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An evaluation of the productivity of two oil mallee species in a revegetation trial in the Central Wheatbelt of Western Australia

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AN EVALUATION OF THE PRODUCTIVITY OF TWO OIL MALLEE SPECIES IN A REVEGETATION TRIAL IN THE CENTRAL WHEATBELT OF WESTERN AUSTRALIA.

An Honours Thesis for a Bachelor of Science Honours

(Environmental Management) Degree

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ABSTRACT

Two of Western Australia's most pressing land degradation problems are waterlogging and increasing soil salinity. Extensive clearing of the native, deep-rooted vegetation and its replacement with shallow-rooted crop and pasture plants has resulted in increased recharge of groundwater tables, causing them to rise. Salts stored in the soil are being brought to the soil surface with the rising watertables. Revegetation with deep-rooted native plants has been identified as the most likely strategy to achieve increased groundwater usage and a lowering of watertables. One area seriously affected by waterlogging and increasing salinity is the Western Australian central wheatbelt region.

The Department for Conservation and Land Management [CALM] is conducting revegetation trials with oil producing mallee-form eucalypts. It is hoped that commercial production of cineole, a major constituent of *eucalyptus* oil, will prove to be an economic catalyst for large-scale revegetation of the Western Australian wheatbelt region. Species used in the oil mallee trials include *Eucalyptus horistes* and *E. loxophleba* subsp. *lissophloia*, about which very little is known. Yet site specific species selection, based on knowledge of a species' preferred site conditions for maximum productivity, is essential in reaching revegetation objectives, such as high water use and cineole production. To gain this knowledge about *E. horistes* and *E. loxophleba* subsp. *lissophloia* a study was conducted on trial sites in the central wheatbelt region of Narrogin-Wickepin. A number of plant growth, water use and cineole production parameters were examined at sites representing recharge and discharge zones, and the chemical and physical characteristics of the sites were determined. It was hypothesised that any differences in species productivity and water

use can be explained in terms of the species' suitability to the site conditions, and that any differences between species are physiological.

Analysis of the data revealed that *E. horistes* prefers recharge sites, while *E. loxophleba* subsp. *lissophloia* appears to be a generalist species. Both species transpire large amounts of water, making them inherently suitable for revegetation projects aimed at controlling rising watertables and associated soil salinity. Cineole production by *E. horistes* plants was larger, and *E. loxophleba* subsp. *lissophloia* showed great variability in leaf cineole content. The study highlighted the need for grazing and weed controls in oil mallee plantations, as well as the necessity to carry out further research with emphasis on species provenance selection and breeding trials for higher cineole yields and improved tolerance to waterlogged and saline site conditions.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Perth, 5 December 1997

BEATRICE L. H. FRANKE

DEDICATION

This thesis is dedicated to my late uncle, Mr Heinz Reimers, without whose love and support I would never have had the opportunity of attempting it.

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Chapter 1

Introduction

"When first the land was ours we thought

that things would never change

- there'd always be the same green hills,

clear rivers and rich range."

Bruce Dawe (1989)

In many parts of the world land degradation is being recognised as a key conservation issue. An ever increasing human population has led to an over-exploitation of natural resources, both in terrestrial and aquatic environments. The continued expansion of food production areas and the management practices used subsequently, have led to widespread environmental degradation. This is particularly evident in arid lands used for agriculture (Barrow, 1991; Saunders, Hobbs and Ehrlich, 1993).

It is difficult to accurately define the term 'land degradation' due to the variety of factors and processes involved. Most explanations include a reduction, loss or change in the physical properties of the land or its surface cover, which leads to declining land capabilities. The term 'land capability' refers to the land's ability to support different types of human and ecological land uses. While some of the causes of land degradation are natural, such as floods, droughts or bushfires, many are the direct or indirect result of human activities. For example, indiscriminate clearing of native

vegetation, irrigation, mining, inappropriate land management practices such as overgrazing, as well as the introduction of exotic flora and fauna species all contribute to a loss in the land's capabilities (Barrow, 1991; McTainsh and Boughton, 1993; Ghassemi, Jakeman and Nix, 1995). Once the land's ability to support food production is reduced, economic and social ramifications are felt. A loss in income can lead to increasing demands on social welfare systems, where they are in place. More often than not people decide to leave areas affected by land degradation, only to congregate in ever increasing numbers in urban centres, where pollution due to waste generation is the result (Miller, 1994), thus causing further negative impacts on the environment.

The most common processes leading to and forming part of land degradation include the loss of soil through water and wind erosion, changes to soil structure, declining soil fertility, soil acidification and pollution, increases in soil salinity, waterlogging, the introduction of pest species, and a degradation of the vegetation cover and its composition. These processes are mostly human-induced and a result of agricultural land use and management practices (Richardson, 1988; McTainsh and Boughton, 1993).

1.1. Waterlogging and Salinisation

Countries in semi-arid and arid climatic zones (seasonally hot and dry), such as Australia, Egypt, Ethiopia, India, Israel, Pakistan, South Africa and the United States of America, have some naturally occurring saline areas. This primary salinity forms salt marshes, salt flats and salt lakes, which are associated with highly saline groundwater and are usually characterised by internal drainage systems. They also provide an indication of the presence of salts in the sub-soil (Williamson, 1990; Ghassemi, *et al.*, 1995). In the agricultural and pastoral regions of these countries one of the major land

degradation problems is increasing soil salinity. Groundwater extracted from aquifers located in sub-surface salt accumulation zones contains dissolved salts, which are being deposited in surface soil horizons through the use of that groundwater in the irrigation of agricultural crops and pastures. Both the arid climate, which causes a large fraction of the water to evaporate, and the high application rates of the irrigation water result in salt accumulation at or near the soil surface. In time salt concentrations in the upper part of the soil profile reach levels impacting negatively on plant growth, and eventually the salt content in the surface soil horizons becomes too high for successful crop and pasture plant establishment. This type of human induced or secondary salinisation occurs in Australia's Murray-Darling basin, for example (Williamson, 1990; Roberts, 1992; Miller, 1994; Ghassemi, *et al.*, 1995).

Another form of secondary salinisation of soils in arid zone agricultural regions takes place as a result of large scale clearing of the perennial, native vegetation. Many component species of native vegetation assemblages, which are usually trees like Australian eucalypts for example, are deep-rooted and thereby gain access to groundwater stored at great depth. Even in the hot and dry climatic conditions prevalent for much of the year, these species continue to access and transpire large amounts of water. The groundwater removed from the watertable in this way is replaced by recharge following rainfall events, but continued extraction by the vegetation keeps the watertable at a relatively constant depth. Once this native vegetation is removed and replaced with shallow-rooted crop and pasture plants, which are smaller, do not intercept the same amount of rainfall and can not access the deep groundwater table, increased recharge of the groundwater leads to rising watertables (Schofield, *et al.*, 1989, Williamson, 1990; McTainsh and Boughton, 1993; Ghassemi, *et al.*, 1995; Salinity Statement, 1996; Wildy, 1996a).

As the watertables rise they reach sub-soil zones of accumulated salts, which are generally very old in geological terms and consist of deeply weathered parent rock or thick alluvial clay deposits. The salts are a product of the weathering of mineral rocks, the result of marine deposition at times of higher sea levels, or were deposited by rainfall originating from the ocean. Over time they were leached from the upper soil horizons and have accumulated in the clay dominated sub-soil zones, often at depths of more than 30 m (Williamson, 1990; Ghassemi, *et al.*, 1995). The salts are dissolved by the intruding groundwater, which continues to carry them in solution to higher soil strata as the watertables continue to rise. This rise in groundwater levels can be fairly rapid. For example, in some areas of south-western Western Australia watertables have risen by more than 25 m since clearing first began in the middle of the 19th century (Hooper and George, 1995).

How saline groundwater reaches the soil surface varies according to the affected area's geology and topography. Groundwater movement may be horizontal, with aquifers discharging their water on the lower slopes of small hills, where they form saline seeps. They may also discharge directly into streams and rivers, adding to the salt load and thereby impacting on freshwater environments. When drainage is internal, e.g. not involving streams or rivers flowing to the coast, groundwater may rise vertically until it comes close to the soil surface in lower parts of the landscape, where it evaporates, leaving the concentrated, recrystallised salts behind (Williamson, 1990; Ghassemi, *et al.*, 1995; Salinity Statement, 1996).

Saline groundwater entering the plant root zone of the soil affects the vegetation's ability to take up water, oxygen and nutrients. Osmotic and toxic effects of the salts, and oxygen deficiency due to waterlogging reduce plant growth and can even lead to plant death (Poljakoff-Mayber, 1975; Fitter and Hay, 1987; Nulsen, 1993; Larcher,

1995; Maas, 1996; Salinity Statement, 1996) As this reduction in growth affects not only commercially valuable crops and pastures, but also impacts on the remaining usually small, stands of native vegetation in the agricultural regions, secondary salinity and waterlogging represent a threat to both economic and conservation values

1.2 Other Land Degradation Processes

Soil erosion, the rate of soil removal by water and wind, which is greater than the rate of soil formation (Barrow, 1991), is linked to changes in vegetation cover as well Tall, deep-rooted plants reduce wind speed and stabilise the soil, thereby providing an effective defence against wind erosion. These plants also intercept a greater amount of rainfall than smaller crop and pasture plants, which reduces run-off and rain splash effects that contribute to soil erosion. Another contributing factor is overgrazing. Due to the almost total removal of any vegetation cover and the dislodging action of hard hoofed animals such as sheep and cattle, large tracts of topsoil are exposed to wind and water. Where these areas are located on slopes or the soil has water repellent characteristics, erosion is inevitable (Roberts, 1992; Miller, 1994).

Loss of topsoil also results in the loss of organic matter and soil nutrients, including nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca). Where such a decline in soil fertility occurs, additional nutrients in the form of fertilisers have to be supplied to ensure continued crop and pasture productivity, thus adding substantially to production costs. Over-application of fertilisers can lead to changes in soil pH, which in turn affects nutrient availability and plant growth. To enhance production even further, herbicides and pesticides are applied, often excessively. Eventually pollution of not only the soil, but also of groundwater resources and rivers is the result. Herbicides and pesticides in strong concentrations can cause the deaths of aquatic flora and fauna,

and elevated nutrient levels lead to algae blooms in affected rivers and wetlands (McTainsh and Boughton, 1993, Miller, 1994).

The term soil structure refers to the size and distribution of pore spaces between soil particles, which govern a soil's ability to hold air and water. Soil structure can be affected by the loss of organic matter, but its degradation is mostly brought about through aggressive cropping techniques and compaction under heavy traffic, with farm machinery and farm animals the most likely cause. Soils with a higher clay content are more at risk than sandy soils, as the smaller clay particles can be compacted to a higher degree than the coarser sand grains (Barrow, 1991; Roberts, 1992; McTainsh and Boughton, 1993). A degraded or compacted soil holds less air and water, and obstructs plant root penetration, all of which impact negatively on plant growth.

1.3 Remedial Actions

The most noticeable aspect of any discussion of land degradation processes and their causes is that they are strongly linked to human land uses and management practices. The obvious course of action is to change these practices, however, the willingness to do so largely depends on people's attitude to and perception of the problems, the value they give to the degraded resource and the cost of any change, both in economic and personal terms (Barrow, 1991; McTainsh and Boughton, 1993). A change in land use and management practices, that mitigates or where possible reverses the causes of land degradation, but does not result in direct and preferably immediate economic gain, is therefore often unacceptable to land owners and managers. However, environmental degradation problems cannot be successfully addressed without their co-operation. What is needed is an appropriate remedial strategy, that addresses the causes of land degradation, while being economically acceptable to land owners and

managers (Guy, Kalajzich and Nelson, 1991; Kubicki, Denby, Stevens, Haagensen and Chatfield, 1993; McTainsh and Boughton, 1993; Miller, 1994).

Research has been undertaken internationally over a number of years to try and determine the most effective ways of combating land degradation. Secondary salinisation and associated waterlogging have been the major focus of this research. Many approaches were tried, but the solutions appear to fall primarily into two categories: engineering and revegetation.

1.3.1 Engineering Strategies

Engineering solutions to waterlogging and increasing salinity are available in the short term and often very expensive, but can bring about changes quickly and help return some non-profitable areas on a farm to productive use. They concentrate on providing drainage (Barrow, 1991). Re-shaping the land to increase surface drainage is the first option. The installation of deep surface drains to intercept seepages as well as surface flow, is the second. The design of these interceptor drains, as well as horizontal sub-surface pipe drains, usually follows the natural contours of the land and redirects excess water to collection areas, such as farm dams for relatively fresh water, and evaporation pans for saline groundwater. In extreme cases the groundwater may have to be pumped to collection sites (Brady, 1990; Guy, *et al.*, 1991; Plaster, 1992; Ghassemi, *et al.*, 1996, Salinity Statement, 1996). The aim is to make some use of the intercepted water. Strategies as diverse as watering stock and crops with relatively fresh water, raising salt water fish in dams and harvesting the salt left behind in evaporation pans are being tried at present (Salinity Statement, 1996, "'Useless' land", 1997). Where drains do not follow contour lines, erosion of the actual drain surface is a

potential hazard. Such erosion can be reduced or prevented by establishing a thick, permanent grass cover to stabilise the drain walls (Kindred Landcare Group, 1994).

1.3.2 Revegetation

Revegetation has a wide range of benefits in addition to reducing recharge and controlling discharge of groundwater. When plantations of native species are established surrounding existing remnant native vegetation, they act as buffers to invading weed species, reduce edge effects, and provide additional fauna habitats (Hobbs, Saunders and Main, 1993; Sisk and Margules, 1993). When established as linkages between native vegetation remnants, they form corridors enabling fauna to move from one remnant to the other, thus reducing genetic isolation and inbreeding (Merriam and Saunders, 1993). Revegetation in rows with farm land between the rows (alley farming) provides wind shelter for stock and crops, helping to prevent wind erosion and increase stock survival (Heinjus, 1992; Haines and Burke, 1993; Kubicki, *et al.*, 1993; Nulsen, 1993; Salinity Statement, 1996; Washusen and Reid, 1996).

Revegetation research carried out in India, Israel, Pakistan, South Africa and the USA found deep-rooted, perennial trees to be successful in lowering watertables and salinity levels (Ghassemi, *et al.*, 1995). Western Australian studies undertaken in areas with more than 600 mm annual rainfall reached similar conclusions, but indicate that species used in revegetation vary in their ability to survive in saline and waterlogged conditions (Schofield, 1988; Schofield, *et al.*, 1989; Pettit and Ritson, 1991; Bari and Boyd, 1994; Farrington, Hingston and Williamson, 1995). Site specific selection of tree species is therefore the most likely strategy to maintain high survival rates during establishment, achieve protection of remnants and rehabilitate salinity and waterlogging affected farmland (Schofield, *et al.*, 1989; Heinjus, 1992; Bowman, 1993;

McFarlane, George and Farrington, 1993; Marcar and Crawford, 1996; Thorburn, 1996, p. 49). Ideally, species selected for revegetation will not only be native, be tolerant of prevailing site conditions and increase evapotranspiration, but will also provide land owners and managers with an income.

1.3.3 Oil Mallees

At the National Conference and Workshop on the Productive Use and Rehabilitation of Saline Lands (March 1996) speakers reported on successful revegetation strategies using trees and deep-rooted crops. One such tree crop, oil producing mallee-form (multi-stemmed) eucalypts [oil mallees], is being trailed by the Western Australian Department of Conservation and Land Management [CALM] in partnership with the Western Australian Oil Mallee Association in the wheatbelt areas of Canna, Kalannie, Narrogin-Wickepin, Narambeen, Woodanilling and Esperance (Arboressence Consultancy, 1996). Mallee eucalypts occur naturally on sandplain soils in New South Wales, Victoria, South Australia and Western Australia. It is believed that climatic factors also influence their distribution (Wasson, 1989), which tends to coincide with the 250 to 400 mm annual rainfall zone (Australian Nature Conservation Agency, 1993). The mallee growth habit is believed to be only partially controlled by genetics. Some *Eucalyptus* species grow predominantly as mallees, but can occasionally occur as single stemmed trees. Conversely, normally single stemmed species may occur as mallees under adverse conditions (Martin, 1989). Two of Australia's major environmental degradation problems occur naturally in mallee areas: salinisation of land and water, and wind erosion (Wasson, 1989). While *Eucalyptus* species have varying degrees of tolerance of saline and waterlogged conditions, most are prolific water users (Prendergast, 1989; Wildy, 1996a; Baxter, 1996). Therefore, some mallee

eucalypts have great potential for use in the revegetation of sandplain dominated regions affected by increasing salinity and waterlogging.

Mallees have the ability to regenerate repeatedly after disturbance, e.g. fire, from a large subterranean or semi-subterranean woody mass called a lignotuber. The lignotuber forms part of both the stems and roots. It is believed to be a storage organ for water and nutrients, and acts as a reservoir of protected subterranean meristems. These meristems are stimulated into growth and ensure the plant's survival, when the above ground parts of the plant have been damaged or destroyed (Pate and McComb, 1981; Noble, 1989). Harvesting of the above ground biomass has the same effect, and the mallees' ability to regenerate repeatedly makes them ideal crop plants.

Mallees have long been exploited commercially for the oil content of their leaves. *Eucalyptus* oil was first produced and marketed for its medicinal properties in the 1850's by Joseph Bosisto, a Melbourne pharmacist. The Australian *Eucalyptus* oil industry was at its peak in 1947, when the total annual production was 1000 tonnes, 70% of which was exported. Since then countries such as Portugal, Spain, South Africa, Brazil and China have entered the market, and Australia's share has steadily decreased. Today the total annual world demand for *Eucalyptus* oil is around 3000 tonnes, with China supplying 45% of it from its eucalypt plantations (mainly *Eucalyptus globulus*, the Tasmanian blue gum), while Australia's market share is only 3% (Markham and Noble, 1989; Boland, 1991).

Cineole, a major component of *Eucalyptus* oil, is used in medicinal, industrial and perfumery applications. The major sources of Australian produced cineole are natural stands of *E. polybractea* (blue mallee) in Victoria and New South Wales, but plantation establishment has occurred in recent years (Markham and Noble, 1989; Boland,

1991). Milthorpe, Hillan and Nicol (1994) examined crop management trials of *E. polybractea* in New South Wales and found that fertiliser application had little effect on dry biomass, while irrigation resulted in higher oil yields. They believe that selected breeding for higher leaf oil concentrations and greater vigour is possible.

Recent research carried out at Western Australia's Murdoch University has shown that cineole has potential as an industrial degreasing agent and solvent. With production of the internationally used solvent trichloroethane, a chlorofluorocarbon, having been stopped recently due to regulations to control ozone depletion, a replacement product will be required once stockpiles run out. With this in mind CALM, Murdoch University, Agriculture Western Australia and the Department of Commerce and Trade have commenced a feasibility study for the establishment of an oil mallee industry in Western Australia (Bartle, 1994; Wildy, 1996a).

1.3.4 Study Rationale and Objectives

CALM's oil mallee trials have so far concentrated on several mallee species endemic to the wheatbelt region of Western Australia, *E. kochii* subsp. *kochii*, *E. kochii* subsp. *plenissima*, *E. horistes*, *E. angustissima* subsp. *angustissima*, *E. vegrandis*, *E. gratiae* and *E. loxophleba* subsp. *lissophloia*, as well as *E. polybractea*. Wildy (1996b) compared the growth, cineole yield and carbon isotope ratios of these oil mallees in an effort to identify a species that combines water use efficiency with vigorous growth and high cineole yields. Biomass production varied greatly, and Wildy believes this to be influenced by water availability. He considers it likely that *E. loxophleba* subsp. *lissophloia* transpires the most water, as it was found to produce the greatest average biomass and has the largest leaf area. Differences in the species' genetically determined leaf cineole concentrations were confirmed, but seasonal variations within

species were also detected. No species was found that consistently performed best in all variables and across all sites examined.

Apart from the results of Wildy's study and Murdoch University's ongoing cineole research, little is known about the Western Australian mallee eucalypts included in the trials. Additional information on their productivity and potential cineole yields in relation to site environmental conditions would form the basis for site specific species selection, and an estimate of their water usage would be used to evaluate their effectiveness in revegetation projects (Wildy, 1996b). It is imperative that this knowledge is obtained to ensure plant survival and growth. Site specific species selection would result in the achievement of a revegetation project's objectives, which might include the productive use of agricultural land, and the control of rising watertables and associated soil salinity. To date species selection for the trials was based on leaf cineole content and visual observations of natural habitat conditions. CALM staff believe *E. horistes* (subgenus *Symphyomyrus*, section *Bisectaria*, series *Oleosae*) to be suitable for both revegetation addressing land degradation and cineole production. It is believed to achieve optimal growth at well-drained sites. *E. loxophleba* subsp. *lissophloia* (subgenus *Symphyomyrus*, section *Bisectaria*, series *Loxophlebae*) is popular with land managers due to its large leaves and overall size, and is thought to favour moister site conditions (W. O'Sullivan, personal communication, January 10, 1997). The differing opinions regarding the species' suitability to particular site conditions, which are based solely on anecdotal evidence, and in terms of cineole production, have resulted in a requirement for additional information on these two oil mallee species. As scientific information is scarce, it was decided to study *E. horistes* and *E. loxophleba* subsp. *lissophloia* at different locations (e.g. high landscape position for recharge and low landscape position for discharge areas) in the central wheatbelt region. The aim was to establish which species is most productive, in terms of growth and cineole

production, and transpires the most water at those differing locations. Therefore, the project objectives are as follows:

1. To compare and evaluate the growth, water use and cineole production achieved by *E. horistes* and *E. loxophleba* subsp. *lissophloia* at different positions in the landscape.
2. To determine the physical and chemical characteristics of the sites that may influence the growth, water use and cineole production of *E. horistes* and *E. loxophleba* subsp. *lissophloia*.
3. To formulate planning and management guidelines for revegetation with *E. horistes* and *E. loxophleba* subsp. *lissophloia*.

It is hypothesised that any differences in species' productivity and water use between sites can be explained in terms of the species' suitability to the physical and chemical characteristics of each site, while differences between species are generally physiological. To support or disprove this hypothesis, several variables representing different aspects of plant growth, water use and cineole production were examined, and water use and cineole yield estimates were carried out. It is hoped that a trend in regards to productivity and particular site characteristics can be established for each species.

The following chapter describes the study area, and chapter 3 examines site characteristics. The results of growth, water use and cineole production comparisons are evaluated in chapters 4, 5 and 6. Finally, the implications of the study's findings for the planning and management of revegetation projects incorporating oil mallee plantations are discussed.

Chapter 2

The Study Area

The Western Australian wheatbelt covers an area of approximately 14 million hectares (Hobbs, Saunders, Lobry de Bruyn and Main, 1993) and extends in a roughly triangular shape from Northampton in the north to Cheyne Bay in the south-west and Esperance in the south-east. The region is broadly delimited by the 600 mm rainfall isohyet in the west and the 250 mm isohyet in the east (Guy, *et al.*, 1991), and is arbitrarily divided into the northern, central and southern wheatbelt zones. The central wheatbelt covers an approximate area extending from the north-east and south-east of Perth to the Southern Cross region in the east.

2.1 Geology and Topography

The central wheatbelt is located on the Darling Plateau, which forms part of an ancient (2300 to 3000 million years old) craton, the Yilgarn Block. It consists of stable, igneous, Archaean parent rocks, mainly the felsic, relatively coarse grained granite and mafic, finer grained dolerite intrusions or dykes (Clark and Cook, 1983; McArthur, 1991). The plateau is believed to have been elevated to almost 10,000 m by tectonic forces, but was subjected to extensive weathering and erosion over long periods of geological time. This occurred mainly during the Miocene, when the region experienced a more tropical (warm and moist) climate. The plateau now has a general elevation of 300 to 450 m above sea level, and its topography is one of low relief, forming broad, shallow valleys between low rounded ridges. Weathering resistant

granite outcrops and flat-topped breakaway formations are common features (Guy, *et al.*, 1991). About 80,000 years ago the climate became more and more arid, eventually leading up to a dune-building phase 20,000 to 15,000 years ago, which added a sandplain complex to the landscape in the eastern part of the plateau (Guy, *et al.*, 1991; McArthur, 1993).

The central wheatbelt can be divided into two topographical zones on either side of the Meckering fault line. Located east of the fault line is a zone of ancient drainage, which is characterised by internal drainage systems and the presence of salt lakes. It is believed that the first production or deposition of saline material in the region occurred during the early Pleistocene (Guy, *et al.*, 1991; McArthur, 1991, 1993). The rejuvenated drainage zone west of the fault line has a more dissected lateritic profile (refer to section 2.2 below), resulting in more breakaways and exposed areas of fresh parent rock. Drainage is via creeks and rivers flowing through steeper, narrower valleys to the coast (McArthur, 1991; Lantzke, 1992).

2.2 Soils

The ancient soils of the Darling Plateau developed directly from granite and dolerite parent rock. Over time granite breaks down to form a mixture of quartz and clay, while dolerite forms clay soils. Feldspar, a major mineral component of granite, breaks down into residual clays and mobile salts (Clark and Cook, 1983). It is believed that some 25 million years ago a soil was formed, that was heavily weathered and leached in the warm, moist climate, leaving behind only materials most resistant to chemical weathering, such as iron and aluminium oxides. After the transition to a more arid climate, these materials were cemented into a dense, hard duricrust. This 'fossil soil'

eventually formed a residual sedimentary rock called laterite (Clark and Cook, 1983; Lapidus, 1990; Guy, *et al.*, 1991).

The plateau's present day soils generally consist of yellowish, leached sandy or gravelly topsoils, which cover the shallow, discontinuous remnants of the laterite duricrust. Below the duricrust reddish-brown and yellow clay subsoils can be found, that fade with depth into a greyish to white clay 'pallid zone', which can be more than 30 m deep and lies on the granitic parent rock. This is referred to as a lateritic soil profile. The landscape's characteristic broad, flat valleys usually have duplex soils, consisting of sandy, darker coloured, alluvial deposits above the clay zone. (Guy, *et al.*, 1991; Lantzke, 1992; McArthur, 1991, 1993).

2.3 Climate and Vegetation

The central wheatbelt region is part of the semi-arid (seasonally hot and dry) climatic zone, which is transitional and reflects some of the characteristics of the mediterranean zone near the south-west coast and the arid zone at the centre of the continent. The southern Australian semi-arid climate is characterised by limited average annual rainfall, generally between 250 and 500 mm, most of which is received during the winter months. Conditions tend to become drier and rainfall less frequent with increasing distance from the coast. Temperature ranges are quite high, with average monthly figures ranging from the low to mid thirties in summer to less than 10° Celsius in winter (Guy, *et al,* 1991).

The central wheatbelt forms part of the Avon Botanical District in the South-west Province of Western Australia. Its natural vegetation cover is a complex mosaic, the composition and structure of which vary considerably with geographical location.

However, wheatbelt vegetation can be divided into four general categories: a scrub-heath mixture of mallee and kwongan on sandplain soils; *Acacia-Casuarina* thickets and mallee eucalypts on lateritic gravels; open woodlands dominated by york gum (*E. loxophleba*), salmon gum (*E. salmonophloia*) and wandoo (*E. wandoo*) on loams; and halophyte communities on saline soils (Wasson, 1989; Beard, 1990; Hobbs, *et al.*, 1993; McArthur, 1993).

Kwongan is a vegetation association well known for its high degree of endemism and species richness. Species composition alters with even slight changes in environmental conditions, such as soil characteristics and aspect. Thicket, mallee and woodland vegetation changes in accordance with environmental conditions as well, particularly in the understorey, but may not be as species rich. Eucalypts belonging to subgenus *Symphyomyrtus,* section *Bisectaria* are dominant in Western Australian mallee communities, with *E. flocktoniae - E. sheathiana - E. oleosa - E. aff. loxophleba* associations an example of those occurring in the central wheatbelt and western goldfields regions. Halophyte communities are generally dominated by samphire species (Wasson, 1989; Beard, 1990; McArthur, 1993). Woodlands are more likely to occur on the western margin of the central wheatbelt, while kwongan and mallee increase towards the east, where sandplain soils are more common and rainfall is lowest for the region.

Since European settlement began the wheatbelt has become the most intensively occupied agricultural region in Western Australia. Clearing of the native vegetation has been so extensive, that today only about 7% of it remains. As a consequence the wheatbelt has the highest number of rare and endangered plant species in Australia, with 348 species listed. Only 23% of these have protected populations in reserves. At least 24 plant species are known to have become extinct, although the actual number

may be much higher. Land degradation processes now pose additional threats to the remnant native vegetation's survival in the wheatbelt (Beard, 1991; Hobbs, *et al.*, 1993).

