.9	21.8	18.3	16	17.1	21.2	25.8	29.5	31.6	33.1
ER/4001/1	291405	273549	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
ER/4001/2	291403	273546	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
ER/4001/4	291358	273538	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
ER/4001/5	291358	273535	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
ER/4001/6	291403	273534	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
ER/2023/1	294730	271006	33.7	30.1	26	21.7	17.8	15.4	16.7	21	25.8	30.1	32.5	34.4
ER/2007/1	285538	280956	32.2	29.2	25.7	21.6	18	15.7	16.9	20.9	25.5	29.4	31.6	33.1
ER/2016/1	285813	280652	32.4	29.3	25.7	21.7	18.1	15.8	17	21	25.6	29.5	31.7	32.2
ER/2016/2	285806	280649	32.4	29.3	25.7	21.7	18.1	15.8	17	21	25.6	29.5	31.7	33.2
ER/5010/1	283805	282627	30.7	28	24.5	20.5	17	14.9	15.9	19.7	24.4	28.1	29.8	31.3
ER/1005/1	293626	273249	32.8	29.4	25.6	21.3	17.6	15.2	16.4	20.5	25.3	29.3	31.9	33.4
ER/1005/2	293623	273250	32.8	29.4	25.6	21.3	17.6	15.2	16.4	20.5	25.3	29.3	31.9	33.4
ER/5006/1	284418	281901	31.1	28.2	24.7	20.5	21	14.7	15.8	19.7	24.7	28.6	30.4	31.9
ER/1026/1	292340	273826	33	29.6	25.7	21.5	17.8	15.5	16.7	20.9	25.5	29.6	32	33.6
ER/2019/1	285510	280700	32.6	29.5	25.9	21.8	18.2	16	17.2	21.2	25.8	29.7	32	33.4
ER/2019/2	284510	280720	32.6	29.5	25.9	21.7	18.2	15.9	17.1	21.1	25.8	29.6	31.8	33.3
ER/2006/1	285359	281140	32.2	29.4	25.7	21.8	18.1	15.9	17.1	21.1	25.7	29.5	31.6	33.1
ER/2009/1	285434	281202	31.7	28.6	25	20.9	17.2	15	16	20	24.9	28.8	30.9	32.4
ER/2009/2	285446	281149	31.7	28.6	25	20.9	17.2	15	16	20	24.9	28.8	30.9	32.4

Appendix 26 Cont.

PSP number	Lat	Long	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
ER/2009/3	285439	281141	31.7	28.6	25	20.9	17.2	15	16	20	24.9	28.8	30.9	32.4
ER/1028/1	292435	273800	33.2	29.9	26	21.7	18.1	15.7	17	21.1	25.8	29.9	32.3	33.8
ER/2012/1	285412	280006	31.8	28.5	24.9	20.6	16.8	14.5	15.6	19.6	24.7	28.8	30.9	32.4
ER/2012/3	285420	280020	31.8	28.5	24.9	20.6	16.8	14.5	15.6	19.6	24.7	28.8	30.9	32.4
ER/2012/4	285423	280024	31.8	28.5	24.9	20.6	16.8	14.5	15.6	19.6	24.7	28.8	30.9	32.4
ER/2012/5	285422	280028	31.8	28.5	24.9	20.6	16.8	14.5	15.6	19.6	24.7	28.8	30.9	32.4
ER/2012/9	285449	280103	31.4	28.1	24.2	19.9	16.1	13.8	14.8	18.8	24.1	28.3	30.4	31.9
ER/2012/10	285504	280056	31.4	28.1	24.2	19.9	16.1	13.8	14.8	18.8	24.1	28.3	30.4	31.9

Appendix 27: Monthly mean solar radiation for *P. radiata* permanent sample plots

PSP number	Lat	Long	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
PR/1031/1	292058	273650	33.2	29.9	26	21.7	18	15.6	16.9	21	25.8	29.6	32.3	33.8
PR/1011/1	292705	273251	33.5	30.1	26.2	21.7	18.2	15.8	17	21.3	26	29.9	32.7	34.2
PR/6008/1	294303	272413	32.8	29.4	25.4	21.2	17.4	15	16.2	20.4	25.1	30.1	31.7	33.4
PR/3033/1	300753	272551	32.7	29.2	25.3	21	17.2	15	16	20.2	24.9	29.2	31.9	33.6
PR/1021/1	293045	273959	32.7	28.4	25.5	21.3	17.6	15.3	16.4	20.6	25.3	29.1	31.6	33.3
PR/1080/1	293039	274232	32.3	29	25.2	20.9	17.2	14.8	16.1	20	25	28.9	31	32.7
PR/Makoae I/1	302217	274429	32.1	28.8	24.9	20.7	16.9	14.8	15.8	19.8	24.5	28.5	31	32.8

Appendix 27 Cont.

PSP number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
PR/Makoae II/2	302518	274827	30.2	26.9	22.8	18.7	14.8	12.6	13.5	17.4	22.5	26.6	28.8	30.7
PR/3037/1	300637	272018	33.1	29.5	25.4	21.1	17.3	15	16.1	20.3	25	29.4	32	33.7
PR/2021/1	285749	274359	33.6	30.3	26.5	22.2	18.5	16.2	17.4	21.6	26.4	30.4	32.6	34.2
PR/2021/2	285748	274417	33.6	30.3	26.5	22.2	18.5	16.2	17.4	21.6	26.4	30.4	32.6	34.2
PR/3029/1	301206	272513	32.7	29.2	25.2	20.9	17.1	14.8	16	20.1	24.8	29	31.6	33.3
PR/4022/1	300509	275915	32.3	29.2	25.5	21.3	17.5	15.4	16.5	20.5	25.1	29	31.6	33.2
PR/3027/1	300712	272937	32	28.8	24.8	20.6	16.8	14.4	15.6	19.6	24.4	28.6	31	32.8
PR/1066/1	292438	274527	32.4	29.3	25.4	21.2	17.5	15.2	16.3	20.4	25.3	29.4	31.6	33.2
PR/1035/1	293508	272032	32.6	29.1	25.3	21	17.4	14.9	16.2	20.3	25.1	29.1	31.3	33.1
PR/1063/1	293445	273131	33.8	30.4	26.4	22	18.2	15.8	17.1	21.5	26.3	30.6	33	34.6
PR/1052/1	293445	273131	32.7	29.2	25.4	21	17.3	14.9	16.1	20.3	25	29.2	31.4	33.3
PR/2038/1	285447	280141	32.9	29.8	26.1	22	18.3	16.1	17.3	21.4	26.1	29.8	32.2	33.6
PR/2038/2	285142	280245	32.4	29.3	25.5	21.3	17.7	15.5	16.7	20.6	25.5	29.4	31.7	33.2
PR/4001/1	291409	273536	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.5	31.7	33.4
PR/3040/1	302018	274328	32.5	29.1	25.3	21.1	17.2	15.1	16.2	20.2	24.8	28.9	31.5	33.1
PR/3003/1	300725	272048	33.1	29.6	25.5	21.3	17.5	15.1	16.4	20.5	25.2	29.4	32.1	33.7
PR/3036/1	300710	272213	33.2	29.7	25.8	21.4	17.7	15.4	16.6	20.8	25.4	29.5	32.3	34
PR/3036/2	300711	272205	32.5	29.7	25.8	21.4	17.7	15.4	16.6	20.8	25.4	29.5	31.5	34
PR/3026/1	295349	273753	32.5	29.2	25.4	21.2	17.5	15.2	16.4	20.5	25	29.1	31.5	33
PR/3026/2	295333	273747	32.5	29.2	25.4	21.2	17.5	15.2	16.4	20.5	25	29.1	31.5	33

Appendix 27 Cont.

PR/1001/1	292333	273316	32.9	29.6	25.7	21.4	17.7	15.3	16.5	20.7	25.4	29.6	32.1	33.7
PR/2026/1	285420	281129	32.5	29.4	25.9	21.8	18.2	16	17.2	21.2	25.8	29.6	31.8	33.2
PR/2026/2	285726	281735	31	28	24.5	20.4	16.9	14.6	15.7	19.6	24.4	28.2	29.8	31.3
PR/1048/1	293342	274315	32	28.7	25	20.9	17.4	14.9	16.1	20	24.7	28.8	30.7	32.5
PR/2014/1	290250	281701	31.4	28.5	25	21	17.5	15.3	16.4	20.3	25	28.6	30.4	32
PR/2014/2	290225	281655	31.4	28.7	25.2	21.1	17.6	15.3	16.4	20.4	25	28.7	30.6	32.1
PR/5016/1	283922	282515	31	28.2	24.8	20.8	17.3	15.2	16.2	20.2	24.7	28.3	30.1	31.6
PR/Pulane Spring/1	302820	274525	30.3	27.1	23.1	19	15.3	13	14.1	17.9	22.7	26.7	28.7	30.5
PR/3016/1	300226	271900	33.2	29.7	25.6	21.3	17.5	15.1	16.4	20.6	25.2	29.5	32.1	33.9
PR/6015/2	294433	272115	33.1	29.6	25.7	21.4	17.7	15.3	16.5	20.7	25.4	29.6	32.1	33.7
PR/Sankatana II/1	301021	272415	33.1	29.7	25.6	21.3	17.6	15.2	16.4	20.6	25.3	29.5	32.1	33.9
PR/Sankatana II/2	301022	272418	33.1	29.7	25.6	21.3	17.6	15.2	16.4	20.6	25.3	29.5	32.1	33.9
PR/2029/1	285854	280826	32.4	29.3	25.6	21.6	18	15.7	16.9	20.9	25.6	29.4	31.4	33.1
PR/2029/2	285902	280822	32.4	29.3	25.6	21.6	18	15.7	16.9	20.9	25.6	29.4	31.4	33.1
PR/3012/1	300051	272201	33.6	30.1	26	21.6	17.8	15.5	16.7	21	25.7	29.9	32.5	34.4
PR/3012/2	300056	272157	33.6	30.1	26	21.6	17.8	15.5	16.7	21	25.7	29.9	32.5	34.4
PR/3023/1	300509	273141	32.5	29.1	25.3	21.1	17.4	15.1	16.3	20.3	24.9	28.9	31.3	33.2

Appendix 28: Monthly mean solar radiation for *E. macarthurii* permanent sample plots

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
EM/1021/1	293035	274003	32.7	29.4	25.5	21.3	17.6	15.3	16.4	20.6	25.3	28.9	31.6	33.3
EM/1052/1	293444	273131	32.7	29.2	25.4	21	17.3	14.9	16.1	20.3	25	29.2	31.4	33.3
EM/4001/1	291359	273532	32.8	29.5	25.6	21.3	17.7	15.4	16.5	20.7	25.4	29.2	31.7	33.4
EM/1006/1	293804	273026	33	29.6	25.7	21.4	17.7	15.3	16.6	20.7	25.4	29.5	32	33.4

Appendix 29: Monthly mean relative humidity for *E. rubida* permanent sample plots

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
ER/5002/1	285223	281707	64	65	64	62	58	58	57	57	59	61	65	63
ER/1021/1	293035	284003	65	66	65	63	59	59	58	58	60	62	65	65
ER/1007/1	291825	273701	62	64	64	62	58	58	57	56	58	60	62	62
ER/1007/2	291826	273701	62	64	64	62	58	58	57	56	58	60	62	62
ER/4011/2	290409	275515	62	63	63	60	56	55	54	54	57	59	61	61
ER/2013/1	284747	281123	63	64	63	61	56	56	55	55	57	60	62	62
ER/4001/1	291405	273549	62	64	64	61	58	57	56	56	58	60	62	62
ER/4001/2	291403	273546	62	64	64	61	58	57	56	56	58	60	62	62
ER/4001/4	291358	273538	62	64	64	61	58	57	56	56	58	60	62	62
ER/4001/5	291358	273535	62	64	64	61	58	57	56	56	58	60	62	62
ER/4001/6	291403	273534	62	64	64	61	58	57	56	56	58	60	62	62
ER/2023/1	294730	271006	61	63	63	60	56	56	54	54	57	59	61	61

Appendix 29 Cont.

