Chapter One: Introduction

The concepts of tree longevity and tree senescence are important for long-term decision-making processes within urban and suburban landscapes. In order to enact well-informed decisions for the future of current landscapes, knowledge on expected tree longevity, and possible senescence patterns or projections are necessary to provide landscape planners, designers and managers with valuable information, in turn fostering well-informed decisions for the future of these landscapes. To gain an insight into tree longevity in urban and suburban landscapes, extant tree longevity data needs to be examined, and figures reflecting these tree longevities assembled. This would assist in ascertaining the level of tree longevity cognition presently available for the possible modelling of future landscape scenarios.

Through an examination of the relevant data on tree longevities within an Australian context, extant longevity figures for the Adelaide Plains region can be established, and subsequently assist in this generation of potential future tree senescence patterns in specific landscapes. With a particular focus upon Australian street trees, Hannah and Yau (1993) noted that there was insufficient data available for estimating when established trees from various climatic regions would require replacement due to senescence.[1] According to Hitchmough (1994c), large proportions of suburban Australia currently retain their 'first crop' of mature trees, with sections of the community believing that replacement of these trees can be left to subsequent generations of landscape custodians.[2] Hitchmough (1994c) also noted that data reflecting the 'useful life span' we could expect from medium to long-lived trees in 'urban public open spaces' was not known with any certainty in Australia.[3] With a focus upon indigenous Australian eucalypt species, Banks (1997) reflected that longevity data for the genus 'remains limited'.[4] Reviewing methods of replacement in mature urban landscapes, Parker (2004) observed that data representing useful tree longevity figures were not available for urban environments in Australia.[5]

The importance of information regarding tree longevity in urban landscapes should be recognised in addition to tree mortality data. Nowak, Kuroda, and Crane (2004) noted that changes wrought through urban tree mortality in landscapes are significant, however, knowledge of these mortality rates remains limited.[6] Nowak *et al.* (2004) pertinently observed that in order to be able to 'project urban tree population effects into the future', data reflecting both mortality and natality rates of trees must be known.[7]

In addition to possessing knowledge on tree longevity for specimens in suburban landscapes, the process of establishing tree age must also be engaged, in order to project tree senescence patterns into the future. Appropriate methods of determining tree age need to be analysed for their suitability of use within Australian landscapes, and these methods of tree age determination assembled. Once both tree ages, and their expected life spans for specific areas have been determined, models interpreting potential tree senescence in these landscapes could be developed.

Technological advances in Geographical Information Systems (GIS) can provide an opportunity to combine important data reflecting tree age and longevity, with spatial mapping outputs to produce changes to landscapes visually. These two-dimensional maps, and three-dimensional landscapes produced through GIS techniques, have the potential to display forecasted tree senescence patterns, potentially influencing decisions on future landscape directions.

From this discussion on modelling tree longevity and senescence in landscapes, one key question will direct the research investigated in this thesis:
Can tree senescence patterns be predicted in landscapes?

This question can be further examined in the form of a series of investigative questions to drive the following research and provide guidance for the further exploration into tree senescence pattern prediction in urban and suburban parkland landscapes:
Can figures of tree longevity be obtained in order to model tree senescence patterns in landscapes?
What are the methods available to determine tree ages in urban landscapes for longevity and senescence modelling?
How accurate are these methods of determining tree age in landscapes?
Can these methods be applied to trees of unknown age to determine tree longevities?
What levels of confidence can we place in these methods of modelling tree growth and senescence?

How can these tree longevity and senescence models be incorporated into tools suitable for landscape design, management, and planning? What sort of visualisations or outputs can be produced from these tools?
What applications would these methods have in landscape design, management, and planning?

The process used in this thesis to investigate these research questions is displayed diagrammatically in Figure 1.1. Prior to the development of models to predict tree senescence in landscapes, literature on the theories of change in landscapes is examined. The purpose of this is to identify important research definitions for changing landscapes, and to establish concepts upon which changing environments can be conceived, and tree senescence models built. Following the identification of definitions and examples of change in landscapes, the concepts surrounding tree longevity and senescence are then investigated, with a particular focus upon establishing the extent of tree longevity knowledge for a range of tree taxa within the Australian environment. This will subsequently determine both the quantity and detail of extant Australian tree longevities published in the literature, and establish areas of knowledge not published in Australian tree longevity literature.

An intrinsic requirement in the prediction of future tree senescence patterns in landscapes are figures reflecting tree ages of the extant specimens modelled. A review of both non-invasive and invasive tree age determination methods investigates the processes involved in each, and their suitability for use within the suburban parkland modelled in this thesis. The landscape of Tuttangga/Park 17 (Park 17) within the Adelaide Park Lands, South Australia, provides the milieu for modelling the tree senescence patterns in this research, with tree specimens from this landscape assigned ages from the methods of tree age determination investigated. Point matrix models developed from the age-determined trees produce growth trends for each growth parameter from each taxon. These equations then provide the basis upon which trees of unknown age are assigned ages for subsequent tree senescence modelling. Tree longevity figures unpublished in the literature are obtained from a peer reference group tree longevity survey, and provide tree senescence data for the Adelaide Park Lands region. These trees with figures reflecting tree age and tree longevity are then be modelled spatially using GIS software to determine future tree senescence patterns for the Park 17 tree population.

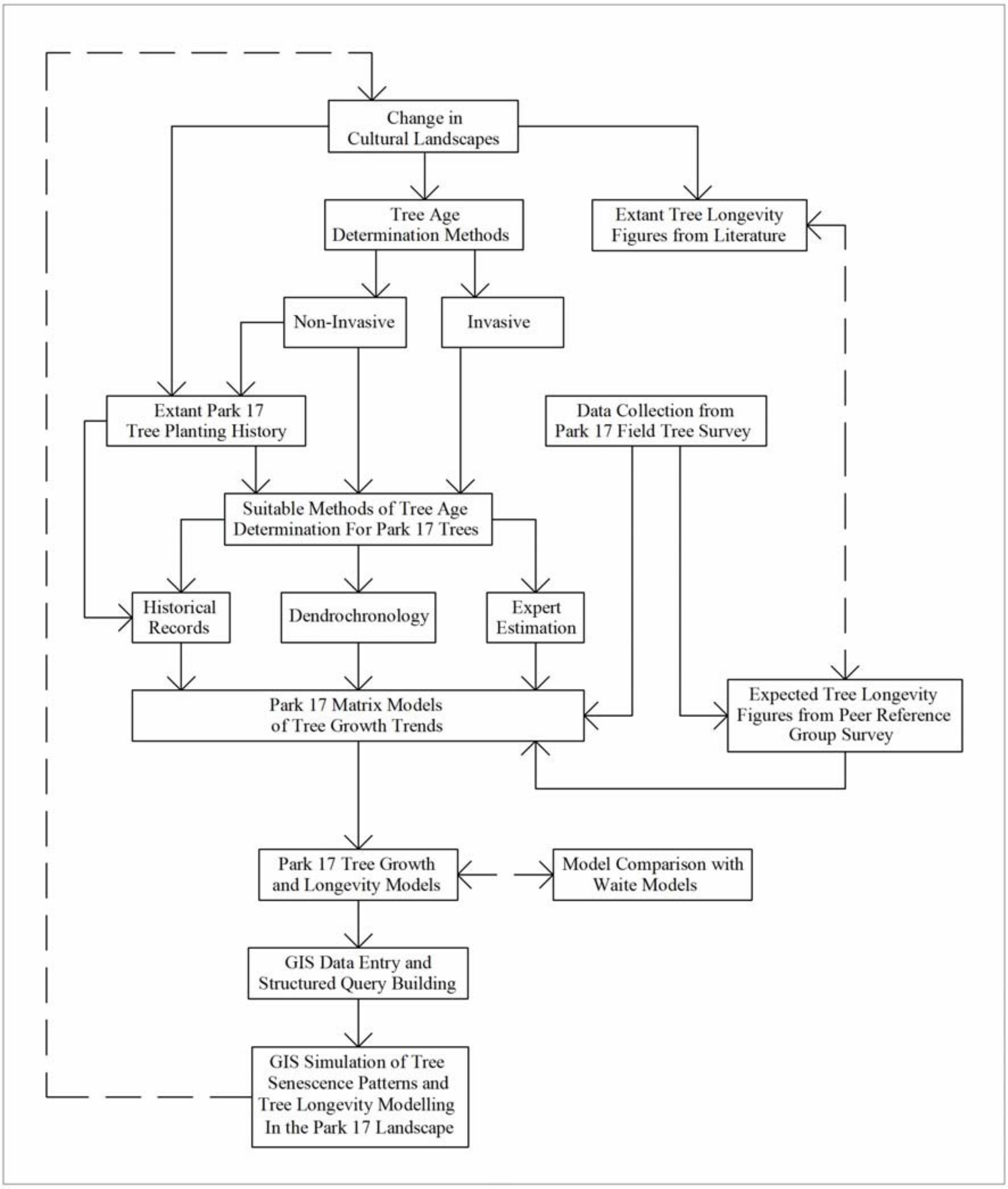

Figure 1.1. Diagram of method proposed to model tree growth and predict tree senescence in the Park 17 landscape.

The research contained in this thesis has been arranged into the following structure of chapters:

Chapter Two defines the term ‘cultural landscapes’, investigating change within those landscapes and how change can be dealt with in cultural landscapes. With particular focus on the nature of tree changes in landscapes, a scenario reflecting community reaction to changes in the Park 17 landscape is presented, highlighting examples of negative community reaction toward change. The inevitability of certain types of change is investigated, along with a review of ‘space’ and ‘time’, to establish their relationship for the purpose of modelling tree senescence patterns through time within changing cultural landscapes.

An examination of the concepts behind tree ageing and senescence, and the inevitability of tree senescence in landscapes, is undertaken in Chapter Three. Various causes of tree death are investigated, along with physiological changes that occur over the lifespan of a tree. Published literature on the subject of tree longevities in Australia is reviewed, in order to ascertain the extent of published longevity figures suitable for use in tree senescence models within an Adelaide Park Lands context.

Chapter Four investigates various methods of non-invasive tree age determination, where damage to living tree tissue can be avoided. Part I of this chapter examines methods that draw upon extant or expert resources to determine the ages of trees in established landscapes. Part II of Chapter Four investigates the use of tree growth models to determine tree age, and to ascertain tree growth parameters suitable for use with the growth models reviewed.

Methods of invasive tree age determination are examined in Chapter Five, where tree tissues are damaged as a part of the age-determination process. As invasive methods, dendrochronology and radiocarbon dating are primarily examined for process, accuracy, practicality, and suitability for use within the Adelaide Plains climate. Chapter Six reviews the available literature on tree planting patterns within the Adelaide Park Lands, with a particular focus upon determining the availability of extant archival records for historical reconstruction of past Park 17 tree planting operations and for tree age determination.

Chapter Seven outlines the methods used to collect field data, tree age determination methods employed, and the process engaged for the collection of tree longevity figures from the peer reference group survey. Along with this are outlined the development of tree growth models and longevity predictions, with a description of the GIS model developed for spatial visualisation of various tree senescence patterns and data in the Park 17 landscape. An overview of the results from this process is outlined in Chapter Eight, and detailed discussions of these processes and results are engaged in Chapter Nine. Conclusions arising from this research, along with proposed areas of further research are also included in Chapter Nine.

The nomenclature of various tree and shrub taxa used in this research came from two primary sources, and must be acknowledged here to avoid confusion from the many differing resources available for use. The vast majority of field specimens were identified using the comprehensive text *Horticultural Flora of South-eastern Australia: The Identification of Garden and Cultivated Plants*, Volumes 1-4, by Spencer *et al* (1997). A small number of taxa from the genera *Angophora, Corymbia*, and *Eucalyptus* were identified from field-collected samples through the use of the multimedia CD-ROM *Euclid: Eucalypts of Southern Australia*, Second Edition, by Brooker (2002).

Chapter 1 Notes

[1] Hannah and Yau (1993) p. 42.
[2] Hitchmough (1994c) p. 269.
[3] Hitchmough (1994c) p. 269.
[4] Banks (1997) p. 45.
[5] Parker (2004) p. 247.
[6] Nowak *et al.* (2004) p. 139.
[7] Nowak *et al.* (2004) p. 139.

Chapter Two: Change in Cultural Landscapes

The concept of cultural landscapes and the notion of change within these landscapes are central to the modelling of environments. As discussed in this chapter, changes in cultural landscapes can be perceived as an expression of change over time, with direct impacts upon the community at the centre of that cultural landscape. Within the context of change in the Adelaide Park Lands, a proposed tree removal scenario is presented, along with a discussion of views that represent a portion of the community's values on cultural landscape change. Within a larger context, this chapter reviews the inevitability of change in cultural landscapes, and the importance of such change.