2.4 Land Use History

Prior to European settlement in the region, the central wheatbelt was home to at least two Aboriginal groups, the Nyaginyagi and the Balardany, but the duration of their occupation, the extent of their territories and the nature of their activities are not well documented (Main, 1993). They were, however, some of the first Aborigines to come into contact with Europeans, and the depth of their knowledge about their environment impressed the early explorers and settlers (McArthur, 1991). Dale (1830) and Roe (1836) were the first European explorers to travel through the region (Main, 1993).

European settlement began in the Williams district in 1832, but was sporadic at first. The area was considered to have good grazing land, however, the presence of poison plants (*Gastrolobium* species) caused many stock losses. In 1845 sandalwood (*Santalum* species) cutting became the first successful export industry to be established in the region, marking the beginning of extensive vegetation modifications in the wheatbelt. Mallet (*E. astringens*) bark was also collected. The discovery of gold at Southern Cross (1888) and Coolgardie (1892) provided a stimulus for the production of meat and flour for the miners and resulted in an influx of settlers into the area. The completion of railway links to Albany in 1889 and to Coolgardie in 1896 provided reliable transport for both people and produce, and saw the region further opened up to settlement (McArthur, 1991; Main, 1993). The scarcity of potable water was the major factor limiting further expansion, but construction of the water pipeline to Kalgoorlie, which was completed in 1903, allowed the agricultural region to be extended even

further. Conditions were found to be ideal for cereal growing and sheep grazing (Guy, *et al.*, 1991), and the government actively encouraged settlement by providing finance for up to 50% of required 'improvements', e.g. clearing, ring-barking and cultivation. Phosphate fertiliser in the form of guano was imported from the Abrolhos Islands as early as the 1880s. By 1910 fertilisers were manufactured locally. But it was the advent of mechanisation and the availability of tractors that allowed larger scale farming to take plac om the 1920s onward. At about the same time rabbits became a serious problem, and the first warnings about salinity were summarily ignored by the authorities.

Following World War II the introduction of pesticides, the War Service Land Settlement Scheme and the availability of surplus heavy machinery further accelerated the clearing of the native vegetation and the expansion of large scale agricultural production. By 1955 salinisation of cultivated lands began to have an effect on productivity, and the Department of Agriculture conducted the first salt land survey, which was followed by a second one in 1962. In the meantime services such as the State Electricity Grid and the Water Scheme were extended into the wheatbelt, compound fertilisers allowed cultivation of previously unsuitable land, and clearing continued unabated. Smaller land holdings were increasingly amalgamated and broad acre farming became a reality. Some of the smaller rural centres began to experience declines in services and populations. A third salt land survey was carried out in 1974, a fourth in 1979, and a fifth in 1984, while land degradation (salinisation, erosion, soil compaction) continued to increase alarmingly.

In the late 1980s community awareness of the environmental problems faced in the wheatbelt led to the establishment of the Remnant Vegetation Protection Scheme, the Save the Bush Programme and a variety of tree planting schemes (Main, 1993). The

1990s have seen the commencement of a detailed aerial salinity survey and an increasing commitment by government authorities and local communities to address the land degradation problems of the wheatbelt region. As part of that commitment commercially viable revegetation options are being explored, with the establishment of oil mallee plantations considered to be the most promising alternative (Salinity Statement, 1996).

One of the locations selected for CALM's oil mallee trials is the Narrogin-Wickepin area in the central wheatbelt, where land degradation through waterlogging and secondary salinisation presents grave problems. Most of the trial plantations established here form part of the Toolibin Lake Recovery Plan and the Toolibin Alley Farming Trial (TAFT). Lake Toolibin is of very high conservation value as it contains the only remaining lake-bed stands of swamp sheoak (*Casuarina obesa*) and paperbark (*Melaleuca strobophylla*) in south-western Australia. It is an important breeding habitat for waterbirds and was recognised as being of international importance under the 1990 Ramsar Convention. However, it is threatened by increasing salinity due to rising, saline watertables throughout its catchment (Baxter, 1996). Lake Taarblin, a neighbouring lake, has already been lost to salt.

Due to the importance of successful, large-scale revegetation of the Toolibin catchment, it was decided to study the performance of *E. horistes* and *E. loxophleba* subsp. *lissophloia* in the Narrogin-Wickepin area. It is hoped that the results of this study will help facilitate an acceleration of the revegetation process.

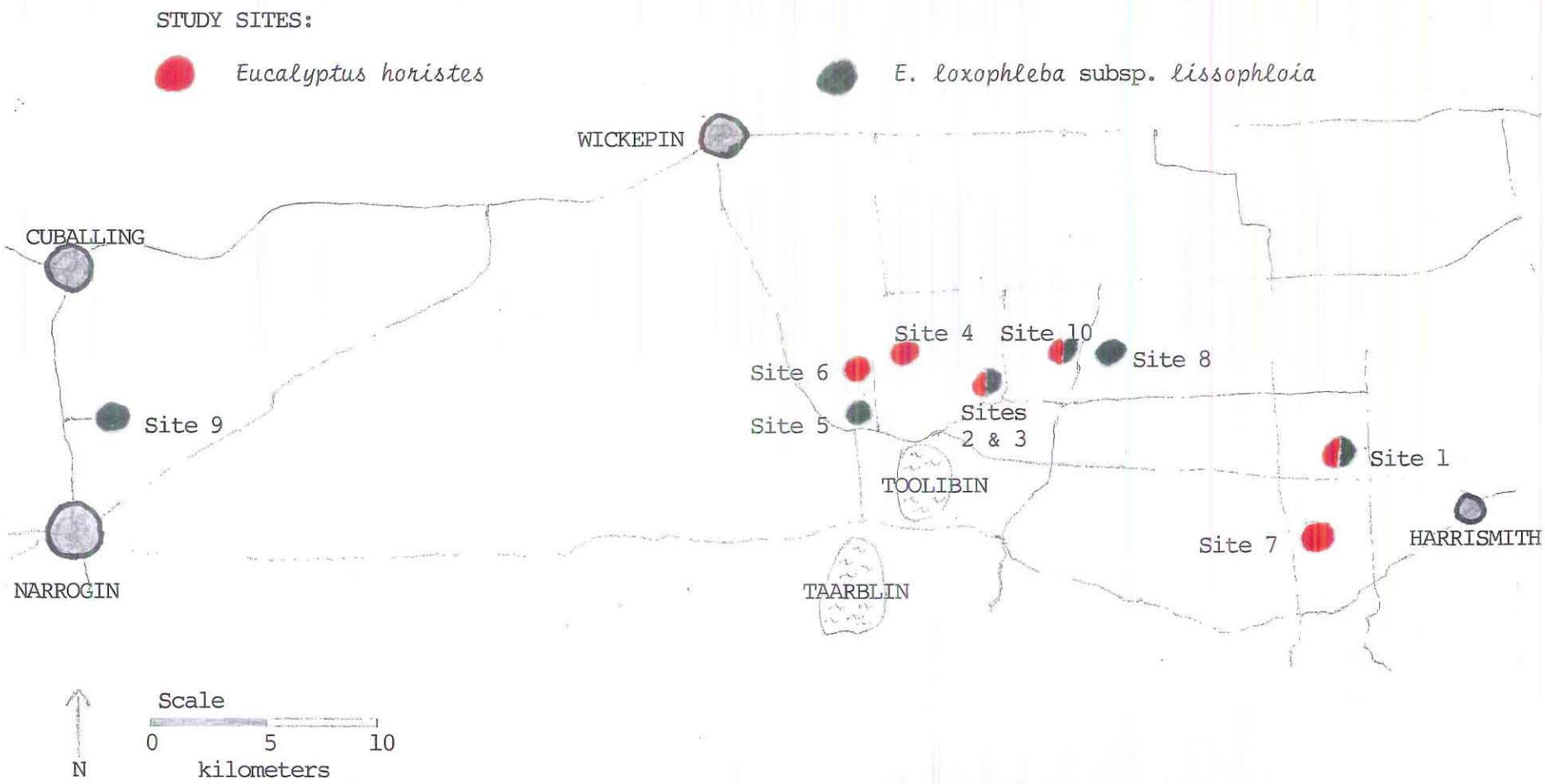
Chapter 3

Environmental Characteristics of Study Sites

3.1 Introduction

The primary land use in the Narrogin-Wickepin district, which experiences an average annual rainfall of around 500 mm (N. Holcz, Bureau of Meteorology, facsimile communication, October 17, 1997), is a combination of sheep grazing and cereal (wheat) production, but remnant vegetation areas of high conservation value, e.g. Dryandra (an important fauna reserve) and Lake Toolibin (refer Chapter 2), are also present (McArthur, 1991). Oil mallee trial plantations were established between 1993 and 1996 on 19 privately owned farming properties. Sites selected for the study were drawn from this somewhat limited pool, and are located within the Lake Toolibin catchment north-east of Narrogin. The exception is Site 9, which is located just north of the Narrogin township (refer Figure 1). Plantations were established in alley design, with alleys consisting of either single or multiple rows and distances between alleys varying from 4 m to approximately 60 m. Land between the alleys is used for either pasture or wheat production. Several of the sites are mixed plantations, where two or more oil mallee species are being trialed. *E. horistes* was studied at Sites 2, 4, 6, and 7, and *E. loxophleba* subsp. *lissophloia* at Sites 3, 5, 8, and 9. Both species could be studied at Sites 1 and 10, resulting in a total of 6 study sites per species (refer Figure 1). All *E. horistes* plantations included in the study were established in 1993, as were *E. loxophleba* subsp. *lissophloia* plantations at Sites 1, 3, 8 and . Due to the small

Figure 1 Sketch of the Narrogin - Wickepin Area



number of *E. loxophleba* subsp. *lissophloia* plantations of that age, a further two sites (Sites 5 and 9), drawn from plantations established in 1995, were included in the study.

Study sites were selected to represent a range of environmental conditions, with emphasis placed on depth to groundwater as an indicator of each site's function in the hydrological cycle (e.g. recharge or discharge site). As the initial site inspections were carried out in summer (February 1997) and not all sites were equipped with piezometers to monitor and sample groundwater, selection was based largely on information obtained from land owners and CALM staff. To confirm that the assumptions made were correct and ensure the validity of conclusions to be drawn from the study, it was necessary to identify the physical and chemical characteristics of the study sites by testing and monitoring a number of soil and groundwater parameters: depth of watertables and water quality (pH and electrical conductivity), and soil composition, structure, nutrient status, pH and electrical conductivity (as an indicator of soil salinity levels).

3.2 Methods

3.2.1 Groundwater monitoring and testing

To establish and monitor the depth to groundwater on all sites, bores where drilled and piezometers installed at sites where they were not already in place. Bores were sunk to a depth of 5.2 m where possible. At three sites impenetrable soil layers were encountered at shallower depths while drilling, which resulted in piezometers being installed to a depth of 2.7 m at Site 1, 2.8 m at Site 4 and 3.0 m at Site 8. This work was completed by early April 1997. Where available, groundwater levels were recorded and water samples collected in March/April, July and September 1997. pH

and electrical conductivity, an indicator of groundwater salinity levels (Brady, 1990; Plaster, 1992; McBride, 1994; Rowell, 1994) were measured in the laboratory using pH and conductivity meters.

3.2.2 Soil profiling and classification

In May 1997 one soil pit was excavated by backhoe at each site to allow examination of the soil profile *in situ*, as well as enabling the collection of samples from different horizons within the soil profile. Pits were between 1.3 and 1.9 m in depth. Samples approximately 500 g in weight were collected from each identifiable soil horizon, packed in resealable, clear plastic bags after expelling the air, labelled and stored in an esky. Photographs of the exposed soil profiles were taken, and visually observed soil characteristics were recorded. Additional samples of the top two soil horizons were collected at each site in July and September. These samples were tested for pH and conductivity only.

Approximately 200 g of each soil sample were oven-dried for 24 hours at 105°C. The samples were then crushed by mortar and pestle if necessary, before being passed through a 2 mm sieve. Obvious pieces of organic matter, such as twigs, leaves and roots, were removed (Rowell, 1994). The resultant fine earth fraction of each subsample was sealed in clear, plastic bags after expelling the air, labelled and sent to CALM's soil laboratory at Como for soil particle size analysis. A-horizon samples were also tested for total nitrogen and total phosphorus levels by CALM staff.

A small, untreated fraction of each sample was retained and viewed under a compound microscope to obtain information on mineral composition, and its texture examined under both dry and moist conditions. Soil colour was determined using a

Munsell Colour Chart. This information, the soil particle size analyses results and soil pH measurements were used to classify and name the soils for each site (Brady, 1990; McArthur, 1991; Lantzke, 1992).

3.2.3 Soil testing

A second subsample of approximately 200 g from each soil sample was oven-dried for 24 hours at 30°C ("air dried"). These samples were then also crushed by mortar and pestle if necessary, before being passed through a 2 mm sieve. Obvious pieces of organic matter, such as twigs, leaves and roots, were removed (Rowell, 1994).

pH:

To obtain a measure of the soil's pH, 10 g from each sample were mixed with 25 ml of deionised water by shaking the solution for approximately 15 minutes. The pH of the mixture was then measured using a pH meter (Rowell, 1994).

Electrical conductivity:

A further 20 g of each air dried, sieved subsample were mixed with 100 ml of deionised water to obtain a 1:5, Soil:Water suspension (Brady, 1990; Rowell, 1994), which was mixed by shaking for 10 minutes. The solution was then left to settle for 15 minutes, after which the electrical conductivity was measured with a conductivity meter.

Organic matter content:

Soil samples collected in May from the top two horizons at each site were also examined for organic matter content. After oven-drying for 24 hours at 105°C and passed through a 2 mm sieve, approximately 10 g of soil where put into a crucible of known weight, and the total weight recorded. The crucibles were then placed in a

laboratory furnace overnight and heated to 500°C. They were cooled in a desiccator and re-weighed. Organic matter content was calculated as the percentage of weight lost on ignition (Rowell, 1994).

3.3 Results

Table 1 summarises the results of analyses and measurements undertaken to achieve an overview of the physical and chemical characteristics of the sites. Over the study period several values were obtained for groundwater depth, and groundwater and soil pH and conductivity. The average value for each of these parameters is shown.

Sites 1, 2, 3 and 5 were found to have the shallowest watertables, with depths ranging from 2.48 m at Site 1 to 0.69 m at Site 5. Groundwater pH values ranged from 6.87 at Site 2 to 8.1 at Sites 1 and 5. Groundwater conductivity varied greatly. Sites 2 and 3 were found to have the highest conductivities of 24.87 and 27.43 mS/cm respectively. Site 6 recorded the lowest conductivity of 1.31 mS/cm. At Sites 4, 7, 8, 9 and 10 the watertable remained below the depths of the piezometers installed, and no water samples could be collected for pH and conductivity testing.

Soil texture in the B horizons at Sites 1, 2, 3, 4 and 7 was dominated by clay, with grey mottles indicating prolonged waterlogged and anaerobic conditions at Sites 2 and 3. Sites 5, 6, 8, 9 and 10 had sandy soils. Ironstone or lateritic gravel was present in the soil profiles at Sites 4, 6, 8, 9 and 10. Hardpans were encountered during drilling for piezometer installation at Sites 1, 4, 8 and 10. They were located at depths ranging from 2.7 m at Site 1 to 4.0 m at Site 10.

Table 1 - Physical and Chemical Characteristics of Sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Ave. Groundwater Depth	2.48 m	1.10 m	0.92 m	> 2.80 m	0.69 m	> 5.20 m	> 5.20 m	> 3.00 m	> 5.20 m	> 5.20 m
Ave. Groundwater E.C.	4.76 mS/cm	24.87 mS/cm	27.43 mS/cm	N/A	2.97 mS/cm	1.31 mS/cm	N/A	N/A	N/A	N/A
Ave. Groundwater pH	8.1	6.87	7.59	N/A	8.1	7.4	N/A	N/A	N/A	N/A
Soil Type	Shallow sandy surfaced valley soil	Red-brown sandy clay with grey mottling	Red-brown sandy clay with grey mottling	Shallow gravelly duplex soil over gravelly sandy loam	Deep reddish-yellow sandy valley soil	Yellow gradational gravelly sand	Duplex soil: Loamy sand over pallid clay	Pale sand over gravel	Brownish yellow gravelly sandy loam	Pale yellow gravelly loamy sand
Hardpan / Duricrust	Strong hardpan at 2.7 m depth			Strong hardpan at 2.8 m depth				Probable duricrust at 3.0 m depth		Medium hardpan at 4.0 m depth
A Horizon Organic Matter Content	1.60%	1.70%	2.99%	2.87%	3.00%	7.30%	6.49%	0.60%	4.65%	1.59%
B_1 Horizon Organic Matter Content	2.49%	2.20%	2.70%	4.90%	0.90%	4.15%	1.90%	0.20%	1.70%	1.75%
A Horizon Total N	0.078%	0.078%	0.010%	0.131%	0.131%	0.194%	0.141%	0.011%	0.181%	0.020%
A Horizon Total P	0.024%	0.008%	0.002%	0.015%	0.021%	0.028%	0.002%	0.005%	0.023	0.002%
A Horizon Ave. E.C.	0.077 mS/cm	0.083 mS/cm	0.147 mS/cm	0.050 mS/cm	0.233 mS/cm	0.030 mS/cm	0.200 mS/cm	0.013 mS/cm	0.050 mS/cm	0.023 mS/cm
B_1 Horizon Ave. E.C.	0.200 mS/cm	0.237 mS/cm	0.330 mS/cm	0.053 mS/cm	0.217 mS/cm	0.020 mS/cm	0.140 mS/cm	0.010 mS/cm	0.023 mS/cm	0.040 mS/cm
B_2 Horizon E.C.	0.600 mS/cm	0.890 mS/cm	0.650 mS/cm	0.060 mS/cm	0.050 mS/cm			0.010 mS/cm	0.020 mS/cm	
B_3 Horizon E.C.									0.030 mS/cm	
C_1 Horizon E.C.	0.700 mS/cm		0.750 mS/cm	0.060 mS/cm	0.060 mS/cm	0.010 mS/cm	0.120 mS/cm	0.010 mS/cm	0.030 mS/cm	0.110 mS/cm
C_2 Horizon E.C.						0.010 mS/cm				
A Horizon Average pH	6.11	7.15	6.99	6.45	6.51	6.42	6.13	6.91	6.14	6.59
B_1 Horizon Average pH	7.82	8.08	7.64	6.86	7.35	6.07	6.53	6.91	6.30	6.81
B_2 Horizon pH	9.02	7.35	8.22	6.99	7.10			7.00	6.90	
B_3 Horizon pH									6.88	
C_1 Horizon pH	8.61		8.01	7.21	7.55	7.08	7.20	6.70	6.91	7.29
C_2 Horizon pH						7.09				
Oil Mallee Species examined	*E. horistes, E. loxophleba* ssp. *lissophloia*	*E. horistes*	*E. loxophleba* subsp. *lissophloia*	*E. horistes*	*E. loxophleba* subsp. *lissophloia*	*E. horistes*	*E. horistes*	*E. loxophleba* subsp. *lissophloia*	*E. loxophleba* subsp. *lissophloia*	*E. horistes, E. loxophleba* ssp. *lissophloia*

Organic matter content of the A horizons at Sites 1, 2, 8 and 10 was quite low, the highest values being found in samples from Sites 6 and 7. B_1 horizon organic matter content was low to medium at all sites. A horizon total nitrogen levels were found to be low at Sites 1, 2, 3, 8 and 10, and total phosphorus levels were deficient at Sites 2, 3, 7, 8 and 10 (Charman and Murphy, 1991).

Soil conductivity generally increased markedly with increasing depth, except at Sites 5 and 7, where it decreased. Sites 4, 6, 8 and 9 returned the lowest conductivity values. Soil pH varied between sites, but also increased with depth. Site 1 displayed the greatest pH range in the soil profile, with pH 6.11 in the A horizon and pH 9.02 in the B_2 horizon. Site 8 on the other hand showed the lowest pH range (C_1: 6.7, B_2: 7.0).

3.4 Discussion

Examination of the results summarised in Table 1 shows that study sites can be grouped according to watertable depths. Sites 1 to 5 have watertables at depths of less than 3 m, while Sites 6 to 10 have depths well in excess of 3 m. Drilling for the placement of the piezometer had to be abandoned at a depth of 2.8 m due to the presence of an impenetrable soil layer. As Site 4 is located on the lower slope of a gentle rise and both the land owner and local CALM staff reported it to be seasonally waterlogged, it is assumed that a perched watertable tends to develop above this impenetrable layer. The presence of some ironstone or laterite gravel suggests that this layer is a duricrust remnant (refer Chapter 2). It is possible that the perched watertable did not develop during the study period, as rainfall in the Narrogin-Wickepin area was well below average for the 12 months from October 1996 to September 1997 (see Figure 2).

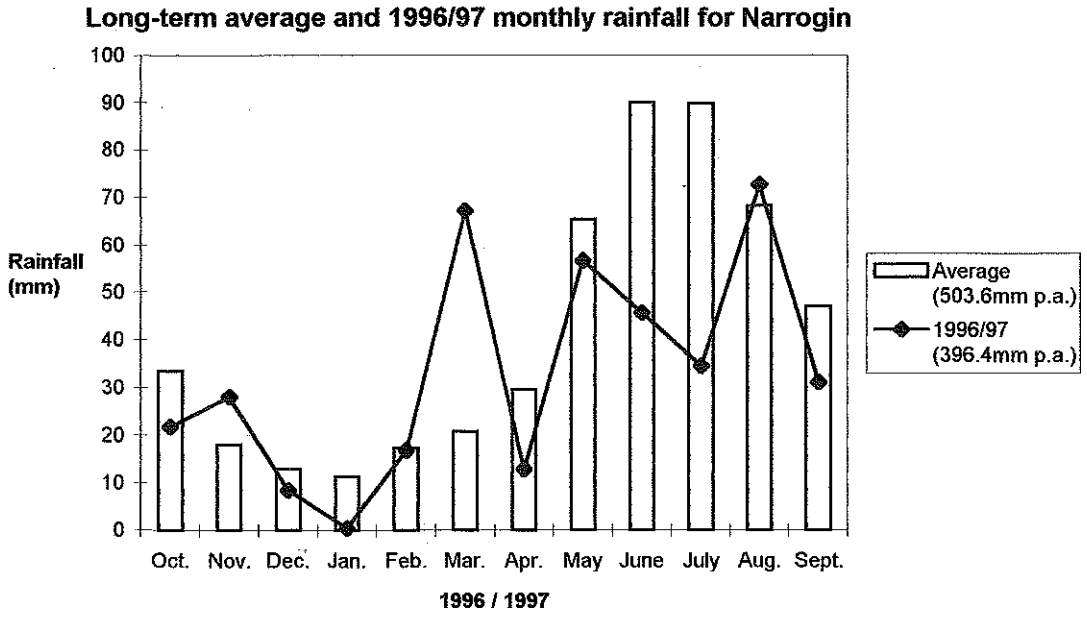


Figure 2 A comparison of the long-term average monthly rainfall for the Narrogin region and the monthly rainfall for the 12 months from October 1996 to September 1997.

A groundwater sample was only obtained once at Site 6, following a rainfall event in April. Therefore, the average groundwater depth for that site was assumed to be greater than the depth of the piezometer (> 5.2 m). Sites 7 to 10 were found to have watertables at depths in excess of 5.2 m, despite an impenetrable soil layer encountered during drilling for piezometer placement at a depth of 3.0 m at Site 8. The site is located at the top of a rise and has a soil profile consisting of pale sand over lateritic gravel. The impenetrable layer is believed to be a lateritic duricrust, but as no evidence of a breakaway formation was observed on the slopes of the rise, it is assumed to be discontinuous (refer Chapter 2). The low soil organic matter content and nitrogen level, phosphorus deficiency, very low electrical conductivity and pale colouration of the sand indicate well-drained, heavily leached site conditions (Brady, 1990; Plaster, 1992; McTainsh and Boughton, 1993). Therefore, any assumption regarding the development of a perched watertable above the duricrust can not be supported at this site.

The electrical conductivity [EC] of groundwater samples taken from shallow watertables at Sites 2 and 3 is quite high. Soil EC measurements for these two sites are also comparatively high, particularly in the B_2 and C_1 horizons. Grey mottling of the subsoil indicates prolonged periods of waterlogging resulting in anaerobic soil conditions (McBride, 1994). Groundwater pH at both sites was found to be near neutral, however, soil pH values show evidence of increasing alkalinity, which points to a potential development of saline-sodic conditions (Brady, 1990). However, for the purposes of this study, both sites will be regarded as saline. Site 1 is reported to be seasonally waterlogged. It has a lower groundwater EC than Sites 2 and 3, but the soil EC is similar. This combined with a groundwater pH of 8.1 and a soil pH greater than 8.5 in the B_2 and C_1 horizons suggest that this site is becoming saline-sodic (Brady, 1990). The EC of the groundwater at Site 5 is lower than at Site 1, and soil EC values are comparatively low in the B_2 and C_1 horizons. The higher EC values of the top two horizons may be due to fertiliser applications, which is also indicated by acceptable levels of nitrogen and phosphorus (Charman and Murphy, 1991). The groundwater pH of 8.1, however, is fairly alkaline, and the soil profile shows evidence of pH increases occurring. This points to a potential for the site to become saline-sodic in the future, but as the groundwater EC is only just above the maximum limit for human consumption (Lloyd, 1997), it should not be classified as such at this point in time. Site 4 has low soil EC values and a near neutral soil pH, indicating that any groundwater found at this site is likely to be fairly fresh. For the purposes of this study Sites 4 and 5 will be classed as waterlogged only.

Sites 6 to 10 show no evidence of encroaching salinity or sodicity. Soil EC values are generally low for all sites, with Site 7 and to a lesser extent Site 10 having indications of

fertiliser applications. Both sites are used to grow sheep pasture between the oil mallee alleys.

Shallow watertables and associated salinity and sodicity of the groundwater and soils indicate low landscape positions. Well-drained sites over deeper watertables not affected by salinity and sodicity are likely to be located at higher points in the landscape. Visual observations of site location and slope tend to confirm this assessment.

Summary: Study sites can be grouped according to groundwater depth and quality. **Sites 1 to 5** have shallow watertables, with Site 1 seasonally waterlogged and becoming saline-sodic, Sites 2 and 3 being waterlogged and saline, Site 4 seasonally waterlogged, and Site 5 waterlogged and in danger of becoming saline-sodic. These sites can be considered as having low landscape positions. **Sites 6 to 10** have deep watertables and are not affected by either salinity or sodicity. These sites are positioned higher in the landscape. Detailed soil profile descriptions of all the sites are included in Appendix 1.

Chapter 4

Evaluation of Growth Parameters

4.1 Introduction

Plants occurring naturally in environments with particular physical and chemical characteristics are believed to have evolved adaptations, that allow them to survive and even take advantage of the prevailing conditions (James and Hopper, 1981). However, there are a large number of factors that influence plant growth, and we still know too little about many of the processes governing it (Larcher, 1995). It is likely that, even under the best conditions possible, sooner or later some environmental factor or factors will become limiting to a plant's growth (Fitter and Hay, 1987). The effects of environmental conditions such as waterlogging and increasing soil salinity have been studied extensively in a variety of settings. Growth reduction was found to be the most immediate plant response to both waterlogging and soil salinity (Poljakoff-Mayber and Gale, 1975; Winter, Osmond and Pate, 1981; Munns and Termaat, 1986; Hale and Orcutt, 1987; Pettit and Ritson, 1988; Rendig and Taylor, 1989; Stewart, 1991; Larcher, 1995).

Rises in watertables are generally associated with increasing soil salinity, though this is not always the case. Over-saturation of the soil root zone poses significant problems for plants, regardless of salinity levels. Under normal conditions sufficient oxygen diffuses into the soil from the atmosphere. Waterlogging prevents this and thereby affects the balance between the amounts of air and water in the soil, which is then no

longer optimal for plant growth (Ghassemi, *et al.*, 1995). Prolonged periods of waterlogging induced oxygen deficiency in the soil lead to anaerobic conditions, which result in reducing chemical reactions, that free ions such as iron (Fe^{2+}), aluminium (Al^{3+}), manganese (Mn^{2+}), sulphides and various acidic compounds in often toxic proportions (Hale and Orcutt, 1987; Rendig and Taylor, 1989; McBride, 1994; Larcher, 1995). Growth impairment followed firstly by root death and then by the death of the plant is the consequence, sometimes occurring within days or weeks. Some plants, such as herbaceous helophytes (swamp plants) and some tree species, e.g. willows and certain eucalypts, are tolerant of seasonal inundation. However, they generally occur naturally at river banks or on flood plains, where groundwater tables are permanently close to the soil surface and usually fresh. Plant species subjected to rising groundwater tables originating from depths of 30 m or more are not normally adapted to waterlogging, and are therefore unlikely to survive it (Hale and Orcutt, 1987; Rendig and Taylor, 1989; Larcher, 1995).