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
ER/2007/1	285538	280956	63	65	64	61	57	57	55	55	58	60	62	62
ER/2016/1	285813	280652	63	64	64	61	57	56	55	55	58	60	62	62
ER/2016/2	285806	280649	63	64	64	61	57	56	55	55	58	60	62	62
ER/5010/1	283805	282627	65	66	66	64	61	60	59	59	60	62	64	64
ER/1005/1	293626	273249	62	64	63	61	57	57	56	56	58	60	62	62
ER/1005/2	293623	273250	62	64	63	61	57	57	56	56	58	60	62	62
ER/5006/1	284418	281901	65	66	66	64	61	61	60	59	60	62	64	64
ER/1026/1	284418	281901	62	64	63	61	57	57	55	55	57	60	62	62
ER/2019/1	285510	280700	62	64	63	60	56	55	54	55	57	60	62	62
ER/2019/2	284510	280720	62	64	63	61	56	56	55	55	57	60	62	62
ER/2006/1	285359	281140	63	64	64	61	56	56	55	55	57	60	62	62
ER/2009/1	285434	281202	64	65	65	63	60	60	59	58	59	61	63	63
ER/2009/2	285446	281149	64	65	65	63	60	60	59	58	59	61	63	63
ER/2009/3	285439	281141	64	65	65	63	60	60	59	58	59	61	63	63
ER/1028/1	292435	273800	62	63	63	60	60	55	54	54	57	59	61	61
ER/2012/1	285412	280006	64	66	65	64	61	62	60	59	60	61	63	63
ER/2012/3	285420	280020	64	66	65	64	61	62	60	59	60	61	63	63
ER/2012/4	285423	280024	64	66	65	64	61	62	60	59	60	61	63	63
ER/2012/5	285422	280028	64	66	65	64	61	62	60	59	60	61	63	63
ER/2012/9	285449	280103	64	66	66	66	64	65	64	62	61	62	64	64
ER/2012/10	285504	280056	64	66	66	66	64	65	64	62	61	62	64	64

Appendix 30: Monthly mean relative humidity for *P. radiata* permanent sample plots

PSP Number	Lat	Long	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
PR/1031/1	292058	273650	62	63	63	60	56	56	55	55	57	60	61	61
PR/1011/1	292705	273251	61	63	62	60	55	55	54	54	56	59	61	61
PR/6008/1	294303	272413	62	64	64	61	58	58	56	56	58	59	62	62
PR/3033/1	300753	272551	63	64	64	62	58	57	56	56	58	60	62	62
PR/1021/1	293045	273959	62	64	64	61	57	57	56	56	58	61	62	62
PR/1080/1	293039	274232	63	64	64	62	59	59	57	57	58	61	63	62
PR/Makoae I/1	302217	274429	63	65	62	65	59	58	57	57	59	62	63	63
PR/Makoae II/2	302518	274827	66	68	67	68	66	67	66	64	53	64	66	65
PR/3037/1	300637	272018	62	64	61	64	58	57	56	56	58	60	62	61
PR2021/1	285749	274359	61	63	59	62	55	54	53	53	56	59	61	61
PR/2021/2	285748	274417	61	63	59	62	55	54	53	53	56	59	61	61
PR/3029/1	301206	272513	62	64	62	64	58	58	56	56	58	61	62	62
PR/4022/1	300509	275915	63	64	61	64	57	56	55	55	58	61	62	62
PR/3027/1	300712	272937	63	65	63	65	60	60	58	58	59	61	63	63
PR/1066/1	292438	272937	63	64	61	64	58	58	57	56	58	60	62	62
PR/1035/1	292351	273847	62	64	62	64	58	59	57	57	58	61	62	62
PR/1063/1	293508	272032	61	63	59	62	55	55	53	53	56	58	60	60
PR/1052/1	293445	273131	62	64	62	64	59	59	57	57	58	60	62	62
PR/2038/1	285447	280141	62	64	60	63	56	55	54	54	57	60	61	62
PR/2038/2	285142	280245	63	64	62	64	58	58	56	56	58	60	62	62

Appendix 30 Cont.

PSP Number	Lat	Long	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
PR/4001/1	291409	273536	63	64	61	64	58	57	56	56	58	60	62	62
PR/3040/1	302016	274328	63	65	64	61	57	56	56	56	59	61	62	62
PR/3003/1	300725	272048	62	64	64	61	57	57	55	55	58	60	61	62
PR/3036/1	300710	272213	62	64	63	61	56	56	54	54	57	60	61	61
PR/3036/2	300711	272205	63	64	63	61	56	56	54	54	57	60	61	61
PR/3026/1	295349	273753	63	64	64	61	57	57	55	55	58	61	62	62
PR/3026/2	295333	273747	63	64	64	61	57	57	55	55	58	61	62	62
PR/1001/1	292333	273316	62	64	63	61	57	57	56	55	58	60	61	61
PR/2026/1	285420	281129	63	64	63	60	56	55	54	55	57	60	62	62
PR/2026/2	285726	281735	64	66	65	64	61	61	60	59	60	62	64	64
PR/1048/1	293342	274315	63	65	64	62	58	58	57	57	59	61	63	63
PR/2014/1	290250	281701	64	65	64	62	58	58	57	57	59	61	64	63
PR/2014/2	290225	281655	64	65	64	62	58	58	57	57	59	61	63	63
PR/5016/1	283922	282515	65	66	65	63	60	59	58	58	60	62	64	64
PR/Pulane Spring/1	302820	274525	65	67	67	66	64	64	63	62	62	64	66	65
PR/3016/1	300226	271900	62	64	63	61	57	57	55	56	58	60	61	61
PR/6015/2	294433	272115	62	64	61	63	57	57	55	55	57	60	61	61
PR/Sankatana II/1	301021	272415	62	64	61	63	56	56	55	55	58	60	62	61
PR/Sankatana II/2	301022	272418	62	64	61	63	56	56	55	55	58	60	62	61

Appendix 30 Cont.

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
PR/2029/1	285854	280826	63	64	61	64	57	56	55	55	58	60	62	62
PR/2029/2	285902	280822	63	64	61	64	57	56	55	55	58	60	62	62
PR/3012/1	300051	272201	61	63	60	63	56	55	54	54	57	59	61	61
PR/3012/2	300056	272157	61	63	60	63	56	55	54	54	57	59	61	61
PR/3023/1	300509	273141	63	64	61	64	57	57	56	56	58	61	62	62

Appendix 31: Monthly mean relative humidity for *E. macarthurii* permanent sample plots

PSP Number	**Lat**	**Long**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
EM/1021/1	293035	274003	62	64	61	64	57	57	56	56	58	61	62	62
EM/1052/1	293444	273131	62	64	62	64	59	59	57	57	58	60	62	62
EM/4001/1	291359	273532	62	64	61	64	58	57	56	56	58	60	62	62
EM/1006/1	293804	273026	62	64	61	63	57	57	55	55	58	60	61	62

Appendix 32: Analysed data of *P. radiata* permanent sample plots based on tree or stand characteristics

Assess	**PSP number**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean HT (m)**	**Mean dom. HT (m)**	**Mean vol. (m3)**	**Trees/ plt**	**TPH**	**BA/plt (m2)**	**BAH (m2/ha)**	**Plt vol (m3)**	**VPH (m3/ha)**	**MAI (M^3/ha/yr)**
1	PR/1001/1	5.00	12.71	7.33	8.63	2.0717	43	1075	0.6115	15.2874	2.0717	51.7930	10.3586
2	PR/1001/1	7.00	13.68	8.06	9.65	2.5881	43	1075	0.7048	17.6202	2.5881	64.7035	9.2434
3	PR/1001/1	9.00	17.24	9.97	10.83	2.0963	21	525	0.5084	12.7093	2.0963	52.4068	5.8230
4	PR/1001/1	11.00	19.45	11.2	13.65	2.8945	21	525	0.6416	16.0409	2.8845	72.3615	6.5783
5	PR/1001/1	13.00	21.32	12.26	15.50	3.6993	21	525	0.7652	19.1305	3.6993	92.4833	7.1141
1	PR/1011/1	7.83	11.47	7.24	7.38	2.0635	59	1475	0.6404	16.0103	2.0635	51.5865	6.5855

Appendix 32 Cont.