2.1. Defining Cultural Landscapes

The term 'cultural landscape' has been used to describe landscapes that have been modified and changed by humans.[1] Often for the benefit of the culture or community at the centre of this modification, these changes inextricably intertwine human culture with landscapes, creating 'cultural landscapes'. Sauer (1927), one of the early authors to identify the term 'cultural landscape', described it as being,

> …fashioned out of the natural landscape by the cultural group. The group is the active force, the natural area the medium (milieu) in which the group works, the cultural landscape is the result.[2]

As Antrop (2005) has noted, 'Landscapes change because they are the expression of the dynamic interaction between natural and cultural forces in the environment'.[3] In environmental landscape terms, a cultural landscape has the opportunity to describe landscapes holistically, without the need to unnecessarily separate humans from the environment. Worster (1993) notes that the term 'ecosystem' has in the past been used to describe 'self contained assemblages of plants and animals, evolving over time but in the absence of any people', and continues on to express that this definition of the term ignores,

> …the fact that many of the world's ecosystems have long been the home of people too. Some of those ecosystems have been profoundly, visibly altered by the human presence, while in other places that presence has been far more subtle and hard to discern.[4]

Urban landscapes, or cultural landscapes within urban settings, can be those landscapes described by Worster (1993) as being more heavily modified by human activity. Parklands, woodlands, urban forests and gardens are all ecosystems modified by humans and as a result they have been customised to varying degrees, depending upon their intended purpose and the urban context in which they are situated.

Melnick (1981) described cultural landscapes as characterising ‘a continuum of land-use that spans many generations’ and that they ‘are integrated composites of overlapping and intersecting elements and qualities’.[5] This is advanced further by Wood and Handley (2001) with their description of landscapes as ‘open systems’, and that ‘their character [is] a reflection of exchanges between diverse constituent elements, and are thus dynamic’.[6] This dynamic nature of cultural landscapes is essential to our understanding of processes of change within the landscapes we study.

Meinig (1979) wrote that ‘Landscapes are ever undergoing change’, suggesting that change is an inevitable part of the landscape.[7] The notion that ‘there is no such thing as a genuinely static human landscape, and that every one of them is constantly changing’ by Jackson (1958) is an important part of this concept of change within the landscape as it specifically links landscape and culture with change.[8] As landscapes have been noted as ‘an interactive “equation” ceaselessly making and remaking itself through processes of continuous (or incremental) and discontinuous change’ by Wood & Handley (2001), the expression ‘discontinuous’ appears at odds with the term ‘dynamic’, as introduced previously.[9] However, this discontinuity is merely apparent, as Lynch (1985) explains:

> How ill-equipped we are to observe this moving, changing world. Our range of detection is so narrow that we are nearly blind and must use ingenuity to extend our sight. A plant appears unconscious to us, but if we visually speed up its movements by time-lapse photography, the plant seems to become a perceiving, reacting animal.[10]

A similar explanation, that landscapes evolve ‘at varying rates’, was suggested by Frawley (1989), once again embracing the dynamic nature of change in the landscape.[11] This dynamic change is advanced further by Funnel (1992) where it is stated that plants in the landscape require ‘time to establish’ and are ‘forever changing’.[12] This ‘extra dimension’, specifically, the dynamic nature of gardens and parks as changing cultural landscapes as expressed by Sales (1990), requires the establishment of ‘a dynamic management system’ to ensure that the change in the landscape is appropriately catered for.[13] As Eyring (1999) noted, ‘the body of information relating to large-scale vegetation management in cultural landscapes is limited’.[14] In order for it to occur appropriately in cultural landscapes, an understanding of the underlying concepts of change in the landscape, and the dynamics of this change within the community is imperative.

2.2 Dealing with Change in Cultural Landscapes

Cultural landscapes within close proximity to established settlement areas are often placed under various pressures from the surrounding community, especially if located within a densely populated region. Open spaces such as urban parklands and public gardens are good examples of such cultural landscapes. As outlined previously, the dynamic nature of these landscapes places their components under varying rates of change. Changes to cultural landscapes, including urban parklands and public gardens, are often not well received by the community. The apparent disapproval and subsequent reactions generated within the community vary depending upon the elements that are changing, the types of change enacted upon them, and the instigating factors behind that change in the landscape. This prompts a discussion to identify and suggest possible reasons behind, and potential causes for, the dislike of change in cultural landscapes.

As an important part of the investigation into identifying potential reasons for community reluctance to changes in the environment, an outline of some of Lowenthal's concepts on desires of 'the past' is valuable here. The community has a strong desire for retaining the past. Lowenthal (1975) explains this need for the past as a tool for coping with 'present landscapes':

> We selectively perceive what we are accustomed to seeing; features and patterns in the landscape make sense to us because we share a history with them. Every object, every grouping, every view is intelligible partly because we are already familiar with it, through our own past and through tales heard, books read, pictures viewed. We see things simultaneously as they are and as we viewed them before; previous experience suffuses all present perception.[15]

This notion is important, as Lowenthal (1975) believes that our concept of the past 'gains further weight' and places become more significant to us as we read and hear about them in addition to any personal experiences with them.[16] The memories of places we carry with us, described by Lowenthal (1979) as nostalgia, may be one reason why 'We seek refuge from the uneasy present, the uncertain future' by means of 'recalling the good old days', the memories of which are sometimes 'so real and vivid we can scarcely believe they do not actually survive'.[17] But Lowenthal (1975) believes that 'Hindsight and overview enable us to comprehend past environments in ways that elude us when we deal with the shifting present' and that nostalgia is not the only influential force we consider as important when we revisit the past; previous images may seem more comprehensible, and can 'often dominate or may wholly replace the present'.[18]

Perhaps this notion of hindsight and overview within the context of changing from the past to the present or future is why 'When we cherish something old or venerable, we usually seek to preserve it from the further ravages of time, halting deterioration and extending life as long as possible'.[19] This desire to extend or prolong memories of past landscapes may explain why some memories 'may endure for eternity', even though a 'swift catastrophe, like a bomb or demolition' may remove the physical 'marks of history'.[20] Through whatever means we maintain these nostalgic memories, Lowenthal (1975) notes that 'An element of mystery and uncertainty distinguishes past from present', and that in our mind's construct of these memories, 'We expect the past not to be precise or specific but rather to be vague and incomplete, waiting to be filled in by our own imaginations'.[21] These imaginations should not necessarily be considered a negative characteristic, as any new discoveries will be a revision of our present interpretations, and Lowenthal (1975) adds that 'to embalm any one version violates both historical truth and verisimilitude'.[22] Although Lowenthal believes that we may not always appreciate, understand, or tolerate change well, we can indeed adapt to it:

> Through awareness of the past, we learn to remake ourselves. Through awareness of our own experience, we also refashion the past and replace what is all the time being altered and lost.[23]

It should also be noted at this point that although we may refashion and replace the past as time goes by, Lowenthal (1975) states that our cultural prejudices have an effect on 'what is preserved, what is suffered to vanish, and what is deliberately destroyed' and elements 'recalled with pride are apt to be safeguarded against erosion and vandalism; those that reflect shame may be ignored or expunged from the landscape'.[24] While the arguments for the 'correct' decision in this matter are certainly dependent upon many contributing factors, Lowenthal (1975) reminds us that 'What to us are historical objects embedded in, but distinct from, our own present were originally a part of the fabric of someone else's contemporary landscape'.[25]

2.2.1 The Community and Change

The community has an inherent desire for stability in landscapes that are continually changing. In pre-industrial European landscapes, Antrop (2005) outlined that,

> For many centuries the changes were local and gradual and seldom were existing landscape structures wiped away completely. In the past, landscapes were experienced as rather stable and having a distinct character or identity.[26]

Antrop (2005) also notes that in comparison to this, recent changes to landscapes are seen as a threat or 'a negative evolution', observed by the community through 'the loss of diversity, coherence and identity' in the landscape and 'New elements and structures are introduced which look alike everywhere'.[27] Lynch (1985) suggests that 'Historical areas are not so much irreplaceable as rarely replaced'. If areas perceived by the community as significant, are removed and then rarely replaced, this may lead to levels of uncertainty or instability within society.[28] But Lynch (1985) also notes however, that people can be encouraged to embrace or accept change through focusing upon symbolic elements within the landscape that are more stable, or perhaps elements that undertake less rapid or obvious changes. Three examples of landscape components that have this particular potential to 'hold a shifting scene' are given as a church, a rock, or a tree.[29]

Whether or not change is accepted, understood, liked or disliked, the importance of heritage landscapes is evident, according to Schapper (1993) by the large number of listed heritage sites in Australia.[30] By 2007, the number of listed heritage sites on the Australian Heritage Council's Register of the National Estate was over 13,000.[31] Frawley (1989) describes cultural landscapes in Australia as being,

> …an important part of our heritage because they provide a cumulative record of human activity and landuse, insights into the values, ideals and philosophies of communities and their relationship with place. They also have socio-historical significance and aesthetic qualities.[32]

The values placed upon cultural landscapes by a society have an influence on the changes that are allowed, and those that are discouraged. As outlined by Schapper (1993), values often associated with the heritage of cultural landscapes include aesthetic, historic, scientific, social and symbolic.[33] While all should be considered important facets or views in cultural landscapes, Johnston's (1992) exploration of social values in the landscape reveals some interesting connections between the community and the acceptance of change in cultural landscapes. Of the descriptions given by Johnston (1992) on the types of landscapes of social value, several appear of particular importance. Identifying those that 'tie the past affectionately to the present', those that 'provide an essential reference point in a community's identity or sense of itself', and those that 'are accessible to the public and offer the possibility of repeated use to build up associations and value to the community of users' are pertinent in developing an understanding of community reluctance to change.[34] Social value is defined by Johnston (1992) as a 'collective attachment to places that embody meanings important to a community'.[35] If this community attachment to the landscape is strong enough, they may become 'places of the heart' as described by Mayne-Wilson (2001):

> A place may generate/emanate values through a community's knowledge of past events and people, or past personal experiences, which create a sense of belonging and attachment.[36]

Interestingly, Johnston (1992) notes that a place may in fact be experiential, rather than purely physical, as places can exhibit 'character, identity and "spirit"'.[37]

Whether or not these landscapes of social significance become 'places', Johnston (1992) notes that values change, as they represent a 'current assessment of meaning for a community' and that these meanings are 'likely to be constantly redefined, reviewed and reiterated' over time.[38] Perhaps in the future one of the intrinsic values may take the form of acceptance of change in the landscape.

2.3 Conservation and Preservation

Around the world, the terms 'conservation' and 'preservation' have differing interpretations. Depending upon the author's country of origin or the country of publication, the two terms have previously referred to the same definition. The classification of these terms will henceforth reflect the definitions as provided by Australia ICOMOS' *Burra Charter*:

> Conservation means all the processes of looking after a place so as to retain its cultural significance … Preservation means maintaining the fabric of a place in its existing state and retarding deterioration.[39]

Upon reflection of the *Burra Charter*, Patrick (1994) argues that landscape preservation is 'difficult to enact' as vegetation in landscapes is organic in nature, and for this reason it is impossible to retain any place "in its existing state" due to changes in plant growth and subsequent changes in microclimates.[40] Change within cultural landscapes is inevitable. Antrop (2005) succinctly observed that 'Landscapes are dynamic and change is one of their properties'.[41] The dynamic character of cultural landscapes extends to every single element as Lowenthal (1985) stated 'No product of man or nature endures forever'.[42] Melnick (1983) also observed landscapes changing constantly and advised that any attempt 'to stop that process through strict preservation policies must be questioned'.[43] Lowenthal (1979) notes that the mere process of preservation [*sic*, conservation], which may include methods employed to slow down deterioration, 'changes the look and feel, if not the form and substance' of the very elements in the landscape that are being preserved.[44] Lynch (1985) also agreed critically observing that 'Every thing, every event, every person is "historic." To attempt to preserve [*sic*, conserve] all of the past would be life-denying'.[45] As Frawley (1989) observed, even the conservation of cultural landscapes can result in attempts to halt change, as this 'inevitably involves intervention to arrest, control or circumscribe' change.[46] These efforts may be in vain, as Goulty (1993) observed that 'by their very nature, gardens are ephemeral' and they exhibit 'an overlapping kaleidoscope of change'.[47] Lynch (1985) ominously warns, 'An environment that cannot be changed invites its own destruction'.[48]

2.4 Value of Trees in the Community

People living within densely populated areas such as cities and towns value urban parkland spaces for many reasons. While the connection the community may experience with the landscape can be very strong, values placed upon elements within the landscape itself can create equally powerful connections. The community may not wholly embrace perceivable changes within these places, and changes wrought by other people are perhaps some of the least well received of all. Trees may form a significant constituent of this urban parkland structure, and unplanned or unexplained changes to these can create turmoil amongst members of the community. Lowenthal (1985) notes that 'trees are frequent symbols of communal unity and patrimonial continuity'.[49] In addition to this, Lowenthal (1985) observes that 'Trees are most often appealing in old age', giving examples such as 'England's gnarled oak' and 'the enduring American redwood' or 'the shade of the old apple tree'.[50] Forests, according to Jönsson and Gustavsson (2002), are 'often perceived as more beautiful, with higher recreational values, in mature stages', with the focus of this desired maturity the established trees.[51]

The attachment the community has to vegetative elements of the landscape is made more evident through Harrison's (1992) statement: 'When forests are destroyed, it is not only an accumulated history of natural growth that vanishes. A preserve of cultural memory disappears'.[52] A reason for this disappearance of cultural memory within an urban parkland context may be explained by Lawrence (1993) where it was noted that 'Most of the trees in the urban forest owe their presence to some human activity', and that 'trees in cities are cultural expressions'.[53] The importance of this observation to understanding community attitudes towards changes in trees within urban parklands is crucial. Further insight into these important community values is also given by Lawrence (1993) through the observation that 'Since the mid-nineteenth century most Western cultures have valued urban forests for their aesthetic, recreational, ecological, and economic contributions to human life', and in addition to this;

> Forests soothe the eyes and spirits, provide shade, form special places for recreation or relaxation, provide habitat for birds and other wildlife, purify the air, and increase the market value of real estate. These qualities are almost universally accepted as valuable.[54]

Jim (2000) echoes these values within the urban context by stating that 'Different peoples and cultures in different places and times have warmly appreciated the practical and spiritual significance of trees in settlements', and 'As cities and towns grow bigger, our detachment from the land becomes more extreme'.[55] These observations suggest that there is an inherent connection between the community and urban parkland spaces and the trees and other plants growing within these spaces. Also pertinent here, Lawrence (1993) describes three principal values of trees in urban landscapes, and appreciably adds that 'each value has gone through its own historical changes' over time.