Groundwater and soil salinity has osmotic effects in plant cells. Plants have to expend more energy to extract water from salt affected soil, and toxic effects due to high ion levels, particularly of sodium (Na) and chloride (Cl), can also occur. Both can lead to a reduction in plant growth, even in the short term. Over time salt ions build up in the leaf tissue. The long-term effect of high salt levels depends on the plant's ability to compartmentalise the salt ions and avoiding toxic effects, or perhaps even make use of the ions as an aid in obtaining water through osmosis. Halophytes and other more salt tolerant plants are able to do this. However, plants unable to utilise the stored salts will experience a reduction in growth (Poljakoff-Mayber, 1975; Munns and Termaat, 1986; Fitter and Hay, 1987; Nulsen, 1993; Larcher, 1995; Maas, 1996; Salinity Statement, 1996). Therefore, successful revegetation of waterlogged and salt affected land with oil mallees should involve only species that have some level of adaptation to

the environmental conditions prevalent at the revegetation site, and are proven to be productive in terms of growth.

The aim of the study is to compare and evaluate the growth of *E. horistes* and *E. loxophleba* subsp. *lissophloia* at the different sites. It is hoped that a growth performance trend in relation to site environmental characteristics can be established. To this end several parameters indicative of growth were examined: crown volume (as a measure of size of the above-ground parts of a plant), dry biomass and fresh weight (as measures of the mass of organic material and the water content of a plant) and lignotuber diameter (as a silvicultural assessment tool of a plant's regenerative ability). Higher values of these parameters are associated with better growth in response to favourable environmental conditions (Jones, Robertson, Forbes and Hollier, 1990), and are also considered to be indicators of water use and cineole production (refer Chapters 5 and 6). Examination of these parameters provides a general basis for site specific species selection.

4.2 Methods

A total of 36 experimental plots (3 plots per site and species), consisting of 10 plants each, were selected at random and marked (see Figures 3 and 4 for examples). For each plot the average crown volume was calculated as hd_1d_2, where h is the plant height or distance between the highest and lowest green leaf, and d is the diameter measured at the plant's widest point both along (d_1) and across (d_2) the row. Crown volume is considered to be an indicator of a plant's vigour and health (Pettit and Ritson, 1991), that varies with the number of leaves and branches. It is used silviculturally to calculate estimates of transpiration and cineole yield.

One plant with a height and diameter most closely resembling the height and diameter averages for the plot was identified, and all leaves and stems with a diameter of 5 mm or less were removed and weighed (the fresh weight). These plant parts were chosen, as they represent the plant matter, that can be harvested mechanically and used for oil distillation (Milthorpe, *et al.*, 1994). A sub-sample was collected, placed in a labelled plastic bag, the air expelled and the bag sealed tightly. The sample bags were cooled and stored in an esky and taken to Perth, where they were weighed, dried for 48 hours at 70°C and reweighed (Wildy, 1996b). Dry leaf and stem biomass was calculated as the percentage of weight retained after drying.

All plants in the experimental plots were cut to a height of 10 cm to simulate a mechanical harvest (Milthorpe, *et al.*, 1994) and allow monitoring of coppice regrowth (Wildy, 1996b). Crown volume and dry biomass were calculated for the regrowth using the above methodology after a field trip in September.

Plant height and diameter measurements for all plants in experimental plots were averaged to obtain a mean plant size for each site. At the time of soil pit excavation, a plant with a height and diameter most closely resembling the site height and diameter averages for the species was identified and its lignotuber and root system partially unearthed. Lignotuber diameter was measured at the widest part, and a root subsample was taken for dry root biomass determination. The sub-sample was placed in a labelled plastic bag, the air expelled and the bag sealed tightly. The sample bags were cooled and stored in an esky and taken to Perth, where they were weighed, dried for 48 hours at 70°C and reweighed (Wildy, 1996b). Dry root biomass was calculated as the percentage of weight retained after drying.

Figure 3 Site 6: *E. horistes* prior to harvesting (Plot B)

Figure 4 Site 8: *E. loxophleba* subsp. *lissophloia* prior to harvesting (Plot B)

Data obtained from the 3 experimental plots per site and species were used to calculate a site average and standard error for each growth parameter. Analysis of variance (ANOVA) of mean plot values was carried out at the 95% confidence level to determine the significance of any differences between sites and between species. In addition Tukey's and Scheffe's post-hoc tests were applied to achieve an understanding of any similarities between sites of the same species. Site averages for each parameter and species were also ranked from highest to lowest to identify the sites on which each species tended to achieve the highest and lowest values. The hypothesis tested implied that no significant differences would be detected.

4.3 Results

Table 2 lists analysis of variance (ANOVA) results. Tables 3, 4 and 5 rank the sites from highest to lowest value for all pre-harvest growth parameters.

Differences in pre-harvest crown volume were found to be significant between sites for both species, however, differences between species were not significant. Figure 5 illustrates this, and shows that the highest values for crown volume occurred at Sites 4, 7 and 10 for *E. horistes*, and at Sites 8 and 10 for *E. loxophleba* subsp. *lissophloia*. Rankings listed in Table 3 confirm this. The highest similarities (*a*) were found to be between Sites 4 and 7 for *E. horistes*, and at Sites 8 and 10 for *E. loxophleba* subsp. *lissophloia*. The crown volume for *E. horistes* at Site 10 was the highest of all the *E. horistes* sites and was found to be quite dissimilar from the others. The lowest crown volume occurred at Site 1 for *E. horistes* and at Site 9 for *E. loxophleba* subsp. *lissophloia*. Sites 8 and 9 were the most dissimilar *E. loxophleba* subsp. *lissophloia* sites.

Table 2 Analysis of Variance Results

Parameter	Differences between species p value	Differences between sites (E. horistes) p value	Differences between sites (E. loxophleba lissophloia) p value
Pre-harvest crown volume	0.665	0.000046	0.000088
Pre-harvest dry leaf and stem biomass	0.019	0.014	0.008
Pre-harvest fresh weight	0.001	0.079	0.000351
Root biomass	0.433	N/A	N/A
Lignotuber diameter	0.226	N/A	N/A
Regrowth crown volume	0.585	0.011	0.0000067
Regrowth dry leaf and stem biomass	0.610	0.000035	0.000104

Differences in pre-harvest dry leaf and stem biomass were found to be significant between sites for both species as well as between the species, however, this is not as clear in Figure 6. Table 3 shows that Sites 1, 4 and 10 have the highest biomass values for *E. horistes*, while Site 7 has the lowest. Site 10 was also quite dissimilar from the others, while Sites 1 and 4 were the most similar (a). For *E. loxophleba* subsp. *lissophloia* Sites 1 and 3 returned the highest biomass values and Site 5 the lowest. Sites 1 and 3 were also the most similar (a), and Sites 1 and 5 the most dissimilar.

Figure 5 AVERAGE PRE-HARVEST CROWN VOLUME

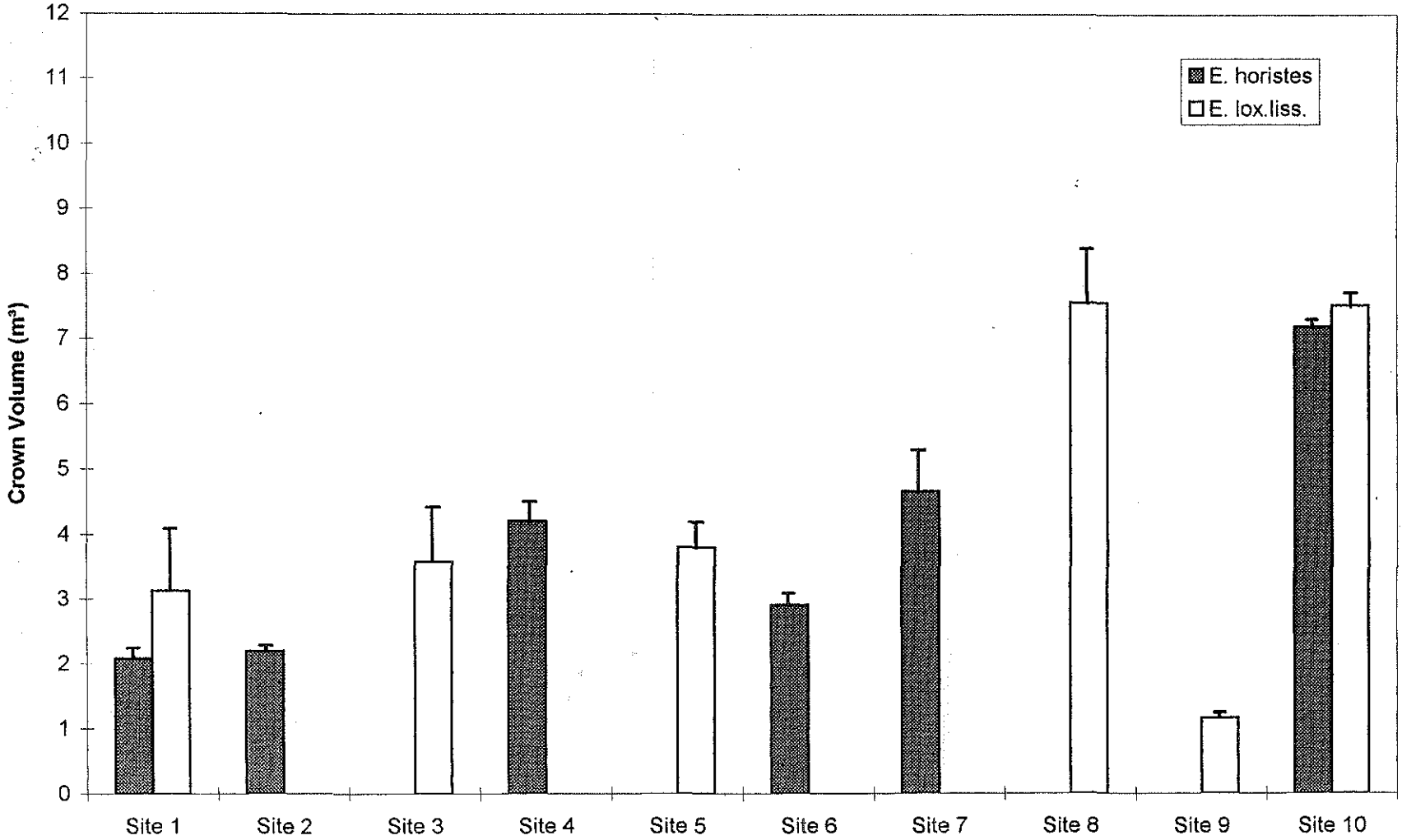


Figure 6 AVERAGE DRY LEAF AND STEM BIOMASS

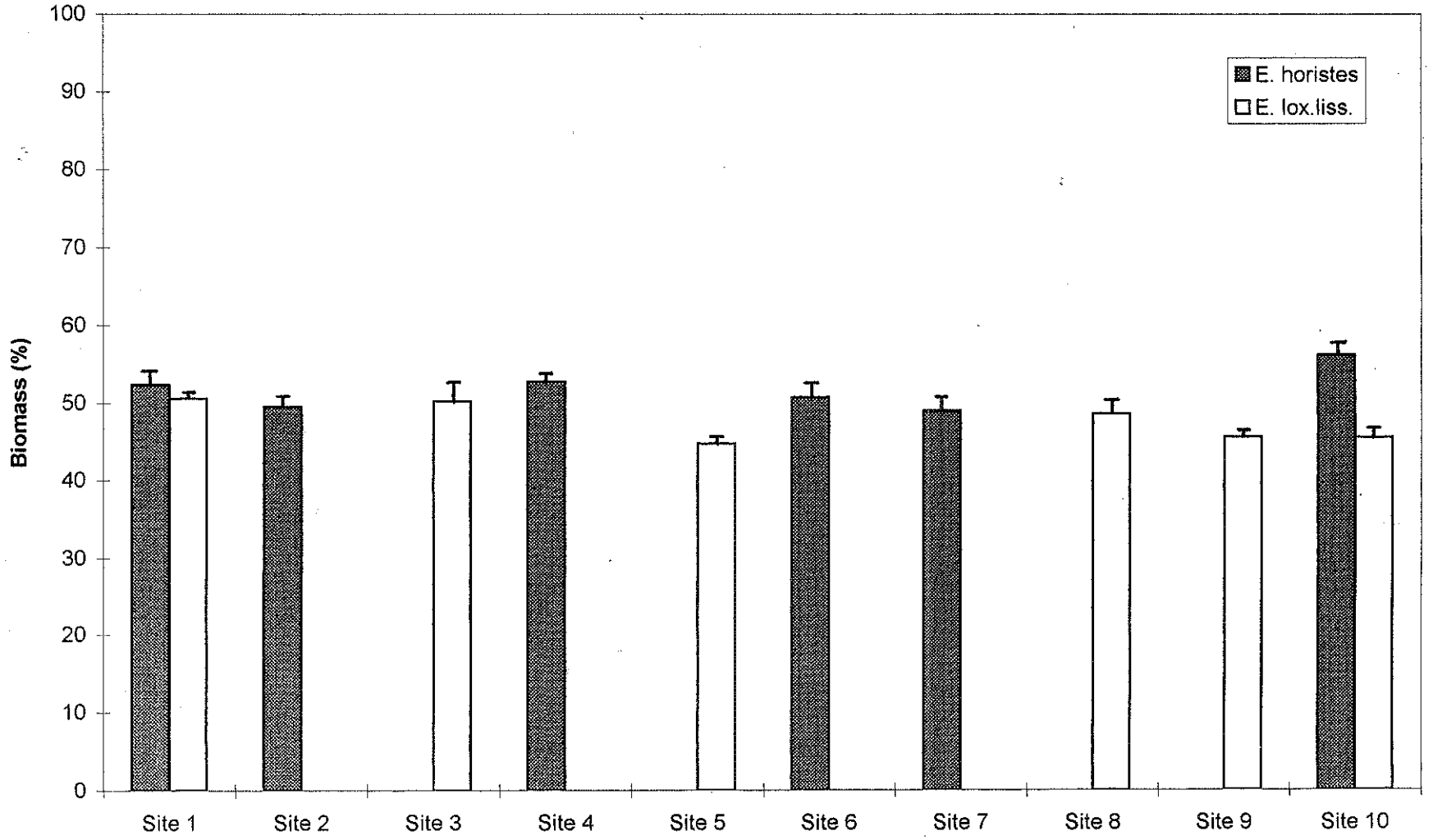


Table 3 Site rankings and similarities in pre-harvest crown volume, dry leaf and stem biomass and fresh weight.

E. horistes

Site	Pre-harvest crown volume (m^3)		Site	Pre-harvest LS biomass (%)		Site	Pre-harvest fresh weight (kg)	
10	7.1857		10	56.19		10	5.03	*d*
7	4.6568	*a*	4	52.77	*a*	6	4.43	*d*
4	4.2127	*a*	1	52.36	*a*	7	3.70	*ab*
6	2.9147	*bc*	6	50.72	*c*	2	3.43	*a*
2	2.1928	*b*	2	49.56	*bc*	1	3.30	*abc*
1	2.0806	*c*	7	49.02	*b*	4	2.80	*c*
	$p < 0.000$			$p = 0.014$			$p = 0.079$	

E. loxophleba* ssp. *lissophloia

Site	Pre-harvest crown volume (m^3)		Site	Pre-harvest LS biomass (%)		Site	Pre-harvest fresh weight (kg)	
8	7.5548	*a*	1	50.59	*a*	8	4.57	
10	7.5127	*a*	3	50.27	*ad*	5	3.00	*b*
5	3.8079	*b*	8	48.64	*d*	3	2.67	*bc*
3	3.5836	*cd*	9	45.59	*bc*	1	1.67	*ac*
1	3.1339	*bc*	10	45.58	*bc*	10	1.40	*ad*
9	1.1591	*d*	5	44.79	*c*	9	0.40	*d*
	$p < 0.000$			$p = 0.008$			$p < 0.000$	

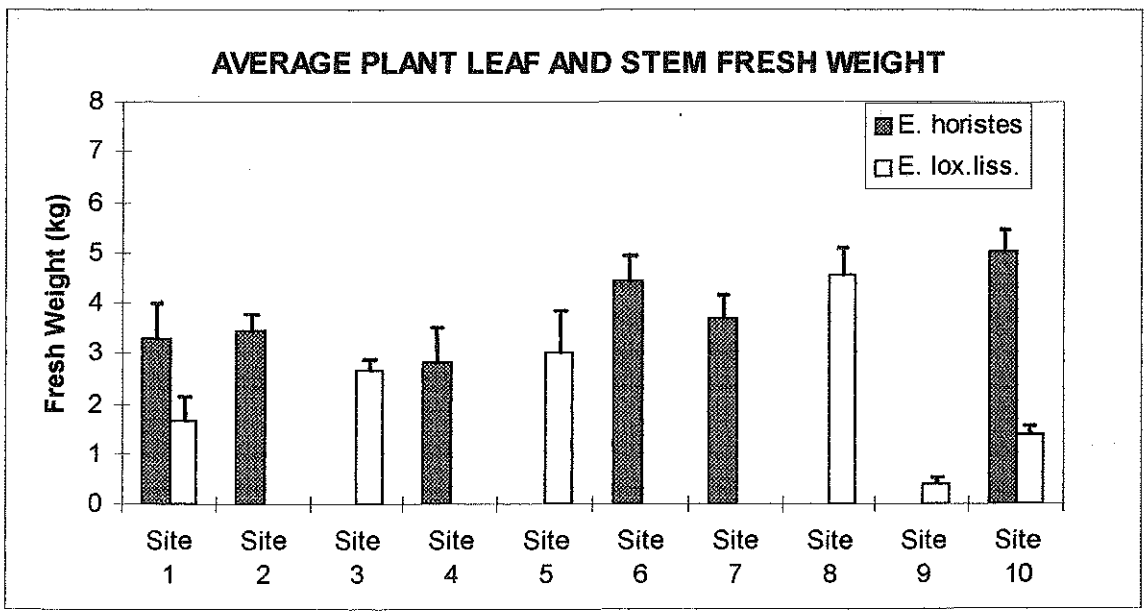


Figure 7 Average plant leaf and stem fresh weight (kg) per species and study site.

Differences in pre-harvest fresh weight were found to be significant between species and between *E. loxophleba* subsp. *lissophloia* sites. However, differences between *E. horistes* sites were not significant. Again, this is not immediately obvious in Figure 7. Rankings showed Sites 6 and 10 to have the highest fresh weight for *E. horistes*, although they were not very similar (*d*). The most similar (*a*) *E. horistes* sites were Sites 1, 2 and 7. The lowest *E. horistes* fresh weight was found on Site 4. *E. loxophleba* subsp. *lissophloia* had the highest fresh weight on Sites 5 and 8, and the lowest on Site 9, while Sites 1 and 10 were the most similar (*a*), and Site 8 was found to be quite dissimilar from the other sites.

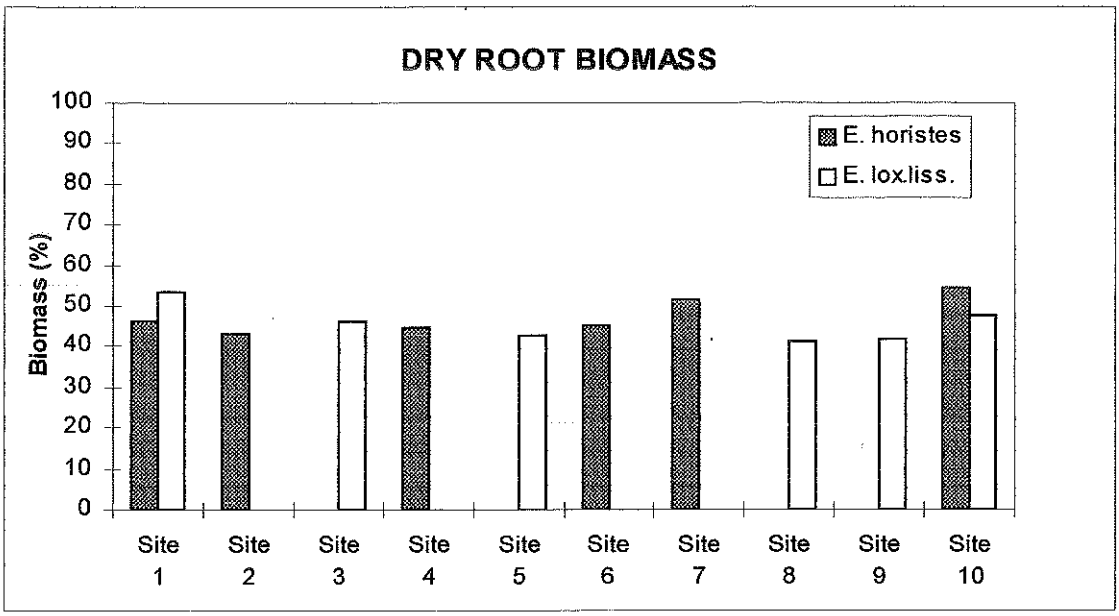


Figure 8 Percentage of dry root biomass per species and study site.

Even though Figures 8 and 9 show some variation in dry root biomass and lignotuber diameter for both species, any differences between species were not significant. Ranking showed that root biomass values were highest at Sites 7 and 10 for *E. horistes* and at Sites 1 and 10 for *E. loxophleba* subsp. *lissophloia*. *E. horistes* lignotuber diameters were largest at Sites 7 and 10 as well, while Sites 8 and 10 had the largest *E. loxophleba* subsp. *lissophloia* lignotuber diameters. Site 2 showed the

lowest values for both parameters for *E. horistes*, while *E. loxophleba* subsp. *lissophloia* root biomass was lowest at Site 8, and lignotuber diameter was smallest at Site 9.

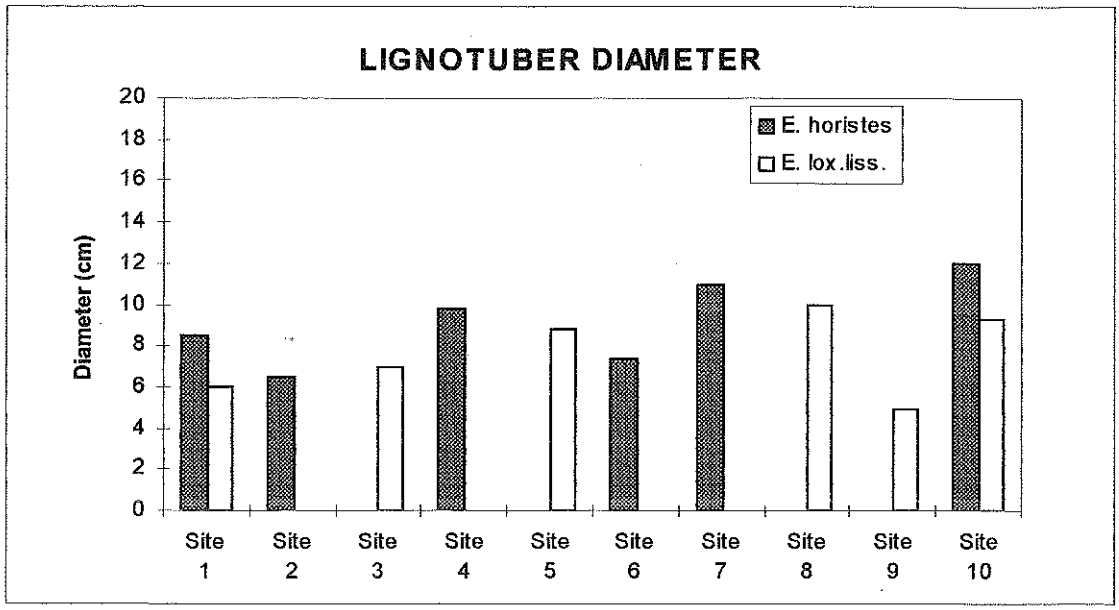


Figure 9 Lignotuber diameter (cm) per species and study site.

Table 4 Site rankings of dry root biomass percentage and lignotuber diameter.

E. horistes

Site	Dry root biomass (%)	Site	Lignotuber Diameter (cm)
10	54.44	10	12.00
7	51.55	7	10.90
1	45.97	4	9.80
6	45.19	1	8.50
4	44.80	6	7.35
2	43.21	2	6.50

E. loxophleba* ssp. *lissophloia

Site	Dry root biomass (5)	Site	Lignotuber Diameter (cm)
1	53.30	8	10.00
10	47.33	10	9.25
3	46.11	5	8.75
5	42.70	3	6.95
9	41.88	1	6.00
8	41.03	9	4.90

Differences in regrowth crown volume were significant between sites for both species, but between the species no significant differences were found. For *E. horistes* Sites 7 and 10 had the highest values, with Site 7 being quite dissimilar from the other sites. Sites 4 and 6 showed the lowest crown volume values, and they were the most similar (*a*) of the sites as well. Sites 1 and 10 had the highest regrowth crown volume for *E. loxophleba* subsp. *lissophloia* (also refer Figure 10). Sites 5, 8 and 9 had the lowest and also the most similar values (*a*). Their dissimilarity from Site 10 was significant, with both Tukey's and Scheffe's post-hoc test p-values < 0.000 in all cases.

Table 5 Site rankings and similarities of regrowth crown volume and leaf and stem biomass percentage.