Assess	PSP number	Mean age (yrs)	Mean DBH (cm)	Mean HT (m)	Mean dom. HT (m)	Mean vol. (m3)	Trees/ plt	TPH	BA/plt (m2)	BAH (m2/ha)	Plt vol (m3)	VPH (m3/ha)	MAI (M^3/ha/yr)
2	PR/1011/1	9.83	12.94	8.23	8.53	2.5065	51	1275	0.7007	17.5182	2.5065	62.6613	6.3723
3	PR/1011/1	11.83	13.99	9.01	9.75	2.7385	53	1325	08571	21.4282	3.3369	83.4218	7.0497
4	PR/1011/1	13.83	22.29	12.78	12.55	3.5247	14	350	0.5523	13.8078	2.7385	68.4613	4.9490
1	PR/1021/1	5.00	4.39	3.27	14.53	0.1605	51	1275	0.0884	2.2109	0.1605	4.0137	5.5653
2	PR/1021/1	7.00	10.42	6.61	4.23	1.3961	51	1275	0.4634	11.5842	1.3961	34.9025	0.8027
3	PR/1021/1	9.00	14.82	8.89	7.78	3.6778	50	1250	0.9385	23.4637	3.6778	91.9438	4.9861
4	PR/1021/1	11.00	17.64	10.42	13.03	5.4023	48	1200	1.2397	30.9923	5.4023	135.0563	10.2160
5	PR/1021/1	13.00	18.67	11.13	15.70	6.6342	48	1200	1.4159	35.3963	6.6342	165.8555	12.2778
1	PR/1031/1	6.50	14.55	8.42	13.20	2.4284	39	975	0.6768	16.9206	2.4284	60.7093	12.7581
2	PR/1031/1	8.50	16.93	9.76	9.28	3.7194	39	975	0.9162	22.9050	3.7194	92.9858	9.3399
3	PR/1031/1	10.50	18.69	10.79	10.33	4.9567	39	975	1.1187	27.9683	4.9567	123.9163	10.9395
4	PR/1031/1	12.50	19.62	11.46	12.43	5.8197	39	975	1.2396	30.9905	5.8197	145.4923	11.8015
5	PR/1031/1	14.50	21.08	12.37	14.58	6.3075	35	875	1.2719	31.7985	6.3075	157.6878	11.6394
1	PR/1052/1	0.75	2.33	1.51	15.35	0.0188	43	1075	0.0186	0.4653	0.0188	0.4694	10.8750
2	PR/1052/1	2.75	6.87	4.19	3.03	0.4378	52	1300	0.2023	5.0572	0.4375	10.9371	0.6259
3	PR/1052/1	4.75	12.49	7.21	5.83	1.8916	44	1100	0.5792	14.4801	1.8916	47.2910	3.9771
4	PR/1052/1	6.75	14.35	8.35	13.38	2.9878	47	1175	0.8128	20.3190	2.9878	74.6960	9.9560
5	PR/1052/1	8.75	16.30	9.50	14.40	3.2979	36	900	0.8041	20.1023	3.2979	82.4485	11.0661
1	PR/1063/1	4.50	4.93	3.47	12.10	0.1677	42	1050	0.0879	2.1976	0.1672	4.1789	9.4227
2	PR/1063/1	6.50	10.11	6.37	4.40	1.1025	42	1050	0.3679	9.1967	1.1025	27.5630	0.9286
3	PR/1063/1	8.50	13.47	8.23	9.03	2.2448	40	1000	0.6149	15.3736	2.2448	56.1205	4.2405
4	PR/1063/1	10.50	14.27	8.89	13.73	2.6027	38	950	0.6611	16.5283	2.6027	65.0680	6.6024
5	PR/1063/1	12.50	16.46	10.17	15.08	3.1125	32	800	0.7222	18.0547	3.1125	77.8133	6.1970
1	PR/1066/1	3.42	2.88	2.19	13.40	0.0365	43	1075	0.0244	0.6103	0.0365	0.9122	6.2251
2	PR/1066/1	5.42	7.31	4.83	3.35	0.4135	35	875	0.1639	4.0979	0.4135	10.3386	0.2670
3	PR/1066/1	7.42	10.47	6.67	7.10	1.0883	35	875	0.3371	8.4268	1.0883	27.2085	1.9087
4	PR/1066/1	9.42	14.04	8.61	8.60	2.0555	31	775	0.5283	13.2083	2.0555	51.3870	3.6686
1	PR/1080/1	2.50	2.27	1.75	11.43	0.0373	82	2050	0.0352	0.8808	0.0373	0.9317	5.4570
2	PR/1080/1	4.05	9.08	5.5	2.63	1.3886	80	2000	0.5448	13.6203	1.3886	34.7150	0.3727
3	PR/1080/1	6.50	9.71	6.19	7.23	1.8543	82	2050	0.6478	16.1958	1.8543	46.3585	8.5716
4	PR/1080/1	8.50	13.15	8.11	8.03	2.5277	50	1250	0.7136	17.8410	2.5277	63.1920	7.1321
1	PR/2014/1	5.50	4.69	3.5	12.40	0.1314	34	850	0.0660	1.6491	0.1314	3.2842	7.4344

Appendix 32 Cont.

Assess	PSP number	Mean age (yrs)	Mean DBH (cm)	Mean HT (m)	Mean dom. HT (m)	Mean vol. (m3)	Trees/ plt	TPH	BA/plt (m2)	BAH (m2/ha)	Plt vol (m3)	VPH (m3/ha)	MAI (M^3/ha/yr)
2	PR/2014/1	7.50	10.02	6.47	4.35	1.0293	37	925	0.3283	8.2069	1.0293	25.7320	0.5971
3	PR/2014/1	9.50	15.30	9.19	7.78	2.5882	33	825	0.6482	16.2061	2.5882	64.7055	3.4309
4	PR/2014/1	11.50	18.12	10.68	11.08	4.1191	33	825	0.9115	22.7872	4.1191	102.9778	6.8111
5	PR/2014/1	13.50	20.71	12	14.63	5.9244	33	825	1.1909	29.7718	5.9244	148.1105	8.9546
6	PR/2014/1	15.50	21.47	12.61	13.20	6.6389	33	825	1.2799	31.9978	6.6388	165.9700	10.9711
1	PR/2014/2	5.50	9.17	5.75	13.15	0.9961	48	1200	0.3532	8.8308	0.1314	3.2842	10.7077
2	PR/2014/2	7.50	14.50	8.55	5.98	2.9223	46	1150	0.7954	19.8859	1.0293	25.7320	0.5971
3	PR/2014/2	9.50	17.57	10.18	9.55	4.4817	45	1125	1.1390	28.4748	2.5882	64.7055	3.4309
4	PR/2014/2	11.50	18.87	11.01	13.58	6.0286	45	1125	1.3290	33.0980	4.1191	102.9778	6.8111
1	PR/2021/1	4.83	7.38	4.77	15.73	0.6445	55	1375	0.2660	6.6501	0.6447	16.1167	8.9546
2	PR/2021/1	6.83	12.52	7.51	6.45	2.6532	54	1350	0.7503	18.7567	2.6532	66.3293	3.3345
3	PR/2021/1	8.83	15.50	9.17	7.50	4.2203	52	1300	1.0564	26.4095	4.2203	105.5078	9.7067
4	PR/2021/1	10.83	19.48	8.77	14.68	4.7740	52	1300	3.9743	99.3578	4.7740	119.3510	11.9443
5	PR/2021/1	12.83	19.00	11.27	16.78	5.2353	38	950	1.1294	28.2358	5.2353	130.8815	11.0170
1	PR/2021/2	4.83	7.03	4.61	14.60	0.3738	38	950	0.1620	4.0502	0.3738	9.3448	10.1986
2	PR/2021/2	6.83	13.18	7.85	6.18	1.7981	36	900	0.5198	12.9939	1.7981	44.9525	1.9334
3	PR/2021/2	8.83	16.37	9.57	9.38	3.3087	37	925	0.8180	20.4504	3.3087	82.7185	6.5784
4	PR/2021/2	10.83	17.23	10.25	14.90	3.8487	37	925	0.9012	22.5312	3.8487	96.2173	9.3644
5	PR/2021/2	12.83	19.33	11.41	11.08	5.2980	37	925	1.1341	28.3535	5.2980	132.4510	8.8816
1	PR/2026/1	4.42	3.95	2.95	16.70	0.0955	44	1100	0.0570	1.4248	0.0955	2.3883	10.3209
2	PR/2026/1	6.83	13.21	7.76	3.90	2.8187	44	1100	0.7271	18.1780	2.8187	70.4675	0.5408
1	PR/2026/2	4.42	3.09	2.49	8.35	0.0564	74	1850	0.0381	0.9522	0.0564	1.4089	10.3123
2	PR/2026/2	6.83	7.14	4.95	3.63	0.9852	74	1850	0.3574	8.9360	0.9852	24.6308	0.3190
1	PR/2029/1	6.42	6.77	4.72	7.75	0.5110	54	1350	0.2149	5.3716	0.5110	12.7749	3.6045
2	PR/2029/1	8.42	13.04	8.05	5.83	2.6543	54	1350	0.7569	18.9226	2.6543	66.3578	1.9909
3	PR/2029/1	10.42	15.70	9.53	10.03	4.4377	54	1350	1.0980	27.4505	4.4377	110.9428	7.8841
4	PR/2029/1	12.42	17.13	10.46	12.05	5.0084	48	1200	1.1528	28.8200	5.0084	125.2103	10.6505
5	PR/2029/1	14.42	20.90	12.3	13.60	7.3233	42	1050	1.4887	37.2170	7.3233	183.0815	10.0840
6	PR/2029/1	16.42	19.96	12.22	18.05	6.0932	37	925	1.2188	30.4705	6.0932	152.3305	12.6993
1	PR/2029/2	6.42	3.40	2.97	15.00	0.0968	52	1300	0.0523	1.3064	0.0968	2.4189	9.2790
2	PR/2029/2	8.42	8.86	6.05	4.03	1.1385	53	1325	0.3760	9.4004	1.1385	28.4623	0.3770
3	PR/2029/2	10.42	12.80	8.19	7.95	3.0382	54	1350	0.7907	19.7675	3.0382	75.9543	3.3817

Appendix 32 Cont.