> The first is the role of trees as natural elements in the human world, both as symbols of the abstract concept of nature and as living organisms…. Second, trees are three-dimensional objects whose color, texture, and form undergo seasonal changes, all of which have aesthetic value…. Third, these changes have been played out in the world of politics and economics, which have also changed over the centuries.[56]

2.4.1 Tangible and Intangible Benefits of Trees

Of the many benefits attributed to trees in urban landscapes, some are more perceptible than others. Hodge (1992) presents an overview of some of the tangible and intangible benefits, and describes some of the tangible benefits of trees as providing screening, noise reduction, dust traps, storing greenhouse gases, summer cooling, shelter, wood, recreation, urban wildlife, and complementing urban architecture.[57] Intangible benefits are described as providing 'contact with nature and seasons', 'the value of peace and tranquillity', 'spiritual and emotional renewal', 'relief from stress and improved recovery from illness', 'improving the attractiveness of urban environments and the quality of everyday urban life', and 'raising senses of pride of place and self worth'.[58] Within this context can be made many connections between trees in urban landscapes and the community.

The many positive aspects of trees in urban landscapes listed here depict a particularly favourable attitude toward all trees. Lowenthal (1985) counters this explaining that 'Even aged trees are odious, however, when numerous and moribund' and that the community can indeed accept the death of an old tree if they are provided with other specimens of various ages 'ranging from infancy to senescence' which can encourage the impression of life cycle.[59] Lowenthal (1985) adds to this warning that while the death of a tree amongst a mature grove of trees can suggest continuity in the landscape, 'Widespread arboreal decay' or 'wholesale extinction' can signal 'ruthless agricultural or industrial change'.[60] For the reasons outlined here, widespread or extensive landscape changes of tree death in urban parklands should be avoided.

2.4.2 Community Association with Trees

The acceptance of landscape change in the community and the dynamics between the perceived importance of the elements at change and the forces driving that change can be observed in a recent community debate in an area of relevance to this research project. The community backlash associated with the proposed removal of three 'significant' trees in the Adelaide Park Lands, South Australia, began a chain of events, as noted in the following section, each expressing important community views associated with change, and acceptance of that change in the landscape.

By the late 20th century, the City of Adelaide (Figure 2.1) was surrounded by the Adelaide Park Lands (Figure 2.2), a 720-hectare green belt containing a diverse mix of indigenous and non-indigenous plants and trees. Originally designed and laid out from the 1830s onwards along with the founding of the city, the Adelaide Park Lands has become an iconic open green space for the Adelaide community.[61] In 1999, Bush for Life, a program of Trees for Life, was granted a 100 square metre patch of the Adelaide Park Lands, located within Park 17. Originally containing *Eucalyptus* woodland species and other indigenous understorey plants and grasses, this area had by the end of the 21st century undergone a series of landscape changes, and little of the original indigenous flora remained.[62]

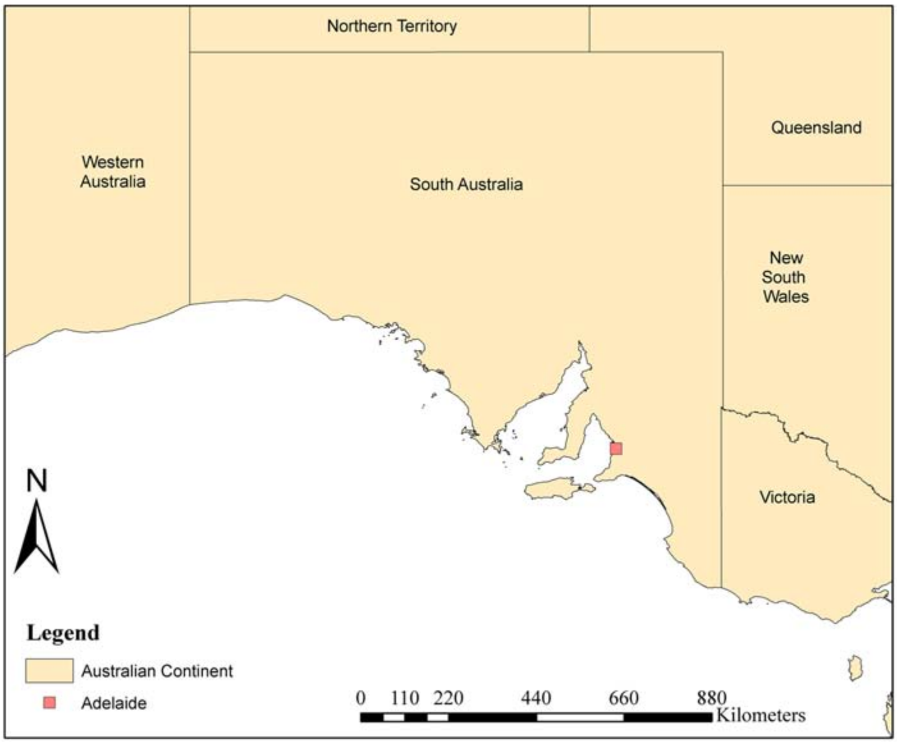

Figure 2.1: Map of Australia, showing location of the city of Adelaide (Copyright © Commonwealth of Australia, Geoscience Australia (2003)).

Bush For Life began their revegetation and regeneration work within this patch in 1999. Through the labour of employees and volunteers over the following three years, weed species were removed and the remnant indigenous understorey plants discovered there were encouraged to regenerate. However, according to Bush For Life, the regeneration of

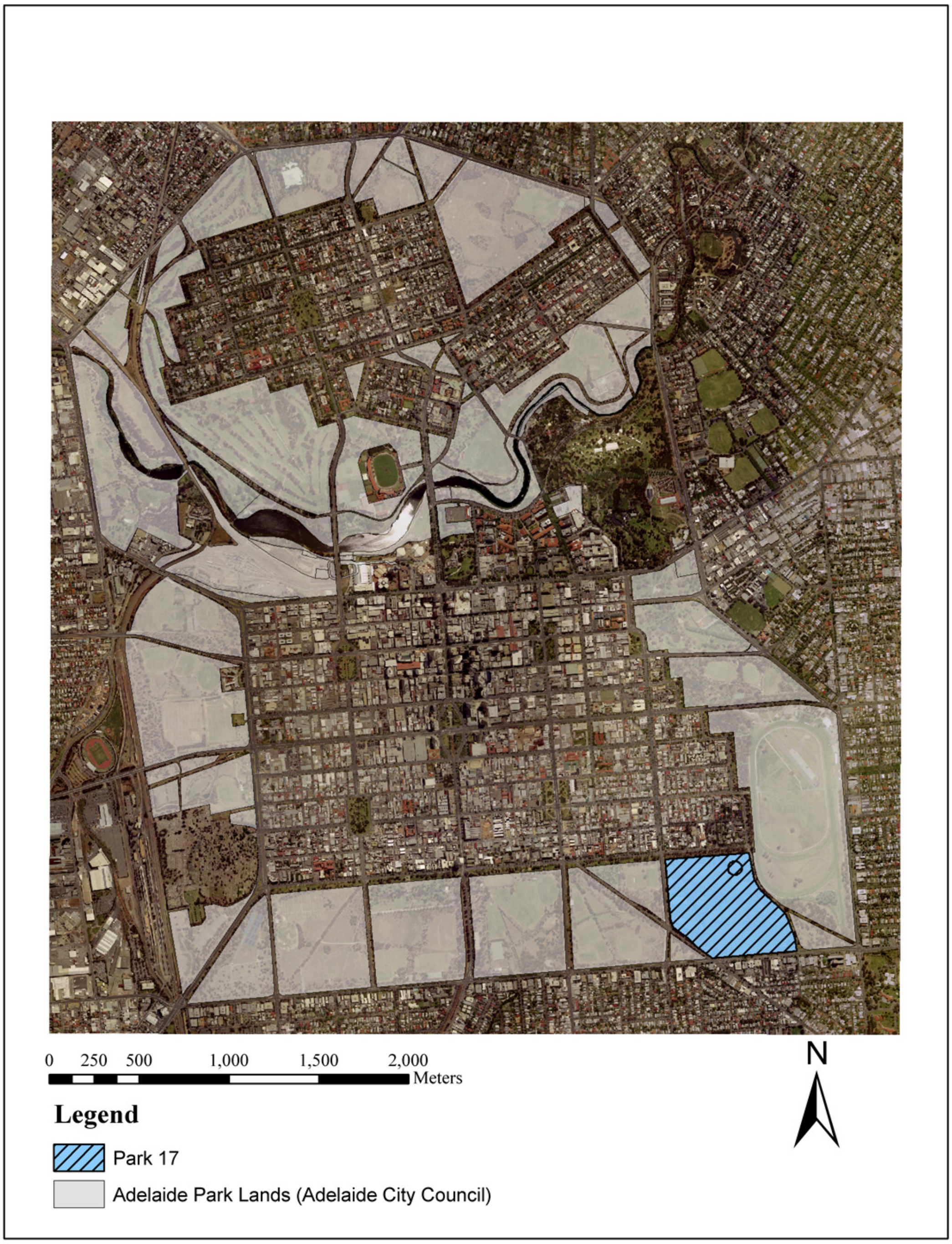

Figure 2.2: Map of the city of Adelaide, showing the Adelaide Park Lands within direct supervision of The Corporation of the City of Adelaide Council (highlighted), and with Park 17 (highlighted). (Aerial Photograph Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002)).

these understorey plants was hampered by the smothering effect of needles dropped from non-indigenous pine trees, and the chemicals leeched from these needles were toxic to the indigenous Adelaide plains plants.[63] Bush For Life applied to the Adelaide City Council, the managers of the Adelaide Park Lands, to have the one Aleppo Pine (*Pinus halepensis*) and two Canary Island Pines (*Pinus canariensis*) removed, claiming that the trees were having an adverse affect on indigenous understorey plant species regenerating there. The debate that ensued was an example of the desire within a community to retain elements of the past, to resist change, and to retain old trees regardless of the consequences to the surrounding environment.[64]

The subsequent approval by the Adelaide City Council for the three-tree removal was not well received by many members of the community. Within a short period of time, a number of people, including several horticulturalists and botanists, opposed the removal. The councillors were divided. Spokespeople for the Adelaide Park Lands Preservation Society, along with other members of the community rallied together to oppose the removal of the 'significant' trees.[65] A number of the arguments presented to subsequent council meetings indicated an obvious public veneration towards the trees. Many of the views were published in local newspaper reports, including comments such as '"They are perfectly healthy trees and I think the madness of pulling trees down to be politically correct has to stop"' from a horticulturalist, and '"We don't believe only indigenous plants should be preserved, we believe there is a place for these pines as well. It's easy to chop down a tree but it can take a century to grow another one"' from a member of the Parklands Preservation Society.[66] Further comments opposing the removal included '"They're large mature trees still in good health and I couldn't suggest their removal on grounds of over-age"' from one botanist, and '"You don't have to cut trees down, especially when they are perfectly good trees and don't have any diseases"' was a telling remark from a 12-year-old.[67] These comments offered an insight into a fraction of the community's desire for preserving the past.