E. horistes

Site	Regrowth crown volume (m^3)		Site	Regrowth LS biomass (%)	
7	0.0379		7	41.32	*b*
10	0.0258	*b*	10	36.27	*b*
1	0.0195	*bc*	1	30.32	*a*
2	0.0106	*cd*	2	29.98	*ac*
4	0.0004	*ad*	4	20.94	*c*
6	0.0004	*a*	6	7.05	
	p = 0.001			p < 0.000	

E. loxophleba* ssp. *lissophloia

Site	Regrowth crown volume (m^3)		Site	Regrowth LS biomass (%)	
10	0.0642	*b*	1	41.35	*b*
1	0.0459	*bc*	10	35.28	*bc*
3	0.0269	*c*	3	28.15	*cd*
9	0.0007	*a*	8	20.54	*ad*
8	0.0001	*a*	9	15.78	*a*
5	0.0000	*a*	5	0.00	
	p < 0.000			p < 0.000	

Differences in regrowth dry leaf and stem biomass were not significant between species, but were significant between sites for both species. *E. horistes* Sites 7 and 10

Figure 10 AVERAGE REGROWTH CROWN VOLUME

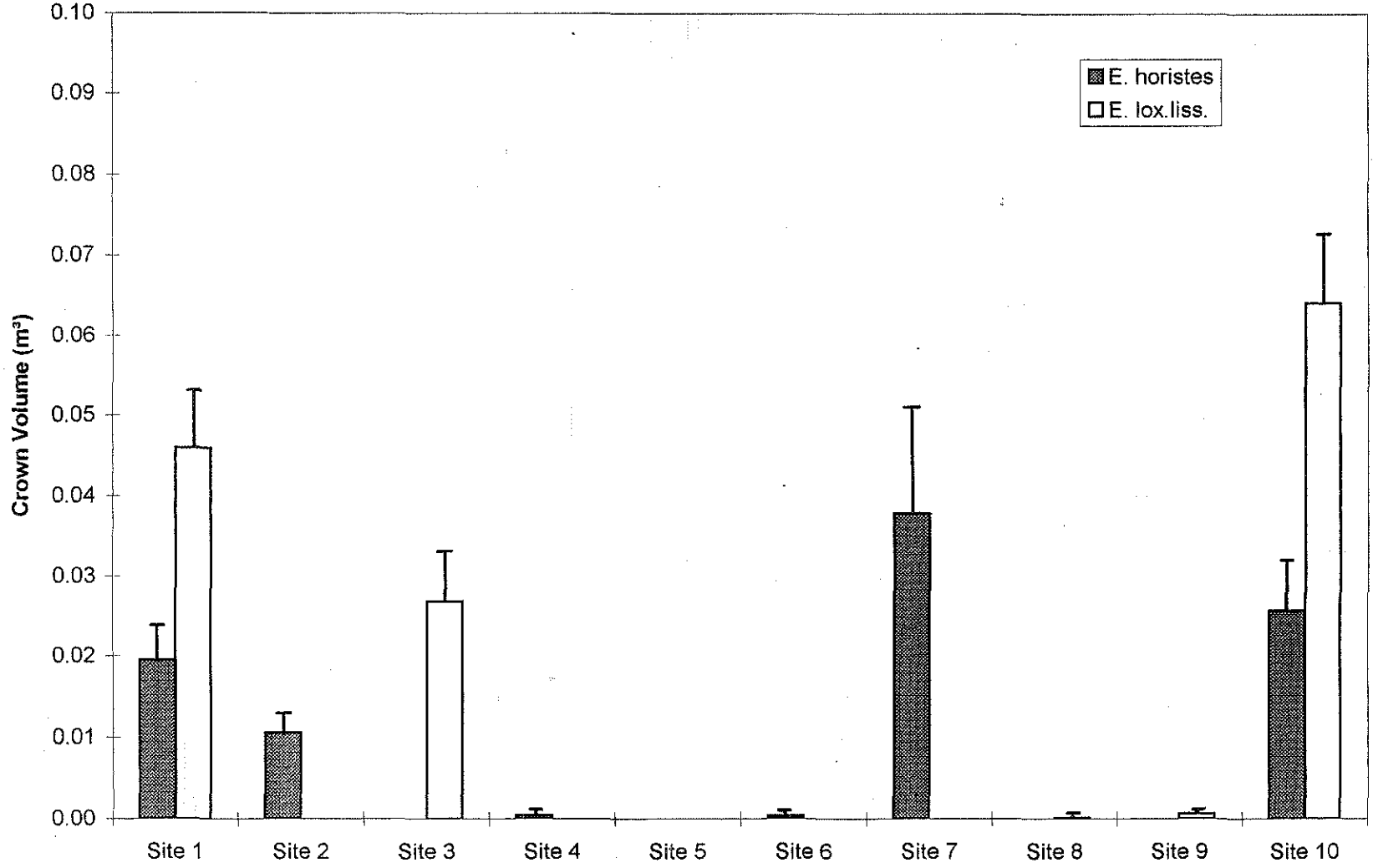
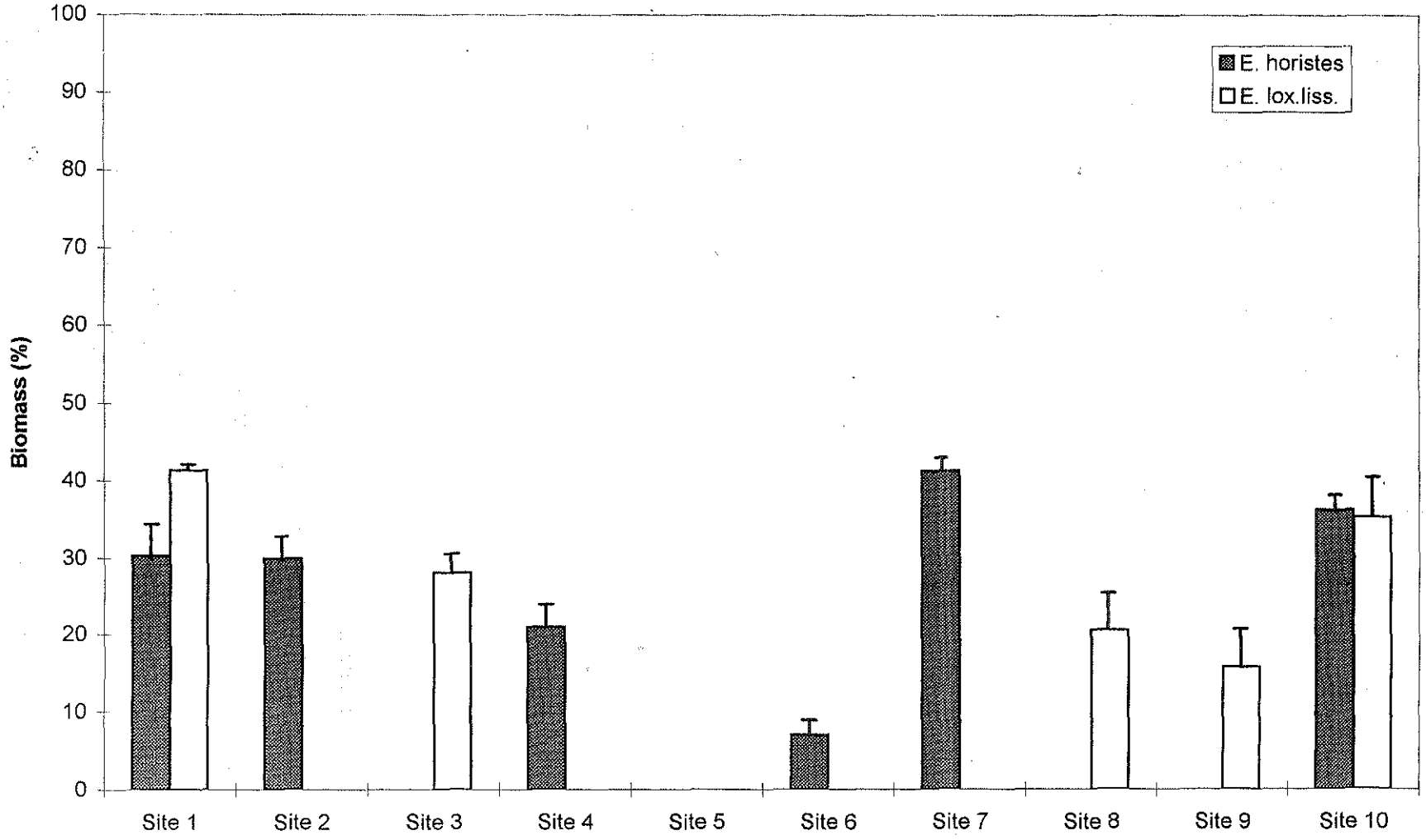


Figure 11 AVERAGE REGROWTH LEAF AND STEM BIOMASS



had the highest values, and they were also quite similar (*b*), although Sites 1 and 2 were the most similar (*a*). Site 6 showed the lowest regrowth biomass and was quite dissimilar from the other sites. For *E. loxophleba* subsp. *lissophloia* Sites 1 and 10 had the highest values, which were quite similar (*b*). Sites 8 and 9 were the most similar (*a*), and Site 5 had the least regrowth biomass and was quite dissimilar from the other sites (refer also Figure 11).

4.4 Discussion

4.4.1 *E. horistes*

Differences in pre-harvest crown volume and dry leaf and stem biomass between *E. horistes* sites were found to be significant ($p < 0.000$), however, in fresh weight they are not ($p = 0.079$). As this still represents a comparatively high confidence level (92%), indications are that a larger sample size would lead to a more significant result. Therefore fresh weight values will be interpreted as being significantly different between sites. The results reiterate those of Wildy's (1996b) study, which indicated significant differences between sites for all 9 oil mallee species examined, including *E. horistes*.

The rankings in Table 3 show that *E. horistes* growing at Site 10 have the largest crown volume, dry biomass and fresh weight, but this trend is not repeated at any of the other sites. The dissimilarity of Site 10 values, when compared to values from the other sites, also sets it apart. This could be due to conditions at Site 10 being particularly favourable for *E. horistes* (Fitter and Hay, 1987).

E. horistes plants at Site 7 have a large crown volume and a medium fresh weight, yet their dry biomass is the lowest of all the sites. This could be due to a comparatively

high leaf water content, which in turn suggests a readily available groundwater source. This trend is shown by Site 6 plants as well, although to a lesser degree. A reason for this could be an ability of *E. horistes* to develop a deep tap root. Plants at Site 4 also have a relatively large crown volume, however, dry biomass values are high, while fresh weight is the lowest of all the sites. Here a low leaf water content is suggested, indicating potential water stress (Cowan, 1981, Larcher, 1995). A similar trend appears for plants at Site 1, and Site 2 shows indications of it as well. Fresh weight and subsamples for dry biomass determination were obtained at the same time and from the same plant, excluding the possibility of genetically controlled differences in transpiration and weather related influences affecting the data.

Below ground growth indicators examined (dry root biomass and lignotuber diameter) are generally ranked similarly, with Sites 10 and 7 showing the most growth and Site 2 the least. Examination of regrowth parameters again showed growth to be highest at Sites 7 and 10, with Sites 1 and 2 having markedly lower values. Site 6 data should be disregarded, as the regrowth on that site was subjected to sheep grazing. Site 4 was the last site to be harvested (by a margin of 4 weeks), and as oil mallee regrowth in the winter months is relatively slow (Wildy, 1996b), a low ranking for Site 4 values was to be expected.

Sites 10, 7 and 6 have watertables at a depth of more than 5.2 m and sandy, well-drained soils. Sites 4, 1 and 2 have shallower watertables and clay dominated soils with a tendency to be waterlogged for at least part of the year (refer Chapter 3). *E. horistes* appears to achieve the highest growth in terms of crown volume, root biomass and lignotuber diameter, as well as showing a potential for high water use, at well-drained sites. Therefore it seems likely that *E. horistes* is better suited to the

environmental conditions experienced at the study sites positioned higher in the landscape (recharge areas).

4.4.2 *E. loxophleba* subsp. *lissophloia*

Differences in pre-harvest crown volume, fresh weight and dry biomass between *E. loxophleba* subsp. *lissophloia* sites were found to be significant, again reiterating Wildy's (1996b) findings. The rankings in Tables 3 and 4 show that growth of *E. loxophleba* subsp. *lissophloia* does not necessarily follow the same trend as *E. horistes*. Plants on Sites 8, 10 and 1 appear to have the highest growth, although ranking position for sites changes appreciably with different parameters.

It is more instructive to examine results for Sites 5 and 9 more closely. These two sites were established in 1995, and the plants are only half the age of plants at other sites. Values for all growth parameters at Site 9, a well-drained site, are consistently ranked in the lower positions in Tables 3 and 4. This can be explained as being due to the younger age of the plants. However, *E. loxophleba* subsp. *lissophloia* plants growing at Site 5 are ranked higher than Site 9's for every growth parameter except dry biomass. In view of the fact that Site 5 has the shallowest watertable of all the study sites, the high fresh weight, indicating high leaf water content, is hardly surprising. The plants still have their large, juvenile leaf form, which, along with the need to transpire more water, contributes to the comparatively large crown volume. Older plants at the other two sites with shallow watertables, Sites 1 and 3, have the highest dry biomass values and are lower in fresh weight. This could be an indication of growth limiting factors operating at those sites.

Site 5 is similar to Sites 8 and 10, in that it has a sandy soil throughout the profile examined. It is also interesting to note that Site 5's groundwater and soil salinity (EC) are the lowest of the waterlogged sites, indicating the possibility of salinity being a limiting factor at Sites 1 and 3. Soil pH may also be a factor, as Site 5 has a more neutral pH than Sites 1 and 3, which have an alkaline tendency. It is therefore possible to conclude that *E. loxophleba* subsp. *lissophloia* appears to prefer sandy soils and may be waterlogging tolerant, as long as site salinity levels remain comparatively low.

Unfortunately it is not possible to accurately assess regrowth parameters for *E. loxophleba* subsp. *lissophloia*, as Site 5 was subjected to sheep grazing in June and July and vigorous competition by weeds in August and September. This resulted in an almost complete failure of the regrowth. Regrowth at Site 9 was also affected by weed competition. Site 8 was the last site to be harvested (by a margin of 4 weeks), and a lower level of regrowth was expected. Regrowth did develop well at Sites 10, 1 and 3, despite Site 10 being briefly subjected to sheep grazing as well. However, sheep grazing of harvest oil mallee plantations should be avoided for several months to allow regrowth to develop. Wildy (1996b) found *E. loxophleba* subsp. *lissophloia* to have the highest rate of regrowth after harvesting of the 9 oil mallee species examined in his study, indicating that such a period of exclusion of stock may be shorter for *E. loxophleba* subsp. *lissophloia* than for other species.

4.4.3 *E. horistes* and *E. loxophleba* subsp. *lissophloia*

Differences between species were significant for only 2 of the growth parameters examined, dry biomass and fresh weight. Wildy (1996b) argues that any differences between species are largely physiological. Visual comparison of *E. horistes* and *E. loxophleba* subsp. *lissophloia* supports that view. *E. horistes* has a more rounded,

compact canopy, smaller, narrower and denser leaves, and a multi-stemmed growth habit. *E. loxophleba* subsp. *lissophloia* has a conical, open canopy, larger, broader and lighter leaves, even in its adult form, and a single-stemmed, tree-like growth habit. *E. loxophleba* subsp. *lissophloia* stems also have a larger diameter than *E. horistes*. Wildy (1996b) found *E. loxophleba* subsp. *lissophloia* to have the fastest growth rate of nine oil mallee species studied (including *E. horistes*) in 1996, and his results also indicate a higher evapotranspiration potential. A comparison of dry biomass and fresh weight values for both species (Table 3), showed *E. horistes* to have the higher values in each case. The contrasting growth habit and leaf characteristics of the two species are likely to be the determining factors.

Unfortunately, correlation and regression analysis of growth and site parameters was not possible due to the limited size of the site data sets. Future studies should endeavour to obtain measurements of groundwater depth and salinity and soil salinity levels on a seasonal basis starting at the time of plantation establishment.

Chapter 5

Evaluation of Water Use Parameters

5.1 Introduction

A plant's water use is governed by many factors, not the least of which is the availability of water in the soil. Soil water storage is dependent on rainfall. In semi-arid regions, which experience comparatively low and seasonal rainfall, plants have developed water use adaptations to help them survive prolonged dry periods. These adaptations include the ability to reduce the amount of water lost through evaporation from the leaves (transpiration), which involve control over the aperture size of the leaves' stomata (Cowan, 1981; Fitter and Hay, 1987; Larcher, 1995).

To be able to grow plants need to obtain carbon dioxide (CO_2) from the atmosphere, and this is achieved by opening the stomata, specially adapted leaf cells, that facilitate the exchange of gases. Water vapour is lost to the atmosphere while CO_2 enters the stomata. As atmospheric water content is at much lower concentrations than leaf water content, water tends to move to the atmosphere (transpiration). When the water vapour departs the leaves, water from roots moves up to the leaves to replace it (Wessells and Hopson, 1988). Water availability in semi-arid and arid regions is limited, and once high temperatures cause the rate of transpiration to exceed the rate of supply, plants experience water stress. Closure of the stomata conserves water, but at the cost of reducing CO_2 intake, and with that the plants' ability to produce more biomass and growth (Cowan, 1981; Fitter and Hay, 1987; Larcher, 1995).

Osmotic adjustment is another adaptation to water stress. To obtain a higher supply of water from the soil, plant cells may increase their osmotic pressure (rate of water movement through permeable cell membranes), however, this strategy comes at a high energy cost. This energy, in the form of plant sugars such as hexose, is no longer available for biomass production, thus limiting plant growth (Cowan, 1981).

Eucalypts are known to perform exceptionally well under dry conditions. Their main adaptations to water stress were thought to be the hard tissue (sclerophylly) and generally vertical alignment of their leaves. Transpiration from the leaves was limited by a thickened epidermic layer and by exposing only the small edge of the leaves to the sun, but sclerophyllic adaptations can also be a response to low nutrient levels. Researchers soon realised that eucalypts generally do not make full use of these recognised water conservation strategies. Yet many species continually transpire large amounts of water throughout the dry season, when water availability is limited. One reason for this is believed to be the lignotuberous growth habit, which allows not only regeneration of the above ground parts of the plant after disturbance (coppice regrowth), but also facilitates the development of a strong root system, particularly at the seedling stage. The morphology of the root system is also thought to be a major factor in the eucalypts' ability to survive well in dry conditions (Florence, 1981; 1996).

The eucalypts' development of a strong root system incorporating a deep tap root, that allows the plants access to groundwater stored deep underground, is their most likely adaptation to seasonally dry climatic conditions. The permanently high transpiration rates found in Australian eucalypts allow for continued growth and assimilation of CO_2. At the same time it could be argued that their ability to access and freely transpire water acts as a major tool in keeping the hydrological cycle in Australian ecosystems

balanced. Eucalypts should therefore be used extensively in the revegetation of areas affected by rising watertables throughout Australia. However, this revegetation may only be effective, when eucalypts are planted on groundwater recharge areas, where watertables are generally deeper. Studies undertaken in regions with > 600 mm average annual rainfall have established that eucalypt trees do lower watertables (Schofield, *et al.*, 1989; Bari and Boyd, 1994) through their high water usage, however, not all species tested were able to survive in saline and waterlogged conditions (Pettit and Ritson, 1991). Research to establish which eucalypts (tree or mallee form) can tolerate waterlogged and saline site conditions, which are often found in groundwater discharge areas, and transpire the most water while attaining the highest growth, must be a priority.

The aim of this study was to identify which of the two species examined (*E. horistes* and *E. loxophleba* subsp. *lissophloia*) is likely to transpire more water, and whether any trends in water use performance could be related to the physical characteristics of the study sites. An understanding of the amount of water used by the plants would allow selection of the highest water users for planting at recharge or discharge sites, depending on the stated target areas and project objectives of revegetation initiatives. As high transpiration rates are generally equated with a large leaf area or crown volume, plants achieving the highest productivity in terms of growth are also believed to transpire the most water.

5.3 Methods

Plant transpiration rates vary considerably throughout the year and are related to changes in climatic conditions. Due to time constraints seasonal variations in transpiration rates could not be examined in this study. It was decided to measure

plant transpiration in spring, when water availability in the study area was at its highest, following winter rainfall. Diurnal differences in transpiration rates, which are lowest during the night and highest during the warmest part of the day, are believed to be at a minimum at this time of the year. This is termed the "one-peak" transpiration pattern (Cowan, 1981).

Transpiration was measured using a 'null-balance' or 'steady state' porometer (Bannister, 1986; Pearcy, Schulze and Zimmermann, 1989). To obtain an indication of the energy expended by the study plants in acquiring water, xylem pressure was measured with a Scholander pressure bomb (Bannister, 1986; Koide, Robichaux, Morse and Smith, 1989). Transpiration and xylem pressure were measured on 3 unharvested plants per site and species, that had a height and diameter most closely resembling the site height and diameter averages (refer Chapter 4). Water use of regrowth was also examined where possible on 1 plant in each plot, which had a height and diameter most closely resembling the plant height and diameter averages for the plot. Both transpiration and xylem pressure measurements were taken twice daily, between 10 am and 4 pm, on three leaves or shoots from each plant. The leaves or shoots were removed from 3 different points in the canopy or crown (e.g. from high and low external positions, and from a position near the centre of the crown) to account for any differences in transpiration and xylem pressure caused by variations in the crown micro-climate.

The total number of leaves making up the plant canopy were counted on one plant in each group (unharvested and harvested or regrowth plants). Average leaf size (leaf area) was calculated on a subsample of 20 leaves from each plant using a Digital Image Acquisition System (DIAS). Porometer transpiration measurements and average leaf area data were then used to calculate an estimate of the amount of water

transpired by the plants during 1 daylight hour. It should be stressed that this technique gives an indication of the amount of water transpired, and is not an accurate measurement.

Measurement of transpiration and xylem pressure was not possible at Site 7, where all plants had been harvested, and regrowth xylem pressure measurements were prevented by technical difficulties. On most of the sites regrowth was too small and soft-stemmed to allow measurement of transpiration and xylem pressure. Weather conditions prevented the acquisition of porometer measurements at Sites 2 and 3.

Data obtained from the study sites were used to calculate a site average and standard error for each water use parameter. Analysis of variance (ANOVA) of mean plot values was carried out at the 95% confidence level to determine the significance of any differences between sites and between species. In addition Tukey's and Scheffe's post-hoc tests were applied to achieve an understanding of any similarities between sites of the same species. Site averages for each parameter and species were also ranked from highest to lowest to identify the sites on which each species tended to achieve the highest and lowest water use values. The hypothesis tested implied that no significant differences would be detected.

5.3 Results

Table 6 lists analysis of variance (ANOVA) results. Tables 7 and 8 rank the sites from highest to lowest value for all water use parameters.

Differences in unharvested plants' estimated hourly transpiration were found to be significant between sites for both species, however, differences between species were

not significant. Figure 12 illustrates the variability of the transpiration estimates, as well as a marked increase in transpiration for both species at Sites 6, 8 and 10. This trend is repeated in the rankings listed in Table 7.

Table 6 Analysis of Variance Results

Parameter	Differences between species p value	Differences between sites (E. horistes) p value	Differences between sites (E. loxophleba lissophloia) p value
Unharvested plants' transpiration	0.802	0.000016	0.000045
Unharvested plants' xylem pressure	0.669	0.00000000	0.00000000004
Regrowth transpiration	0.005	0.000138	0.324
Regrowth xylem pressure	0.733	0.00000029	0.00000025

Table 7 Site rankings and similarities in estimated pre-harvest transpiration and pre-harvest xylem pressure.

E. horistes

Site	Pre-harvest transpiration (g/hour)	Site	Pre-harvest xylem pressure (kPa)	
6	791.85	10	2161.00	
10	546.00	1	2088.00	
1	111.29	4	1567.00	
4	40.81	6	1368.00	
2		2	1042.00	
7		7		
	$p < 0.000$		$p < 0.000$	

E. loxophleba* ssp. *lissophloia

Site	Pre-harvest transpiration (g/hour)	Site	Pre-harvest xylem pressure (kPa)	
8	1158.79	1	2620.69	*c*
10	791.85	10	2295.02	*c*
9	135.73	9	1839.09	*b*
1	97.91	5	1547.89	*ab*
5	65.14	8	1394.64	*a*
3		3	1042.15	
	$p < 0.000$		$p < 0.000$	

Figure 12 ESTIMATED HOURLY TRANSPIRATION PER PLANT

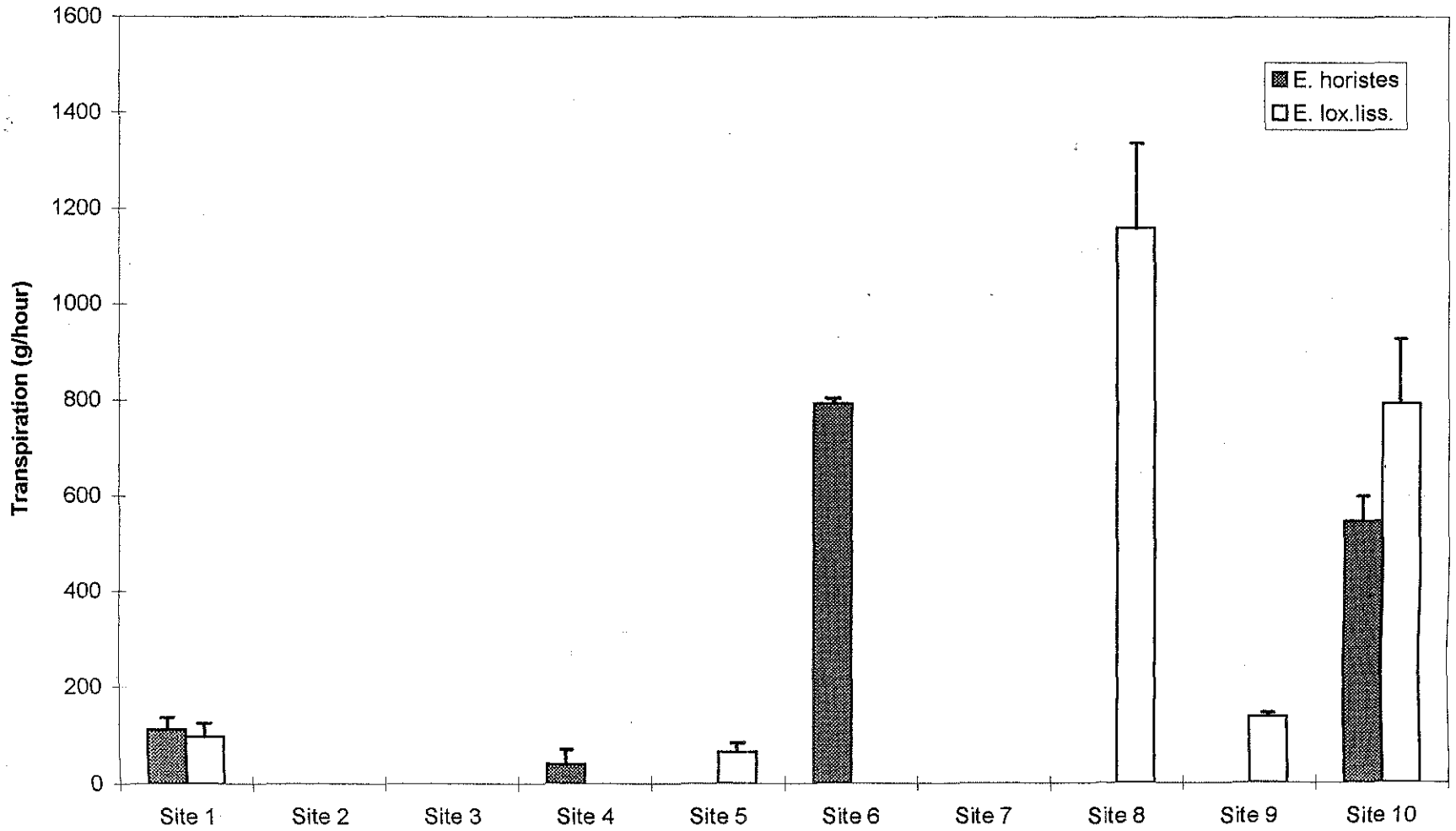
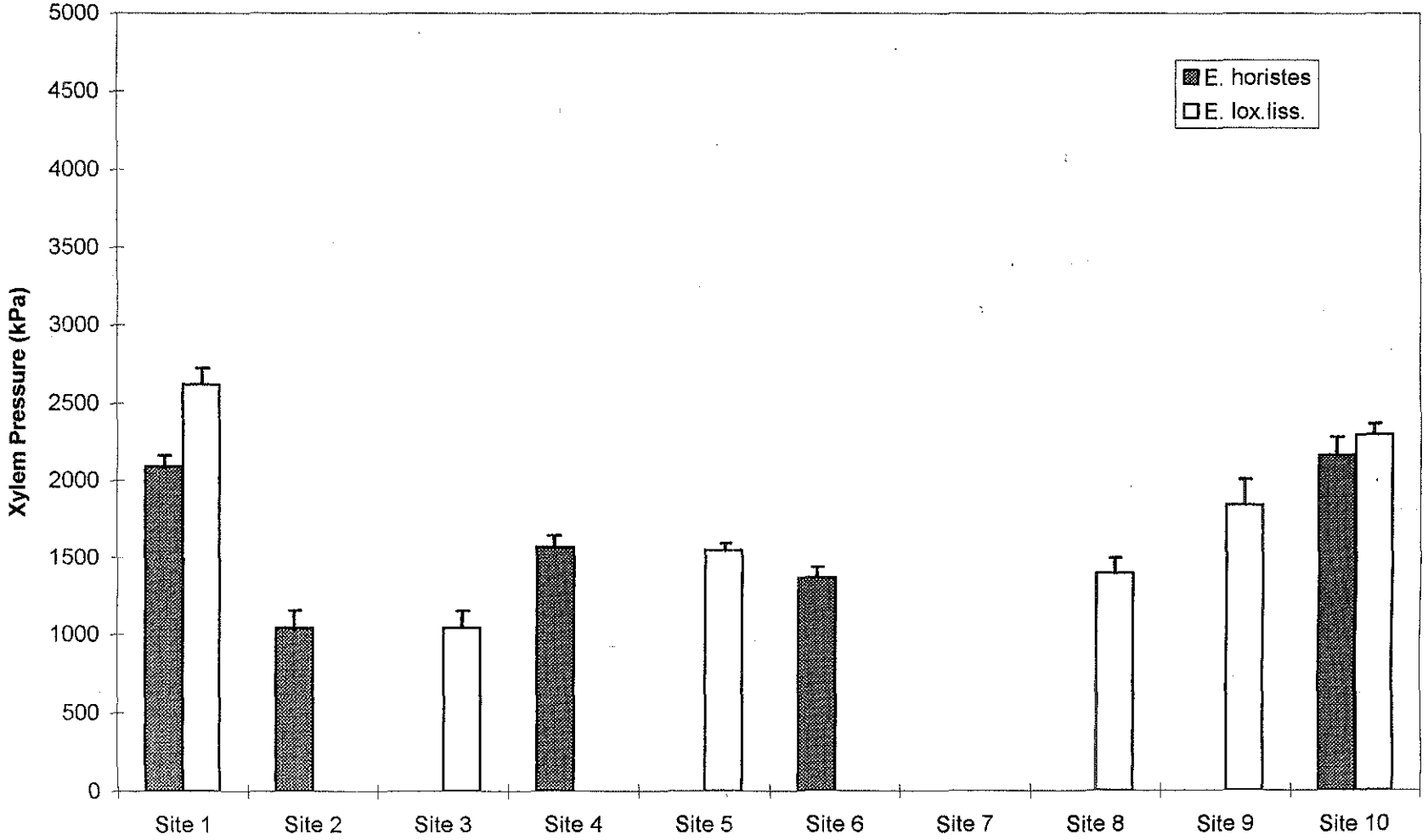


Figure 13 AVERAGE PRE-HARVEST XYLEM PRESSURE



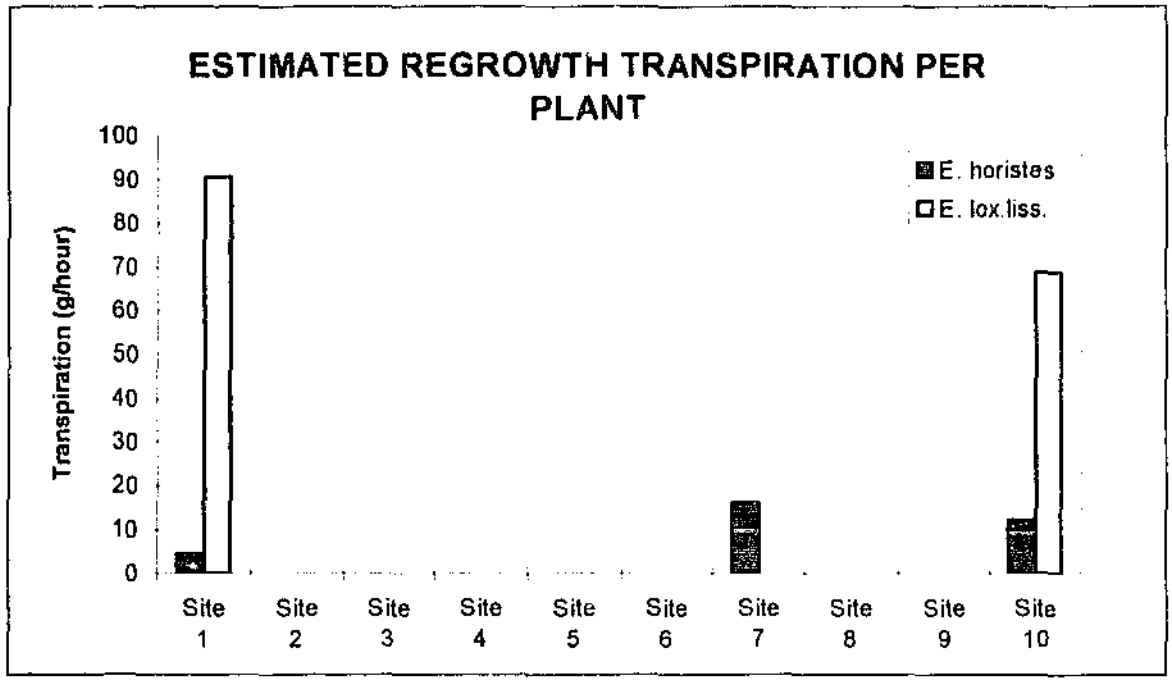


Figure 14 Average plant regrowth transpiration (g / hour) per species and study sites.