Assess	**PSP number**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean HT (m)**	**Mean dom. HT (m)**	**Mean vol. (m3)**	**Trees/ plt**	**TPH**	**BA/plt (m2)**	**BAH (m2/ha)**	**Plt vol (m3)**	**VPH (m3/ha)**	**MAI (M³/ha/yr)**
4	PR/2029/2	12.42	13.94	9.03	10.55	3.5249	51	1275	0.8630	21.5758	3.5249	88.1235	7.2916
5	PR/2029/2	14.42	17.11	10.68	13.85	6.0933	51	1275	1.3015	32.5370	6.0933	152.3335	7.0972
1	PR/2038/1	3.67	3.28	2.48	17.88	0.0546	43	1075	0.0371	0.9282	0.0546	1.3639	10.5665
2	PR/2038/1	5.67	9.42	5.91	3.60	0.8351	39	975	0.2971	7.4275	0.8351	20.8782	0.3720
3	PR/2038/1	7.67	11.59	7.25	7.03	1.4478	39	975	0.4414	11.0358	1.4478	36.1943	3.6844
4	PR/2038/1	9.67	12.81	8.1	8.93	1.9508	37	925	0.5272	13.1797	1.9508	48.7705	4.7210
5	PR/2038/1	11.67	16.89	10.25	9.68	2.0510	21	525	0.4855	12.1368	2.0510	51.2760	5.0452
1	PR/2038/2	3.67	3.18	2.43	10.05	0.0573	44	1100	0.0402	1.0038	0.0573	1.4330	4.3951
2	PR/2038/2	5.67	12.39	7.29	3.58	1.9067	43	1075	0.5707	14.2673	1.9067	47.6685	0.3908
3	PR/2038/2	7.67	14.40	8.53	8.83	2.7246	43	1075	0.7394	18.4854	2.7246	68.1155	8.4121
4	PR/2038/2	9.67	14.92	9.08	10.00	2.8858	41	1025	0.7486	18.7138	2.8858	72.1458	8.8846
5	PR/2038/2	11.67	16.74	10.17	11.25	2.9521	30	750	0.6931	17.3275	2.9521	73.8028	7.4634
1	PR/3003/1	3.83	4.28	3.03	11.88	0.1035	41	1025	0.0597	1.4922	0.1035	2.5865	6.3259
2	PR/3003/1	5.83	10.70	6.52	4.13	1.3149	41	1025	0.4189	10.4736	1.3149	32.8720	0.6747
3	PR/3003/1	7.83	15.29	8.92	8.70	3.0109	39	975	0.7726	19.3158	3.0109	75.2725	5.6352
4	PR/3003/1	9.83	15.26	9.19	13.43	3.4058	41	1025	0.8315	20.7872	3.4058	85.1443	9.6093
5	PR/3003/1	11.83	19.53	11.25	14.90	6.2964	40	1000	1.3152	32.8793	6.2964	157.4100	8.6587
1	PR/3012/1	10.00	16.81	9.90	16.73	3.5790	35	875	0.8368	20.9188	3.5790	89.4750	13.3023
2	PR/3012/1	12.00	18.29	10.79	9.90	4.5891	34	850	0.9806	24.5157	4.5891	114.7275	8.9475
3	PR/3012/1	14.00	21.69	12.48	11.08	5.2136	26	650	1.0214	25.5353	5.2136	130.3393	9.5606
4	PR/3012/1	16.00	23.67	13.51	12.28	6.8908	27	675	1.2650	31.6253	6.8908	172.2700	9.3099
1	PR/3012/2	10.00	16.60	9.87	16.27	3.8266	42	1050	0.9376	23.4390	3.8266	95.6653	10.7669
2	PR/3012/2	12.00	17.39	10.51	10.85	4.4568	42	1050	1.0308	25.7703	4.4568	111.4200	9.5665
3	PR/3012/2	14.00	19.33	11.63	11.95	5.4770	39	975	1.1729	29.3215	5.4770	136.9243	9.2850
4	PR/3012/2	16.00	20.98	12.58	14.38	6.9830	39	975	1.3907	34.7673	6.9830	174.5753	9.7803
5	PR/3012/2	18.00	24.49	13.02	16.38	9.5010	30	750	2.1257	53.1425	9.5010	237.5238	10.9110
1	PR/3016/1	5.50	4.90	3.62	15.70	0.1205	34	850	0.0617	1.5427	0.1205	3.0135	13.1958
2	PR/3016/1	7.50	8.01	5.51	4.43	0.4563	32	800	0.1706	4.2646	0.4563	11.4084	0.5479
3	PR/3016/1	9.50	11.38	7.45	5.93	1.1560	32	800	0.3464	8.6604	1.1560	28.8993	1.5211
4	PR/3016/1	11.50	12.08	8.06	9.43	1.4516	31	775	0.3934	9.8351	1.4516	36.2910	3.0420
5	PR/3016/1	13.50	13.77	9.15	10.60	1.8845	29	725	0.4666	11.6646	1.8845	47.1120	3.1557
6	PR/3016/1	15.50	15.81	10.35	10.15	2.1534	23	575	0.4847	12.1167	2.1534	53.8350	3.4898

Appendix 32 Cont.

Assess	PSP number	Mean age (yrs)	Mean DBH (cm)	Mean HT (m)	Mean dom. HT (m)	Mean vol. (m3)	Trees/ plt	TPH	BA/plt (m2)	BAH (m2/ha)	Plt vol (m3)	VPH (m3/ha)	MAI (M³/ha/yr)
1	PR/3023/1	4.33	5.52	3.74	10.10	0.3418	56	1400	0.5123	3.8081	0.3418	8.5441	3.4732
2	PR/3023/1	6.33	9.53	6.03	6.95	1.2224	46	1150	0.3957	9.8915	1.2224	30.5598	1.9717
3	PR/3023/1	8.33	12.83	7.87	9.93	2.5244	46	1150	0.6812	17.0305	2.5244	63.1093	4.8252
1	PR/3026/1	4.42	5.36	3.69	13.28	0.2085	46	1150	0.1088	2.7189	0.2085	5.2133	7.5731
2	PR/3026/1	6.42	11.14	6.55	5.15	1.3823	46	1150	0.4717	11.7923	1.3823	34.5568	1.1804
1	PR/3026/2	4.42	4.69	3.34	8.90	0.1488	44	1100	0.0806	2.0157	0.1488	3.7192	7.8242
2	PR/3026/2	6.42	10.12	6.35	3.98	1.2198	45	1125	0.4025	10.0630	1.2198	30.4943	0.8421
1	PR/3027/1	4.42	3.20	2.55	7.60	0.0594	44	1100	0.0406	1.0140	0.0594	1.4839	4.7523
2	PR/3027/1	6.42	9.51	6.09	3.55	0.8794	43	1075	0.3185	7.9628	0.8794	21.9859	0.3360
3	PR/3027/1	8.42	17.10	9.81	7.43	4.2019	43	1075	1.0285	25.7128	4.2019	105.0478	3.4264
1	PR/3029/1	3.33	2.33	1.91	11.90	0.0273	47	1175	0.0219	0.5487	0.0273	0.6815	12.4809
2	PR/3029/1	5.33	8.14	5.24	2.93	0.6767	47	1175	0.2643	6.6071	0.6767	16.9185	0.2044
1	PR/3033/1	3.83	4.44	3.12	6.20	0.1493	48	1200	0.0855	2.1386	0.1493	3.7332	3.1722
2	PR/3033/1	5.83	10.51	6.47	4.00	1.3115	48	1200	0.4428	11.0705	1.3115	32.7865	0.9739
3	PR/3033/1	7.83	13.63	8.21	8.03	2.5507	46	1150	0.7096	17.7404	2.5507	63.7683	5.6205
4	PR/3033/1	9.83	18.04	10.45	13.93	1.3412	12	300	0.3153	7.8835	1.3412	33.5298	8.1406
1	PR/3036/1	3.83	6.08	3.97	5.15	0.3064	47	1175	0.1502	3.7542	0.3064	7.6590	1.9980
2	PR/3036/1	5.83	11.46	6.91	8.05	1.6239	47	1175	0.5182	12.9545	1.6239	40.5975	6.9596
3	PR/3036/1	7.83	15.65	9.12	12.75	3.0384	40	1000	0.7954	19.8843	3.0384	75.9603	9.6971
1	PR/3036/2	2.50	2.93	2.11	2.90	0.0409	49	1225	0.0313	0.7822	0.0409	1.0213	0.4085
2	PR/3036/2	4.50	12.29	6.94	7.95	2.8392	49	1225	0.7435	18.5885	2.8392	70.9793	15.7732
3	PR/3036/2	6.50	16.81	9.21	16.03	5.6967	48	1200	1.2787	31.9675	5.6967	142.4170	21.9103
1	PR/3037/1	2.83	5.00	3.25	5.18	0.2552	65	1625	0.1399	3.4968	0.2552	6.3796	2.2516
2	PR/3037/1	4.83	9.04	5.59	8.50	1.0724	56	1400	0.3970	9.9252	1.0724	26.8090	5.5467
3	PR/3037/1	6.83	10.75	6.72	11.05	1.6491	52	1300	0.5222	13.0559	1.6491	41.2280	6.0334
1	PR/3040/1	2.83	2.43	1.89	3.00	0.0264	37	925	0.0182	0.4542	0.0264	0.6607	0.2332
2	PR/3040/1	4.83	7.42	4.75	8.93	0.6163	37	925	0.2100	5.2508	0.6163	15.4068	3.1876
3	PR/3040/1	6.83	12.90	7.64	16.00	2.1647	37	925	0.5724	14.3088	2.1647	54.1183	7.9197
4	PR/3040/1	8.83	15.81	9.29	13.20	3.2153	37	925	0.7903	19.7576	3.2153	80.3815	9.0998
5	PR/3040/1	10.83	20.03	11.31	15.13	5.9892	37	925	1.2615	31.5385	5.9892	149.7293	13.8212
1	PR/4001/1	8.67	14.59	8.75	9.73	1.8730	27	675	0.4860	12.1488	1.8730	46.8240	5.4028
2	PR/4001/1	10.67	16.70	9.96	11.25	2.7315	27	675	0.6363	15.9084	2.7315	68.2868	6.4019

Appendix 32 Cont.

Assess	PSP number	Mean age (yrs)	Mean DBH (cm)	Mean HT (m)	Mean dom. HT (m)	Mean vol. (m3)	Trees/ plt	TPH	BA/plt (m2)	BAH (m2/ha)	Plt vol (m3)	VPH (m3/ha)	MAI (M^3/ha/yr)
3	PR/4001/1	12.67	18.89	11.17	12.78	3.8404	27	675	0.8144	20.3611	3.8404	96.0090	7.5796
4	PR/4001/1	14.67	20.58	12.14	15.43	4.8831	27	675	0.9666	24.1639	4.8831	122.0778	8.3235
5	PR/4001/1	16.67	21.19	12.65	14.90	5.5090	27	675	1.0397	25.9915	5.5090	137.7253	8.2635
6	PR/4001/1	18.67	21.93	13.26	12.90	5.8155	26	650	1.0627	26.5663	5.8155	145.3865	7.7885
1	PR/4022/1	3.50	6.32	4.04	5.03	0.3116	46	1150	0.1548	3.8704	0.3116	7.7910	2.2260
2	PR/4022/1	5.50	12.92	7.54	8.68	2.0365	46	1150	0.6250	15.6240	2.0365	50.9115	9.2566
1	PR/5016/1	4.58	4.12	3.06	4.23	0.1386	43	1075	0.0716	1.7891	0.1386	3.4649	0.7560
2	PR/5016/1	6.58	8.76	5.71	6.90	0.8201	41	1025	0.2793	6.9820	0.8201	20.5032	3.1144
3	PR/5016/1	8.58	11.55	7.32	10.58	1.9300	43	1075	0.5323	13.3087	1.9301	48.2520	5.6216
4	PR/5016/1	10.58	13.58	8.56	10.10	2.6967	41	1025	0.6727	16.8175	2.6967	67.4168	6.3701
5	PR/5016/1	12.58	14.77	9.38	10.33	3.4073	40	1000	0.7831	19.5780	3.4073	85.1823	6.7695
6	PR/5016/1	14.58	16.04	10.23	12.95	3.8623	36	900	0.8301	20.7521	3.8623	96.5563	6.6210
1	PR/6008/1	9.33	9.95	6.73	9.50	1.4662	53	1325	0.4558	11.3939	1.4662	36.6558	3.9274
2	PR/6008/1	11.33	12.41	8.2	11.05	2.1661	45	1125	0.5871	14.6780	2.1661	54.1513	4.7781
1	PR/6015/2	5.75	4.28	3.34	4.38	0.1008	47	1175	0.0561	1.4028	0.1008	2.5207	0.4384
2	PR/6015/2	7.75	8.17	5.62	6.75	0.6930	45	1125	0.2474	6.1860	0.6930	17.3239	2.2353
3	PR/6015/2	9.75	9.56	6.61	6.28	0.7219	30	750	0.2301	5.7533	0.7219	18.0469	1.8510
1	PR/Makoae I/1	5.25	4.71	3.48	5.35	0.1186	31	775	0.0596	1.4892	0.1186	2.9650	0.5648
2	PR/Makoae I/1	7.25	9.50	6.14	14.33	0.8807	31	775	0.2702	6.7560	0.8807	22.0166	3.0368
1	PR/Makoae II/2	4.75	3.82	2.93	4.13	0.0489	29	725	0.0293	0.7332	0.0489	1.2223	0.2573
2	PR/Makoae II/2	6.75	6.94	4.86	7.20	0.3066	29	725	0.1241	3.1034	0.3066	7.6649	1.1355
3	PR/Makoae II/2	8.75	10.65	6.97	10.55	0.9268	29	725	0.2837	7.0920	0.9268	23.1703	2.6480
1	PR/Pulane Spring/1	3.75	1.87	1.73	2.90	0.0116	42	1050	0.0106	0.2652	0.0116	0.2888	0.0770
2	PR/Pulane Spring/1	5.75	6.15	4.29	7.88	0.3958	44	1100	0.1600	3.9995	0.3958	9.8948	1.7208
3	PR/Pulane Spring/1	7.75	11.02	7.01	11.23	1.2091	38	950	0.3839	9.5975	1.2091	30.2273	3.9003

Appendix 32 Cont.