To avoid further conflict on the matter, Bush For Life withdrew its tree removal application. Within weeks, and on World Environment Day 2004, the three pine trees were ringbarked by vandals. Placards were left by the vandals at the ringbarked trees and called 'for a halt to "the butcher of old-growth forests" and to "destroy invasive foreign plants"'.[68]

The Adelaide City Council announced they would save the trees and subsequently spent $7200 on an attempt to 'bridge graft' the damaged trunks.[69] The process, undertaken to prevent their deaths involved removing strips of live bark from higher up the tree's trunk and attaching them to the ringbarked section, effectively bridging the ringbark, and returning the natural flow of nutrients and water required to keep the tree alive.[70] Although the operation was carried out swiftly following the vandalism, the death of the Aleppo pine was evident about 18 months later.[71] The two Canary Island pines survived the ringbarking attempt.[72] This sequence of events has particular relevance to the discussion of cultural landscape attachment. Hitchmough (1994a) warns of this conflict between the conservation of landscape elements considered cultural, and those considered natural. To this Hitchmough (1994a) added that Australian cultural landscapes 'of some antiquity, generally nineteenth century' are particularly prized in such a debate.[73] An important observation by Lynch (1985) may also assist in explaining some of the community reactions to such changes in the Adelaide Park Lands:

> Many symbolic and historic locations in a city are rarely visited by its inhabitants, however they may be sought out by tourists. But a threat to destroy these places will evoke a strong reaction, even from those who have never seen, and perhaps never will see, them. The survival of these unvisited, hearsay settings conveys a sense of security and continuity. A portion of the past has been saved as being good, and this promises that the future will so save the present. We have the sense that we and our works will also reach uninterrupted old age.[74]

Johnston (1992) also shared this observation, noting that,

> Our attachment to place is fundamental, but may be unconscious in our daily lives until a place to which we are connected is threatened. Our response to such a threat will be charged with emotion, as it is our emotions that are touched by the connection.[75]

The change in the Adelaide Park Lands situation was the removal of trees that formed part of this connection, and the trees were still alive at the time of the removal application by Bush For Life. Hitchmough (1994c) notes that many people have an interest in their surrounding environment and respond strongly to proposals for the removal of trees that are not dead.[76] Within an urban forest context, Grey and Deneke (1992) noted that 'Many people would view the sight of large live trees being cut down as offensive, and some would find it intolerable'.[77] McPhee (1999) also noted this community veneration of old trees where it was added that the removal and replacement of unsafe trees can cause 'major public relations difficulties for the responsible authorities' and due to this many trees in

Australian urban parks and gardens 'pose safety risks'.[78] A possible explanation to these actions, or lack thereof by landscape managers, is also provided by McPhee (1999), where it was noted that there is an 'emotional awe, even reverence, for historic places' within the community, and 'their value in a society's consciousness is deep rooted'.[79] Some techniques used by decision makers to adapt the landscape to change are hampered, according to Lynch (1985), 'by the common attitude that things should last forever and never change and that if they do change it is for the worse'. In addition to this, Lynch (1985) explains that 'acceding to change' may appear as a form of betrayal within the community.[80]

Threats to places considered important within the community, according to Johnston (1992), could be a very powerful motivation for members of the community to mobilise and take action.[81] Certainly, the elected officials within the Adelaide City Council would have experienced pressure to take action on the community's behalf; unpopular decisions may significantly shorten tenure in local government. The popular approach to undertake a period of community consultation allowing all community and Bush For Life views to be expressed did not take place. However, as pointedly outlined by Fakes (2006), community consultation processes can 'be hijacked by politicians and the media and thus sensationalised'.[82] As was evident by the powerful and emotionally charged community comments published in the newspaper reports at the time, a community consultation may indeed have turned into an unhappy situation. Kerr (1990) however, notes that tension between those opposing change and those encouraging it may not necessarily be negative. Instead it may be seen as a 'useful testing process' and it 'can establish a society's priorities'.[83] Importantly, Kerr (1990) adds that the information relevant to the decision-making process must be made available to all.

Although it was clear that the community had an influence upon the decisions made in this particular situation, Schapper (1990) noted that the concept of heritage conservation was not viewed as a vote-winner amongst politicians and decision makers, instead they prefer to give it a low priority, believing that the potential investment returns may not be as profitable as other business or development enterprises.[84] According to Jönsson and Gustavsson (2002) there is a need for 'good strategic thinking in long-term management planning' for the future, due to 'increasing public concern and uncertainty' in the stability of cultural landscapes.[85]

For appropriate cultural landscape management policies to be implemented, and 'because landscape is a reflection of society, if we wish to change the landscape' for the benefit of the community, according to Meinig (1979), 'we will have to change the society which created it'.[86] Lynch (1985) projects this notion further by stating that 'Many political and social changes must occur before the image of the future can be built'.[87]

2.5 Understanding Change in the Landscape

In order for necessary changes to take place in the landscape, an understanding within the community of the changes occurring and the driving forces behind those changes, are important. The community needs to be informed and understand these changes to enable important cultural landscape decision-making processes to take place. Jönsson and Gustavsson (2002) noted that 'The information flow nowadays is enormous, but information should not be confused with knowledge, or the understanding of knowledge'.[88] The importance of knowledge within the community is a vital component in cultural landscape management.

Providing an example of this community-based understanding of change in cultural landscapes within an Australian context was *Design for Change: Community Renewal After the 1983 Bushfires* (1985). Undertaken by the School of Environmental Planning at the University of Melbourne, the research project centred around the devastating bushfires that ravaged the Mount Macedon Ranges, Victoria, in 1983. This document was developed primarily for use by the community, to enable them to achieve a greater understanding of the landscape both before and after the fires, and to provide planning guidelines for potential future landscapes.[89]

While sections of the community may wish to retain a particular cultural landscape in a certain state for an indefinite period of time without change, in reality such a demand on any landscape is not possible. Lowenthal (1979) explained that 'It may or may not be wrong to alter the past; but it is inevitable'.[90] Bell (2001) suggested that it is not reasonable to preserve or even maintain landscapes in the long-term, 'even though members of the public may want or insist on it'.[91] Bell (2001) added that community 'Perceptions of the static climax ecosystem and the unchanging natural scene should be challenged in order for truly sustainable solutions to be achieved' and observed that if information to the community is provided and communicated appropriately, enhanced decisions on the future of cultural landscapes may be achieved.[92]

Methods of preservation of the landscape in any chosen state appear extremely difficult, however alternatives do exist. Heyer (1976) suggested, as garden landscapes could not 'be preserved in any formal way', they should be accurately documented and may then be shared with later generations in the future.[93] Lynch (1985) warns of the dangers of attempting to preserve the environment, as this may 'encapsulate some image of the past', and this image may later 'prove to be mythical or irrelevant'.[94] Lowenthal (1979) outlined how 'Many natural scenes are episodic' and therefore proposed that in order to preserve nature we must shift our focus towards considering 'process' or even 'time-scales' as opposed to preserving 'form'. [95]

This focus upon process rather than form has particular relevance to plants in landscapes. As living elements within cultural landscapes, trees and plants are organic and are therefore vulnerable to the natural processes of growth and decay. These processes may not result in swift changes, as Workman (1991) described this 'gradual growth and decay' of trees and plants often occurring within a period of time longer than that of the growth and decay of humans.[96] As organic constituents within a changing landscape, trees cannot remain static and Sales (1975) notes that the 'process of development and decay is constant' and that each species 'has its own time scale of development and senescence,' and this creates 'a fascinating pattern of overlapping growth cycles'.[97]

The understanding of these ever-changing qualities within trees and plants, proposed Rose (1939), requires 'deeper knowledge and experience in their use than any other material' in a landscape.[98] Due to the dynamic nature of plant growth, agreed Funnell (1992), they require care and conservation in landscapes.[99] Dynamic changes in plants and trees are inevitable, and Sales (1990) believes that this constant change in the form of development and decay should be perceived as 'a marvellous thing', as opposed to 'an inconvenience', and notes that it is this quality that 'we like about gardens' and change should not be 'apologised for'.[100] The irreversible nature of this organic change is an intrinsic component of landscapes, and should be considered integral to the concept of process discussed here.

Sales (1990) also observed that these environmental processes need to be managed, and any attempts to halt them are ‘both unnatural and expensive’.[101]

Also analysing the concept of plants as process, Eyring (1999) suggested a focus upon managing the ecological system within cultural landscapes, and the conservation of vegetation patterns as opposed to individual vegetation features.[102] Eyring (1999) added to this that these conservation methods diverged from ‘traditional’ conservation philosophy, which places an emphasis upon ‘original fabric’ rather than on environmental processes.[103] Hitchmough (1990) proposed that plants themselves might form the ‘living fabric’ of the landscape. [104] Patrick (1994) noted that while the maintenance of the plantings in their original detail may become impossible, the preservation focus should shift to an understanding of the period in which the plantings were undertaken, and new vegetation fabric be introduced progressively as older plantings reached the end of their effective lives. Through this conservation process, the ‘spirit and mood of the historic period’ may be captured and retained through the vegetation.[105] Heathcote (1995) also agreed with these concepts, and added that plants and trees must be managed under different preservation philosophies to buildings where the emphasis is on interfering little to retain original fabric. Instead, Heathcote (1995) believed the preservation focus of vegetation in landscapes should be on the content of the planting scheme palettes, as plants and trees can be grown again with only a temporary loss in scale and texture.[106] Within a social context, Johnston (1992) suggested that the importance of continuing practices or processes can be more significant to a community than attempts to preserve fabric in any one state for an extended period of time.[107]

2.6 Types of ‘Time’

In order to situate this notion of ‘time’ as an intrinsic concept of change in cultural landscapes, the need arises to establish the definition of time, as used within this construct of cultural landscape.

There are many varied explanations and definitions of the word ‘time’. The physical manifestation, or form, of time is one of the areas of thought often debated in both scientific and philosophical circles. As potential descriptions for the form, suggestions and discussions have explained time as linear, parallel, multiple parallel, branching or tree structures, cyclical, discrete, and non-existent times have been explored.[108] The individual attributes of each of these are lengthy discussions in themselves; however, a brief discussion of several of the more commonly accepted models may assist in forming a temporal framework around which further essential discourse can be built.

Branching time has been attributed to modelling applications where multiple futures or possibilities may exist or unknown changes may occur.[109] This form of time has interesting applications to environmental modelling in particular, where unpredictable changes may occur, often without warning. While this form of time appears to have direct applications to our known reality in predicting attributes of the future, the branching nature suggests a potentially infinite number of future possibilities giving this model an increasingly unpredictable form. Cyclical time has also been proposed, where certain points in time are revisited repeatedly over an undefined cycle length. The length of this cycle may vary, depending upon the life cycle at the centre of the focus.[110] Perhaps the most popular belief of time is that of a line. The notion of time existing as a 'line without endpoints that stretches into the past and the future' as outlined by Langran (1992) is one of the more popular views.[111] According to Simpson and Weiner (1989), the definition of time as an 'Indefinite continuous duration regarded as that in which the sequence of events takes place' dates from the 14th Century.[112]

The concept of time existing in the form of a line, offers potential here to be discussed with the view for further development within this research. To refine the concept, Stead (1998) defines a 'time line' as,

> [A] single ordered line of time along which temporal extent of data values may be plotted, where a value can only exist in one state at any one time: the line may not go back and overlap itself.[113]

Stead (1998) continues this discussion further, stating that the 'real world operates along one such line'.[114] As a 'continuous stream regularly floating', Frank (1998) builds on this line concept, adding that 'Time is dense, meaning that between any two events, another one can be inserted, and it is regularly progressing; thus, the calculation of intervals makes sense'.[115] Olwig (2005) adds that a 'point' in time, perhaps another term for an 'event', is 'infinitely small', supporting the notion that it may indeed be possible to add an infinite number of events into a stream of time.[116] The model of time proposed, and outlined here as a line, will be used as it is preferred within the scientific fields, and as a result mathematical, analytical, and statistical models can be developed and tested based upon this particular concept of time.[117] Within this line context Lynch (1985) identifies time as a mental device, employed as a tool for sorting and identifying sequences of events.[118] The notion of the human construct of, and desire for, the knowledge of time is a well-known phenomenon.[119] Wristwatches and wall clocks, strangers asking strangers for the time, and daily schedules based upon hours within the day are deeply embedded in the psyche of many people. Lynch (1985) evolved this discussion even further, suggesting that 'Even more than current timing, we are eager to know predicted timing'.[120] The interest for knowledge of predicted time has enticed many people for millennia.

2.6.1 Space and Time

The definition of the term time has been a topic debated by many realms of thought over many centuries. Aristotle wrote that,

> …time exists alike both everywhere and with all things. Moreover, every change is faster or slower, but time is not; for the slow and the fast are defined in terms of time…but time is not defined in terms of time.[121]

The existence of time and subsequent derivations of time measurement have been the focus of scientific and philosophical thought as people attempted to explain existence or being.

Space, the three-dimensional world within which we exist is a potentially tangible element, which we can experience through our senses. The relationship between space and time has been explored and arguments exist linking the two together. There also exists a series of arguments, stating in fact, that the two are not separable as a part of our tangible existence. This link between space and time is perhaps an appropriate method of identifying a definition for time, and linking units of measurement to a seemingly non-existential entity. One definition outlines this potential space-time relationship as '"the four dimensional order within which every physical existent may be determined by specifying its three spatial coordinates and one temporal coordinate"'.[122] Blaut (1961) also links space and time inseparably, stating that,

> Relative space is inseparably fused to relative time, the two forming what is called the space-time manifold, or simply *process*. Nothing in the physical world is purely spatial or temporal; everything is process. The time dimension may be neglected, but it is always implied.[123]

Dragicevic, Marceau and Marois (2001) build on this notion, arguing that time and space need to be connected to fundamental concepts and add the expression 'change' to the term 'process'[124]. This change is essentially a 'composite of processes that occur on a wide band of timescale in space', and as a result, 'specific processes determine specific temporal and spatial conceptualization'.[125] A similar view that indicated the inseparable link between space and time was observed by Wegener (2000) where it was stated that everything that occurs, 'occurs in space and time' and as a consequence, 'our perception of the world is inherently spatial and temporal: objects have a location, and events are embedded in a stream of time'.[126]

While Lynch (1985) acknowledges this space-time dialectic and it is recognized as the 'great framework within which we order our experience', the term is given a decidedly humanistic perspective when it is suggested that we live within 'time-places'.[127] The concept of time as being inherently embedded within space, creating a space-time construct, is an important element of the world within which we exist. The development of this combined construct into the term process, and developed further still into the concept of change, enables the distillation of the primarily theoretical construct of time into a tangible, and more critically, visible expression in the environment.