Table 8 Site rankings of estimated regrowth transpiration and regrowth xylem pressure.

E. horistes

Site	Regrowth transpiration (g/hour)
7	15.99
10	12.22
1	4.43
2	
4	
6	

$p < 0.000$

Site	Regrowth xylem pressure (kPa)
1	2279.69
10	2130.27
4	1440.61
2	1264.37
6	
7	

$p < 0.000$

E. loxophleba* ssp. *lissophloia

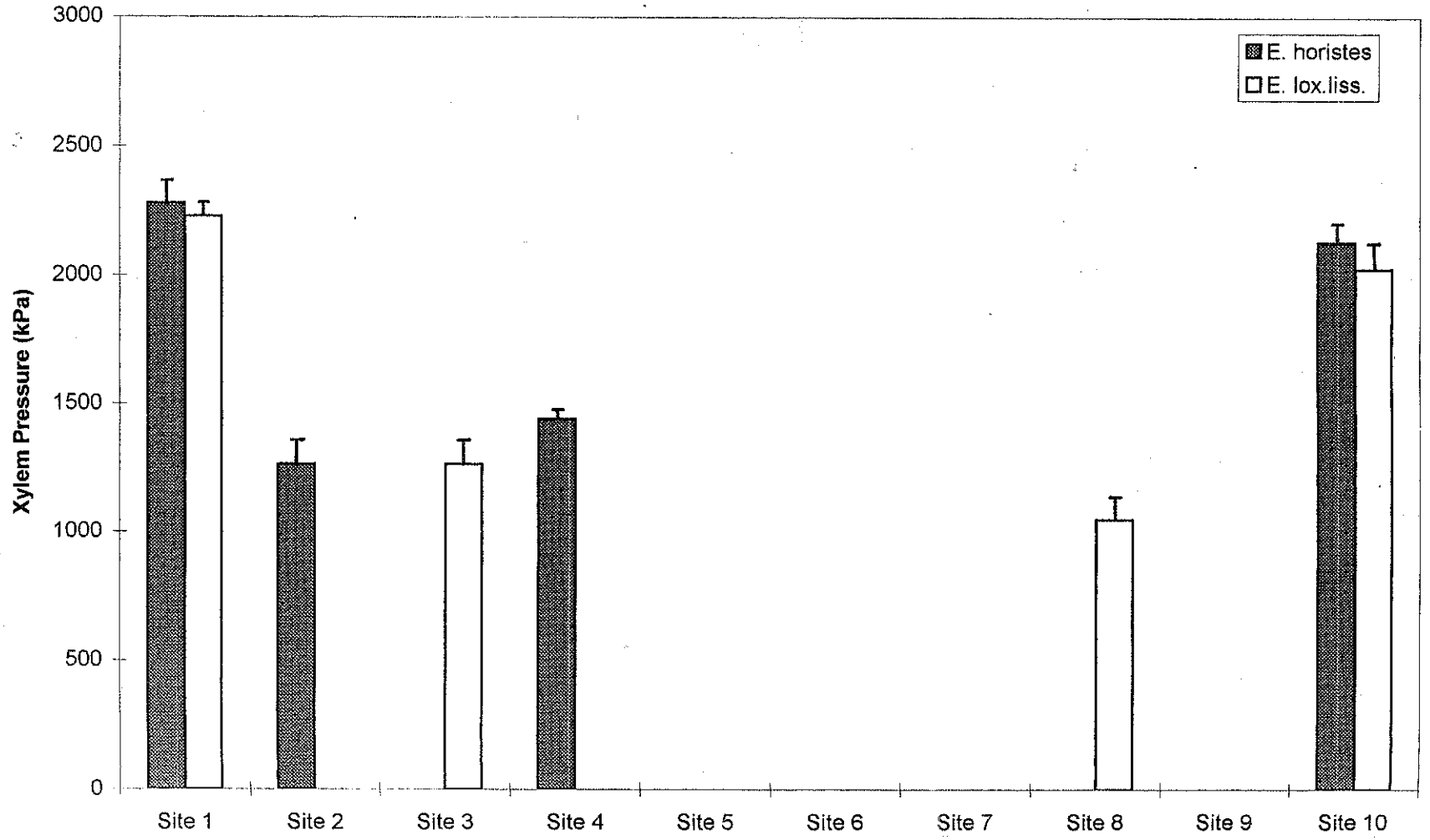
Site	Regrowth transpiration (g/hour)
1	90.76
10	68.84
3	
5	
8	
9	

$p = 0.324$

Site	Regrowth xylem pressure (kPa)
1	2229.89
10	2026.82
3	1264.37
8	1049.81
5	
9	

$p < 0.000$

Figure 15 AVERAGE REGROWTH XYLEM PRESSURE



Differences in regrowth transpiration were found to be significant between species and between *E. horistes* sites (3 sample sites). For *E. loxophleba* subsp. *lissophloia* measurements from only 2 sites (Sites 1 and 10) were available for analysis, and differences between them were not significant. Both results of the comparison between sites of the same species are unreliable, due to the small sample size. Figure 14 illustrates the significant differences in regrowth transpiration between species growing at the same sites. At both Site 1 and Site 10 transpiration estimates for *E. loxophleba* subsp. *lissophloia* are markedly higher than for *E. horistes*. This is also borne out by the values listed in Table 8.

Differences in regrowth xylem pressure were not significant between species, but were significant between sites for both species. Figure 15 and Table 8 show that Sites 1 and 10 had the highest values for the two species, but no trend in relation to environmental characteristics and landscape position was detected.

5.4 Discussion

In Chapter 3 the possibility of grouping the study sites into shallow watertable and deep watertable sites was discussed. Such a grouping would include Sites 1, 2, 3, 4 and 5 in the shallow watertable or low landscape position group, while Sites 6, 7, 8, 9 and 10 would make up the deep watertable or high landscape position group. With that in mind, the marked difference between transpiration estimates for sites belonging to the 2 groups, is very interesting. Transpiration is projected as being greater in a high landscape position. Even at Site 9, the younger plants of which were outperformed by *E. loxophleba* subsp. *lissophloia* on every other site, transpiration estimates are higher. Based on the rankings for growth parameters (Tables 3 and 4), it is deemed likely that Sites 2 (*E. horistes*) and 3 (*E. loxophleba* subsp. *lissophloia*) would have returned

transpiration estimates similar to Site 1, and Site 7 (*E. horistes*) to have shown a value comparable to Site 10's. The indication given by this division, which applies equally to both species, is that they appear to transpire higher amounts of water at recharge sites, and may be well suited to accessing and extracting water from deep watertables.

Transpiration rates for mature trees native to the central wheatbelt were studied at Durokoppin Nature Reserve in the neighbouring Kellerberrin district. *E. wandoo* was found to transpire in excess of 2.5 kg of water per hour, and *E. salmonophloia* transpired an average of 1.9 kg of water per hour during spring (McFarlane, *et al.*, 1993). Studies undertaken in the Wellington Dam catchment during the 1980s found that *E. wandoo* had the highest transpiration rate per unit leaf area (m^2) of 6 *eucalyptus* tree species monitored (Schofield, *et al.*, 1989). While it is hardly surprising that the trees transpired more water than the smaller oil mallees studied here, transpiration estimates, particularly for *E. loxophleba* subsp. *lissophloia*, compare favourably with those of the trees (refer Table 7). When grown commercially, oil mallees are planted at a higher density per unit area than trees growing in an open woodland setting, and can therefore be expected to transpire as much, if not more, water over a given area of land. This indicates the high potential of oil mallees for use in revegetation to combat rising watertables.

Another interesting comparison is possible with tagasaste or tree lucerne (*Chamaecytisus palmensis*), a nutritious, leguminous fodder shrub recommended for groundwater recharge control (Heinjus, 1992). A study of ungrazed tagasaste shrubs planted at a density of 600 plants per hectare in a region receiving an average annual rainfall of 700 mm estimated the total transpiration per hectare to be approximately 0.950 kg per hour (McFarlane, *et al.*, 1993). Based on the results listed in Table 7, *E. horistes* planted at a density of 600 plants per hectare at Site 1 would transpire more

than 60 kg of water per hour per hectare. This comparison exemplifies the superiority of native eucalypt species for revegetation aiming to lower groundwater tables.

Differences between species in the xylem pressure of unharvested plants are not significant, suggesting that both *E. horistes* and *E. loxophleba* subsp. *lissophloia* are well able to access and extract groundwater. The values measured are not particularly high, indicating that none of the plants experienced water stress (N. Pettit, personal communication, September 12, 1997). As measurements were taken at spring time, when water availability is highest following winter rains, this result was expected.

Estimates for regrowth transpiration could only be made for 3 sites (see Figure 14), making statistical analysis unreliable. However, they did show a marked difference between species, with *E. loxophleba* subsp. *lissophloia* regrowth transpiring 20 times more water than *E. horistes* regrowth at Site 1, and more than 5 times more at Site 10. This would reiterate Wildy's (1996b) results, which indicate that *E. loxophleba* subsp. *lissophloia* produced the highest level of regrowth while using the most water of the 9 oil mallee species studied.

Regrowth xylem pressure was measured on 6 sites. Figure 15 illustrates the significant differences found between the sites. It is noticeable that Sites 1 and 10 again stand out by having the highest values for both species. High transpiration rate seems to be accompanied by high energy expenditure in obtaining water for coppice regrowth. Environmental characteristics do not appear to be of influence, as Site 1 has a low landscape position and Site 10 is situated high in the landscape.

Overall, an evaluation of the water use parameters studied indicates the superior suitability of both species for revegetation projects, due to their high water usage.

Once harvested, the regrowth produced by *E. loxophleba* subsp. *lissophloia* may use larger amounts of water than that of *E. horistes*, however, further investigation is required to establish this. Should this be the case, high water use as well as some cineole production can become the objectives of a revegetation project incorporating this species. Intermittent harvesting (e.g. less frequently than for cineole production alone) of *E. loxophleba* subsp. *lissophloia* would yield some returns through cineole production, while high water use can still be achieved. Both species appear to be better able to access and use water from deep watertables, which indicates that they would be most appropriately planted in recharge areas.

Chapter 6

Evaluation of Cineole Production Parameters

6.1 Introduction

Eucalyptus oils are complex mixtures of volatile organic compounds belonging to groups of chemicals such as hydrocarbons, alcohols, aldehydes, ketones, acids and esters. They are predominantly made up of mono- and sesquiterpenes, and are believed to be formed in photosynthetically active cells surrounding the oil glands of the *eucalyptus* leaf (Doran, 1991). Their function is still being debated. Theories include their role as a defence mechanism against herbivory (James and Hopper, 1981; Doran, 1991), their potentially allelopathic influence (Doran, 1991; Larcher, 1995), their contribution, although minor, to the flammability of Australian eucalypt forests (Doran, 1991; Florence, 1996), and their potential function as a reservoir of biochemical compounds for the synthesis of other plant components such as pigments, sugars, amino acids, respiratory coenzymes and compounds used in root lipid biosynthesis. The last theory would at least partially explain the often documented seasonal variations in leaf oil concentrations (Doran, 1991; Wildy, 1996b), as well as the high energy cost associated with its production. Leaf ontogeny and extraction and analysis techniques can also affect reported oil concentrations. However, it is still believed that oil production is largely under genetic control, and environmental factors can only affect it to a limited degree. Studies have shown that leaf oil concentration as well as the oil's composition are highly heritable (Doran, 1991; Wildy, 1996a).

One of the major components of *Eucalyptus* oil, 1,8-cineole ($C_{10}H_{18}O$) is a monoterpene belonging to the ether family. It has a boiling point of 176.4°C and is present in most of the oils produced by eucalypt species, although in varying concentrations. It is valued for its medicinal properties, is used in perfumery applications, and has potential as a fuel additive and an industrial solvent (refer Chapter 1). ALCOA of Australia Ltd uses it as a degreasing agent (Doran, 1991; Wildy, 1996a). The oil mallee trials established at present should yield 30 to 35 kg of cineole per tonne of harvested leaves and stems. If solvent market penetration is to be achieved, the oil price after processing should be around $3 per kg (Bartle, 1994), or $3,000.00 per tonne. Should cineole be accepted and used as a replacement product for thrichloroethane solvents, an estimated 20 million hectares of oil producing mallees would need to be established world-wide to meet the demand of approximately 1 million tonnes per year (Baxter, 1996), worth about $3 billion at present. An economic argument of this magnitude could result in the large-scale establishment of oil mallee plantations and has the potential to address land degradation problems like waterlogging and salinity, which are being experienced in many semi-arid zone countries.

The aim of this study was to compare and evaluate the cineole production of *E. horistes* and *E. loxophleba* subsp. *lissophloia* to identify the species more likely to consistently produce high cineole yields. As leaf cineole content is thought to be genetically determined, rather than being related to environmental conditions, differences between sites of each species are not expected. However, yield estimates are likely to fluctuate with changes in growth parameters, such as fresh weight and crown volume. Crown volume has been used previously as an indicator of potential cineole yields (refer Chapter 4).

6.2 Methods

Samples for cineole concentration analysis were collected prior to harvesting (March / April 1997) and from coppice regrowth (September 1997), where sufficient leaf material was available (refer Chapter 5, also Figures 19 and 20). Four leaves were collected from every plant in each experimental plot. One leaf each was taken from a high, low, inside and outside position within the crown. The sample leaves were pooled and cut into approximately 5 mm wide strips, excluding leaf tips and petioles. A 3 g subsample was then placed into a marked sample bottle containing 50 ml of ethanol, and the bottle number recorded. This methodology is believed to reduce potential errors, as the placement of subsamples into the ethanol solution while in the field avoids leaf desiccation and oil evaporation (Wildy, 1996b). The bottles were sent to Murdoch University in Perth, where samples were reweighed, and the solvent was analysed for cineole concentration using the gas chromatography technique (Brophy, House, Board, Lassak, *et al.*, 1991; Wildy, 1996b). Results were given as a percentage of leaf fresh weight and deemed accurate to within 0.14 of reported concentrations. Leaf and stem fresh weight (refer Chapter 4) and average cineole content were used to calculate the estimated cineole yield per plant for each plot (Wildy, 1996b).

Data obtained from the 3 experimental plots per site and species were used to calculate a site average and standard error for each cineole production parameter. Analysis of variance (ANOVA) of mean plot values was carried out at the 95% confidence level to determine the significance of any differences between sites and between species. In addition Tukey's and Scheffe's post-hoc tests were applied to achieve an understanding of any similarities between sites of the same species. Site averages for each parameter and species were also ranked from highest to lowest to

identify the sites on which each species tended to achieve the highest and lowest values.

6.3 Results

Table 9 lists analysis of variance (ANOVA) results. Table 10 ranks the sites from highest to lowest value for all cineole production parameters.

Differences in pre-harvest cineole content were found to be significant between species and between sites for *E. loxophleba* subsp. *lissophloia*, while differences between *E. horistes* sites were not significant. Figure 16 illustrates this. Rankings listed in Table 10 show Site 2 as having the highest cineole content for *E. horistes*, and Site 6 has the lowest. Sites 7 and 4 are the most similar (*a*). For *E. loxophleba* subsp. *lissophloia* Site 1 returned the highest value. Sites 5 and 9 showed the lowest values, which were also quite similar (*b*), however, the highest similarity was found to be between Sites 8 and 10 (*a*).

Table 9 Analysis of Variance Results

Parameter	Differences between species p value	Differences between sites (E. horistes) p value	Differences between sites (E. loxophleba lissophloia) p value
Pre-harvest cineole content	0.00041	0.254	0.000013
Estimated cineole yield per plant	0.001	0.054	0.001
Regrowth cineole content	0.165	0.004	0.000414

Differences in estimated cineole yield were significant between species and between sites for *E. loxophleba* subsp. *lissophloia*. Differences between *E. horistes* sites were found to be not significant, however, this is not confirmed in Figure 17, which shows noticeable variations in yield estimates between *E. horistes* sites. Estimated cineole yield values were highest at Site 4, which was quite dissimilar from the other *E. horistes* sites and lowest at Site 6. The highest similarities were found between Sites 10 and 2 (*a*). *E. loxophleba* subsp. *lissophloia* yield estimates were markedly lower than for *E. horistes*. The highest value was calculated for Site 8, which also proved to be quite dissimilar from other sites. The lowest value was found at Site 9, with Sites 1 and 5 the most similar (*a*).

Table 10 Site rankings and similarities in average pre-harvest cineole content, estimated cineole yield and average regrowth cineole content.

E. horistes

Site	Pre-harvest cineole content (% w/w)		Site	Pre-harvest cineole yield (kg)		Site	Regrowth cineole content (% w/w)
2	3.30	*e*	4	0.158		1	2.37
7	3.17	*ae*	10	0.130	*a*	7	2.03
4	3.13	*ad*	2	0.123	*ac*	10	1.73
1	3.00	*bd*	7	0.109	*bc*	2	0.97
10	2.93	*bc*	1	0.098	*bd*	4	
6	2.83	*c*	6	0.078	*d*	6	
	p = 0.254			p = 0.054			p = 0.004

E. loxophleba* ssp. *lissophloia

Site	Pre-harvest cineole content (% w/w)		Site	Pre-harvest cineole yield (kg)		Site	Regrowth cineole content (% w/w)
1	2.67	*d*	8	0.090		1	1.70
3	2.33	*cd*	10	0.061	*c*	9	1.40
10	2.03	*ac*	1	0.044	*abc*	10	1.00
8	1.97	*a*	5	0.043	*abc*	3	0.50
5	1.6	*b*	3	0.032	*b*	5	
9	1.37	*b*	9	0.005		8	
	p < 0.000			p = 0.001			p < 0.000

Figure 16 AVERAGE PRE-HARVEST LEAF CINEOLE CONTENT

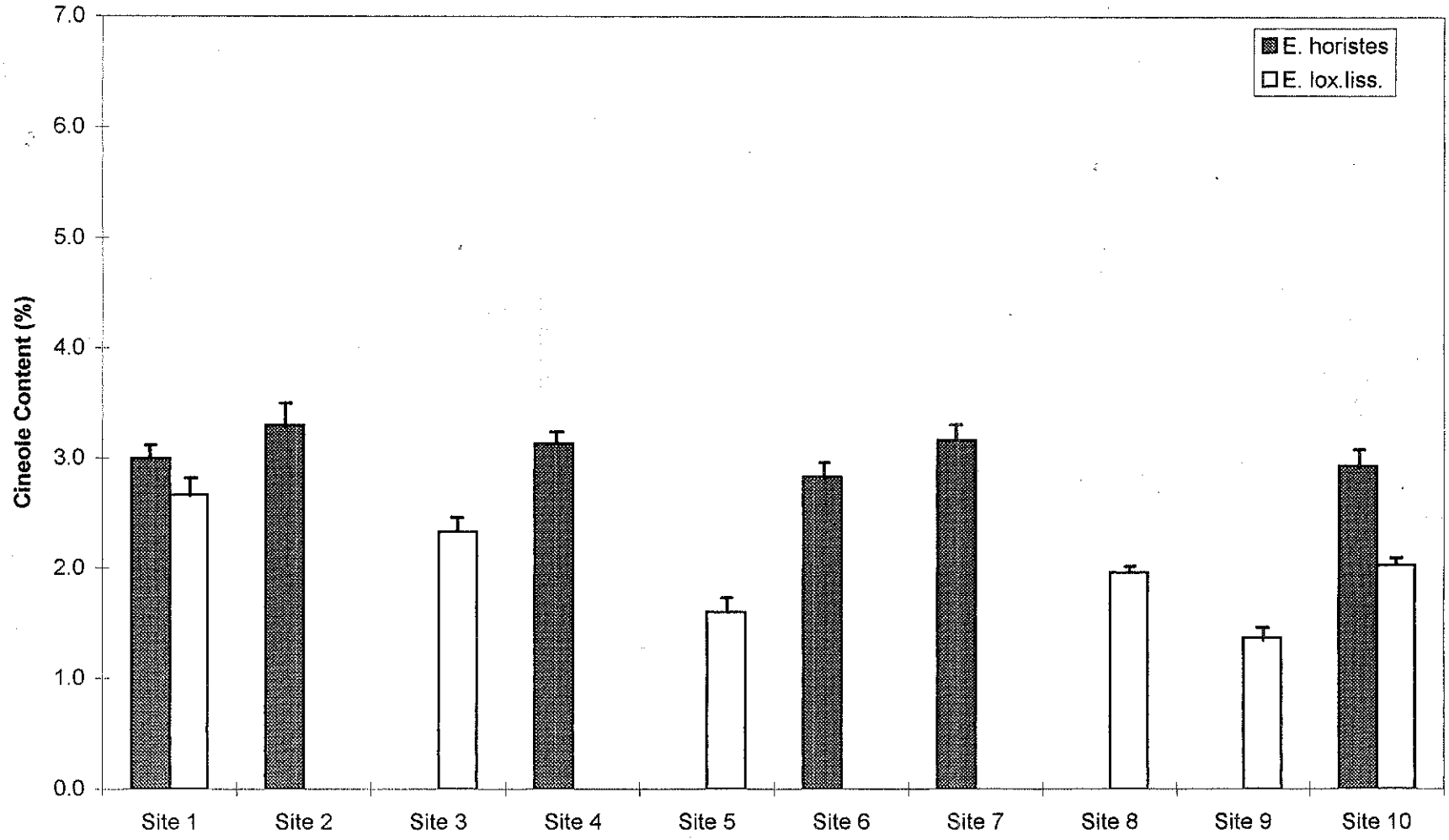


Figure 17 ESTIMATED PRE-HARVEST CINEOLE YIELD PER PLANT

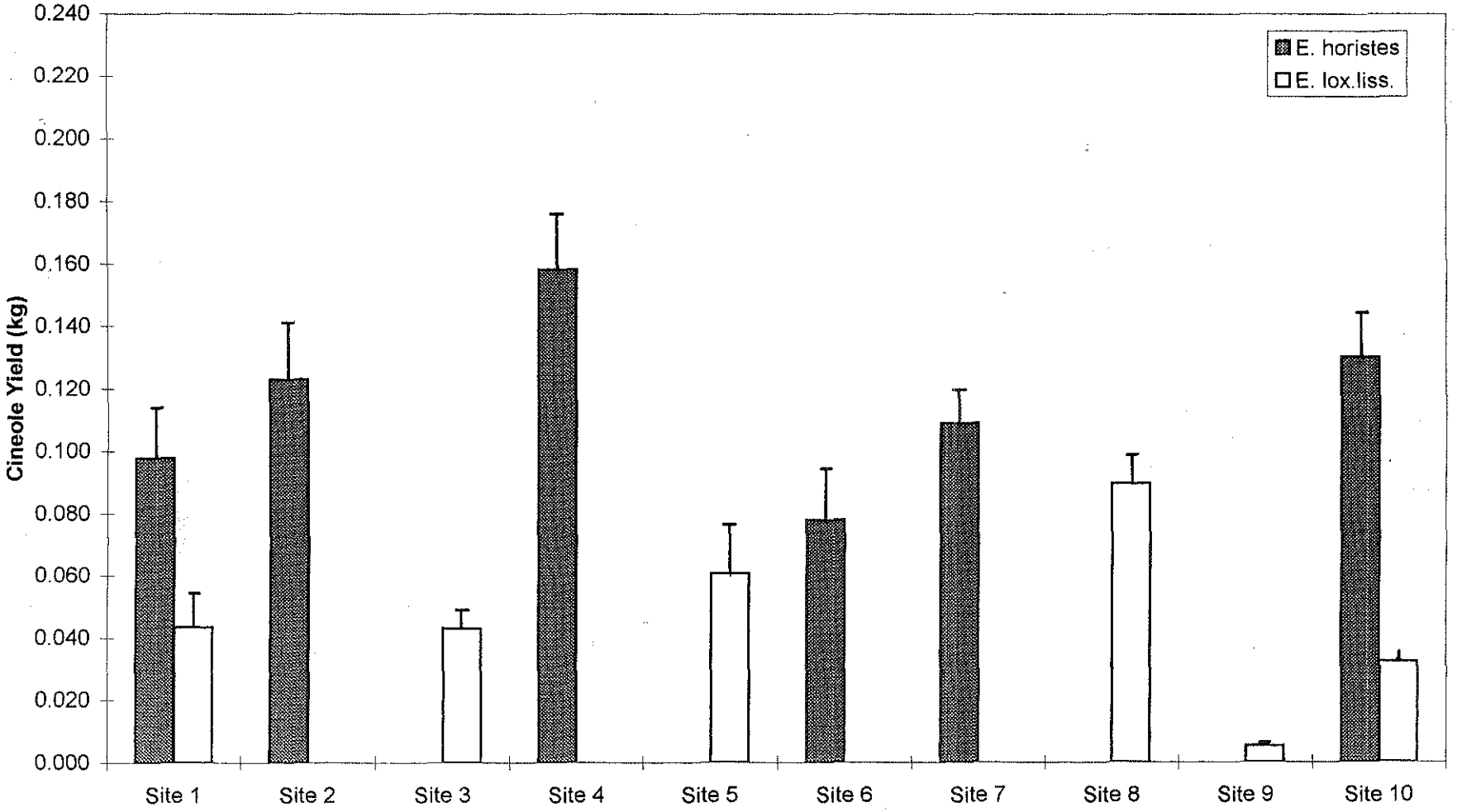
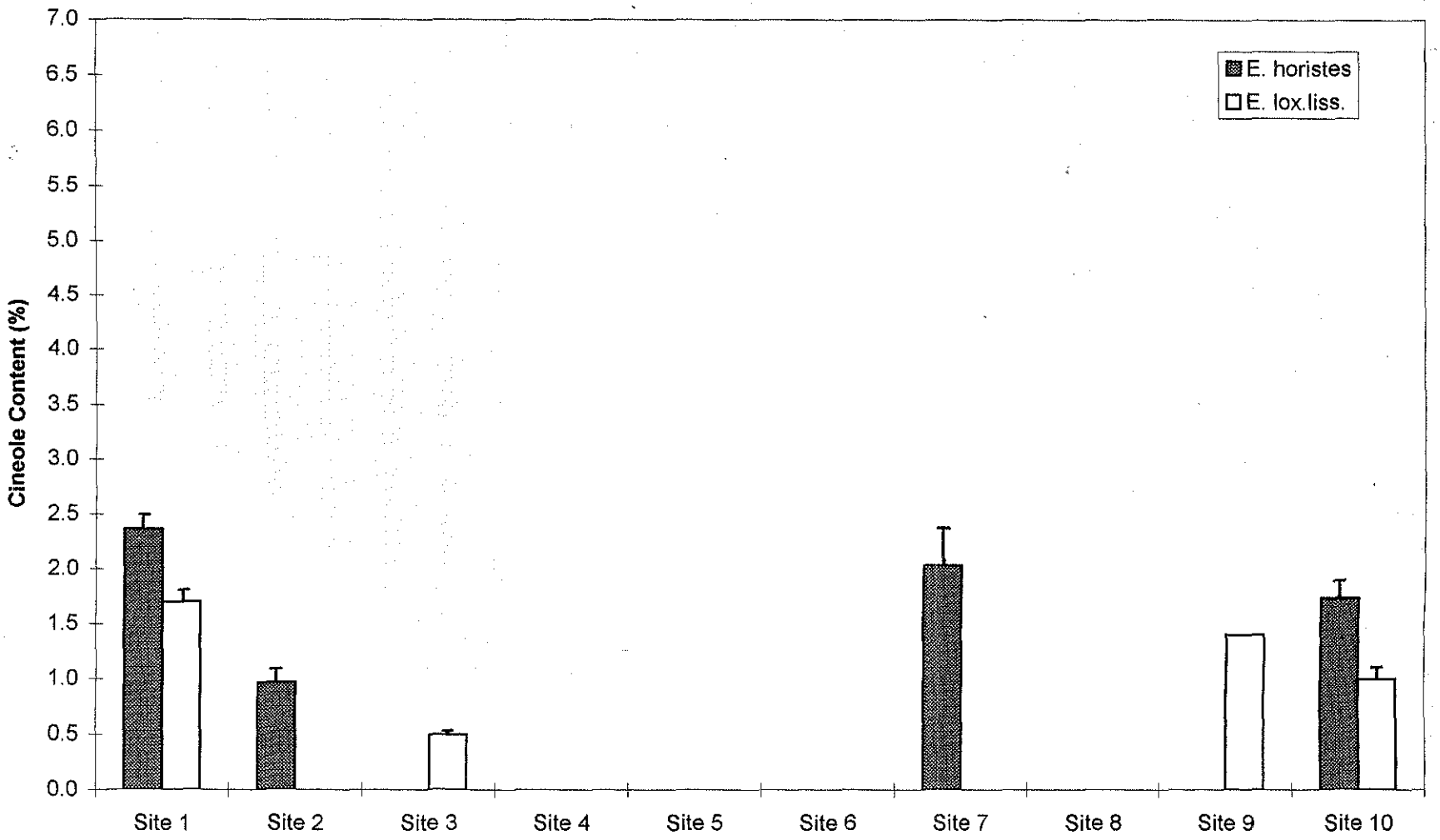


Figure 18 AVERAGE REGROWTH CINEOLE CONTENT



Regrowth cineole content was noticeably lower than the pre-harvest values and differences between sites were found to be significant for both species. However, differences between species were not significant, although *E. horistes* again returned higher values than *E. loxophleba* subsp. *lissophloia*. Rankings showed Site 1 to have the highest values for both species, while Site 2 (*E. horistes*) and Site 3 (*E. loxophleba* subsp. *lissophloia*) had the lowest. Regrowth cineole content could not be determined for Sites 4 and 6 (*E. horistes*) and Sites 5 and 8 (*E. loxophleba* subsp. *lissophloia*) due to the small size of the coppice regrowth (refer Figures 19 and 20).