Assess	**PSP number**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean HT (m)**	**Mean dom. HT (m)**	**Mean vol. (m3)**	**Trees/ plt**	**TPH**	**BA/plt (m2)**	**BAH (m2/ha)**	**Plt vol (m3)**	**VPH (m3/ha)**	**MAI (M^3/ha/yr)**
4	Pulane Spring/1	9.75	12.86	8.17	10.28	1.5578	32	800	0.4370	10.9247	1.5578	38.9460	3.9945
1	PR/Sankatana II/1	2.83	2.46	1.91	2.75	0.0245	41	1025	0.0215	0.5374	0.0245	0.6119	0.2160
2	PR/Sankatana II/1	4.83	6.49	4.34	7.95	0.3646	49	1225	0.1722	4.3042	0.3646	9.1145	1.8857
3	PR/Sankatana II/1	6.83	8.67	5.74	8.88	0.6464	39	975	0.2424	6.0603	0.6464	16.1608	2.3650
1	PR/Sankatana II/2	2.83	1.92	1.62	2.60	0.0112	46	1150	0.0117	0.2913	0.0112	0.2797	0.0987
2	PR/Sankatana II/2	4.83	5.48	3.82	6.48	0.2331	49	1225	0.1187	2.9663	0.2331	5.8280	1.2058
3	PR/Sankatana II/2	6.83	7.02	4.91	8.35	0.5076	49	1225	0.2085	5.2121	0.5076	12.6912	1.8572
4	PR/Sankatana II/2	8.83	8.80	6.11	12.10	0.8592	46	1150	0.2994	7.4840	0.8592	21.4800	2.4317
1	PR/1035/1	5.00	6.33	4.27	5.55	0.2923	39	975	0.1297	3.2414	0.2923	7.3070	1.4614
2	PR/1035/1	7.00	11.17	6.92	8.25	1.4674	40	1000	0.4446	11.1157	1.4674	36.6843	5.2406
3	PR/1035/1	9.00	16.22	9.49	14.70	3.5451	38	950	0.8567	21.4174	3.5451	88.6280	9.8476
4	PR/1035/1	11.00	18.44	10.74	16.98	4.6200	36	900	1.0263	25.6573	4.6200	115.5003	10.5000
5	PR/1035/1	13.00	20.18	11.47	13.75	5.4237	35	875	1.1656	29.1408	5.4237	135.5913	12.3265
1	PR/1048/1	2.25	2.04	1.59	2.55	0.0140	45	1125	0.0140	0.3504	0.0140	0.3491	0.1551
2	PR/1048/1	4.25	8.58	5.26	7.08	0.0783	45	1125	0.2927	7.3182	0.7828	19.5689	4.6044
3	PR/1048/1	6.25	12.05	7.23	9.25	1.7346	42	1050	0.5229	13.0719	1.7346	43.3653	6.9384
4	PR/1048/1	8.25	14.46	8.61	11.40	2.7525	40	1000	0.7173	17.9329	2.7525	68.8115	8.3408

Appendix 33: Analysed data of *E. rubida* PSPs based on tree or stand characteristics

Assess	**PSP number**	**Regen. type**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean dom. Ht (m)**	**Mean HT (m)**	**Mean vol. (m^3)**	**Trees/plt**	**TPH Actual**	**TPH**	**BA/plt (m^2)**	**BAH (m^3/ha)**	**Plt vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
1	ER/1005/1	Seedlin	8.67	6.95	7.02	8.60	0.0161	33	825	825	0.1373	3.4314	0.5147	12.8685	1.4848
2	ER/1005/1	Seedlin	10.67	8.78	8.40	10.78	0.0275	33	825	825	0.2128	5.3196	0.8800	21.9999	2.0625
3	ER/1005/1	Seedlin	12.67	10.00	9.45	10.65	0.0384	32	800	825	0.2673	6.6831	1.1915	29.7880	2.3517
1	ER/1005/1a	Coppic	2.08	3.41	6.38	9	0.0036	105	2625	2625	0.1084	2.7095	0.3721	9.3017	4.4719
2	ER/1005/1a	Coppic	4.08	5.07	7.67	11.13	0.0089	93	2325	2325	0.2118	5.2945	0.8196	20.4890	5.0218
3	ER/1005/1a	Coppic	6.08	5.46	8.28	12.10	0.0118	72	1800	1800	0.2033	5.0826	0.8403	21.0068	3.4551
1	ER/1005/2	Seedlin	8.67	6.86	6.97	9.93	0.0161	55	1375	1375	0.2087	5.2172	0.7864	19.6596	2.2683
2	ER/1005/2	Seedlin	10.67	7.70	7.83	12.08	0.0219	55	1375	1375	0.2761	6.9021	1.1164	27.9105	2.6166
3	ER/1005/2	Seedlin	12.67	8.73	8.78	12.10	0.0295	55	1375	1375	0.3491	8.7273	1.5061	37.6535	2.9726
1	ER/1005/2a	Coppic	2.08	3.00	6.16	10.43	0.0029	120	3000	3000	0.1001	2.5018	0.3410	8.5247	4.0984
1	ER/1007/1	Seedlin	7.33	4.62	5.51	8.80	0.0080	42	1050	1025	0.0956	2.3911	0.3357	8.3934	1.1446
2	ER/1007/1	Seedlin	9.33	5.30	6.28	9.00	0.0107	41	1025	1025	0.1149	2.8713	0.4291	10.7277	1.1494
3	ER/1007/1	Seedlin	11.33	5.72	6.92	9.20	0.0190	41	1025	1025	0.1265	3.1630	0.4926	12.3158	1.0867
1	ER/1007/1a	Coppic	2.08	3.53	6.17	7.13	0.0037	100	2500	2475	0.1086	2.7158	0.3648	9.1206	4.3849
1	ER/1007/2	Seedlin	7.33	5.80	6.14	9.33	0.0117	47	1175	1150	0.1439	3.5981	0.5155	12.8867	1.7581
2	ER/1007/2	Seedlin	9.33	6.42	6.87	9.83	0.0161	50	1250	1225	0.1989	4.9726	0.7747	19.3684	2.0759
3	ER/1007/2	Seedlin	11.33	6.93	7.56	9.73	0.0445	49	1225	1225	0.2202	5.5042	0.8947	22.3684	1.9743
1	ER/1021/1	Seedlin	4.00	4.84	4.95	8.00	0.0081	62	1550	1550	0.1480	3.6997	0.48863	12.1580	3.0395

Appendix 33 Cont.

Assess	**PSP number**	**Regen. type**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean dom. Ht (m)**	**Mean HT (m)**	**Mean vol. (m^3)**	**Trees/plt**	**TPH Actual**	**TPH**	**BA/plt (m^2)**	**BAH (m^3/ha)**	**Plt vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
2	ER/1021/1	Seedlin	6.00	7.65	6.84	10.65	0.0230	59	1475	1475	0.3432	8.5797	1.3551	33.8773	5.6462
3	ER/1021/1	Seedlin	8.00	10.14	8.57	16.28	0.0243	57	1425	1400	0.5663	14.1564	2.5386	63.4655	7.9332
1	ER/1026/1	Seedlin	6.25	5.88	5.96	8.35	0.0128	30	750	750	0.0953	2.3825	0.3454	8.6362	1.3818
2	ER/1026/1	Seedlin	8.25	7.23	7.08	8.13	0.0197	26	650	650	0.1056	2.6400	0.4134	10.3347	1.2527
1	ER/1026/1a	Coppic	2.08	7.58	7.68	8.73	0.0037	23	575	575	0.1154	2.8843	0.4851	12.1266	5.8301
2	ER/1026/1a	Coppic	4.08	9.05	8.87	14.90	0.0364	23	575	575	0.1838	4.5954	0.8366	20.9160	5.1265
1	ER/1028/1	Seedlin	6.42	4.11	5.05	8.05	0.0060	89	2225	2225	0.1557	3.8915	0.5192	12.9807	2.0229
2	ER/1028/1	Seedlin	8.42	5.69	6.30	7.73	0.0130	42	1050	1050	0.1397	3.4914	0.5344	13.3598	1.5873
1	ER/1028/1a	Coppic	2.08	3.32	5.46	6.58	0.0398	95	2375	2350	0.1010	2.5242	0.3404	8.5092	4.0910
2	ER/1028/1a	Coppic	4.08	3.79	6.12	9.28	0.0068	54	1350	1350	0.0972	2.4288	0.3672	9.1806	2.2501
1	ER/2006/1	Seedlin	8.58	7.75	7.43	6.15	0.0232	74	1850	1850	0.3892	9.7301	1.5744	39.3600	4.5858
2	ER/2006/1	Seedlin	10.58	8.39	8.17	11.85	0.0316	58	1450	1450	0.4074	10.1856	1.8016	45.0393	4.2557
3	ER/2006/1	Seedlin	12.58	9.44	9.14	11.63	0.0465	53	1325	1325	0.4492	11.2306	2.0713	51.7823	4.1152
1	ER/2006/1a	Coppic	2.08	3.32	6.31	6.49	0.0034	98	2450	2450	0.0947	2.3665	0.3226	8.0641	3.8770
1	ER/2007/1	Seedlin	4.83	6.96	6.24	8.40	0.0156	45	1125	1125	0.1940	4.8502	0.6878	17.1948	3.5578
2	ER/2007/1	Seedlin	6.83	8.72	7.58	11.85	0.0272	45	1125	1125	0.1940	7.7036	1.2220	30.5495	4.4707
3	ER/2007/1	Seedlin	8.83	10.92	9.15	11.63	0.0464	45	1125	1125	0.4724	11.8092	2.0901	52.2518	5.9153
1	ER/2009/1	Seedlin	4.25	8.19	6.77	9.15	0.0220	35	875	875	0.2086	5.2153	0.7698	19.2443	4.5281
2	ER/2009/1	Seedlin	6.25	8.53	7.36	9.57	0.0254	35	875	875	0.2228	5.5712	0.8591	21.4764	3.4362

Appendix 33 Cont.