2.7 Acceptance of Change in Cultural Landscapes

This dialogue of time relating directly to change is an important concept in understanding change in the landscape and especially in varying rates of change. The speed at which elements in the landscape change and age varies considerably. Lowenthal (1985) observed these varying rates of change through time:

> Some things endure for millennia, others for moments; each species and kind of object ages at its own tempo. A cat may look old at seven years, a man at seventy, a cathedral at a thousand, a mountain in a hundred million. [128]

An awareness of changes taking place within various landscape components is essential for the acceptance of this change within the community. This awareness must be provided through knowledge of evident time in the form of change in the landscape. We cannot see time; we can only perceive its effects. Lynch (1985) proposed a number of important concepts, many of which are relevant to a community's awareness, perception, appreciation, and understanding of change through time. Lynch (1985) observed, 'we have two kinds of evidence of the passage of time': 'rhythmic repetition' and 'progressive and irreversible change'.[129] Rhythmic repetition can be in the form of breathing, the heartbeat, hunger, sleeping and waking, the environmental seasons, and the cycles of the sun and the moon. Progressive and irreversible change is 'growth and decay, not recurrence but alteration'.[130] Every one of these changes are observed and even appreciated amongst society. As added by Lynch (1985), the 'Environment is the clock we read to tell real time, to tell personal time'.[131] The changes, through time, expressed here provide confirmation that not all change in cultural landscapes is viewed in a negative fashion. As stated again by Lynch (1985),

> Our real task is not to prevent the world from changing but to cause it to change in a growth-conducive and life-enhancing direction. The environmental image of time-places can play a role in speeding that necessary change, and its analysis can tell us what some of the features of a life-enhancing universe would be. We can change our minds so that we enjoy the dynamics of the world. [132]

If the awareness of change in cultural landscapes can move through stages of perception and awareness and into appreciation, then perhaps it may eventually become accepted. Managers of these cultural landscapes undertake the important role of affecting changes appropriately. Through the employment of various tools such as community consultation, education, and interpretation, landscape managers can undertake an educational role within the community, creating effective feedback mechanisms to encourage appreciation, and therefore community acceptance of change in the landscape. Lynch (1985) contemplated these concepts positively:

> We also assert that the nature of visible environmental change can reduce the costs of transformation and help to teach a better concept of change. Shared experience with legible, desired transformation makes people not only used to change but understanding of it. It may even lead them to find delight in it.[133]

Landscape managers will continue to play important roles within the community's understanding and acceptance of change in cultural landscapes. They will require the appropriate tools for this task.

Chapter 2 Notes

[1] Sauer (1927) p. 190; Taylor (1983) p. 29.
[2] Sauer (1927) p. 190.
[3] Antrop (2005) p. 21.
[4] Worster (1993) p. 25.
[5] Melnick (1981) p. 56.
[6] Wood and Handley (2001) p. 46.
[7] Meinig (1979) p. 229.
[8] Jackson (1958) p. 21.
[9] Wood & Handley (2001) p. 46.
[10] Lynch (1985) p. 187.
[11] Frawley (1989) p. 19.
[12] Funnell (1992) p. 35.
[13] Sales (1990) p. 32.
[14] Eyring (1999) p. 21.
[15] Lowenthal (1975) p. 6.
[16] Lowenthal (1975) p. 6.
[17] Lowenthal (1979) p. 104.
[18] Lowenthal (1975) p. 7.
[19] Lowenthal (1975) p. 112.
[20] Lowenthal (1975) p. 10.
[21] Lowenthal (1975) p. 26.
[22] Lowenthal (1975) p. 26.
[23] Lowenthal (1975) p. 24.
[24] Lowenthal (1975) p. 31.
[25] Lowenthal (1975) p. 26.
[26] Antrop (2005) p23.
[27] Antrop (2005) p. 22.
[28] Lynch (1985) p. 57.
[29] Lynch (1985) p. 110.
[30] Schapper (1993) p. 344.
[31] Australian Heritage Council (2007) <http://www.ahc.gov.au/register/index.html> (accessed on 2/1/2007).
[32] Frawley (1989) p. 19.
[33] Schapper (1993) p. 346.
[34] Johnston (1992) p. 7.
[35] Johnston (1992) p. 10.
[36] Mayne-Wilson (2001) p. 13.
[37] Johnston (1992) p. 10.
[38] Johnston (1992) p. 17.
[39] Australia ICOMOS (1999) p. 2.
[40] Patrick (1994) p. 480.
[41] Antrop (2005) p. 32.
[42] Lowenthal (1985) p. 125.
[43] Melnick (1983) p. 95.
[44] Lowenthal (1979) p. 121.
[45] Lynch (1985) p. 36.
[46] Frawley (1989) p. 19.
[47] Goulty (1993) p. 2.
[48] Lynch (1985) p. 39.
[49] Lowenthal (1985) p. 135.
[50] Lowenthal (1985) p. 135.
[51] Jönsson and Gustavsson (2002) p. 44.
[52] Harrison (1992) p. 62.
[53] Lawrence (1993) p. 26.
[54] Lawrence (1993) p. 26.
[55] Jim (2000) p. 271.

[56] Lawrence (1993) p. 27.
[57] Hodge (1992) pp. 30-31.
[58] Hodge (1992) pp. 31-32.
[59] Lowenthal (1985) p. 135.
[60] Lowenthal (1985) p. 135.
[61] Long (2003) p. 1.
[62] Long (2003) p. 1 and p. 25.
[63] Milbank (2004a) p. 2.
[64] Milbank (2004b) p. 22.
[65] Milbank (2004a) p. 2.
[66] Milbank (2004b) p. 22.
[67] Milbank (2004b) p. 22.
[68] Pippos (2004) p. 16.
[69] Anonymous (2005) p. 5.
[70] Graham (2005) p. 9.
[71] Graham (2005) p. 9.
[72] Day (2006) p. 5.
[73] Hitchmough (1994a) p. 8.
[74] Lynch (1985) p. 40.
[75] Johnston (1992) p. 4.
[76] Hitchmough (1994c) pp. 269-270.
[77] Grey and Deneke (1992) p. 176.
[78] McPhee (1999) p. 5.
[79] McPhee (1999) p. 4.
[80] Lynch (1985) p. 201.
[81] Johnston (1992) p. 23.
[82] Fakes (2006) p. 19.
[83] Kerr (1990) p. iv.
[84] Schapper (1990) p. 21.
[85] Jönsson and Gustavsson (2002) p. 39.
[86] Meinig (1979) p. 229.
[87] Lynch (1985) p. 116.
[88] Jönsson and Gustavsson (2002) p. 41.
[89] Latreille (1985) p. 2.
[90] Lowenthal (1979) p. 125.
[91] Bell (2001) p. 204.
[92] Bell (2001) p. 204.
[93] Heyer (1976) pp. 246-247.
[94] Lynch (1985) p. 53.
[95] Lowenthal (1979) p. 116.
[96] Workman (1991) p. 174.
[97] Sales (1975) p. 50.
[98] Rose (1939) p. 227.
[99] Funnell (1992) p. 37.
[100] Sales (1990) p. 32.
[101] Sales (1990) p. 32.
[102] Eyring (1999) p. 21.
[103] Eyring (1999) p. 21.
[104] Hitchmough (1990) p. 17.
[105] Patrick (1994) pp. 385-386.
[106] Heathcote (1995) p. 15.
[107] Johnston (1992) p. 24.
[108] Dragicevic, Marceau and Marois (2001) p. 546; Frank, (1998) pp. 40-62; Langran (1992) Ch. 3; Langran & Chrisman, (1988) pp.1-2.
[109] Dragicevic *et al.* (2001) p. 546.
[110] Isard (1970) p. 26.
[111] Langran (1992) p. 27.
[112] Simpson and Weiner (1989) p. 103.
[113] Stead (1998) p. 214.

[114] Stead (1998) p. 214.
[115] Frank, (1998) p. 52.
[116] Olwig (2005) p. 260.
[117] Frank, (1998) p. 52.
[118] Lynch (1985) p. 120.
[119] Lynch (1985) pp. 69-71.
[120] Lynch (1985) p. 71.
[121] Apostle (1969) p. 80 (218b. 14-18).
[122] Olwig (2005) p. 260 (Quote from: Merriam-Webster, (1968) *Webster's Third International Dictionary of the English Language, Unabridged* Springfield, M.A: G. & C. Merriam).
[123] Blaut (1961) p. 2.
[124] Dragicevic *et al.* (2001) p.545
[125] Dragicevic *et al.* (2001) p.545
[126] Wegener (2000) p. 3.
[127] Lynch (1985) p. 241.
[128] Lowenthal (1985) p. 126.
[129] Lynch (1985) p65.
[130] Lynch (1985) p65.
[131] Lynch (1985) p. 66.
[132] Lynch (1985) 242.
[133] Lynch (1985) pp. 213-214.

Chapter Three: Tree Longevity

The subject of tree longevity is important to modelling tree senescence patterns in cultural landscapes. An understanding of how and why trees senesce is vital to providing information for use in modelling the latter stages of tree life, where senescence is reached, and trees in landscapes arrive at the end of their expected life spans. In order to predict this tree senescence and therefore model potential future landscape scenarios, tree longevity figures reflecting the number of years expected from tree life spans are reviewed in the literature, with a particular focus upon sourcing longevity figures for use in the Adelaide Park Lands.

3.1 Introduction

Trees are both the longest-lived and largest organisms on Earth.[1] These are distinguishing factors within the plant kingdom; however, they have also been described by Shigo (1982) as being 'A perennial, woody, compartmented, shedding plant; may be short or very tall, single or many-stemmed, sometimes massive, and long-lived'.[2] Due to their longevity, Cobham (1990) observed that these plants can 'provide long-term structure' to the landscape.[3] Importantly though, Fakes (2006) noted that in order for a tree to provide this structure and therefore make this significant contribution to the landscape, it must 'live long enough'.[4] If they do live long enough however, old trees may become 'important points of reference' in the landscape, and may assist to 'determine the character of an area', according to Russell, Cutler and Walters (2006).[5]

As 'integral parts of cities around the world', and within a planning context, trees in urban landscapes have been considered to be features almost as important as buildings themselves, noted Russell *et al.* (2006), and 'have a higher priority in our towns and cities now than at any time previously'.[6] The importance of trees in the landscape has resulted in a need for appropriate levels of understanding of these living organisms. A review of the literature on tree longevities and the various aspects related to tree longevity provide a structure for identifying areas of interest in this topic not previously covered through published research.

3.2 Tree Senescence

Definitions of both 'senescence' and 'aging' within the plant kingdom were examined in studies by Leopold (1980), and Noodén (1980, 1988). Leopold (1980) defined senescence as 'the deteriorative processes that are natural causes of death', and aging as the 'processes of accruing maturity with the passage of time'.[7] Within this context, aging was identified as incorporating,

> …a much wider span of physiological changes, some of which may lead to the weakening of the organism while others may be quite neutral with respect to the capability of the biological organism to survive.[8]

Examples of aging provided by Leopold (1980) included the 'physiological changes in a plant', such as those causing 'its conversion from a seedling to a juvenile plant, from a juvenile plant to a mature plant' or in the 'gradual decline' in vigorous growth as age increases.[9]

Salisbury and Ross (1992) defined senescence as 'The processes of deterioration that accompany aging and that lead to the death of an organ or organism'.[10] Examples of senescence provided by Leopold (1980) include the changes leading to the colouring and eventual death of leaves on deciduous trees in autumn, and the death of annual and biennial plant species following their fruiting period.[11] Noodén's (1980) definitions were concurring, with senescence described as 'a decline in physiological functions leading to death', with the following concise explanation:

> During the course of their lives, all multicellular organisms and their organs or tissues reach a peak in terms of their physiological function, and then they decline until they die. This process of decline leading to death has been termed senescence, and a distinction has been made between degenerative changes that lead to death (senescence), and those that do not necessarily cause death even though they accumulate with age (aging).[12]

It is important also to note that Noodén (1988) described senescence as 'a natural developmental process', and this process 'can be represented as endogenously controlled deteriorative changes, which are natural causes of death in cells, tissues, organs, or organisms'.[13] The importance of these definitions, and the explanations defining the terms, assist in outlining the intended direction of the following research.

3.2.1 The Inevitability of Tree Senescence

An important aspect of a study into tree longevity is an examination of the various factors that influence the lifespan of trees. The purpose of this is to identify the factors that cause tree death, and therefore potential limitations to tree life spans. The misconception within the wider community of trees being bestowed with 'eternal' life and not requiring replacement due to senescence was observed by Pescott (1968) as having a detrimental effect in landscapes, as authorities can be influenced by these community-based attitudes.[14] Patrick (1988) established 'that amenity tree plantings have a finite life' and will eventually succumb to senescence.[15] Shigo (1989) also observed that 'Trees, like all living things, grow old and die'.[16] Hannah and Yau (1993) stated that 'Trees have a finite lifespan'.[17] Building upon this Hannah and Yau (1993) reasoned that beyond their optimal age, trees 'will start to decline, reach senescence and ultimately die'.[18] Crucially within this context of the inevitable nature of tree death, Clark and Matheny (1991) observed that at some point in the lifespan of the tree, the amount of energy produced cannot meet the demands for continued 'growth and survival', resulting in tree decline and death.[19] Shigo (1989) had also noted this through the observation that 'No living system can grow beyond the limits of energy available to operate the system', and that 'no matter what you do, all living things will eventually die'.[20] If tree senescence exists and tree death can be substantiated, there must also exist upper limits to tree longevity.