6.4 Discussion

As leaf cineole concentrations are considered to be genetically determined, significant differences between species were expected. However, the significant differences in cineole content detected between *E. loxophleba* subsp. *lissophloia* sites were surprising. The inclusion of 2 sites with much younger plants (Sites 5 and 9) could be causing this result, as the younger leaves had much lower levels of cineole content than the older plants. This ontogenetic effect has been observed in other oil producing eucalypts (Doran, 1991; Wildy, 1996a). However, even when excluding Sites 5 and 9, the variability between the remaining *E. loxophleba* subsp. *lissophloia* sites is still somewhat greater than that found between *E. horistes* sites. This may point to different seed sources (provenances) of the *E. loxophleba* subsp. *lissophloia* plants studied, or may be due to natural variation in response to environmental conditions (Doran, 1991; Wildy, 1996a). No trend relating to site characteristics could be established to support the latter possibility. Unfortunately, detailed information on species provenance was not available at the time of writing.

Estimates of *E. horistes* cineole yield showed no significant differences at the 95%

confidence level. However, a p-value of 0.054 would still represent statistically significant differences at a 94% confidence level. It is likely that a larger sample size would have resulted in a lower p-value, indicating significance in cineole yield differences between sites. A similar situation was assumed for *E. horistes* pre-harvest fresh weight, where p = 0.079, which would indicate significance at a 92% confidence level (refer Chapter 4). As cineole yield estimates were calculated using fresh weight and leaf cineole content values, a similarity in site rankings between fresh weight, cineole content and cineole yield may have resulted. However, this is not necessarily the case. For example, Site 6 had the lowest cineole content and the second highest fresh weight, yet still returned the lowest yield estimate. Site 10 also had a low cineole content, and the highest fresh weight, but returned the highest yield estimate. An attempt of qualify these results by comparing them to a second growth parameter was not successful either. While both sites occupied the same positions in their rankings for crown volume and dry biomass (refer Table 3, Chapter 4), this trend did not hold for other sites. It is therefore possible, that an additional parameter, which was not examined in this study, has a bearing on cineole yield. It is suggested that crown density, a measure of the number of leaves in relation to crown volume, may be of influence. Crown density is likely to be affected by herbivory and shading caused by neighbouring plants. A study currently being conducted by CALM on plant densities (distances between individual plants) may be able to incorporate an assessment of the effect of shading on projected cineole yields.

It is difficult to argue similarly for *E. loxophleba* subsp. *lissophloia*, as the significant differences in leaf cineole content are likely to be the major determinant in cineole yield estimates. Here a closer look at Site 5 proves to be of interest once again. As expected the young plants at this site had a low leaf cineole content, however, their fresh weight was surprisingly high (refer Table 3, Chapter 4), resulting in a yield

estimate closely resembling that of older plants at Site 1. While Site 1 plants had a lower fresh weight than Site 5's, their cineole content was the highest of all *E. loxophleba* subsp. *lissophloia* sites. It is likely that Site 5 plants will return markedly higher cineole yields once they reach the same age as Site 1's. The performance of *E. loxophleba* subsp. *lissophloia* at Site 5 should be closely monitored over the next 2 years, and compared to other sites of the same age. Site characteristics, particularly in regards to groundwater and soil salinity levels, should be monitored at the same time, as higher salinities may prove to be limiting the growth of this species (refer Chapter 4).

For both species the cineole content of coppice regrowth was lower than pre-harvest cineole concentrations. Site 9 proved to be the only exception. Here *E. loxophleba* subsp. *lissophloia* regrowth had a slightly higher cineole content than that found in pre-harvest analysis. This site is the second of the 2 younger sites, and the result may support the view, that the leaf cineole content of coppice regrowth is higher than that of juvenile growth forms, although still lower than that of more mature plants. Unfortunately, data from Site 5 was not available and no comparison was possible. However, this trend has not been confirmed for other *Eucalyptus* species and may vary between species (Doran, 1991). The theory that leaf oil content could be affected by environmental conditions may prove to be an interesting line of inquiry, as disturbance could be included in that category and coppicing occurs after disturbance.

Overall it can be concluded that *E. horistes* has higher leaf cineole concentrations than *E. loxophleba* subsp. *lissophloia* resulting in higher yield estimates. Juvenile growth forms of *E. loxophleba* subsp. *lissophloia* appear to have lower cineole content than older plants, and some environmental conditions, such as shading, salinity levels and disturbance, may indirectly influence cineole concentrations and yields of both species.

Figure 19 Site 6: Example of *E. horistes* regrowth (Plot C) after sheep grazing (September 1997).

Figure 20 Site 8: Example of *E. loxophleba* subsp. *lissophloia* regrowth (Plot B) (September 1997).

Chapter 7

Planning and Management Considerations for Revegetation Initiatives Incorporating Oil Mallees

"For we are part of the shimmering web

that binds the vast and small,

and what is done to a single strand

has meaning to it all."

Bruce Dawe (1989)

The major difficulty faced by land managers today is the need to integrate environmental and ecological requirements with social and economic considerations. While the necessity of addressing environmental degradation issues has been demonstrated many times, the social and economic costs of doing so usually outweigh it. A tool that combines a solution to the problems posed by land degradation with social and economic benefits represents a much sought after 'win-win' scenario. Revegetation of waterlogged and saline land with oil mallee plantations has the potential to become such a tool. Before that can happen, however, we need to learn more about oil mallees to be able to use them most effectively.

This study has shown that both oil mallee species examined, *E. horistes* and *E. loxophleba* subsp. *lissophloia*, are suitable for use in revegetation projects in the central wheatbelt, due to their comparatively high water usage. Determination of site

characteristics, such as groundwater depth and salinity status, and the comparison and evaluation of various growth, water use and cineole production parameters, have led to the following conclusions:

- *E. horistes* achieves the highest productivity when grown on recharge areas, which are positioned high in the landscape, and are characterised by well-drained, sandy soil, low soil salinity and deep groundwater tables. This species is able to access and use large amounts of groundwater, thereby reducing recharge of the watertable. Its high leaf cineole concentrations, when combined with high productivity in terms of growth, result in high cineole yields.

- *E. loxophleba* subsp. *lissophloia* appears to be a generalist, as it achieves the highest productivity when grown in sandy soil, regardless of landscape position. It is a potentially waterlogging tolerant species, provided soil and groundwater salinities are not excessive (e.g. < 5 mS/cm). This species has the ability to transpire large amounts of water, and may be equally as effective in controlling groundwater levels in recharge as in discharge zones. The particularly high water use estimates for *E. loxophleba* subsp. *lissophloia* coppice regrowth may make periodical harvesting of plants, whether for cineole production or not, an additional management tool in achieving the lowering of watertables. The generally low leaf cineole concentrations result in low yields for this species, except where compensated for by exceptionally high productivity in terms of growth.

- Crown volume, dry biomass or leaf cineole content, when used on their own, are not reliable indicators of a plant's performance in respect of water use or cineole yield. A combination of factors, including fresh weight and crown density, are likely to determine whole plant transpiration and oil yield.

- *E. loxophleba* subsp. *lissophloia* should not be harvested for cineole production before the plants have reached an age of 3 to 4 years. Harvesting as a silvicultural treatment applied at a younger age will induce coppicing and the resulting regrowth may develop higher leaf cineole concentrations.

- Leaf cineole content of parent populations (species provenance) should be studied and recorded prior to seed collection to ensure plantations consist of plants with the highest possible leaf cineole content.

- Sheep should be excluded from oil mallee plantations for a period of 9 to 12 months after harvesting, as they graze the soft shoots of the coppice regrowth. Such exclusion would ensure the successful re-establishment of the plants.

- Weeds compete with coppice regrowth for access to sunlight, therefore weed control measures should be applied prior to harvesting. Pasture does not appear to cause a competition problem.

This study has highlighted that gaps in our knowledge of *E. horistes* and *E. loxophleba* subsp. *lissophloia* still exist. Further research is needed to establish the factors determining crown density, and its effect on cineole yields. Coppice regrowth should be studied in regards to water use and leaf cineole content. Breeding trials to produce plants with higher leaf cineole concentrations, that are also able to tolerate saline soil and groundwater conditions, should be initiated. Water use monitoring of oil mallee species in established trial plantations should be undertaken over a period of 12 months, and compared to the water use of other species recommended for revegetation projects.

Once these gaps in our knowledge have been filled, planners of revegetation projects in the central wheatbelt need to establish the main objective(s) to be achieved, as well as the physical and environmental characteristics of sites available for revegetation. Only then can site specific selection of oil mallee species be attempted. Based on the results of this study, the use of *E. loxophleba* subsp. *lissophloia* is recommended, where the major goal is to reduce groundwater levels, and suitable sites are available. If a combination of high water use and high cineole production is required, and suitable sites are available, the use of *E. horistes* is recommended.

The opening up of a world-wide, industrial market for cineole in fuel additive and solvent applications should be vigorously pursued. The establishment of a cineole producing oil mallee industry in Western Australia would result not only in sound environmental management, but in a range of social and economic benefits as well. Chief among the latter would be income generation and job creation, both of which would aid in stabilising the populations of rural centres, which are currently declining. This in turn would ensure the continued provision of services in these centres. Such flow-on benefits would provide the incentive to revegetate sizeable portions of the central wheatbelt, thus ensuring the survival of the region's native vegetation. Oil mallees can help protect Lake Toolibin.

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Appendices

Appendix 1

Environmental Characteristics Data

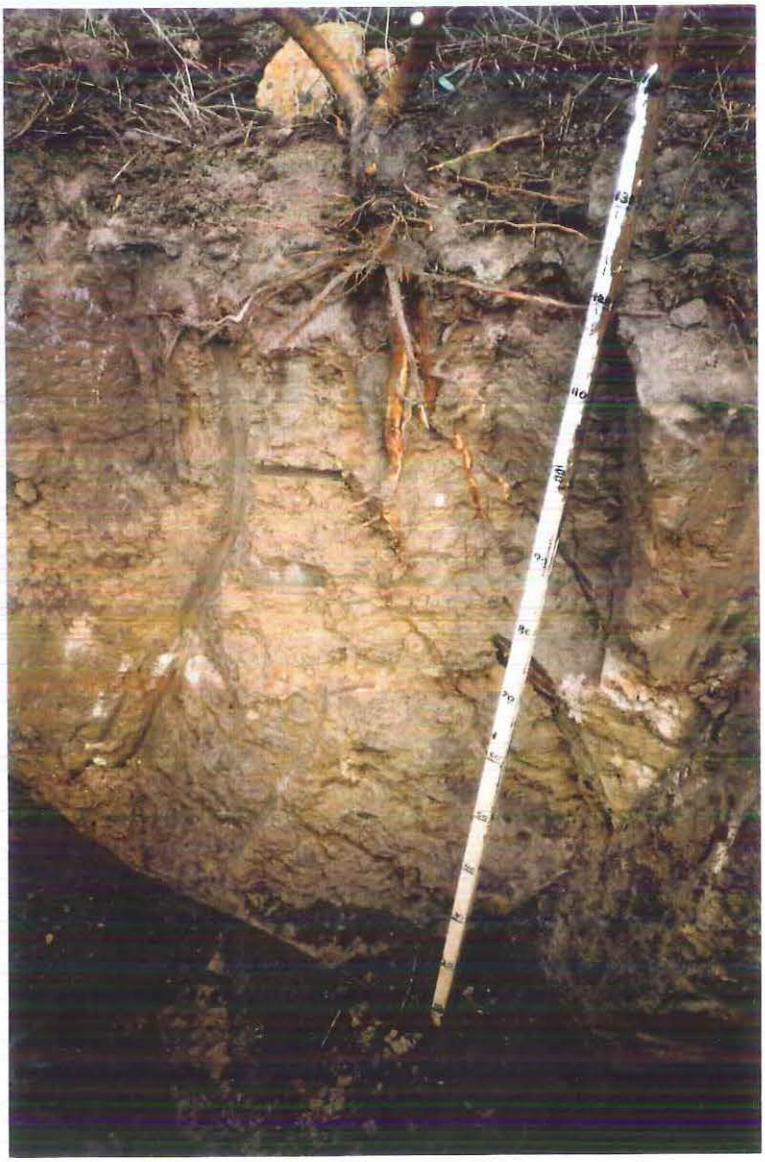
and

Soil Profile Descriptions

Soil Profile Description - Site 1

Horizon	At Depth	Description
A	0 m	Dark grey (10YR4/1D) to very dark greyish brown (10YR3/2M) sand with decomposing plant litter and very fine roots, discrete, columnar quartz crystals of < 2 mm in diameter, polyhedral white feldspar (orthoclase) aggregates of < 1 mm in diameter and organic matter bound soil aggregates of 3 - 9 mm. Gritty texture; non-plastic, consistence non-cohesive under both moist and dry conditions. Abrupt and wavy boundary to B_1 horizon
B_1	0.10 m	Yellowish brown (10YR5/4D) to light brownish grey (10YR6/2M) sandy clay loam with decomposing plant matter of < 2 mm, very fine roots and charcoal fragments of < 2.5 mm; discrete, columnar quartz crystals (< 2 mm); some polyhedral white feldspar aggregates (< 1 mm); and strongly cemented, polyhedral soil aggregates (1 - 11 mm). Slightly soapy texture; slightly plastic when moist; hard consistence when dry, slightly sticky when moist. Clear, wavy boundary to B_2 horizon.
B_2	0.60 m	Very pale brown (10YR7/4D) to light grey (10YR7/2M) sandy clay with few very fine roots; discrete, columnar quartz crystals (< 3 mm); polyhedral white feldspar aggregates (< 4 mm); and moderately cemented, polyhedral soil aggregates (2 - 21 mm). Moderately soapy texture; non-plastic when dry, moderately plastic when moist; strongly cohesive consistence when dry, moderately sticky when moist. Clear, tongued boundary to C horizon.
C	1.00 m	Very pale brown (10YR7/4D) to very pale brown (10YR7/3M) sandy clay with very little recognisable organic matter; discrete, columnar quartz crystals (< 3 mm); polyhedral white feldspar aggregates (< 6 mm); and moderately cemented, polyhedral soil aggregates (3-7 mm). Moderately smooth texture, non-plastic when dry, moderately plastic when moist; slightly sticky consistence when dry, moderately plastic when moist.

Site 1 Soil profile and *E. horistes* lignotuber and roots.



Soil Profile Description - Site 2

Horizon	At Depth	Description
A	0 m	Brown (7.5YR5/2D) to brown (7.5YR4/2M) sand with fine roots and decomposing plant matter; discrete, columnar quartz crystals (< 4 mm); polyhedral white feldspar aggregates (< 1 mm); and very friable, polyhedral soil aggregates (< 5 mm). Gritty texture; non-plastic, non-cohesive consistence. Sharp, smooth boundary to B_1 horizon
B_1	0.09 m	Light yellowish brown (2.5YR6/4D) to light yellowish brown (2.5YR6/3M) sandy clay with few very fine roots and some decomposing plant matter; discrete, columnar quartz crystals (< 4 mm); very few polyhedral white feldspar aggregates (< 0.5 mm); and moderately cemented, polyhedral soil aggregates (3 - 21 mm). Moderately smooth texture; moderately plastic when moist; hard consistence when dry, moderately sticky when moist. A structureless compaction layer begins at 0.30 m depth. Abrupt, smooth boundary to B_2 horizon.
B_2	0.45 m	Dark red (2.5YR4/6D) to dark red (2.5YR3/6M) sandy clay, mottled light grey (10YR7/1D) to light grey (10YR7/2M), with few very fine roots; discrete, columnar quartz crystals (< 2 mm); few polyhedral yellow / white feldspar aggregates (< 0.5 mm); and strongly cemented, polyhedral soil aggregates (< 15 mm). Moderately smooth texture; moderately plastic when moist; hard consistence when dry, sticky when moist. Moist *in-situ*.

Site 2 Soil profile and *E. horistes* lignotuber and roots.

Soil Profile Description - Site 3

Horizon	At Depth	Description
A	0 m	Pale brown (10YR6/3D) to light grey (10YR7/2M) sandy clay with fine roots, some decomposing plant matter and a few charcoal fragments (< 5 mm); discrete, columnar quartz crystals (< 2 mm); no other recognisable minerals; and moderately cemented, polyhedral soil aggregates (2 - 15 mm). Gritty to moderately smooth texture; moderately plastic when moist; slightly sticky consistence when dry, moderately sticky when moist. Moist *in-situ*. Diffuse boundary to B_1 horizon.
B_1	0.15 m	Light yellowish brown (10YR6/4D and M) sandy clay with charcoal fragments (< 4 mm); discrete, columnar quartz crystals (< 5 mm); polyhedral white feldspar (< 4 mm); and well cemented, polyhedral soil aggregates (2 - 26 mm). Moderately smooth texture; moderately plastic when moist; hard consistence when dry, moderately sticky when moist. Moist *in-situ*. Diffuse boundary to B_2 horizon
B_2	0.50 m	Brownish yellow (10YR6/6D) to yellow (10YR7/4M) sandy clay with very few charcoal fragments (< 2 mm), mostly aggregated with minerals; discrete, columnar quartz crystals (< 2 mm); few polyhedral white feldspar aggregates; and moderately cemented, polyhedral soil aggregates (1 -16 mm). Moderately smooth texture; moderately plastic when moist; moderately hard consistence when dry, moderately sticky when moist. Moist *in-situ*. Abrupt, smooth boundary to C horizon.
C	1.40 m	Dark red (2.5YR4/8D and M) sandy clay, mottled light grey (2.5Y7/1D and M), without visible organic matter; discrete, columnar quartz crystals (< 3 mm); polyhedral white feldspar aggregates (< 1.5 mm); and moderately cemented, polyhedral soil aggregates (0.8 - 25 mm). Moderately smooth texture; moderately plastic when moist; moderately hard consistence when dry, moderately sticky when moist. Moist *in-situ*.

Site 3 Soil profile and *E. loxophleba* subsp. *lissophloia* roots.

Soil Profile Description - Site 4

Horizon	At Depth	Description
O	0 m	Dry litter made up of leaves, twigs, blades, bark, fruits, flowers, bud caps and little mineral matter
A	0 01 m	Greyish brown (10YR5/2D) to dark greyish brown (10YR4/2M) sand with very fine roots, decomposing plant matter and charcoal fragments (< 5 mm),discrete, columnar quartz crystals (< 13 mm), friable, granular ironstone aggregates (< 7 mm) and very friable, polyhedral soil aggregates (2 - 14 mm) Gritty texture, non-plastic, consistence non-cohesive Gradual, gammate boundary to B_1 horizon
B_1	0.10 m	Light brown (7 5YR6/4D) to light brown (7 5YR6/3M) clay with some very fine roots and numerous charcoal fragments (2 - 24 mm); discrete, columnar to polyhedral quartz crystals (< 4 mm); and polyhedral, moderately friable ironstone and soil aggregates (< 12 mm). Includes a distinct, but discontinuous charcoal layer at 0.30 m depth Moderately smooth texture; moderately plastic when moist; consistence moderately sticky when moist. Diffuse boundary to B_2 horizon
B_2	0 40 m	Pinkish grey (7.5YR7/2D) to pink (7.5YR7/3M) sandy clay with a few very fine roots and charcoal fragments (< 1 5 mm), discrete, columnar to polyhedral quartz crystals (< 6 mm), and moderately friable to hard ironstone and soil aggregates (3 - 12 mm). Slightly smooth texture; very slightly plastic when moist; moderately hard consistence when dry, slightly sticky when moist. Diffuse boundary to C horizon.
C	1.00 m	Pink (7.5YR7/3D) to pink (7.5YR7/4M) sandy loam with charcoal fragments (< 4 mm); discrete, columnar to polyhedral quartz crystals (< 20 mm); discrete, granular to polyhedral biotite particles (< 5 mm); and slightly cemented granular ironstone and soil aggregates (< 14 mm). Slightly smooth texture, slightly plastic when moist, slightly sticky consistence when moist.

Site 4 Soil profile and part of *E. horistes* lignotuber and roots.

Soil Profile Description - Site 5

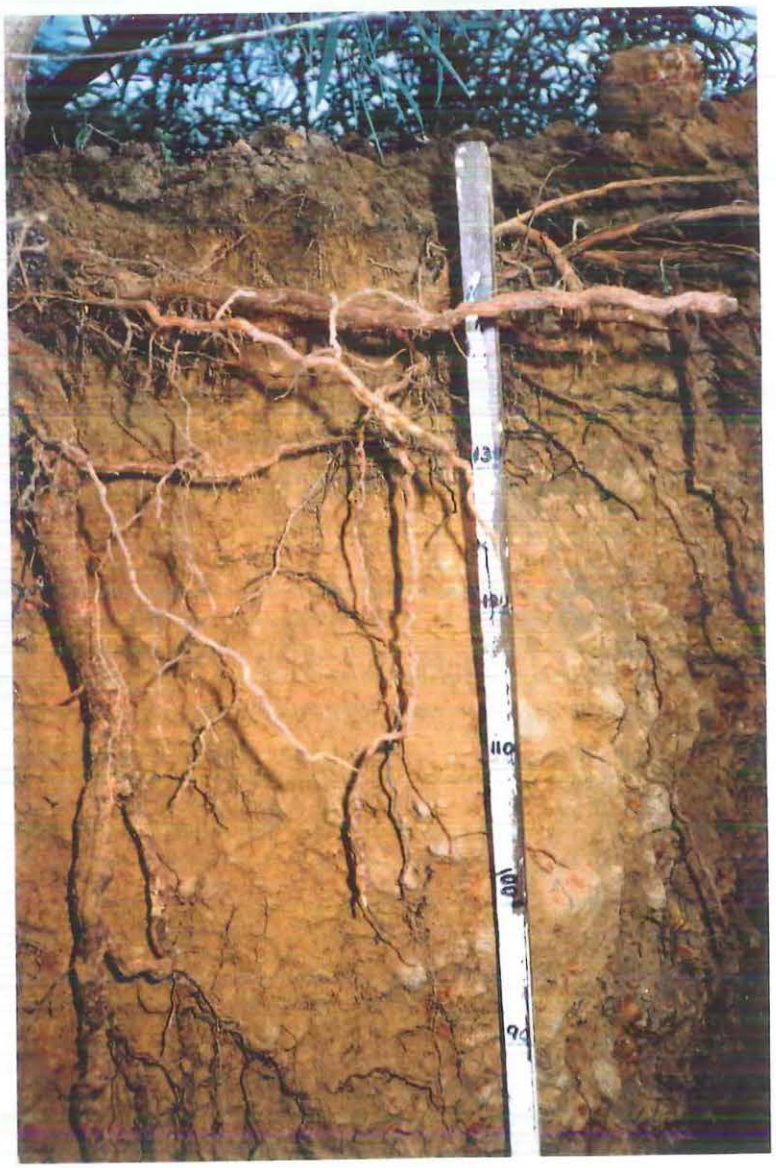
Horizon	At Depth	Description
A	0 m	Dark reddish grey (5YR4/2D and M) sand with very fine roots, decomposing plant matter and a few charcoal fragments (< 1 mm), discrete, columnar quartz crystals (< 3 mm); some polyhedral white feldspar aggregates (< 1 mm), and very friable polyhedral soil aggregates (< 7 mm). Gritty texture, non-plastic, consistence non-cohesive under both dry and moist conditions. Moist *in-situ*. Abrupt, smooth boundary to B_1 horizon.
B_1	0.12 m	Yellowish red (5YR5/6D) to reddish yellow (5YR6/6M) sand with very fine roots; dominated by discrete, columnar quartz crystals (< 3 mm), and some polyhedral white feldspar aggregates (< 1 mm). No soil aggregates, and a discontinuous layer of charcoal at a depth of 0.25 m. Gritty texture; non-plastic; consistence non-cohesive under both dry and moist conditions. Moist *in-situ*. Clear, smooth boundary to B_2 horizon.
B_2	0.70 m	Reddish yellow (7.5YR6/8D) to reddish yellow (7.5YR7/6M) sandy loam with fine roots; dominated by discrete, columnar quartz crystals (< 7 mm); some discrete, semi-lenticular biotite particles (< 6 mm); very few polyhedral feldspar aggregates (< 3 mm); and polyhedral to lenticular, very friable soil aggregates (1 - 11 mm). Slightly sticky texture; non-plastic; consistence non-cohesive when dry, slightly sticky when moist. Moist *in-situ*, and showing a to tendency to mottling. Diffuse boundary to C horizon.
C	1.10 m	Reddish yellow (7.5YR6/6D) to reddish yellow (7.5YR7/6M) sandy clay loam without visible organic matter; dominated by discrete, columnar quartz crystals (< 4 mm); with discrete, semi-lenticular biotite particles (< 6 mm); some polyhedral to lenticular, very friable soil aggregates (1 - 20 mm). Moderately smooth texture; slightly plastic; slightly sticky consistence when moist. Moist *in-situ*.

Site 5 Soil profile and *E. loxophleba* subsp. *lissophloia* lignotuber and roots.

Soil Profile Description - Site 6

Horizon	At Depth	Description
A	0 m	Light brown (7 5YR6/4D) to brown (7 5YR5/3M) sand with fine roots and decomposing plant matter, granular, strongly cemented ironstone pebbles (4 - 36 mm), discrete columnar quartz crystals (< 2 mm) polyhedral white feldspar aggregates (< 3 mm) discrete lenticular to polyhedral biotite particles (< 6 mm), and no soil aggregates Gritty texture, non-plastic, non-cohesive consistence, water repellent (infiltration tap water up to 5 minutes, deionised water up to 4 minutes 0 5M ethanol/deionised water up to 3 minutes 1M ethanol/deionised water less than 10 seconds) Clear, irregular boundary to B horizon
B	0.10 m	Brownish yellow (10YR6/6D) to yellowish brown (10YR5/6M) sand with very fine roots and decomposing plant matter, platy to granular, strongly cemented ironstone pebbles (2 - 43 mm); discrete, columnar quartz crystals (< 4 mm); polyhedral white feldspar aggregates (< 2 mm); and discrete, lenticular to polyhedral biotite particles (< 7 mm). Gritty texture, non-plastic, consistence non-cohesive under both dry and moist conditions. Gradual boundary to C_1 horizon
C_1	0.90 m	Yellow (10YR7/6D) to brownish yellow (10YR6/8M) sandy loam with very fine roots; granular, strongly cemented ironstone pebbles (< 58 mm); discrete, columnar quartz crystals (< 5 mm); polyhedral white feldspar aggregates (< 3 mm); discrete, lenticular to polyhedral biotite particles (< 6 mm); and platy to polyhedral, strongly cemented ironstone, quartz and feldspar aggregates (2 - 58 mm). Slightly soapy texture; non-plastic; slightly sticky consistence when moist. Diffuse boundary to C_2 horizon.
C_2	1.40 m	Brownish yellow (10YR6/6D) to brownish yellow (10YR6/8M) sand with fine roots; very strongly cemented ironstone pebbles and cobbles (1.5 - 84 mm); discrete, columnar quartz crystals (< 4 mm); polyhedral white feldspar aggregates (< 3 mm); and lenticular biotite particles (< 3 mm). Gritty texture; non-plastic; consistence very slightly sticky when moist.