Assess	**PSP number**	**Regen. type**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean dom. Ht (m)**	**Mean HT (m)**	**Mean vol. (m^3)**	**Trees/plt**	**TPH Actual**	**TPH**	**BA/plt (m^2)**	**BAH (m^3/ha)**	**Plt vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
1	ER/2009/2	Seedlin	5.08	8.32	7.01	8.20	0.0209	41	1025	1025	0.2368	5.9195	0.8584	21.4602	4.2219
2	ER/2009/2	Seedlin	7.52	8.79	7.76	8.80	0.0246	41	1025	1025	0.2623	6.5570	1.0071	25.1775	3.3470
1	ER/2009/3	Seedlin	3.25	5.30	5.03	7.95	0.0077	63	1575	1600	0.1511	3.7772	0.4646	11.6143	3.5736
2	ER/2009/3	Seedlin	5.25	6.40	6.03	8.77	0.0123	64	1600	1600	0.2314	5.7859	0.7858	19.6447	3.7418
1	ER/2012/1	Seedlin	6.00	10.39	8.29	11.88	0.0394	47	1175	1200	0.4449	11.1230	0.4646	11.6143	1.9357
2	ER/2012/1	Seedlin	8.00	10.47	8.74	12.75	0.0475	49	1225	1200	0.5200	13.0005	0.7858	19.6447	2.4556
1	ER/2012/10	Seedlin	3.25	6.03	5.42	7.60	0.0096	67	1675	1675	.2024	5.0596	0.6306	15.7651	4.8508
2	ER/2012/10	Seedlin	5.25	8.22	6.99	9.78	0.0213	62	1550	1550	0.3475	8.6878	1.2797	31.9920	6.0937
3	ER/2012/10	Seedlin	7.25	10.65	8.69	12.35	0.0434	54	1350	1350	0.5324	13.3108	2.2994	57.4860	7.9291
4	ER/2012/10	Seedlin	9.25	1065	9.10	12.35	0.0445	54	1350	1350	0.5324	13.3108	2.3591	58.9785	6.3761
5	ER/2012/10	Seedlin	11.25	10.31	9.33	13.40	0.0519	46	1150	1150	0.4583	11.4578	2.2304	55.7598	6.3761
1	ER/2012/3	Seedlin	5.25	9.27	7.55	10.95	0.0292	43	1075	1075	0.3128	7.8200	1.2251	30.6285	5.8340
2	ER/2012/3	Seedlin	7.25	9.58	8.12	10.95	0.0320	43	1075	1075	0.3307	8.2672	1.3435	33.5873	4.6327
1	ER/2012/4	Seedlin	5.33	7.72	6.74	9.70	0.0206	40	1000	1000	0.2084	5.2089	0.7842	19.6044	3.6760
2	ER/2012/4	Seedlin	7.33	8.38	7.51	10.28	0.0253	40	1000	1000	0.2415	6.0378	0.9601	24.0029	3.2731

Appendix 32 Cont.

Assess	PSP number	Regen. type	Mean age (yrs)	Mean DBH (cm)	Mean dom. Ht (m)	Mean HT (m)	Mean vol. (m^3)	Trees/plt	TPH Actual	TPH	BA/plt (m^2)	BAH (m^3/ha)	Plt vol. (m^3)	VPH (m^3/ha)	MAI (m^3/ha/yr)
1	ER/2012/5	Seedlin	5.33	8.92	7.38	9.98	0.0264	45	1125	1125	0.3098	7.7452	1.1880	29.6993	5.5690
2	ER/2012/5	Seedlin	7.33	9.09	7.88	10.05	0.0284	45	1125	1125	0.3204	8.0110	1.2767	31.9180	4.3525
1	ER/2012/9	Seedlin	3.25	5.59	5.19	7.28	0.0088	60	1500	1500	0.1572	3.9294	0.4901	12.2514	3.7697
2	ER/2012/9	Seedlin	5.25	6.93	6.31	9.73	0.0172	66	1650	1650	0.3053	7.6322	1.1195	27.9885	5.3311
3	ER/2012/9	Seedlin	7.25	10.38	8.54	11.60	0.0409	47	1175	1175	04423	11.0569	1.8806	47.0158	6.4849
4	ER/2012/9	Seedlin	9.25	10.36	8.94	13.95	0.0489	52	1300	1300	0.5542	13.8544	2.5443	63.6070	6.8764
5	ER/2012/9	Seedlin	11.25	10.33	9.34	13.83	0.0573	43	1075	1075	0.4050	10.1262	2.0049	50.1218	4.4553
1	ER/2013/1	Seedlin	7.33	8.25	7.43	11.77	0.0240	60	1500	1500	0.3613	9.0324	1.4142	35.3553	4.8214
2	ER/2013/1	Seedlin	9.33	8.81	8.14	11.98	0.0283	60	1500	1500	0.3923	9.8080	1.6118	40.2938	4.3172
1	ER/2013/1a	Coppic	2.08	2.23	5.07	5.28	0.0020	127	3175	3175	0.0451	1.1263	0.1496	3.7409	1.7985
2	ER/2013/1a	Coppic	4.08	5.78	7.36	10.05	0.0127	128	3200	3175	0.4042	10.1057	1.6051	40.1273	9.8351
3	ER/2013/1a	Coppic	6.08	8.68	9.30	14.75	0.0340	121	3025	3025	0.8778	21.9439	4.1085	102.713	16.8936
1	ER/2016/1	Seedlin	6.42	8.12	7.18	10.18	0.0221	106	2650	2625	0.6157	15.3917	2.3400	58.5008	9.1165
2	ER/2016/1	Seedlin	8.42	8.81	7.95	12.75	0.0276	101	2525	2525	0.6621	16.5533	2.6780	66.9498	7.9544
3	ER/2016/1	Seedlin	10.42	10.78	9.41	16.23	0.0469	97	2425	2425	0.9946	24.8644	4.5051	112.6280	10.8123
4	ER/2016/1	Seedlin	12.42	11.50	10.20	16.50	0.0572	89	2225	2225	1.0491	26.2270	5.0298	125.7445	10.1270
5	ER/2016/1	Seedlin	14.50	11.82	10.79	14.13	0.0624	80	2000	2000	0.9690	24.2247	4.8076	120.1908	8.2890

Appendix 33 Cont.

Assess	PSP number	Regen. type	Mean age (yrs)	Mean DBH (cm)	Mean dom. Ht (m)	Mean HT (m)	Mean vol. (m^3)	Trees/plt	TPH Actual	TPH	BA/plt (m^2)	BAH (m^3/ha)	Plt vol. (m^3)	VPH (m^3/ha)	MAI (m^3/ha/yr)
1	ER/2016/2	Seedlin	6.42	8.04	7.13	11.53	0.0230	49	1225	1225	0.2905	7.2631	1.1276	28.1905	4.3931
2	ER/2016/2	Seedlin	8.42	9.04	8.08	12.48	0.0297	45	1125	1125	0.3106	7.7639	1.2779	31.9475	3.7957
3	ER/2016/2	Seedlin	10.42	10.54	9.28	14.98	0.0453	44	1100	1100	0.4399	10.9970	1.9934	49.8355	4.7842
4	ER/2016/2	Seedlin	12.42	11.34	10.11	15.78	0.0541	41	1025	1025	0.4686	11.7138	2.2166	55.4153	4.4630
5	ER/2016/2	Seedlin	14.50	11.20	10.47	14.80	0.0559	40	1000	1000	0.4463	11.1563	2.1789	54.4725	3.7567
1	ER/2019/1	Seedlin	4.33	6.29	5.78	10.05	0.0122	43	1075	1075	0.1546	3.8653	0.5234	13.0858	3.0200
2	ER/2019/1	Seedlin	6.33	7.42	6.79	10.88	0.0185	45	1125	1125	0.2242	5.6040	0.8326	20.8143	3.2865
3	ER/2019/1	Seedlin	8.33	10.91	9.05	12.48	0.0444	39	975	975	0.3989	9.9730	1.7306	43.2643	5.1917
4	ER/2019/1	Seedlin	10.33	1095	9.48	12.48	0.0458	40	1000	1000	0.4114	10.2847	1.8305	45.7628	4.4287
5	ER/2019/1	Seedlin	12.33	12.67	10.80	12.68	0.0674	34	850	850	0.4717	11.7917	2.2930	57.3245	4.6479
6	ER/2019/1	Seedlin	14.33	13.26	11.52	15.10	0.0751	36	900	900	0.5399	13.4978	2.7035	65.5880	4.7155
1	ER/2019/2	Seedlin	4.33	7.68	6.52	8.40	0.0167	37	925	950	0.1796	4.4900	0.6185	15.4617	3.5684
2	ER/2019/2	Seedlin	6.33	9.02	7.64	9.08	0.0252	38	950	950	0.2463	6.1578	0.9328	23.3207	3.6822
3	ER/2019/2	Seedlin	8.33	11.45	9.33	10.25	0.0465	37	925	900	0.3792	9.4798	1.6362	40.9050	4.9086
4	ER/2019/2	Seedlin	10.33	11.97	10.02	13.33	0.0568	37	925	925	0.4574	11.4359	2.1024	52.5605	5.0865
5	ER/2019/2	Seedlin	12.33	12.70	10.82	12.88	0.0658	31	775	775	0.4255	10.6382	2.0394	50.9843	4.1339
6	ER/2019/2	Seedlin	14.33	13.15	11.47	11.22	0.0747	33	825	825	0.4770	11.9245	2.3889	59.7225	4.1667
1	ER/2023/1	Seedlin	5.75	7.10	6.50	8.95	0.0155	49	1225	1225	0.2101	5.2528	0.7461	18.6532	3.2440
2	ER/2023/1	Seedlin	7.75	8.23	7.51	9.75	0.0242	48	1200	1200	0.2938	7.3461	1.1620	29.0495	3.7483

Appendix 33 Cont.