3.2.2 Programmed Senescence in Trees

The notion of tree longevity as being predetermined by genetic variations between the different tree species has been proposed by a number of authors on the subject. Leopold (1980) observed the phenomena of 'internally programmed senescence' through such pertinent illustrations,

> …as the simultaneous death of entire populations of soybeans, corn, and the small grains; among animals, the death of the entire breeding population of salmon is a well-known example.[21]

According to Leopold (1980), 'internally regulated senescence' appears more frequently in the plant kingdom, however other causes of plant death were also noted including environmental stresses, disease, predation, or the 'gradual deteriorative effects of aging'.[22] Noodén (1980) agreed, adding that while 'externally-imposed disasters' such as disease and predation may have a significant impact upon plant death, 'longevity is still clearly determined by the genetic constitution of the organism'.[23] In addition, Noodén (1980) observed that it remained uncertain whether 'longevity-determining genes control a senescence program', or just the ability of the organism to withstand or succumb to 'life-terminating disasters'.[24] Salisbury and Ross (1992) noted that 'senescence is genetically programmed into each species and into organs and tissues of individual plants'.[25] Research by Molisch (1938) also noted that upon collation of the available longevities within the plant kingdom, different periods of individual longevity were noted; however, longevity 'within the species' was 'characteristically constant'.[26] With regard to the issue of plant or tree size as a longevity determinate, Molisch (1938) also observed that although the plants with the shortest life spans were found to be some of the smallest, and the longest life spans amongst the largest, 'size alone cannot control longevity, for size and longevity do not always run parallel'.[27] While the term 'longevity' is primarily used in this research within a whole organism lifespan context, Leopold (1980) noted that the term also refers to the lifespan of cells, organs, and tissues. Within the biological subject of trees, Leopold (1980) gave examples such as the 'programmed death of leaves' with a single growing season for deciduous trees, and between two and four years for leaves on evergreen trees.[28]

An argument against the existence of programmed senescence in whole trees, however, was also put forward by Leopold (1980), where it was stated that although short-lived plants may potentially possess genetically programmed life spans, perennials had 'much less precise limits of longevity', instead, dying 'through a gradual attrition associated with aging'.[29] Felix and Shigo (1977) also noted this, stating that 'It is impossible to generalize about living things. Survival depends on variations within a species'.[30] Felix and Shigo (1977) also made the subsequent observation that 'There is not much we can do to extend the life of a tree far beyond its genetic potential for longevity'.[31] Clark and Matheny (1991) proposed that 'trees do not appear to have fixed life spans', 'unlike annual, biennial, and some perennial plants'.[32]

Within the context of amenity tree plantings of similar age and of the same species, Patrick (1988) maintained that we could potentially 'expect them to die at the same time, give or take a few years'.[33] Andrews, Harris and Skipper (2000) also agreed that 'Longevity or aging of trees is a genetically programmed period', however it is crucially linked to and 'affected by the environment in which the organism is found'.[34] It would appear from the literature pertaining to genetically controlled senescence in trees that its influence on tree death is of relevance within the wider subject of tree longevity.

3.2.3 The Environment as a Tree Longevity Determinate

While arguments presented support the existence of some form of regulated or programmed senescence influencing the longevity of trees in the landscape, arguments also exist that support environmental influences having an impact upon tree longevity. A study into tree senescence patterns in the environment by Clark and Matheny (1991) noted that ‘Trees develop in balance with their environment’, and their relational vigour, form and size are direct responses to environmental conditions, governing their survival and optimising their growth.[35] Andrews *et al.* (2000) also recognised this relationship, noting that trees placed in urban environments may age differently to those still within their original plant communities.[36] Trees growing in urban streets, according to Hitchmough (1994c), have ‘generally shorter’ life spans than the identical species growing within urban parklands ‘exposed to less severe forms of stress’.[37]

Loehle (1988) investigated relationships between tree growth, defences, and longevities in North America, and found that favourable habitats ‘can contribute to longevity’.[38] However, the study also discovered trees of the genera *Salix* and *Taxodium*, each with dramatically different longevity figures, growing next to one another in almost identical environmental conditions.[39] In addition, the study found that ‘very long-lived species’, such as *Juniperus occidentalis* with a maximum lifespan of 900 years, can be found growing in adverse desert conditions.[40] Noodén (1980) also observed that ‘stressful’ or ‘suboptimal’ environments do not necessarily decrease longevity, though they may ‘be expected to cause more “wear and tear”’.[41] The relevant example given in this argument by Noodén (1980) was the world’s oldest known tree at the time, a Bristlecone Pine (*Pinus longaeva*) found growing in the White Mountains in California and radiocarbon dated at 4700 years old.[42] While this specimen appeared to have been growing in difficult or harsh conditions, trees such as this one ‘may attain their greatest age in the harsher environments’.[43] Banks (1997) noted that ‘longevity depends largely’ upon the tree’s ability ‘to develop mechanisms to minimise the effects of environmental and biological stresses’.[44] Given these examples, it would appear that there is a direct correlation between the growing environment and the longevity of trees; however, the tree species appears to be the distinguishing factor in this particular association.

3.2.4 Balance in Tree Systems

In order for tree life systems to continue in the form of tree growth and longevity, evidence provided by Clark and Matheny (1991) suggests that trees require 'a balance between growth and the environment'.[45] They also note that either 'internal balance' within the tree itself requires a relatively stable living environment, or the tree must respond to environmental changes brought upon it.[46] Within a landscape management perspective, tree growth is most commonly disrupted within urban landscapes, placing pressure on mature trees and, as observed by Clark and Matheny (1991), it is easier to maintain the internal balance of 'a mature tree on an undisturbed site than it is to restore balance following disturbance'.[47] Disrupting a tree's internal balance may therefore affect longevity.

3.3 Trees as Generating Systems

As observed by Banks (1997) and others previously discussed, the 'tree is an ideal form of life to attain great age'.[48] The reason for this appears to lie within the growing tissues of the tree and the method employed for new tissue creation. Shigo (1989) explained this through the comparison that 'Trees are generating systems' and 'Animals are regenerating systems'.[49] As regenerating systems, animals can survive if they can 'restore parts faster than they are breaking down', whereas in order for trees to survive they need to be able to 'form new parts in new positions faster than old parts are breaking down'.[50] Jacobs (1955) noted that trees add new tissues 'on the outside of the accumulated tissues of former years, and this accumulated mass is continually increasing in size'.[51] Also noted by Andrews *et al.* (2000), 'Trees are obligatory generators; they must produce new cells every growing season in different locations otherwise the tree will die'.[52] As this new tissue is being continually added within plants, 'tissue senescence is generally not the cause of plant senescence' according to Loehle (1988).[53] As 'generating systems', Shigo (1989) observed that as trees get bigger they require enough energy for a continued increase in mass and if this were not possible, senescence would result. However, Shigo (1989) added that,

> …as long as the generation of new parts in new positions exceeds the rate of breakdown of old parts in old positions; and there is enough energy to maintain the ratio in favour of generation, life will continue'[54]

With the concept of the inevitability of tree death previously considered, the notion of trees possessing perpetual life may appear out of context. However, the theoretical concept behind perpetual life in trees is discussed here as it is of relevance to tree physiology and growth.

Molisch (1938) noted that the growing tips of buds and roots consist of meristem, and that these growing tips do not 'grow old but always remain young', 'never reaching a condition where its growth appears to be completed'.[55] Molisch (1938) did however note that in order to obtain perpetual life, trees must be able to live free from detrimental environmental influences such as predators, disease or environmental catastrophes. Vegetative propagation or cloning of plants may have the potential for extending periods of life. Leopold (1980) noted that the grape industry is one such example, where graftage of selected vines has enabled their continued life for centuries.[56] Also observed by Leopold (1980) are the examples of clonal prairie grasses in North America with suspected life spans of up to 15,000 years.[57] The lignotubers of various Australian mallee species, observed Moore (2008), also reflect these clonal properties, with stems up to hundreds of years in age emanating from plants that could be millennia old.[58] These however are examples of clonal plants, and as significantly observed by Loehle (1988),

> In the case of nonclonal plants, however, structural integrity of the plant must be maintained. Even with continued generation of new cells at the cambium and growing tips, a bounded (as opposed to a fragmenting clonal type) organism should have some upper limit to longevity.[59]

These discussions are important in understanding the affects of tree physiology on potential tree longevity. Unless vegetatively cloned, there are limits for individual tree specimen longevity.

3.3.1 Tree Physiology Changes over Time

The focus of the literature review at this point is directed towards methods employed in tree systems to prolong senescence, with the principle intention of obtaining further insight into tree longevity and the systems influencing tree longevity. Many biological changes occur within a tree over its lifespan. These influence development from the sapling stage, through maturity, and into senescence.[60] As opposed to focusing upon whole tree growth as will be discussed in further detail in Chapter 4, the biological changes specifically associated with influences upon tree senescence are investigated as they can directly and indirectly impact upon tree longevity. Clark (1983) observed that the ‘myriad of phenomena’ normally associated with tree development do not occur randomly and are typical events in normal tree life cycles.[61] Clark and Matheny (1991) noted some of the post-maturity ‘age-related changes’ as decreases in both ‘rates of net carbon assimilation’ and ‘rates of growth in all organs’, an increase in ‘susceptibility to disease, insect and other stresses and altered patterns of dry matter partitioning’.[62] Also noted by Clark and Matheny (1991),

> As a direct result of their long life span, trees have the potential to become extremely complex. This ever-increasing complexity may play a significant role in the gradual decline of the individual over time.[63]

While the patterns of growth rates in trees are investigated in further detail in Chapter 4.2.1.3, a discussion on tree growth and tree systems specifically related to senescence is valuable here. Leopold (1980) observed one of the ‘most conspicuous’ changes in maturing and aging trees was a ‘decline in growth rate’, visible in trees through ‘a decline in height increments’, with a less outwardly visible change in the form of a decline in trunk girth increments.[64] Other symptoms of old age in trees observed by Molisch (1938) include a general decrease in wood production, shorter branch and twig elongation and therefore a finer foliar network, and in general a lowered resistance to parasite and disease attack.[65]

According to Shigo (1989), trees have two different types of mass: dynamic and static. The cells and tissues of the tree that are living form the dynamic mass; the tissues containing cells that are not alive form the static mass.[66] Live cambium sending water and nutrients between the leaves and roots would be considered dynamic mass, and the heartwood forming part of the structural support for the tree would be defined as static mass. The regulating process whereby trees change dynamic mass to static mass, notes Shigo (1989), is one of the strategies they employ to stay alive, and shedding older parts is one function of this process.[67] Several of the contributing factors outlined by Loehle (1988) for reducing growth rates in mature trees included limitations to water and nutrients from site conditions, and a decreased respiration to photosynthesis ratio as a direct result of the increased demands on respiration from the support tissues.[68] As a direct result of this, the radial increment of the trunk decreases, as the wood is required to be spread over an increasingly large area.[69] As observed by Loehle (1988), the tree at this point cannot quickly cover exposed wounds through bark growth, increasing the risk of attack from pathogens.[70] Jacobs (1955) observed that as trees increase in age 'the proportion of trunk to crown decreases in size', resulting in 'progressively thinner' layers of new wood deposited on an increasingly large trunk surface.[71] It was noted that this 'thinning of the sheath of new tissues would [eventually] kill a tree', however, Jacobs (1955) added that other factors such as fungal attack or natural disasters are more typical causes of tree death.[72]

3.3.2 Tree Defences and Structural Integrity

Tree defences can have a significant impact upon tree longevities. If the structural support of the tree is weakened through pathogen attack, the longevity of the tree may also be severely compromised. An example may be a fungal disease entering into the wood structure of the tree, causing rot, ultimately resulting in tree failure followed by tree death. A study by Loehle (1988) investigated the longevities of 159 tree species in North America with a particular focus upon the energy trade-offs and other selective pressures relating to tree growth and defences.[73] Not specifically focusing upon tree longevity predictions, the study investigated important areas of influence on longevity in various forest types. The importance of Loehle's (1988) research is worthwhile reviewing as it was noted that,

> Most work on longevity has focused on senescence of tissues (e.g. leaf drop) or of whole monocarpic plants resulting from flowering … with little said about determinants of longevity in nonmonocarpic plants.[74]

Loehle (1988) proposed that the combination of the structural strength of wood to resist breakages, and chemical defences to resist wood pathogens are 'significant determinants of tree longevity', in particular the 'structural integrity of the support system' is chiefly crucial to tree longevity.[75] Trees develop structural wood that is decay-resistant, and increase their defences at wounds and decay sites, protecting their support tissues and vascular systems and thereby prolonging their life span.[76] Loehle (1988) also proposed that wood with a higher resistance to insect and pathogen attack should be found in the longer-lived tree species.[77] The energy cost of tree defences 'implies a strategic trade-off', according to Loehle (1988), as tree growth can be fast and have few defences, or slow and possess more defences.[78] The study proposed that trees growing in favourable conditions can maintain rapid growth as a defence, and in less favourable growing conditions slower growth occurs and more energy is invested in structural defences.