Site 6 Soil profile and part of *E. horistes* lignotuber and roots.



Soil Profile Description - Site 7

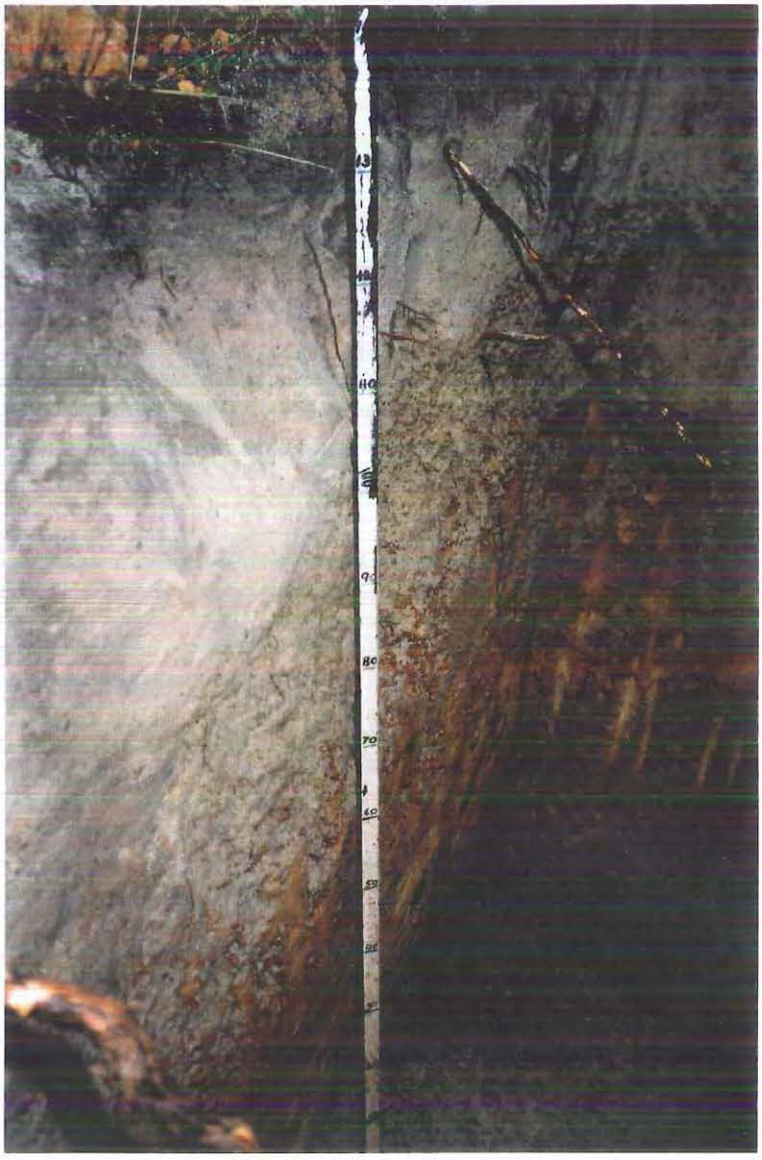
Horizon	At Depth	Description
O	0 m	Dry litter made up of leaves, twigs, blades and very little mineral matter
A	0.05 m	Dark greyish brown (10YR4/2D) to very dark grey (10YR3/1M) loamy sand with very fine roots and decomposing plant matter, discrete columnar quartz crystals (< 5 mm); polyhedral white feldspar aggregates (< 3 mm); and friable polyhedral soil aggregates (< 25 mm) Moderately smooth texture; non-plastic when dry, moderately plastic when moist; non-cohesive consistence when dry, moderately sticky when moist. Diffuse boundary to B horizon.
B	0.25 m	Brown (10YR5/3D) to brown (10YR4/3M) loamy sand with fine roots; discrete, columnar quartz crystals (< 5 mm); polyhedral white feldspar (< 4 mm); and strongly cemented, polyhedral soil aggregates (< 18 mm). Moderately soapy texture; moderately plastic when moist; hard consistence when dry, moderately sticky when moist. Diffuse boundary to C horizon.
C	0.85 m	Very pale brown (10YR8/2D) to very pale brown (10YR8/3M) clay without visible organic matter; very few discrete, columnar quartz crystals (< 5 mm); no visible feldspar; friable, polyhedral soil aggregates (< 12 mm) showing slightly pink hue (5YR8/4D) internally when broken up. Smooth texture; very plastic when moist; smooth consistence when dry, soft and smooth when moist.

Site 7 Soil profile and part of *E. horistes* lignotuber and roots.

Soil Profile Description - Site 8

Horizon	At Depth	Description
A	0 m	Grey (10YR6/1D) to grey (10YR5/1M) sand with very fine roots and decomposing plant matter; discrete, columnar quartz crystals (< 4 mm); a few very friable, polyhedral ironstone aggregates (< 2 mm), and highly friable, polyhedral soil aggregates of varying sizes. Gritty texture; non-plastic; non-cohesive consistence. Clear, wavy boundary to B_1 horizon.
B_1	0.12 m	Light grey (10YR7/2D) to very pale brown (10YR7/3M) sand with fine roots and decomposing plant matter; discrete, columnar quartz crystals (< 4 mm); and a few friable, granular ironstone aggregates (< 3 mm). Gritty texture; non-plastic; consistence non-cohesive. Diffuse boundary to B_2 horizon.
B_2	0.32 m	Very pale brown (10YR7/4D) to very light brown (10YR7/3M) sand with very fine roots; discrete, columnar quartz crystals (< 3 mm); and moderately cemented, granular to polyhedral ironstone pebbles (3.5 - 37 mm), forming a transition zone between B_1 and C horizons. Gritty texture; non-plastic; -consistence non-cohesive under both dry and moist conditions.
C	0.80 m	Reddish yellow (7.5YR7/6D) to reddish yellow (7.5YR6/6M) sand with very fine roots; discrete, columnar quartz crystals (< 5 mm); a few very friable white feldspar aggregates (< 1.5 mm); and very strongly cemented, polyhedral ironstone aggregates and pebbles (0.2 - 80 mm). Gritty texture; non-plastic; hard consistence when dry, slightly sticky when moist.

Site 8 Soil profile and part of *E. loxophleba* subsp. *lissophloia* roots.



Soil Profile Description - Site 9

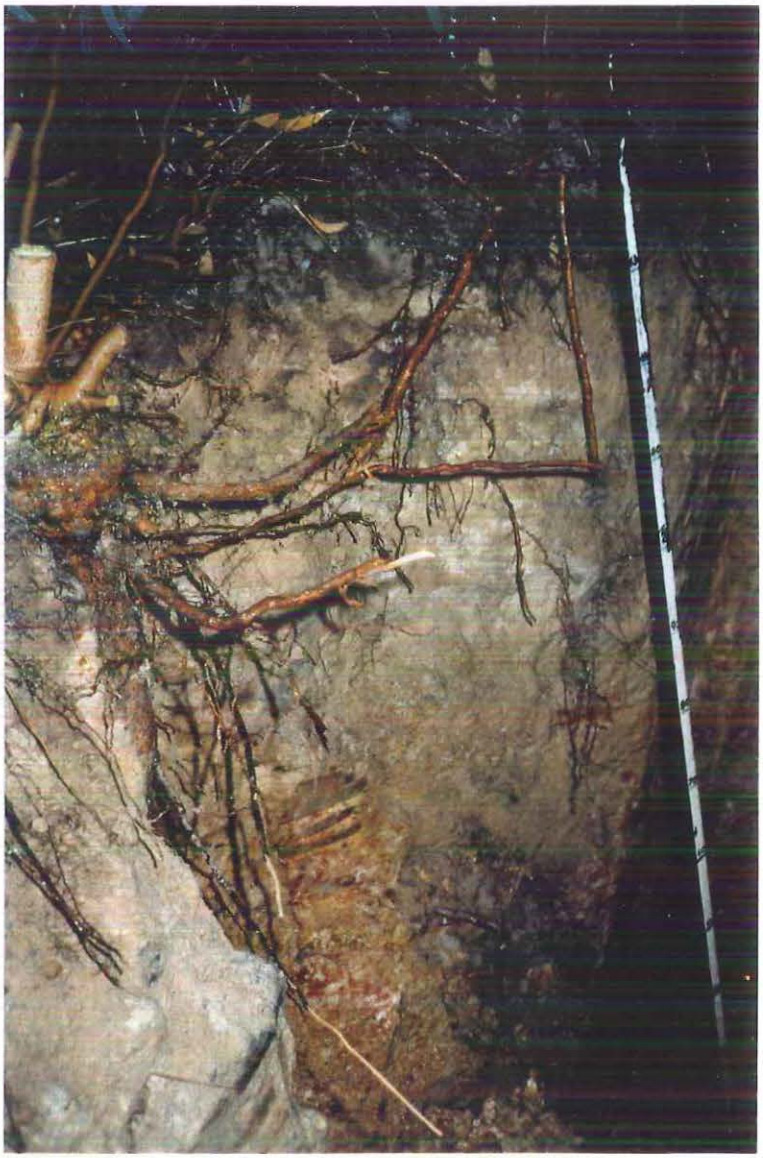
Horizon	At Depth	Description
O	0 m	Densely matted fine to very fine roots and mosses with some very dark grey (10YR3/1M) sand consisting of discrete, columnar quartz crystals (< 2 mm) and very friable, granular ironstone aggregates (< 3 mm) attached to the roots. Moist *in-situ*. Sharp, smooth boundary to A horizon.
A	0.02 m	Brown (10YR5/3D) to dark greyish brown (10YR4/2M) sand with fine roots and charcoal fragments (< 4 mm); discrete, columnar to polyhedral quartz crystals (< 4 mm); friable, granular ironstone pebbles (2 - 15 mm); and very friable lenticular to polyhedral soil aggregates (2 - 51 mm). Gritty texture; non-plastic; consistence non-cohesive under both dry and moist conditions. Moist *in-situ*. Gradual, irregular boundary to B_1 horizon.
B_1	0.14 m	Brownish yellow (10YR6/6D) to yellow (10YR7/6M) sandy clay loam with very fine roots; discrete, columnar quartz crystals (< 4 mm); and very friable, polyhedral soil aggregates (3 - 31 mm). Slightly smooth texture; moderately plastic when moist; consistence slightly sticky when moist. Moist *in-situ*. Clear, smooth boundary to B_2 horizon.
B_2	0.48 m	Brownish yellow (10YR6/8D) to brownish yellow (10YR6/6M) sandy loam with a few fine roots; discrete, columnar quartz crystals (< 5 mm); a few white feldspar aggregates (< 3 mm); and friable, polyhedral soil aggregates (2 - 65 mm). Moderately smooth texture; very slightly plastic when moist; consistence moderately sticky when moist. Gradual boundary to B_3 horizon.
B_3	0.58 m	Brownish yellow (10YR6/6D and M) sandy loam without visible organic matter; discrete, columnar quartz crystals (< 3 mm); polyhedral white feldspar aggregates (< 4 mm); very friable, polyhedral ironstone pebbles and cobbles (< 10 mm); and very friable, polyhedral soil aggregates (2 - 67 mm). Gritty to moderately smooth texture; moderately plastic when moist; consistence moderately hard when dry, moderately sticky when moist. Diffuse boundary to C horizon.
C	0.98 m	Yellow (10YR7/6D and M) clay loam without visible organic matter; discrete, columnar quartz crystals (< 4 mm); very friable, polyhedral white feldspar aggregates (< 4 mm); and lenticular to polyhedral, moderately friable to hard ironstone cobbles and soil aggregates (1 - 83 mm). Moderately soapy texture; moderately plastic when moist; consistence moderately hard when dry, moderately sticky when moist.

Site 9 Soil profile and part of *E. loxophleba* subsp. *lissophloia* lignotuber and roots.

Soil Profile Description - Site 10

Horizon	At Depth	Description
O	0 m	Dry litter made up of leaves, twigs, blades and some ironstone gravel (8 - 19 mm diameter).
A	0.05 m	Pale yellow (2.5Y7/3D) to light olive brown (2.5Y5/3M) sand with fine roots, decomposing leaves and charcoal fragments (< 5 mm); dominated by discrete, columnar quartz crystals (< 3 mm); some polyhedral white feldspar aggregates (< 2 mm); and granular ironstone pebbles (5 - 26 mm). Gritty texture; non-plastic; non-cohesive consistence. Abrupt and almost smooth boundary to B horizon.
B	0.13 m	Light yellowish brown (10YR6/4D and M) sandy clay with few very fine roots, some decomposing plant matter, and charcoal fragments (< 3 mm); discrete, columnar quartz crystals (< 3 mm); polyhedral red and white feldspar aggregates (< 0.8 mm); and strongly cemented polyhedral soil aggregates (< 15 mm). Gritty texture; non-plastic; hard consistence when dry, slightly sticky when moist. A discontinuous charcoal layer is located at 0.33 m depth, and a structureless compaction layer begins at 0.35 m. Diffuse boundary to C horizon.
C	0.63 m	Reddish yellow (7.5YR7/6D) to reddish yellow (7.5YR6/6M) sandy clay loam without visible organic matter; discrete, columnar quartz crystals (< 5 mm); polyhedral white feldspar (< 3 mm); and polyhedral, strongly cemented aggregates (< 14 mm) showing red (2.5YR5/6D) discolourations. Moderately smooth texture; moderately plastic when moist; hard consistence when dry, slightly sticky when moist.

Site 10 Soil profile and *E. horistes* lignotuber and roots.



GROUNDWATER DATA

Site	Bore Depth (m)	Depth #1 (m)	Depth #2 (m)	Depth #3 (m)	mS/cm #1	mS/cm #2	mS/cm #3	pH #1	pH #2	pH #3
1	2.70		1.87	2.58		4.60	4.92		8.14	8.06
2	not known	1.30	1.01	0.99	25.80	25.60	23.22	5.70	6.90	8.01
3	not known	1.29	0.96	0.51	27.30	28.30	26.70	7.19	7.10	8.47
4	2.80	No samples obtained.								
5	not known	0.70	0.70	0.68	3.20	2.94	2.77	8.23	8.21	7.85
6	5.20	4.97	No samples obtained.		1.31			7.40		
7	5.20	No samples obtained.								
8	3.00	No samples obtained.								
9	5.20	No samples obtained.								
10	5.20	No samples obtained.								

CALM Soil Particle Size Analysis

Site	Horizon	% Sand	% Silt	% Clay
1	A	92.48	2.76	4.76
	B_1	68.00	2.19	29.82
	B_2	61.32	2.84	35.84
	C	65.47	1.81	32.72
2	A	95.77	2.44	1.78
	B_1	66.23	1.43	32.35
	B_2	57.22	1.94	40.85
3	A	60.68	3.47	35.85
	B_1	62.15	2.95	34.90
	B_2	60.75	4.44	34.81
	C	59.30	2.86	37.84
4	A	92.09	3.24	4.67
	B_1	51.78	5.45	42.77
	B_2	62.30	3.47	34.23
	C	83.96	2.14	13.89
5	A	94.67	2.96	2.37
	B_1	95.61	0.72	3.66
	B_2	81.61	0.46	17.92
	C	80.08	1.08	18.84
6	A	93.26	2.15	4.59
	B	90.59	1.64	7.77
	C_1	81.17	1.48	17.35
	C_2	89.74	1.89	8.37
7	A	84.86	6.36	8.78
	B	81.88	9.46	8.67
	C	39.92	6.08	54.00
8	A	97.91	0.18	1.91
	B_1	98.93	0.75	0.32
	B_2	97.82	1.50	0.67
	C	97.02	2.33	0.65
9	A	93.98	3.26	2.76
	B_1	73.24	4.55	22.21
	B_2	84.70	5.16	10.14
	B_3	79.31	5.54	15.15
	C	65.28	8.98	25.74
10	A	96.16	1.98	1.87
	B	68.39	1.65	29.96
	C	67.65	6.13	26.22

SOIL DATA

Site	Horizon	% O.M. Content	mS/cm #1	mS/cm #2	mS/cm #3	pH #1	pH #2	pH #3
1	A	1.60	0.12	0.06	0.05	6.78	5.52	6.02
	B_1	2.49	0.40	0.12	0.08	8.13	7.70	7.64
	B_2		0.60			9.02		
	C		0.70			8.61		
2	A	1.70	0.02	0.09	0.14	7.07	6.93	7.45
	B_1	2.20	0.21	0.26	0.24	7.64	8.18	8.43
	B_2		0.89			7.35		
3	A	2.99	0.24	0.06	0.14	7.32	6.81	6.83
	B_1	2.70	0.63	0.22	0.14	7.78	7.24	7.90
	B_2		0.65			8.22		
	C		0.75			8.01		
4	A	2.87	0.06	0.02	0.07	6.60	6.88	5.88
	B_1	4.90	0.08	0.02	0.06	6.74	7.01	6.84
	B_2		0.06			6.99		
	C		0.06			7.21		
5	A	3.00	0.20	0.06	0.44	6.63	7.11	5.79
	B_1	0.90	0.02	0.37	0.26	7.02	8.38	6.65
	B_2		0.05			7.10		
	C		0.06			7.55		
6	A	7.30	0.04	0.01	0.04	6.61	6.94	5.72
	B	4.15	0.02		0.02	6.45		5.69
	C_1		0.01			7.08		
	C_2		0.01			7.09		
7	A	6.49	0.17	0.07	0.36	6.20	6.35	5.83
	B	1.90	0.20	0.10	0.12	7.60	6.11	5.88
	C		0.12			7.20		
8	A	0.60	0.01	0.01	0.02	7.05	7.08	6.61
	B_1	0.20	0.01	0.01	0.01	7.09	7.13	6.51
	B_2		0.01			7.00		
	C		0.01			6.70		
9	A	4.65	0.05	0.04	0.06	6.41	6.15	5.85
	B_1	1.70	0.02	0.02	0.03	6.57	6.38	5.95
	B_2		0.02			6.90		
	B_3		0.03			6.88		
	C		0.03			6.91		
10	A	1.59	0.01	0.03	0.03	7.07	6.56	6.13
	B	1.75	0.04	0.05	0.03	7.05	7.08	6.29
	C		0.11			7.29		

Soil Nutrient Analysis - A Horizon only

Site #	Soil Type	Total N (%)	Total N (ppm)	N Status*	Total P (%)	Total P (ppm)	P Status**
1	Sand	0.078	780.00	Low.	0.024	239.39	Ok.
2	Sand	0.078	780.00	Low.	0.008	78.58	Deficient.
3	Sandy Clay	0.010	100.00	Low.	0.002	20.61	Deficient.
4	Sand	0.131	1310.00	Ok.	0.015	145.31	Very low.
5	Sand	0.131	1310.00	Ok.	0.021	213.13	Ok.
6	Sand	0.194	1940.00	Ok.	0.028	280.95	Ok.
7	Loamy Sand	0.141	1410.00	Ok.	0.002	24.98	Deficient.
8	Sand	0.011	110.00	Low.	0.005	45.77	Deficient.
9	Sand	0.181	1810.00	Ok.	0.023	227.35	Ok.
10	Sand	0.020	200.00	Low.	0.002	24.98	Deficient.

* Desirable range: 0.05 to 0.3% or 500 to 3000 ppm; Deficiency limit: 0.007% or 70 ppm total nitrogen (Charman and Murphy, 1991).

** Desirable range: 0.02 to 0.15 % or 200 - 1500 ppm; Deficiency limit: 0.0006 % or 6 ppm total phosphorus (Charman and Murphy, 1991).

Appendix 2

Data for Growth Parameters

SAMPLE SHEET FOR FIELD DATA COLLECTION

SITE No.: 5 **SITE NAME:** *Bird's* **DATE:** *5.4.97*

General Comments: *Waterlogged, remnant next door: trees dying. Bottom of slope. Existing bore. No pasture. About 7m between twin rows. All plots 5 x 2 plants. Rows roughly E-W. Lots of ants!*

PLOT: *A* **Species:** *E. lox.liss.* **Location ID:** *Third twin row from gate.* **Photo:** *20*

Oil Sample Bottle No.: *A0996* **Depth to Water Table:** *50 cm*

Soil Sample Notes: *In row 8, near road end. Paddock has been cultivated (ripped) to about 40 cm! B horizon moist.*

Plant No.	1	2	3	4	5	6	7	8	9	10
Height (cm)	*180*	*170*	*141*	*175*	*195*	*250*	*170*	*116*	*141*	*163*
Crown ø al. (cm)	*145*	*140*	*115*	*152*	*170*	*158*	*138*	*94*	*137*	*124*
Crown ø ac. (cm)	*144*	*132*	*112*	*157*	*142*	*16*	*145*	*65*	*131*	*115*
Stem ø (cm)	*3.2*	*4.5*	*2.55 (9)*	*4.7*	*4.2*	*4.9*	*4.0*	*2.25*	*2.9*	*3.05*
Biomass (kg)		*2.4*								

Average Height: *170.1* Ave. Crown ø al.: *137.3* Ave. Crown ø ac.: *115.9*

CROWN VOLUME INDEX
#1

Site & Plot	Species	Ave Height (cm)	Ave ø Across (cm)	Ave ø Along (cm)	CVI (m^3)	Std. error
1A	Eh	119.40	122.70	122.70	1.7976	
1C	Eh	112.80	140.60	140.60	2.2299	
1F	Eh	114.60	139.00	139.00	2.2142	
Ave.	**Eh**	**115.60**	**134.10**	**134.10**	**2.0806**	0.1415
1B	Ell	173.50	125.00	125.00	2.7109	
1D	Ell	142.40	112.00	112.00	1.7863	
1E	Ell	228.20	146.60	146.60	4.9044	
Ave.	**Ell**	**181.37**	**127.87**	**127.87**	**3.1339**	0.9246
2A	Ell	146.90	118.00	128.50	2.2274	
2B	Ell	131.40	122.90	132.10	2.1333	
2C	Ell	133.00	131.60	126.70	2.2176	
Ave.	**Ell**	**137.10**	**124.17**	**129.10**	**2.1928**	0.0299
3A	Eh	124.80	132.20	140.50	2.3180	
4B	Eh	143.80	151.10	154.90	3.3657	
3C	Eh	172.20	165.40	177.90	5.0669	
Ave.	**Eh**	**146.93**	**149.57**	**157.77**	**3.5836**	0.8010
4A	Eh	161.50	164.20	169.80	4.5028	
4B	Eh	155.80	144.30	163.70	3.6803	
4C	Eh	144.00	177.80	174.00	4.4550	
Ave.	**Eh**	**153.77**	**162.10**	**169.17**	**4.2127**	0.2666
5A	Ell	170.10	137.30	130.00	3.0361	
5B	Ell	183.10	152.30	149.30	4.1634	
5C	Ell	182.50	150.30	154.00	4.2242	
Ave.	**Ell**	**178.57**	**146.63**	**144.43**	**3.8079**	0.3863
6A	Eh	129.30	151.80	164.90	3.2366	
6B	Eh	116.10	150.80	155.50	2.7225	
6C	Eh	118.60	151.50	155.00	2.7850	
Ave.	**Eh**	**121.33**	**151.37**	**158.47**	**2.9147**	0.1620
7A	Eh	188.00	141.30	141.30	3.7535	
7B	Eh	167.00	163.50	163.50	4.4643	
7C	Eh	190.00	174.00	174.00	5.7524	
Ave.	**Eh**	**181.67**	**159.60**	**159.60**	**4.6568**	0.5850
8A	Ell	219.10	171.70	175.60	6.6060	
8B	Ell	206.90	187.20	182.50	7.0685	
8C	Ell	229.20	207.20	189.30	8.9899	
Ave.	**Ell**	**218.40**	**188.70**	**182.47**	**7.5548**	0.7299
9A	Ell	131.00	102.30	92.00	1.2329	
9B	Ell	118.10	92.00	99.40	1.0800	
9C	Ell	122.10	103.20	92.40	1.1643	
Ave.	**Ell**	**123.73**	**99.17**	**94.60**	**1.1591**	0.0442
10A	Eh	165.50	206.50	206.50	7.0573	
10B	Eh	178.30	200.70	200.70	7.1820	
10C	Eh	184.60	199.10	199.10	7.3177	
Ave.	**Eh**	**176.13**	**202.10**	**202.10**	**7.1857**	0.0752
10D	Ell	231.20	198.50	198.50	9.1098	
10E	Ell	201.80	160.00	160.00	5.1661	
10F	Ell	225.30	191.50	191.50	8.2623	
Ave.	**Ell**	**219.43**	**183.33**	**183.33**	**7.5127**	1.1986

CROWN VOLUME INDEX
#2

Site & Plot	Species	Ave Height (cm)	Ave ø Across (cm)	Ave ø Along (cm)	CVI (m^3)
1A	Eh	23.50	22.90	26.60	0.0143
1C	Eh	28.90	32.60	33.10	0.0312
1F	Eh	23.78	26.67	26.44	0.0168
Ave.	**Eh**	**25.39**	**27.39**	**28.71**	**0.0208**
1B	Ell	32.80	34.60	36.60	0.0415
1D	Ell	28.60	33.90	34.70	0.0336
1E	Ell	34.90	37.80	40.80	0.0538
Ave.	**Ell**	**32.10**	**35.43**	**37.37**	**0.0430**
2A	Ell	15.50	26.60	23.40	0.0096
2B	Ell	24.30	35.70	36.30	0.0315
2C	Ell	17.90	27.60	27.10	0.0134
Ave.	**Ell**	**19.23**	**29.97**	**28.93**	**0.0182**
3A	Eh	16.60	24.80	28.80	0.0119
3B	Eh	12.80	20.50	21.40	0.0056
3C	Eh	17.90	23.90	26.20	0.0112
Ave.	**Eh**	**15.77**	**23.07**	**25.47**	**0.0096**
4A	Eh	0.10	0.10	0.10	0.0000
4B	Eh	0.00	0.00	0.00	0.0000
4C	Eh	1.80	2.05	1.70	0.0000
Ave.	**Eh**	**0.63**	**0.72**	**0.60**	**0.0000**
5A	Ell	2.10	2.50	3.30	0.0000
5B	Ell	1.60	2.70	2.20	0.0000
5C	Ell	3.10	5.00	4.80	0.0001
Ave.	**Ell**	**2.27**	**3.40**	**3.43**	**0.0000**
6A	Eh	7.90	6.55	5.75	0.0003
6B	Eh	8.70	9.00	10.55	0.0008
6C	Eh	9.70	14.30	12.90	0.0018
Ave.	**Ell**	**8.77**	**9.95**	**9.73**	**0.0010**
7A	Eh	31.70	35.10	36.70	0.0408
7B	Eh	25.40	29.70	30.00	0.0226
7C	Eh	38.70	41.40	42.90	0.0687
Ave.	**Eh**	**31.93**	**35.40**	**36.53**	**0.0441**
8A	Ell	0.10	0.05	0.10	0.0000
8B	Ell	0.60	0.55	0.55	0.0000
8C	Ell	0.22	0.22	0.27	0.0000
Ave.	**Ell**	**0.31**	**0.27**	**0.31**	**0.0000**
9A	Ell	1.90	1.50	1.50	0.0000
9B	Ell	11.80	7.90	7.90	0.0007
9C	Ell	8.50	6.05	7.25	0.0004
Ave.	**Ell**	**7.40**	**5.15**	**5.55**	**0.0004**
10A	Eh	26.20	39.90	41.10	0.0430
10B	Eh	21.30	29.50	33.00	0.0207
10C	Eh	24.20	33.60	32.50	0.0264
Ave.	**Eh**	**23.90**	**34.33**	**35.53**	**0.0300**
10D	Ell	31.70	44.30	41.40	0.058
10E	Ell	30.00	41.00	44.90	0.0552
10F	Ell	35.70	42.90	47.90	0.0734
Ave.	**Ell**	**32.47**	**42.73**	**44.73**	**0.0622**