Assess	**PSP number**	**Regen. type**	**Mean age (yrs)**	**Mean DBH (cm)**	**Mean dom. Ht (m)**	**Mean HT (m)**	**Mean vol. (m^3)**	**Trees/plt**	**TPH Actual**	**TPH**	**BA/plt (m^2)**	**BAH (m^3/ha)**	**Plt vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
3	ER/2023/1	Seedlin	9.75	10.78	9.27	11.68	0.0446	44	1100	1100	0.4501	11.2513	2.0394	50.9843	4.1339
4	ER/2023/1	Seedlin	11.75	15.87	12.38	16.15	0.1127	44	1100	1100	0.9453	23.6337	4.9603	124.0068	10.5538
1	ER/4001/1	Seedlin	5.83	8.82	7.43	11.73	0.0259	59	1475	1475	0.3963	9.9073	1.5280	38.1988	6.5487
2	ER/4001/1	Seedlin	7.83	9.51	8.20	12.05	0.0328	59	1475	1475	0.4698	11.7443	1.9370	48.4260	6.1820
1	ER/4001/2	Seedlin	3.83	4.82	4.90	8.00	0.0080	59	1475	1475	0.1465	3.6615	0.4727	11.8178	3.0832
1	ER/4001/2a	Coppic	2.08	3.75	4.74	7.13	0.0073	46	1150	1150	0.0940	2.3495	0.3341	8.3522	4.0155
2	ER/4001/2a	Coppic	4.08	4.32	5.45	7.93	0.0091	49	1225	1225	0.1103	2.7573	0.4084	10.2092	2.5022
1	ER/4001/2b	Coppic	2.08	4.87	6.16	8.28	0.0073	75	1875	1850	0.1589	3.9735	0.5444	13.6088	6.5427
2	ER/4001/2b	Coppic	4.08	8.63	8.56	11.63	0.0250	71	1775	1775	0.4364	10.9102	1.7761	44.4013	10.8827
1	ER/4001/4	Seedlin	2.25	2.04	3.11	4.30	0.0010	57	1425	1425	0.0239	0.5976	0.4727	11.8178	5.2524
2	ER/4001/4	Seedlin	4.25	4.11	4.61	6.40	0.0050	67	1675	1650	0.1084	2.7101	0.3341	8.3522	1.9652
3	ER/4001/4	Seedlin	6.25	7.53	6.83	8.80	0.0192	64	1600	1600	0.3235	8.0863	0.4084	10.2092	1.6335
4	ER/4001/4	Seedlin	8.25	9.79	8.44	12.33	0.0392	60	1500	1500	0.4998	12.4948	0.5444	13.6088	1.6496
5	ER/4001/4	Seedlin	10.25	10.10	9.01	14.15	0.0392	44	1100	1100	0.3940	9.8501	1.7761	44.4013	4.3318
1	ER/4001/4a	Coppic	2.08	3.45	5.90	5.18	0.0047	33	825	850	0.0390	0.9740	0.1416	3.5390	1.7014
1	ER/4001/5	Seedlin	3.42	2.63	3.65	5.30	0.0022	39	975	975	0.0293	0.7332	0.0797	1.9933	0.5833

Appendix 33 Cont.

Assess	PSP number	Regen. type	Mean age (yrs)	Mean DBH (cm)	Mean dom. Ht (m)	Mean HT (m)	Mean vol. (m^3)	Trees/plt	TPH Actual	TPH	BA/plt (m^2)	BAH (m^3/ha)	Plt vol. (m^3)	VPH (m^3/ha)	MAI (m^3/ha/yr)
2	ER/4001/5	Seedlin	5.42	4.54	5.08	6.88	0.0062	38	950	950	0.0712	1.7806	0.2243	5.6087	1.0355
3	ER/4001/5	Seedlin	7.42	7.46	7.03	8.28	0.0197	35	875	875	0.1807	4.5180	0.6891	17.2263	2.3223
1	ER/4001/6	Seedlin	2.42	3.55	3.94	4.55	0.0031	53	1325	1325	0.0584	1.4595	0.1547	3.8675	1.6001
2	ER/4001/6	Seedlin	4.42	5.78	5.53	6.55	0.0096	50	1250	1250	0.1422	3.5551	0.4589	11.4720	2.5974
1	ER/4011/2	Seedlin	3.58	3.03	3.90	5.43	0.0027	59	1475	1475	0.0545	1.3626	0.1520	3.7988	1..0602
2	ER/4011/2	Seedlin	5.58	4.60	5.14	7.13	0.0061	57	1425	1425	0.1082	2.7044	0.3389	8.4726	1.5175
3	ER/4011/2	Seedlin	7.58	5.99	6.29	7.68	0.0109	58	1450	1425	0.1792	4.4795	0.6231	15.5763	2.0540
1	ER/5002/1	Seedlin	4.75	3.48	4.38	5.18	0.0033	78	1950	1950	0.0824	2.0600	0.2366	5.9150	1.2453
2	ER/5002/1	Seedlin	6.75	6.96	6.63	9.08	0.0184	87	2175	2175	0.4159	10.3974	1.5991	39.9775	5.9226
3	ER/5002/1	Seedlin	8.75	9.19	8.22	13.20	0.0377	84	2100	2100	0.7117	17.7933	3.1657	79.1423	9.04448
4	ER/5002/1	Seedlin	10.75	11.82	10.02	16.00	0.0636	78	1950	1950	1.0161	25.4020	4.9611	124.0263	11.5373
1	ER/5006/1	Seedlin	8.33	8.80	7.93	11.50	0.0276	66	1650	1650	0.4509	11.2728	1.8207	45.5185	5.4624
2	ER/5006/1	Seedlin	10.33	12.19	10.14	10.85	0.0580	22	550	575	0.2773	6.9318	1.2762	31.9060	3.0877
1	ER/5006/1a	Seedlin	2.08	2.65	5.49	4.65	0.0020	79	1975	1975	0.0463	1.1567	0.1448	3.6196	1.7402
1	ER/5010/1	Seedlin	3.67	2.95	3.87	4.98	0.0025	52	1300	1300	0.0415	1.0384	0.1141	2.8528	0.7773
2	ER/5010/1	Seedlin	5.67	5.82	5.81	7.33	0.0110	55	1375	1375	0.1702	4.22542	0.5842	14.6043	2.5772
3	ER/5010/1	Seedlin	7.67	6.84	6.76	8.43	0.0166	55	1375	1375	0.2386	5.9656	0.8967	22.4179	2.9241
1	ER/5010/1a	Coppic	2.08	4.00	5.66	6.89	0.0043	133	3325	3300	0.1767	4.4173	0.5583	13.9569	6.7101

Appendix 34: A calculated site indices for the 33 permanent sample plots of *E. rubida* in Lesotho

Plot number	**SI**
ER/1005/1	8.308288
ER/1005/2	12.02026
ER/1007/1	7.355462
ER/1007/2	7.779201
ER/1021/1	14.40435
ER/1026/1	7.116321
ER/1028/1	6.719547
ER/2006/1	9.086144
ER/2007/1	9.95441
ER/2009/1	9.380081
ER/2009/2	7.966362
ER/2009/3	9.432925
ER/2012/1	11.28105
ER/2012/10	10.73129
ER/2012/3	10.05589
ER/2012/4	9.399426
ER/2012/5	9.189128
ER/2012/9	11.77059

Appendix 34 Cont.

PSP number	**SI**
ER/2013/1	10.08248
ER/2016/1	12.92538
ER/2016/2	12.36136
ER/2019/1	9.948215
ER/2019/2	10.10513
ER/2023/1	12.80458
ER/4001/1	10.74467
ER/4001/2	10.14937
ER/4001/4	11.59914
ER/4001/5	7.534539
ER/4001/6	7.887073
ER/4011/2	7.745692
ER/5002/1	13.19573
ER/5006/1	8.875848
ER/5010/1	7.574469

Appendix 35: A calculated site indices for the 44 *P. radiata* permanent sample plots in Lesotho

PSP number	**SI**
PR/1001/1	16.84957
PR/1011/1	14.08912
PR/1021/1	14.44213
PR/1031/1	15.93133
PR/1052/1	16.11066
PR/1063/1	15.03133
PR/1066/1	15.955915
PR/1080/1	16.01934
PR/2014/1	17.23349
PR/2014/2	18.42496
PR/2021/1	16.44959
PR/2021/2	16.09245
PR/2026/1	16.3979
PR/2026/2	15.53238
PR/2029/1	18.42955
PR/2029/2	18.25782
PR/2038/1	12.05282
PR/2038/2	14.07417

Appendix 35 Cont.

PSP number	**SI**
PR/3003/1	17.20031
PR/3012/1	15.71167
PR/3012/2	15.81969
PR/3016/1	12.80351
PR/3023/1	16.13841
PR/3026/1	16.25891
PR/3026/2	16.25891
PR/3027/1	18.01248
PR/3029/1	17.10771
PR/3033/1	17.83581
PR/3036/1	17.60523
PR/3036/2	16.9508
PR/3037/1	15.90961
PR/3040/1	15.10443
PR/4001/1	15.62606
PR/4022/1	15.8843
PR/5016/1	13.17841
PR/6008/1	13.45202

Appendix 35 Cont.

PSP number	**SI**
PR/6015/2	12.35324
PR/Makoae I/1	14.38065
PR/Makoae II/2	15.82594
PR/PULANE SPRING/1	14.17505
PR/SANKATANA II/1	17.14841
PR/SANKATANA II/2	17.60175
PR/1035/1	16.96025
PR/1048/1	17.68021

Appendix 36: Long term average monthly temperatures at ten stations in Lesotho taken over standard 30 year period (1931-1960) (degrees centigrade) (Russell, 1979; Jayamaha 1980; Bureau of Statistics, 2003)

Station	**Elevation (m)**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct.**	**Nov.**	**Dec.**	**Average**
Butha-Buthe	1770	19.8	19.1	17.4	14.6	10.1	6.9	7.3	9.6	13.1	16.2	18.0	19.5	14.3
Leribe	1740	20.3	19.2	17.8	14.4	10.4	7.3	7.1	9.9	13.7	16.9	18.3	19.8	14.6
Maseru	1530	21.0	20.4	18.3	14.7	10.3	6.7	6.7	10.1	13.3	16.0	18.3	20.5	14.7
Mafeteng	1610	20.4	19.5	17.5	14.4	10.9	7.9	7.4	10.3	13.2	16.4	17.6	19.9	14.6
Mohale's Hoek	1600	21.4	20.2	18.6	14.9	10.9	7.3	8.1	10.7	13.8	16.9	18.8	20.4	15.2
Mokhotlong	2200	16.6	16.3	14.4	11.6	7.4	5.0	4.9	9.8	10.9	13.6	14.4	16.3	11.8
Qacha's Nek	1970	18.5	18.0	16.5	13.9	10.6	7.6	7.4	9.8	12.7	14.9	15.9	17.6	13.6
Quthing	1740	20.5	19.3	17.5	13.9	10.8	7.8	6.9	10.4	13.2	16.1	17.7	19.4	14.5
Teyateyaneng	1750	20.3	19.6	17.8	14.7	11.5	8.4	8.0	10.7	13.9	16.9	18.0	20.1	15.0
Thaba-Tseka	2160	16.9	15.9	14.7	11.8	8.3	5.6	5.6	7.9	11.1	14.0	15.1	17.1	12.0
Average		19.6	18.8	17	13.9	10.1	7.1	6.9	9.9	12.9	15.8	17.2	19.1	14.0