Loehle (1988) also proposed that in order to increase longevity, the tree must have a 'specific investment' in both their chemical and structural defences to resist death from environmental influences such as wind, herbivores, decay, and fire.[79] In order to resist pathogen attack, trees may utilise 'increased wood density, incorporation of defensive chemicals, and compartmentalization of wound sites'; additionally noted in this study, an increase in density can also increase wood strength.[80] Furthermore, the study found that rapid tree growth might actually compensate for lacking defences with the more vigorous trees 'simply outgrowing' pathogen attack.[81] In addition to this, Loehle (1988) proposed 'that growth rate and life-span are necessarily inversely related in trees' as 'long life requires energetic investments' in tree defences and this slows down the rate of growth and potentially increases longevity.[82]

Interestingly, Loehle's (1988) research noted that with the exception of forests that experience catastrophic fires, the major cause of mortality in mature forest trees was the failure of their structural support, and therefore trees with stronger resistance to structural decline have an extended period of time in which to live and therefore reproduce.[83] This 'selective pressure' may favour trees with better defences and stronger support systems for reproductive purposes.[84] In addition to this, it was observed that 'extreme longevity in trees can be achieved only on fire-free sites or those with low-intensity fires', or through investment in structural integrity in the form of 'wood strength and pathogen resistance'.[85] Loehle's (1988) work on these topics provides much information of significance in the field of tree longevity.

3.3.3 Post-maturity in Trees

In addition to processes within tree systems that prolong longevity, a comprehension of events leading to tree death is an important aspect in understanding the life patterns of trees in landscapes. A study by Clark and Matheny (1991) investigated tree senescence processes in the landscape, with a particular focus upon trees that are well into their mature stages of their life, and are potentially entering into the last stages of their lifespan. Clark and Matheny (1991) noted that an understanding of the reasons behind tree death can provide us with insight into tree system requirements and therefore enhanced tree management techniques ultimately maximising potential tree life span.[86] Within this context, they observed that 'There does not appear to be a single cause of death in trees, rather multiple paths may occur'.[87] This process of senescence was termed a 'mortality spiral', whereby mature trees become stressed, then injured, followed by a period of decline, and ultimately resulting in tree death.[88] Plausibly, Clark and Matheny (1991) note that as the first stage of the mortality spiral begins with stressed trees, prevention of this stress may be crucial to promoting enhanced tree longevity. While there may be countless contributing 'factors or events' that lead to tree death, each on their own is not enough to cause death; instead, 'it is their cumulative effect which is important' resulting in reduced tree vigour and therefore increasing their 'susceptibility to stress'.[89] Research by Roberts, Jackson and Smith (2006) concurred with the mortality spiral concept, noting that notwithstanding catastrophic events such as severe winds or fire, tree death 'is a complex event', often the result of 'cumulative effects of multiple stresses over a prolonged period'.[90]

A crucial part of Clark and Matheny's (1991) study was the discovery that once they are declining, a tree's 'opportunities to escape death are limited'.[91] Therefore, they deduced that 'the primary goal' in mature tree management is to delay the point at which the tree shifts from a mature stage to a declining stage and into the mortality spiral.[92] An interesting example they provide is the lifespan process of the Coast Live Oak (*Quercus agrifolia*) over approximately 300 years. Maturity of this species is however reached at about 50 years of age, therefore,

> The ability to attain the additional 250 years of potential life is a direct function of delaying the transition from a stage of maturity to one of decline.[93]

Although mature trees may possess 'inherent structural problems and numerous internal compartments', noted by Clark and Matheny (1991), their structure may in fact be quite sound, with vigorous growth, 'and may persist in this condition for long periods of time; indeed, for much of their life span' as observed in their illustration of the Coast Live Oak lifespan.[94] However, once the tree enters into a mortality spiral, the changes experienced may become irreversible and outside intervention may not have any effect whatsoever.[95] Ultimately, Clark and Matheny (1991) proposed that by avoiding the shift from a mature condition to a state of decline is 'the key' to maximising tree longevity.[96]

Other authors also noted that a combination of factors was usually required to initiate a sequence leading to tree death. Banks (1997) observed that ‘Typically a combination of biological and environmental stresses bring an individual into decline until a single event finally kills it.’[97] Banks (1997) decisively lists the following factors; one or more of which may result in tree death, if:

> …the connecting linkage between the crown and roots is broken, the mechanical strength of the bole and/or roots fails, or access to adequate water and nutrients is no longer possible.[98]

Noodén (1988) also observed that the aging of the tree might not, in itself cause death; instead, the aging process may result in a decrease in the trees’ ‘resistance to stress’, in turn increasing the chances of death.[99]

3.4 Human Intervention in Tree Longevity

The form or ‘design’ of the tree, according to Shigo (1989), originated in forests where the close proximity of one tree to another influenced its shape and structure. Removing trees from forest conditions they evolved in and placing them in urban environments changes the structure of the tree and, according to Shigo (1989), the lower branches became larger and the trunks became shorter and robust, essentially changing ‘the architecture of the tree’.[100] Clark and Matheny (1991) observed that in order to maintain tree ‘vigour and internal balance’, important for sustained tree longevity, a stable environment needs to be maintained, with this being a ‘long-term’ and ‘on-going process’.[101] The consequence of human intervention on mature trees in the form of arboricultural practices or care when the tree had previously experienced none may in fact, according to Clark and Matheny (1991), produce changes to their environment, and upset the internal balance of the tree.[102] This balance, if not restored, can lead to tree stress and the potential to enter a mortality spiral. Arborists, Clark and Matheny (1991) observed, can ‘play an active role in optimizing tree longevity’ through the creation of stable living environments and stable physical tree structures.[103] Although declining trees may require intervention from experts in order to prolong longevity, Clark and Matheny (1991) note that “heroic” tree preservation efforts ‘must be done judiciously’, as senescing trees have significantly reduced chances of survival.[104]

3.5 Tree Longevity Figures from the Literature

As a significant part of developing further insight into knowledge on tree longevities, a review of the literature on this subject establishes the depth of existing knowledge on this topic. The primary goals here are to determine where the longevity gaps lie, and the validity of developing further knowledge in this subject. Information on general tree longevities exists in tree species publications worldwide. Often these longevities are very general or give examples of champion or exemplar specimens found growing in their indigenous environments. Longevities tend to be present when known with some degree of certainty, and are absent when knowledge is unavailable on the species.

The Longevity of Plants by Molisch (1938) contained an assemblage of known life spans of trees and plants, gathered 'from the very scattered literature'.[105] Molisch's (1938) compilation of longevities noted that although the numbers are 'only estimates and undoubtedly involve serious errors', they are 'of importance in connection with the general question of longevity'.[106] Although published in 1938, this text critically observed that 'we do not possess definite reliable information concerning the age of many trees and shrubs'.[107] Mitchell's (1974) text, *A Field Guide to the Trees of Britain and Northern Europe*, contains various tree species and, where known, the ages of the longest-lived specimens. Importantly, Mitchell (1974) observed that the 'top height' of many could not be provided, as they had 'not yet been in cultivation long enough'.[108] If these top heights were unknown due to a lack of time under cultivation, then it would stand to reason that the potential longevity of many were also unknown, as they had not yet been reached. Clark and Matheny (1991) noted in their study on tree senescence that they were 'not aware of mortality studies for mature trees in urban and/or landscape situations'.[109] A study by Nowak *et al.* (2004) on urban and street tree mortality in North America observed that,

> Urban tree mortality is a significant factor affecting urban landscape change, yet little is known about the rates of urban tree mortality or the various factors that affect mortality rates. To help managers to minimize urban tree mortality, factors that affect mortality must be understood. In addition, to project urban tree population effects into the future, mortality and natality rates must be known. Most of the limited research to date on urban tree mortality has focused on street tree populations.[110]

Within an Australian context, other authors have also noted the dearth in tree longevity figures for urban landscapes. Pescott (1968) observed that information regarding this subject was lacking in publications:

> The important factor that still remains the unknown quantity, is what length of life can we expect to obtain from the trees that have been planted.[111]

The three major factors influencing tree longevity, according to Pescott (1968), include the species of the tree concerned, the method of its propagation, and its growing conditions.[112] Interestingly, Pescott (1968) noted that all tree species have a life expectancy that cannot 'be expressed in mathematical terms, as it is dependent on a large number of factors'.[113] Pescott (1968) also observed that when and where information on longevity details are found, 'they can be most confusing and not always of much value', adding that 'there is very little data available on this subject'.[114] By 1968, Pescott had discovered that among the majority of indigenous Australian street trees, 'no definite life expectancy span can as yet be determined'; although Pescott suggested 'there are means available for some approximate determination of this position', the point is not elaborated further.[115] Writing on the management of avenue and boulevard trees in Melbourne, Victoria, Hannah and Yau (1993) noted that 'Not enough data is available to estimate when street tree species located within different climatic regions and edaphic situations would need replacing due to senescence'.[116] Hitchmough (1994c) added the significant observation:

> Much of urban, and especially suburban, Australia is still living with their first crop of planted trees. Few professionals, let alone the public, have ever witnessed the wholesale aging and death of large numbers of trees in the streets and parks around them.[117]

In addition to this, Hitchmough (1994c) stated that within 'medium to long-lived' tree species, 'useful life spans in urban public open space are not known with any degree of certainty'.[118] A study on aging in Yellow Box (*Eucalyptus melliodora*) by Banks (1997) discovered that 'Data on the longevity of eucalypts remains limited'.[119] Even more recently, research conducted by Parker (2004) on the replacement of mature trees in urban landscapes noted the distinct absence of tree lifespan data within urban Australian environments.[120]

While the knowledge of tree longevities in Australian urban landscapes appears to be presently lacking in depth, such knowledge could contribute significantly to many fields, such as landscape architecture and landscape management. Within management of trees in landscapes, Clark and Matheny (1991) noted that the 'knowledge of potential life spans for species involved is a critical component of decision-making', with management regimes of short-lived tree species differing significantly from longer-lived tree species.[121] Due to the often-extended periods of longevity, Clark and Matheny (1991) argued that tree management and restoration programs should be implemented over a period of between 5 and 50 years, as opposed to single seasons.[122] French (1988) also noted this, stating that tree management involves species with potential life spans exceeding 200 years, and therefore management plans must indeed be long-term.

A review of the literature regarding actual tree longevity figures reveals a number of significant points for discussion. Much of the published data on tree longevity originates from countries with written records of tree plantings, combined with periods of extended duration in which tree senescence was observed to take place. These resulted in tree longevities being proposed for various species in different locations throughout the world. While the potential exists for tree longevity figures to be translocated from one region to another, there appears to be inherent dangers in such practices. Pescott (1968) noted that figures from one country should not be used as a guide in another country.[123] This is in addition to a number of tree species having not actually existed in certain areas for a period of time long enough for them to attain their longevity potential.

While written records provide an accurate method of determining tree longevity, several authors noted other methods of rough longevity determination. Molisch (1938) noted that plants with a brief juvenile period often experience short longevity, and plants with longer juvenile periods can generally be expected to have an extended longevity.[124] More specifically, Russel, Cutler and Walters (2006) observed 'There is a saying that "an oak tree spends 300 years growing, 300 years resting and 300 years dying"'.[125] More generally, although perhaps more relevant, Leopold (1980) expressed longevity as 'a natural correlate of aging and senescence'.[126]

Reported throughout the world, tree longevities, unless recorded in written reports or tested using radiocarbon dating procedures, tend to be fairly generalised. Descriptions such as 'may be 800 years old', 'easily reaching 150 years old', and 'said to have been planted at the time of Christ' are all published in texts.[127] While exact dates or figures may not be known, estimates such as these may indeed prove useful. They are, however, not always specific, and therefore not generically relevant across different countries or climate ranges. Other reports appear to be based upon personal experiences such as the 'biggest and oldest trees dead at 80-85 years' and 'A few old trees are now collapsing and the life span is about 180 years' seem to be far more useful as longevity figures, although not as intriguing as 'Age-limit not yet reached here'.[128] Molisch (1938), upon presenting a table of worldwide tree longevity figures, stressed,

> It must again be noted that the ages are only approximate because the longevity of any species varies within certain limits and the figures given are often based only on estimates.[129]

General descriptions of tree longevities combined with indistinct longevity proposals suggest reluctance amongst almost all tree-related disciplines toward the supply of tangible longevity figures for use within broad scale landscape applications. Variations within environmental conditions, combined with multiple species differentiation, and other factors such as deficient observational periods of time or perhaps an overly litigious society, may for example, discourage authors from publishing detailed tree longevity information. The possibility of tree death through poor management and other unforseen future events may also promote such reluctance to publish. Additionally, longevities may not be published due to possible backlash or ridicule from peers, as future projections, by their very nature, engender measures of scepticism.

3.5.1 Australian Tree Longevity Figures

Specifically more relevant to this study are tree longevity figures from Australia. However, unless tested through logically accurate scientific methods such as radiocarbon dating or tree-ring counting (dendrochronology), many of the published life spans of trees in Australia are generalised and appear to be intended as rough guides only.[130] A collation of Australian longevity figures from the literature is contained in Appendix 1.