CROWN VOLUME INDEX
#3

Site & Plot	Species	Ave Height (cm)	Ave ø Across (cm)	Ave ø Along (cm)	CVI (m^3)	Std. error
1A	Eh	25.67	20.56	24.56	0.0130	
1C	Eh	31.33	29.56	30.78	0.0285	
1F	Eh	24.63	26.75	25.88	0.0171	
Ave.	**Eh**	**27.21**	**25.62**	**27.07**	**0.0195**	0.0047
1B	Ell	32.44	36.44	37.00	0.0437	
1D	Ell	29.22	34.11	34.22	0.0341	
1E	Ell	36.89	40.33	40.33	0.0600	
Ave.	**Ell**	**32.85**	**36.96**	**37.18**	**0.0459**	0.0076
2A	Eh	21.89	26.67	27.00	0.0158	
2B	Eh	15.44	20.22	20.44	0.0064	
2C	Eh	18.67	22.78	22.67	0.0096	
Ave.	**Eh**	**18.67**	**23.22**	**23.37**	**0.0106**	0.0027
3A	Ell	18.22	34.22	34.44	0.0215	
3B	Ell	26.44	40.11	37.78	0.0401	
3C	Ell	19.89	28.00	34.44	0.0192	
Ave.	**Ell**	**21.52**	**34.11**	**35.55**	**0.0269**	0.0066
4A	Eh	6.30	2.60	4.85	0.0001	
4B	Eh	7.90	3.40	4.90	0.0001	
4C	Eh	10.70	8.40	11.70	0.0011	
Ave.	**Eh**	**8.30**	**4.80**	**7.15**	**0.0004**	0.0003
5A	Ell	0.30	0.20	0.80	0.0000	
5B	Ell	1.78	1.11	2.00	0.0000	
5C	Ell	1.05	0.75	1.30	0.0000	
Ave.	**Ell**	**1.04**	**0.69**	**1.37**	**0.0000**	0.0000
6A	Eh	9.40	4.00	7.20	0.0003	
6B	Eh	10.40	5.20	6.30	0.0003	
6C	Eh	10.50	7.40	6.60	0.0005	
Ave.	**Eh**	**10.10**	**5.53**	**6.70**	**0.0004**	0.0001
7A	Eh	32.89	31.22	34.78	0.0357	
7B	Eh	23.33	23.67	26.44	0.0146	
7C	Eh	38.00	40.67	41.11	0.0635	
Ave.	**Eh**	**31.41**	**31.85**	**34.11**	**0.0379**	0.0142
8A	Ell	4.55	1.90	3.50	0.0000	
8B	Ell	7.70	4.00	6.00	0.0002	
8C	Ell	5.80	2.80	6.50	0.0001	
Ave.	**Ell**	**6.02**	**2.90**	**5.33**	**0.0001**	0.0000
9A	Ell	12.20	6.00	7.30	0.0005	
9B	Ell	9.90	7.00	6.90	0.0005	
9C	Ell	12.60	8.60	8.70	0.0009	
Ave.	**Ell**	**11.57**	**7.20**	**7.63**	**0.0007**	0.0001
10A	Eh	26.33	35.67	39.44	0.0370	
10B	Eh	22.44	23.78	28.89	0.0154	
10C	Eh	26.22	29.33	32.44	0.0249	
Ave.	**Eh**	**25.00**	**29.59**	**33.59**	**0.0258**	0.0063
10D	Ell	30.33	40.78	38.78	0.0480	
10E	Ell	37.00	44.22	48.89	0.0800	
10F	Ell	37.00	38.89	44.89	0.0646	
Ave.	**Ell**	**34.78**	**41.30**	**44.19**	**0.0642**	0.0092

Site	Mat. Growth % Dry Leaf Biomass	Std. error	Regrowth % Dry Leaf Biomass	Std. error
1 - Eh	50.21		23.30	
	51.82		38.43	
	55.04		29.23	
	52.36	1.42	**30.32**	4.40
1 - Ell	51.29		41.12	
	50.66		40.58	
	49.83		42.35	
	50.59	0.42	**41.35**	0.52
2 - Eh	48.20		23.90	
	49.21		32.75	
	51.26		33.29	
	49.56	0.90	**29.98**	3.04
3 - Ell	51.31		32.27	
	52.73		23.66	
	46.77		28.51	
	50.27	1.80	**28.15**	2.49
4 - Eh	52.82		22.77	
	53.94		25.00	
	51.56		15.06	
	52.77	0.69	**20.94**	3.01
5 - Ell	44.49		0.00	
	46.06		0.00	
	43.82		0.00	
	44.79	0.66	**0.00**	0.00
6 - Eh	52.95		5.00	
	48.22		11.35	
	50.98		4.80	
	50.72	1.37	**7.05**	2.15
7 - Eh	50.50		44.55	
	50.32		40.94	
	46.25		38.48	
	49.02	1.39	**41.32**	1.76
8 - Ell	51.38		12.96	
	48.03		17.77	
	46.53		30.89	
	48.64	1.43	**20.54**	5.36
9 - Ell	45.40		25.31	
	44.62		7.06	
	46.75		14.99	
	45.59	0.62	**15.78**	5.28
10 - Eh	58.28		39.85	
	53.58		36.49	
	56.71		32.46	
	56.19	1.38	**36.27**	2.14
10 - Ell	44.07		42.00	
	47.49		24.66	
	45.18		39.18	
	45.58	1.01	**35.28**	5.37

Average Plant Fresh Weight

Site & Plot	Plant Fresh Weight (kg)	Average site Plant Fresh Weight (kg)	s.e.
1A	4.40		
1C	3.30	3.30	0.64
1F	2.20		
1B	2.00		
1D	0.80	1.67	0.44
1E	2.20		
2A	2.90		
2B	3.90	3.70	0.42
2C	4.30		
3A	1.30		
3B	1.20	1.40	0.15
3C	1.70		
4A	4.70		
4B	5.90	5.03	0.44
4C	4.50		
5A	2.40		
5B	2.60	2.67	0.18
5C	3.00		
6A	4.10		
6B	2.50	2.80	0.68
6C	1.80		
7A	3.90		
7B	3.50	3.43	0.29
7C	2.90		
8A	4.90		
8B	3.60	4.57	0.49
8C	5.20		
9A	0.30		
9B	0.30	0.40	0.10
9C	0.60		
10A	4.20		
10B	5.30	4.43	0.45
10C	3.80		
10D	4.60		
10E	2.20	3.00	0.80
10F	2.20		

Site ID	% Dry Biomass	Lignotuber Diameter (cm)	Ave. Stem Diameter (cm)	Ave. No. Stems	Root Depth (cm)	Root Width (cm)
1 Eh	53.30	6.00	6.75	1.43	80	150
1 Ell	45.97	8.50	4.12	1.00	100	>200
2 Eh	46.11	6.95	4.27	3.90	150	>200
3 Ell	43.21	6.50	3.50	1.90	135	130
4 Eh	44.80	9.80	5.15	4.00	98	160
5 Ell	42.70	8.75	3.58	2.43	100	105
6 Eh	45.14	7.35	4.30	3.50	>190	>200
7 Eh	51.55	10.90	5.58	1.63	>175	>300
8 Ell	41.03	10.00	6.07	2.00	>165	>200
9 Ell	41.88	4.90	2.61	1.57	145	150
10 Eh	47.33	9.25	5.89	1.43	>165	>200
10 Ell	54.44	12.00	5.65	1.40	>165	>200

Appendix 3

Data for Water Use Parameters

Water Relations Data

Porometry

Site #	Mature Plant #	Rel. Hum. (%) #1	Rel. Hum. (%) #2	Leaf Temp. (°C) #1	Leaf Temp. (°C) #2	Quantum (µmol/s/m²) # 1	Quantum (µmol/s/m²) # 2	Diffusive Resistance (s/cm) #1	Diffusive Resistance (s/cm) #2	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2	
1	Eh 1	39.47	39.47	20.27	20.40	330.00	190.67	0.74	1.50	11.967	6.103	
	Eh 2	44.00	42.00	19.07	19.30	301.27	157.00	1.59	2.27	5.164	3.837	
	Eh 3	44.00	42.00	18.47	18.80	257.67	239.00	0.85	1.47	8.802	6.446	
	Ave.	**42.49**	**41.16**	**19.27**	**19.50**	**296.31**	**195.55**	**1.06**	**1.75**	**8.644**	**5.462**	
1	Ell 1	47.60	37.60	16.20	20.47	282.33	149.66	0.18	0.18	20.843	31.557	
	Ell 2	47.60	38.40	16.20	20.50	305.67	167.50	0.18	0.18	21.680	29.260	
	Ell 3	48.40	47.20	18.00	18.33	573.27	853.30	0.37	1.14	15.440	7.169	
	Ave.	**47.87**	**41.07**	**16.80**	**19.77**	**367.09**	**390.15**	**0.24**	**0.50**	**19.321**	**22.662**	
2	Eh	Raining!										
3	Ell	Raining!										
4	Eh 1	54.53	48.13	18.33	20.47	459.97	469.97	0.18	0.69	21.687	10.281	
	Eh 2	54.13	56.13	17.80	19.60	493.27	510.00	0.52	0.81	10.537	7.662	
	Eh 3	57.00	45.94	18.00	21.17	385.00	1238.32	0.95	0.54	5.673	16.259	
	Ave.	**55.22**	**50.07**	**18.04**	**20.41**	**446.08**	**739.43**	**0.55**	**0.68**	**12.632**	**11.401**	
5	Ell 1	71.20	44.60	15.70	19.30	495.00	259.00	0.22	0.96	11.660	7.785	
	Ell 2	69.80	54.20	14.40	18.60	331.00	199.50	0.34	0.58	9.051	9.229	
	Ell 3	75.07	53.80	15.13	18.10	629.93	217.00	0.17	0.12	13.852	24.050	
	Ave.	**72.02**	**50.87**	**15.08**	**18.67**	**485.31**	**225.17**	**0.24**	**0.55**	**11.521**	**13.688**	
6	Eh 1	61.00	60.13	17.10	16.73	168.00	390.00	0.24	0.31	4.155	14.026	
	Eh 2	63.53	60.60	16.80	16.70	206.67	344.95	1.01	0.30	2.000	11.625	
	Eh 3	61.20	60.40	16.60	16.27	217.00	329.67	1.19	0.56	3.799	8.753	
	Ave.	**61.91**	**60.38**	**16.83**	**16.57**	**197.22**	**354.87**	**0.81**	**0.39**	**3.318**	**11.468**	
7	Eh 1	53.40		18.30		177.00		0.68		8.943	Measured mature	
	Eh 2	50.80		19.20		360.00		0.86		8.568	leaves left on	
	Eh 3	50.40		19.80		241.50		0.52		11.220	harvested plants -	
	Ave.	**51.53**		**19.10**		**259.50**		**0.69**		**9.577**	may be interesting.	

Site #	Mature Plant #	Rel. Hum. (%) #1	Rel. Hum. (%) #2	Leaf Temp. (°C) #1	Leaf Temp. (°C) #2	Quantum (µmol/s/m²) # 1	Quantum (µmol/s/m²) # 2	Diffusive Resistance (s/cm) #1	Diffusive Resistance (s/cm) #2	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2
8	Ell 1	36.40	37.60	16.00	18.40	470.00	729.90	0.00	0.00	65.180	79.310
	Ell 2	38.40	48.00	16.40	18.40	709.90	400.00	0.00	0.02	75.700	47.450
	Ell 3	46.10	56.00	16.20	18.90	147.00	664.95	0.00	0.07	50.540	31.540
	Ave.	**40.30**	**47.20**	**16.20**	**18.57**	**442.30**	**598.28**	**0.00**	**0.03**	**63.807**	**52.767**
9	Ell 1	44.13	27.60	22.13	25.73	1760.00	1620.00	0.02	0.08	72.707	80.350
	Ell 2	36.73	26.80	24.40	26.73	1533.30	1583.33	0.06	0.22	69.907	66.173
	Ell 3	38.00	26.80	25.07	27.53	1406.67	1763.33	0.12	0.13	62.577	75.133
	Ave.	**39.62**	**27.07**	**23.87**	**26.67**	**1566.66**	**1655.56**	**0.07**	**0.14**	**68.397**	**73.886**
10	Eh 1	34.67	35.60	22.87	20.87	810.00	483.27	0.15	0.46	40.330	19.503
	Eh 2	34.93	35.60	23.00	20.60	1486.67	596.60	0.26	0.62	32.283	14.543
	Eh 3	34.80	37.20	23.50	20.60	1454.95	400.00	0.12	0.62	52.600	13.755
	Ave.	**34.80**	**36.13**	**23.12**	**20.69**	**1250.54**	**493.29**	**0.16**	**0.57**	**41.738**	**15.934**
10	Ell 1	35.20	37.40	23.10	20.40	439.95	257.50	0.03	0.75	63.005	11.470
	Ell 2	35.87	32.40	22.60	21.60	585.63	719.97	0.01	0.50	94.787	24.487
	Ell 3	36.27	32.53	22.67	21.80	2076.67	471.63	0.04	0.12	93.167	45.657
	Ave.	**35.78**	**34.11**	**22.79**	**21.27**	**1034.08**	**483.03**	**0.03**	**0.46**	**83.653**	**27.204**

Estimating Transpiration per Plant

Site #	Mature Plant #	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2	Ave. Transp. per site + sp.	Ave. Area per leaf (cm²)	Transpiration per leaf (µg/s)	Ave. No. of Leaves/plant	Est. Transp. per plant (g/s)	Est. Transp. per plant per daylight hour (g)
1	Eh 1	11.967	6.103						
	Eh 2	5.164	3.837	7.053	7.447	8.02762117	3851	0.03091437	111.29
	Eh 3	8.802	6.446						
	Ave.	**8.644**	**5.462**	**7.053**					
1	Ell 1	20.843	31.557						
	Ell 2	21.680	29.260	20.991	12.484	17.7991709	1528	0.02719713	97.91
	Ell 3	15.440	7.169						
	Ave.	**19.321**	**22.662**	**20.991**					
2	Eh	DNM	DNM						
3	Ell	DNM	DNM						
4	Eh 1	21.687	10.281						
	Eh 2	10.537	7.662	12.016	7.241	13.298161	3244	0.04313923	155.30
	Eh 3	5.673	16.259						
	Ave.	**12.632**	**11.401**	**12.016**					
5	Ell 1	11.660	7.785						
	Ell 2	9.051	9.229	12.604	17.281	14.7942324	1223	0.01809335	65.14
	Ell 3	13.852	24.050						
	Ave.	**11.521**	**13.688**	**12.604**					
6	Eh 1	4.155	14.026						
	Eh 2	2.000	11.625	7.393	7.487	8.45960309	1340	0.01133587	40.81
	Eh 3	3.799	8.753						
	Ave.	**3.318**	**11.468**	**7.393**					
7	Eh 1	8.943							
	Eh 2	8.568	DNM	9.577	N/A				
	Eh 3	11.220							
	Ave.	**9.577**		**9.577**					

Site #	Mature Plant #	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2	Ave. Transp. per site + sp.	Ave. Area per leaf (cm²)	Transpiration per leaf (µg/s)	Ave. No. of Leaves/plant	Est. Transp. per plant (g/s)	Est. Transp. per plant per daylight hour (g)
8	Ell 1	65.180	79.310						
	Ell 2	75.700	47.450	58.287	16.675	66.0144106	4876	0.32188627	1158.79
	Ell 3	50.540	31.540						
	Ave.	**63.807**	**52.767**	**58.287**					
9	Ell 1	72.707	80.350						
	Ell 2	69.907	66.173	71.141	20.479	98.953937	381	0.03770145	135.73
	Ell 3	62.577	75.133						
	Ave.	**68.397**	**73.886**	**71.141**					
10	Eh 1	40.330	19.503						
	Eh 2	32.283	14.543	28.836	4.976	21.929865	6916	0.15166695	546.00
	Eh 3	52.600	13.755						
	Ave.	**41.738**	**15.934**	**28.836**					
10	Ell 1	63.005	11.470						
	Ell 2	94.787	24.487	55.429	16.523	62.2051852	3536	0.21995753	791.85
	Ell 3	93.167	45.657						
	Ave.	**83.653**	**27.204**	**55.429**					

Water Relations Data

Porometry

Site #	Regrowth Plant #	Rel. Hum. (%) #1	Rel. Hum. (%) #2	Leaf Temp. (°C) #1	Leaf Temp. (°C) #2	Quantum (µmol/s/m²) # 1	Quantum (µmol/s/m²) # 2	Diffusive Resistance (s/cm) #1	Diffusive Resistance (s/cm) #2	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2
1	Eh 1	45.60	44.00	18.00	19.27	389.97	1079.93	0.69	1.61	10.155	8.753
	Eh 2	46.00	44.20	17.40	19.50	210.33	720.00	0.40	0.52	16.431	17.173
	Eh 3	48.80	43.60	16.80	20.40	201.00	919.95	0.80	0.48	11.069	21.630
	Ave.	**46.80**	**43.93**	**17.40**	**19.72**	**267.10**	**906.63**	**0.63**	**0.87**	**12.552**	**15.852**
1	Ell 1	52.93	40.80	16.27	18.80	366.67	238.00	0.03	0.06	35.773	41.507
	Ell 2	53.20	40.80	16.73	18.00	406.67	165.50	0.08	0.31	29.873	26.275
	Ell 3	51.60	44.20	17.27	17.50	509.97	101.50	0.19	0.00	41.027	65.685
	Ave.	**52.58**	**41.93**	**16.76**	**18.10**	**427.77**	**168.33**	**0.10**	**0.12**	**35.558**	**44.489**
7	Eh 1	54.00		18.60		243.00		0.31		17.375	
	Eh 2	52.20		18.70		324.95		0.39		15.220	
	Eh 3	51.20		20.70		469.90		0.46		13.525	
	Ave.	**52.47**		**19.33**		**345.95**		**0.38**		**15.373**	
10	Eh 1	33.47	37.60	27.93	19.60	856.63	290.97	0.31	0.57	39.733	15.210
	Eh 2	33.40	37.60	23.70	20.00	390.00	281.33	0.24	0.61	39.180	15.583
	Eh 3	33.47	38.27	23.00	20.27	463.30	420.97	0.18	0.98	41.373	13.197
	Ave.	**33.44**	**37.82**	**24.88**	**19.96**	**569.98**	**331.09**	**0.24**	**0.72**	**40.096**	**14.664**
10	Ell 1	36.13	40.10	22.47	20.20	509.97	533.27	0.14	0.20	48.630	46.897
	Ell 2	36.80	39.73	23.40	20.13	1285.00	523.27	0.10	0.39	56.525	19.117
	Ell 3	37.80	37.60	24.30	19.60	1855.00	573.27	0.00	0.38	99.855	26.507
	Ave.	**36.91**	**39.14**	**23.39**	**19.98**	**1216.66**	**543.27**	**0.08**	**0.32**	**68.337**	**30.840**

2 Eh Raining! **3** Ell Raining! **4** Eh Regrowth too small to measure.
5 Ell Weeds have smothered stems = no regrowth. **6** Eh Regrowth too small to measure.
8 Ell Regrowth too small to measure. **9** Ell Regrowth too small to measure.

Site #	Regrowth Plant #	Transpiration (µg/cm²/s) #1	Transpiration (µg/cm²/s) #2	Ave. Transp. per site + sp.	Ave. Area per leaf (cm²)	Transpiration per leaf (µg/s)	Ave. No. of Leaves/plant	Est. Transp. per plant (g/s)	Est. Transp. per plant per daylight hour (g/ml)
1	Eh 1	10.155	8.753						
	Eh 2	16.431	17.173	14.202	1.281	2.78044349	443	0.00123174	4.43
	Eh 3	11.069	21.630						
	Ave.	**12.552**	**15.852**	**14.202**					
	Ell 1	35.773	41.507						
	Ell 2	29.873	26.275	40.023	7.747	47.388165	532	0.0252105	90.76
	Ell 3	41.027	65.685						
	Ave.	**35.558**	**44.489**	**40.023**					
7	Eh 1	17.375	DNM						
	Eh 2	15.220	DNM	15.373	1.790	4.20575679	1056	0.00444128	15.99
	Eh 3	13.525	DNM						
	Ave.	**15.373**	**DNM**	**15.373**					
10	Eh 1	39.733	15.210						
	Eh 2	39.180	15.583	27.380	2.091	8.7499084	388	0.00339496	12.22
	Eh 3	41.373	13.197						
	Ave.	**40.096**	**14.664**	**27.380**					
	Ell 1	48.630	46.897						
	Ell 2	56.525	19.117	49.588	8.979	68.0503813	281	0.01912216	68.84
	Ell 3	99.855	26.507						
	Ave.	**68.337**	**30.840**	**49.588**					

Pressure Bomb Data

Site #	Time	Mature Plants							Regrowth Plants							
		Plant 1		Plant 2		Plant 3		Site Ave	Plant 1		Plant 2		Plant 3		Site Ave	
		(psi)	kPa	(psi)	kPa	(psi)	kPa	kPa	(psi)	kPa	(psi)	kPa	(psi)	kPa	kPa	
1 Eh	10:00 AM	320	2207	283	1954	333	2299		383	2644	300	2069	320	2207		
	2:00 PM	290	2000	307	2115	283	1954		360	2483	300	2069	320	2207		
	Ave.		2103		2034		2126	2088		2563		2069		2207	2280	
1 Ell	11:00 AM	377	2598	373	2575	373	2575		320	2207	333	2299	350	2414		
	3:00 PM	443	3057	367	2529	347	2391		293	2023	333	2299	310	2138		
	Ave.		2828		2552		2483	2621		2115		2299		2276	2230	
2 Eh	11:00 AM	113	782	120	828	170	1172		247	1701	197	1356	177	1218	Rain delay.	
	3:00 PM	167	1149	127	874	210	1448		160	1103	163	1126	157	1080	Old leaves left on:260	
	Ave.		966		851		1310	1042		1402		1241		1149	1264	
3 Ell	12 noon	250	1724	133	920	133	920		213	1471	207	1425	227	1563	Rain delay.	
	2:00 PM	73	506	133	920	167	1149		167	1149	177	1218	167	1149		
	Ave.		1115		920		1034	1023		1310		1322		1356	1330	
4 Eh	11:00 AM	247	1701	230	1586	183	1264		Regrowth in Plots A and B				200	1379		
	12 noon	DNM	--	DNM	--	247	1701		too small to measure.				213	1471		
	1:00 PM	240	1655	250	1724	193	1333						213	1471		
	Ave.		1655		1724		1517	1632						1471	1471	
5 Ell	10:00 AM	240	1655	220	1517	220	1517		No regrowth to measure.							
	2:00 PM	243	1678	210	1448	213	1471									
	Ave.		1667		1483		1494	1548	Regrowth too small to							
6 Eh	10:00 AM	233	1609	207	1425	190	1310		measure.							
	3:00 PM	203	1402	187	1287	170	1172									
	Ave.		1506		1356		1241	1368								
7 Eh	4:00 PM	DNM	--	DNM	--	DNM	--		No comparison possible.							
	Ave.	(Assumed value: average of site 3 and 6 Eh averages)						1765								
8 Ell	10:00 AM	167	1149	160	1103	257	1770		Regrowth A & C		117	805	180	1241		
	12 noon	187	1287	223	1540	220	1517		too small.		160	1103	DNM	--		
	Ave.		1218		1322		1644	1395				954		1241	1098	

Site #	Time	Mature Plants							Regrowth Plants						
		Plant 1		Plant 2		Plant 3		Site Ave	Plant 1		Plant 2		Plant 3		Site Ave
		(psi)	kPa	(psi)	kPa	(psi)	kPa	kPa	(psi)	kPa	(psi)	kPa	(psi)	kPa	kPa
9 Ell	11:00 AM	333	2299	253	1747	347	2391		Regrowth too small to						
	3:00 PM	207	1425	240	1655	220	1517		measure.						
	Ave.		1862		1701		1954	1839							
10 Eh	12 noon	350	2414	317	2184	357	2460		307	2115	290	2000	360	2483	
	3:00 PM	247	1701	287	1977	323	2230		293	2023	307	2115	297	2046	
	Ave.		2057		2080		2345	2161		2069		2057		2264	2130
10 Ell	12 noon	370	2552	310	2138	343	2368		300	2069	337	2322	293	2023	
	3:00 PM	327	2253	300	2069	347	2391		227	1563	317	2184	290	2000	
	Ave.		2402		2103		2379	2295		1816		2253		2011	2027

Appendix 4

Data for Cineole Production Parameters

PERCENTAGE CINEOLE WEIGHT OF LEAF FRESH WEIGHT

Sample collection times in 1997:		Pre-harvest March / April	Regrowth #1 July	Regrowth #2 September	
SITE ID	**SPECIES**	**% CINEOLE**	**% CINEOLE**	**% CINEOLE**	
Site 1	*E. horistes*	2.8	2.7	2.5	
"	"	3.1	1.5	2.2	
"	"	3.1	1.5	2.4	
Site 1	*E. lox. liss.*	2.4	2.2	1.9	
"	"	2.9	2.4	1.6	
"	"	2.7	1.5	1.6	
Site 2	*E. horistes*	3.0	no samples	1.2	No Samples (n/s) =
"	"	3.7	n/s	0.8	not enough regrowth
"	"	3.2	n/s	0.9	present for 3 g sample
Site 3	*E. lox. liss.*	2.2	0.9	0.5	
"	"	2.6	0.6	0.5	
"	"	2.2	0.6	0.5	
Site 4	*E. horistes*	3.0	n/s	n/s	
"	"	3.3	n/s	n/s	
"	"	3.1	n/s	n/s	
Site 5	*E. lox. liss.*	**1.4**	no samples	no samples	No Samples (n/s) =
"	"	**1.6**	n/s	n/s	not enough regrowth
"	"	**1.8**	n/s	n/s	present for 3 g sample.
Site 6	*E. horistes*	2.7	n/s	n/s	
"	"	2.7	n/s	n/s	
"	"	3.1	n/s	n/s	
Site 7	*E. horistes*	3.1	1.2	1.7	
"	"	3.4	2.4	1.8	
"	"	3.0	1.9	2.6	
Site 8	*E. lox. liss.*	2.0	n/s	n/s	
"	"	2.0	n/s	n/s	
"	"	1.9	n/s	n/s	
Site 9	*E. lox. liss.*	**1.4**	n/s		Composite
"	"	**1.5**	n/s	1.4	sample from
"	"	**1.2**	n/s		all 3 plots.
Site 10	*E. horistes*	3.2	0.5	2.0	
"	"	2.9	2.1	1.8	
"	"	2.7	2.4	1.4	
Site 10	*E. lox. liss.*	2.0	2.1	0.8	
"	"	2.1	1.3	1.0	
"	"	2.0	1.3	1.2	

Estimating cineole yield per plot

Fresh Weight: weight of average sized plant, incl. leaves and twigs < 0.5 cm ø,
excl. stem and twigs > 0.5 cm ø

Eh Sites

Site and Plot ID	Pre-harvest Plant Fresh Weight (kg)	Pre-harvest Cineole Concentration	Pre-harvest Est. Cineole Yield (kg)	Average Est. Cineole Yield (kg)	s.e.
1A	4.40	2.8%	0.123		
1C	3.30	3.1%	0.102	0.098	0.016
1F	2.20	3.1%	0.068		
2D	2.90	3.0%	0.087		
2E	3.90	3.7%	0.144	0.123	0.018
2F	4.30	3.2%	0.138		
4A	4.70	3.0%	0.141		
4B	5.90	3.3%	0.195	0.158	0.018
4C	4.50	3.1%	0.140		
6A	4.10	2.7%	0.111		
6B	2.50	2.7%	0.068	0.078	0.017
6C	1.80	3.1%	0.056		
7A	3.90	3.1%	0.121		
7B	3.50	3.4%	0.119	0.109	0.011
7C	2.90	3.0%	0.087		
10A	4.20	3.2%	0.134		
10B	5.30	2.9%	0.154	0.130	0.015
10C	3.80	2.7%	0.103		

Ell Sites

Plot ID	Pre-harvest Plant Fresh Weight (kg)	Pre-harvest Cineole Concentration	Pre-harvest Est. Cineole Yield (kg)	Average Est. Cineole Yield (kg)	s.e.
1B	2.00	2.4%	0.048		
1D	0.80	2.9%	0.023	0.044	0.011
1E	2.20	2.7%	0.059		
3A	1.30	2.2%	0.029		
3B	1.20	2.6%	0.031	0.032	0.003
3C	1.70	2.2%	0.037		
5A	2.40	1.4%	0.034		
5B	2.60	1.6%	0.042	0.043	0.006
5C	3.00	1.8%	0.054		
8A	4.90	2.0%	0.098		
8B	3.60	2.0%	0.072	0.090	0.009
8C	5.20	1.9%	0.099		
9A	0.30	1.4%	0.004		
9B	0.30	1.5%	0.005	0.005	0.001
9C	0.60	1.2%	0.007		
10D	4.60	2.0%	0.092		
10E	2.20	2.1%	0.046	0.061	0.016
10F	2.20	2.0%	0.044		