Appendix 37: Long term average monthly rainfall at ten stations in Lesotho taken over standard 30 year period (1931-1960) (Russell, 1979; Jayamaha, 1980; Bureau of Statistics, 2003) (milli-metres)

Station	**Elevation (m)**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annul Total**	**Average**	**Period May-Nov**
Butha-Buthe	1770	127	107	105	58	30	13	12	14	27	78	99	110	780	65	273
Leribe	1740	132	115	112	60	34	13	13	13	30	76	104	117	819	68	235
Maseru	1530	108	91	99	60	29	11	12	13	21	61	88	89	682	57	235
Mafeteng	1610	104	106	107	66	33	13	12	15	26	59	82	88	711	59	240
Mohale's Hoek	1600	113	101	106	61	37	15	14	15	26	62	86	95	731	61	255
Mokhotlong	2200	105	78	66	36	21	9	9	14	23	57	78	90	586	49	211
Qacha's Nek	1970	163	140	120	46	26	18	13	19	39	66	103	147	900	75	284
Quthing	1740	101	93	102	67	37	15	14	17	34	64	83	98	725	60	264
Teyateyaneng	1750	111	93	99	57	31	11	11	12	22	68	90	93	698	58	245
Thaba-Tseka	2160	96	72	74	39	27	8	11	14	22	59	67	86	575	48	208
Average		116	100	99	55	30	13	12	15	27	65	88	101	721	60	245

Appendix 38: *E. rubida* permanent sample plots which were legally and illegally felled

PSP number	**Woodlot**	**Species**	**Remarks**
ER/1005/1a	Matsieng	*E. rubida*	1st coppice assessment, 2nd rotation crop
ER/1005/2a	Matsieng	*E. rubida*	1st coppice assessment
ER/1028/1a	Thaba-Khupa	*E. rubida*	1st, 2nd 3rd coppice assessment, 1st rotation crop, illegal felling noticed
ER/2006/1a	Ha Seetsa	*E. rubida*	Illegal felling occurred and drought noticed, 1st & 2nd coppice assessment

Appendix 38 Cont.

PSP number	**Woodlot**	**Species**	**Remarks**
ER/2013/1a	Koenaneng	*E. rubida*	1st, 2nd, 3rd coppice assessments
ER/4001/2a	Leshoboro plateau	*E. rubida*	1st coppice assessment
ER/4001/2b	Leshoboro plateau	*E. rubida*	2nd coppice assessment, 3rd rotation crop
ER/4001/4a	Leshoboro plateau	*E. rubida*	First, second & third coppice assesments
ER/5006/1a	Manamela	*E. rubida*	1st coppice assessment, 2nd rotation crop
ER/5010/1a	Makhunoane	*E. rubida*	1st coppice assessment, 2nd rotation crop

Appendix 39: *P. radiata* permanent sample plots which were thinned and illegally felled

PSP number	**Woodlot**	**Species**	**Remarks**
PR/1001/1	Masianokeng West	*P. radiata*	Thinned on 23/10/90, illegal felling noticed
PR/1011/1	Fika le Mohala	*P. radiata*	Thinned on 12/01/1988 , illegal felling noticed
PR/1031/1	Boqate Rock	*P. radiata*	Illegal felling noted
PR/2014/2	Pontseng	*P. radiata*	Illegal felling recorded down by a big percentage
PR/3012/1	Tsoloane I	*P. radiata*	The villagers felled down trees, PSP was clearfelled and volume recorded.
PR/3012/2	Tsoloane I	*P. radiata*	The villagers felled down trees, PSP was clear felled and volume recorded.

Appendix 39 Cont.

PR/3033/1	Ha Bolokoe	*P. radiata*	Many trees were illegally felled, this affected the volume to decrease instead of increasing
PR/Sankatana II/1	Ha Sankatana II	*P. radiata*	A lot of trees were felled down illegally, thus bringing down the volume by about 50 %

Appendix 40: *E. macarthurii* plots (study sites) calculated information

Assess no.	**Woodlot**	**Species**	**PSP number**	**Mean age (yrs)**	**Mean dbh (cm)**	**Mean HT (m)**	**Trees/ plot**	**TPH**	**BA/plot (m^2)**	**BAH (m^2/ha)**	**Mean tree vol. (m^3)**	**Plot vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
1	Ha Khoeli	*E. macarthurii*	EM/1021/1	4	6.29	6.8	40	1000	0.0930	2.325	0.0067	0.1675	6.7	1.675
2	Ha Khoeli	*E. macarthurii*	EM/1021/1	6	8.51	10.08	39	975	0.1461	3.6525	0.0182	0.455	17.745	2.96
3	Ha Khoeli	*E. macarthurii*	EM/1021/1	8	11.2	15.08	39	975	0.2455	6.1375	0.0473	1.1825	46.1175	5.76
4	Ha Khoeli	*E. macarthurii*	EM/1021/1	10	13.64	16.03	39	975	0.3727	9.3175	0.0745	1.8625	72.6375	7.26
1	Lekhoareng	*E. macarthurii*	EM/1052/1	4.83	5.91	6.83	48	1200	0.1646	4.115	0.0040	0.1	4.8	0.99
2	Lekhoareng	*E. macarthurii*	EM/1052/1	6.83	7.37	9.25	47	1175	0.2134	5.335	0.0127	0.3175	14.9225	2.18
3	Lekhoareng	*E. macarthurii*	EM/1052/1	8.83	10.67	10.48	47	1175	0.3578	8.945	0.0298	0.745	35.015	3.97
4	Lekhoareng	*E. macarthurii*	EM/1052/1	10.83	10.67	14.7	29	725	0.0582	1.455	0.0418	1.045	30.305	2.80
1	Leshoboro Plateau	*E. macarthurii*	EM/4001/1	2.17	1.36	3.8	122	3050	0.0295	0.7375	0.00018	0.0045	0.549	0.25
2	Leshoboro Plateau	*E. macarthurii*	EM/4001/1	4.17	3.01	6.2	119	2975	0.0126	0.315	0.0014	0.035	4.165	9.99
1	Morija South	*E. macarthurii*	EM/1006/1	4.83	4.51	6.25	45	1125	0.0993	2.4825	0.0032	0.08	3.6000	0.75
2	Morija South	*E. macarthurii*	EM/1006/1	6.83	7.56	8.55	45	1125	0.2788	6.97	0.0122	0.305	13.725	2.01
3	Morija South	*E. macarthurii*	EM/1006/1	8.83	10.14	13.1	44	1100	0.4228	10.57	0.0354	0.885	38.94	4.41

Appendix 41: *P. halepensis* plots (study sites) calculated information

Assess no.	**Woodlot**	**Species**	**PSP number**	**Mean age (yrs)**	**Mean dbh (cm)**	**Mean HT (m)**	**Trees/ plot**	**TPH**	**BA/plot (m^2)**	**BAH (m^2/ha)**	**Mean tree vol. (m^3)**	**Plot vol. (m^3)**	**VPH (m^3)**	**MAI (m^3/ha/yr)**
1	Masemouse	*P. halepensis*	PH/3026/1	4.42	1.26	2.9	53	1325	0.0096	0.24	0.00012	0.0030	0.159	0.04
2	Masemouse	*P. halepensis*	PH/3026/1	6.42	4.71	4.83	53	1325	0.1209	3.0225	0.0027	0.0675	3.578	0.56
1	Ha Makoae II	*P. halepensis*	PH/Makoae II/1	4.83	0.80	2.1	58	1450	0.0058	0.145	0.000034	0.0009	0.049	0.01
2	Ha Makoae II	*P. halepensis*	PH/Makoae II/1	6.83	3.22	4.08	58	1450	0.0526	1.315	0.0011	0.0275	1.595	0.23
3	Ha Makoae II	*P. halepensis*	PH/Makoae II/1	8.83	14.41	14.23	58	1450	1.0545	26.3625	0.0739	1.8475	107.155	12.14
1	Tri Hoek	*P. halepensis*	PH/3023/1	5.50	1.09	2.93	50	1250	0.0089	0.2225	0.000087	0.0022	0.109	0.02
2	Tri Hoek	*P. halepensis*	PH/3023/1	7.50	6.76	4.89	50	1250	0.0306	0.765	0.0056	0.1400	7.000	0.93
3	Tri Hoek	*P. halepensis*	PH/3023/1	9.50	7.62	8	50	1250	0.2798	6.995	0.0116	0.2900	14.500	1.53
4	Tri Hoek	*P. halepensis*	PH/3023/1	11.50	8.97	8.65	50	1250	0.3776	9.44	0.0174	0.4350	21.750	1.89
5	Tri Hoek	*P. halepensis*	PH/3023/1	13.50	13.58	16.48	50	1250	0.8913	22.2825	0.0760	1.9000	47.500	3.52

Appendix 42: *E. nitens* plot (study site) calculated information

Assess no.	**Woodlot**	**Species**	**PSP number**	**Mean age (yrs)**	**Mean dbh (cm)**	**Mean HT (m)**	**Trees/plot**	**TPH**	**BA/plot (m^2)**	**BAH (m^2/ha)**	**Mean tree vol. (m^3)**	**Plot vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
1	Ha Khoarai	*E. nitens*	EN/1080/1	2.50	4.45	5.98	53	1325	0.1088	2.72	0.0030	0.075	3.975	1.59
2	Ha Khoarai	*E. nitens*	EN/1080/1	4.50	8.90	8.42	53	1325	0.4225	10.5625	0.0167	0.41	22.1275	4.92
3	Ha Khoarai	*E. nitens*	EN/1080/1	6.50	10.78	12.05	56	1400	0.5751	14.3775	0.0350	0.875	49	7.54

Appendix 43: *P. pinaster* plot (study site) calculated information

Assess no	**Woodlot**	**Species**	**PSP number**	**Mean age (yrs)**	**Mean dbh (cm)**	**Mean HT (m)**	**Trees/plot**	**TPH**	**BA/plot (m^2)**	**BAH (m^2/ha)**	**Mean tree vol. (m^3)**	**Plot vol. (m^3)**	**VPH (m^3/ha)**	**MAI (m^3/ha/yr)**
1	Phomolong	*P. pinaster*	PP/1048/1	6.42	7.41	5	27	675	0.1373	3.4325	0.0069	0.1725	4.6575	0.73
2	Phomolong	*P. pinaster*	PP/1048/1	8.42	13.22	7.75	25	625	0.0714	1.785	0.0339	0.8475	21.1875	2.52
3	Phomolong	*P. pinaster*	PP/1048/1	10.42	15.92	9.3	25	625	0.0856	2.14	0.0451	1.1268	28.1515	2.70
4	Phomolong	*P. pinaster*	PP/1048/1	12.42	15.33	7.75	21	525	0.1190	2.975	0.0455	23.8875	1.1375	1.92