Hanna and Yau (1993) in their publication classed trees into three distinct longevity groups: 'short life span', less than 50 years; 'medium life span', between 50 and 150 years; and 'long life span', greater than 150 years. For each category six or seven genera were suggested, although further details were not provided.[131] The trees suggested in Hanna and Yau's (1993) guidelines were provided as 'examples for Melbourne conditions' and were part of their component on valuating amenity trees.[132] Spencer, Beetham and Lumley (1981) published a 'Table of Trees Suitable for Street Planting in Victoria' containing longevities for a number of indigenous and introduced tree species. Proposed longevities were also divided into age bracket groupings: 10-50 years 'A', 50-100 years 'B', and 'more than 100' years 'C'.[133] Out of the 304 taxa listed as potential street trees, 140 were allocated a longevity code of either A, B or C. Only 33 of these 140 are indigenous to Australia, and out of the 70 listed species of *Angophora*, *Corymbia* or *Eucalyptus*, only ten had proposed longevities. An asterisk was placed instead of an A, B, or C to indicate that 'information has not been located' on that particular tree species' longevity.[134] While the primary reason for this publication was to advise on the suitability of various street tree species in Victoria, it did however prove to be a fruitful source of Victorian tree longevity figures. The sources of the longevity estimates provided by Spencer *et al.* (1981) were not identified, and therefore must be assumed knowledge from the authors themselves. Richards (1983) observed that tree 'longevity can be estimated from experience for any given species and growth situation'.[135] Practitioners with tree-based longevity knowledge may potentially provide additional statistics on unknown tree longevities for urban landscapes.

On tree longevity data where dendrochronology-dating methods are used, figures provided are the age reached by the trees at the time of testing. These tests are usually carried out on felled trees or cored tree samples, and often omit useful data on possible future ages attainable by the specimen or species. Instead, they tend to focus on providing results that have the potential to be re-tested using identical methods, to achieve similar findings, and to support rigorous and irrefutable scientific methodologies. Research conducted by Banks (1997) however, tested Yellow Box (*Eucalyptus melliodora*) using both radiocarbon dating and tree ring counts to report a located specimen with a maximum-recorded age of 400 years, and valiantly added that 'This tree was in good condition and could have lived on for perhaps another 100 years'.[136]

South Australian tree longevity data for *Callitris columellaris* were published by Lange (1965) from data collected near Woomera, with the longest series of tree rings suggesting one specimen reached approximately 90 years of age when felled. Radiocarbon dating undertaken on a River Red Gum (*Eucalyptus camaldulensis*) heartwood sample obtained from a specimen located in southeast South Australia provided an age of 950 years. Gill (1971), who collated the latter longevity figure, added the following comment: 'The laboratory concerned made a rapid test and not a definitive assay, but the order of age is of great interest.'[137]

From the information obtained in the literature, the majority of the figures given are general, perhaps indicating levels of uncertainty within the various tree-related fields. In addition, broad descriptions of growing conditions and climates appear to engender generalised longevity figures. Figures with higher degrees of accuracy tend to be supported by scientific processes using rigorously tested methodologies to attain these levels of accuracy.

Understanding tree longevity is an important aspect of urban landscape management in Australia. Published data on the lifespan of many tree species is presently lacking as a resource for landscape related professions. The issue regarding the scarcity of published knowledge on this subject arises when landscape planners, designers and managers require tree longevities in order to assist improved long term landscape planning, design, and management to take place. A greater understanding of tree longevities within the landscape would allow necessary changes to occur in an informed manner, enabling appropriate future decisions to be made.

3.6 Summary

Unless produced through clonal material or vegetatively propagated, trees appear to have upper limits to their longevity. Although the Australian literature reveals some information existing on various tree species and their recorded age or longevity, the figures are either too broad across a wide climatic range, or age determinations based on limited samples sourced from felled, often still-living trees. There is also a distinct lack of tree longevity figures across all states of Australia, with the exception of Victoria where the majority of the longevity figures arise. Many of the figures provided for Victoria generalise the state as a whole, with little or no environmental differentiation across its many climatic variances. From the literature reviewed, published figures or estimates for many tree longevities for South Australia, and more specifically the Adelaide Park Lands, do not presently exist.

Chapter 3 Notes

---

[1] Russell *et al.* (2006) p. 11; Shigo (1989) p. 5; Clark (1983) p. 201.
[2] Shigo (1982) p. 93.
[3] Cobham (1990) p. 206.
[4] Fakes (2006) p. 17.
[5] Russell *et al.* (2006) p. 9.
[6] Russell *et al.* (2006) p. 80.
[7] Leopold (1980) pp. 3-4.
[8] Leopold (1980) pp. 3-4.
[9] Leopold (1980) pp. 3-4.
[10] Salisbury and Ross (1992) p. 406.
[11] Leopold (1980) pp. 3-4.
[12] Noodén (1980) pp. 226, 220.
[13] Noodén (1988) p. 3.
[14] Pescott (1968) p. 53.
[15] Patrick (1988) p. 251.
[16] Shigo (1989) p. 137.
[17] Hannah and Yau (1993) p. 41; Clark and Matheny (1991) p. 182.
[18] Hannah and Yau (1993) p. 41.
[19] Clark and Matheny (1991) p. 182.
[20] Shigo (1989) pp. 142-143.
[21] Leopold (1980) p. 2.
[22] Leopold (1980) p. 2.
[23] Noodén (1980) p. 221.
[24] Noodén (1980) p. 221.
[25] Salisbury and Ross (1992) p. 406.
[26] Molisch (1938) p. 79.
[27] Molisch (1938) p. 79.
[28] Leopold (1980) pp. 4-5.
[29] Leopold (1980) p. 4.
[30] Felix and Shigo (1977) p. 79.
[31] Felix and Shigo (1977) p. 190.
[32] Clark and Matheny (1991) p. 176.
[33] Patrick (1988) p. 251.
[34] Andrews *et al.* (2000) p. 26.
[35] Clark and Matheny (1991) p. 175.
[36] Andrews *et al.* (2000) p. 26.
[37] Hitchmough (1994c) p. 269.
[38] Loehle (1988) p. 211.
[39] Loehle (1988) p. 211.
[40] Loehle (1988) p. 211.
[41] Noodén (1980) p. 222.
[42] Noodén (1980) p. 222; Bristlecone pine (*Pinus longaeva*) data from Russell *et al.* (2006) p. 39.
[43] Noodén (1980) p. 222.
[44] Banks (1997) pp. 44-45.
[45] Clark and Matheny (1991) p. 176.
[46] Clark and Matheny (1991) p. 176.
[47] Clark and Matheny (1991) p. 176.
[48] Banks (1997) p. 44.
[49] Shigo (1989) p. 141.
[50] Shigo (1989) p. 141.
[51] Jacobs (1955) p. 67.
[52] Andrews *et al.* (2000) p. 26.
[53] Loehle (1988) p. 209.
[54] Shigo (1989) p. 143.
[55] Molisch (1938) p. 176.

[56] Leopold (1980) p. 4.
[57] Leopold (1980) p. 4.
[58] Moore (2008) p. 2.
[59] Loehle (1988) pp. 209-210.
[60] Clark and Matheny (1991) p. 182.
[61] Clark (1983) p. 205.
[62] Clark and Matheny (1991) p. 173.
[63] Clark and Matheny (1991) p. 201.
[64] Leopold (1980) p. 5.
[65] Molisch (1938) p. 165.
[66] Shigo (1989) p. 142.
[67] Shigo (1989) p. 144.
[68] Loehle (1988) p211
[69] Loehle (1988) p211
[70] Loehle (1988) p211
[71] Jacobs (1955) p. 67
[72] Jacobs (1955) pp. 67-68.
[73] Loehle (1988) p. 212.
[74] Loehle (1988) p. 209.
[75] Loehle (1988) p. 210.
[76] Loehle (1988) p. 210.
[77] Loehle (1988) p. 210.
[78] Loehle (1988) p. 210.
[79] Loehle (1988) p. 210.
[80] Loehle (1988) p. 210.
[81] Loehle (1988) p. 211.
[82] Loehle (1988) p. 217.
[83] Loehle (1988) p. 210.
[84] Loehle (1988) p. 210.
[85] Loehle (1988) p. 210.
[86] Clark and Matheny (1991) p. 176.
[87] Clark and Matheny (1991) p. 176.
[88] Clark and Matheny (1991) p. 178.
[89] Clark and Matheny (1991) p. 177.
[90] Roberts *et al.* (2006) p. 256.
[91] Clark and Matheny (1991) p. 177.
[92] Clark and Matheny (1991) p. 178.
[93] Clark and Matheny (1991) p. 178.
[94] Clark and Matheny (1991) p. 178.
[95] Clark and Matheny (1991) p. 178.
[96] Clark and Matheny (1991) p. 179.
[97] Banks (1997) p. 44.
[98] Banks (1997) p. 44.
[99] Noodén (1988) p. 3.
[100] Shigo (1989) pp. 5 & 144.
[101] Clark and Matheny (1991) p. 181.
[102] Clark and Matheny (1991) p. 181.
[103] Clark and Matheny (1991) p. 179.
[104] Clark and Matheny (1991) p. 182.
[105] Molisch (1938) pp39-40
[106] Molisch (1938) pp39-40
[107] Molisch (1938) pp39-40
[108] Mitchell (1974) p. 13.
[109] Clark and Matheny (1991) p. 177.
[110] Nowak *et al.* (2004) p. 139.
[111] Pescott (1968) p53
[112] Pescott (1968) p53
[113] Pescott (1968) p53
[114] Pescott (1968) pp. 53-54.

[115] Pescott (1968) p. 54.
[116] Hannah and Yau (1993) p. 42.
[117] Hitchmough (1994c) p. 269.
[118] Hitchmough (1994c) p. 269.
[119] Banks (1997) p. 45.
[120] Parker (2004) p. 247.
[121] Clark and Matheny (1991) p. 178.
[122] Clark and Matheny (1991) p. 176.
[123] Pescott (1968) p. 54.
[124] Molisch (1938) p. 82.
[125] Russell *et al.* (2006) p. 28.
[126] Leopold (1980) p. 4.
[127] English Oak (*Quercus robur*), Location: England, In: Mitchell (1974) p. 244; Red Spruce (*Picea rubens*), Location: North America, In: Russell *et al.* (2006) p. 129; European Olive (*Olea europaea*), Location: Jerusalem, In: Russell *et al.* (2006) p. 39.
[128] Veitch's Silver Fir (*Abies veitchii*), Location: England, In: Mitchell (1974) p. 102; Red Oak (*Quercus borealis*), Location: England, In: Mitchell (1974) p. 233; Monterey Cypress (*Cupressus macrocarpa*), Location: England, In: Mitchell (1974) p. 102.
[129] Molisch (1938) p. 74.
[130] For more detailed discussion on Australian dendrochronology and radiocarbon dating see Chapter 5.
[131] Hannah and Yau (1993) pp. 64-65.
[132] Hannah and Yau (1993) p. 65.
[133] Spencer *et al.* (1981) p. 66.
[134] Spencer *et al.* (1981) p. 66.
[135] Richards (1983) p. 168.
[136] Banks (1997) p. 45.
[137] Gill (1971) p. 79.

Chapter Four: Non-Invasive Tree Age Determination Methods

Part 1 – Extant and Expert Resources

4.1 Introduction

In order to develop predictive models for tree longevity simulation in parkland situations, trees within the landscape need to have their age determined to provide an indication of age parameters from which to base projected landscapes upon. The use of non-invasive methods of determining tree age is of particular importance in this research, as invasive methods have the potential to initiate premature senescence in trees. In addition, as outlined in Chapter 2, portions of the Adelaide community place a high value on living trees in the Adelaide Park Lands, subsequently warranting non-invasive methods of tree age determination.

4.1.1 Tree History Interpretation

Determining the age of trees using non-invasive techniques is essential for understanding past landscapes and for the management of future landscapes. Urban parkland spaces containing trees may be interpreted through the age determination of those trees. Jacques (1987) noted that an understanding of planting history in parks and gardens could assist in the following areas:

- Determining what plantings were undertaken and if and when these influenced any particular spatial layouts;
- Estimating any changes occurring through either later designs or natural influences;
- Developing an understanding of tree 'growth characteristics' and their changes over time; and,
- Incorporating information gathered into future management plans for the landscape.[1]

Lukaszkiewicz, Kosmala, Chrapka, and Borowski (2005) also noted the importance of determining the ages of trees in landscapes, the knowledge of which would be useful in:

- setting the chronology of parks and gardens,
- determining the age structure of tree stands for protection and conservation,
- forecasting and assessing threats associated with increasing age,
- forecasting the size of trees in the future.[2]

Although not within the context of urban parks or gardens, Woodgate, Ritman, Coram, Brady, Rule, and Banks (1994) identified that 'tree age data' would be invaluable in understanding forest dynamics, ecological interpretation, predictive modelling, and the modelling of impacts of management actions within old growth forests.[3] In addition, Woodgate *et al.* (1994) noted that such age information would 'give a precise measure to the characteristic of antiquity' of old growth forests.[4]

The reasons argued here encourage further investigation into methods for revealing tree age data in urban landscapes. This chapter in particular examines methods avoiding damage or injury to trees during the age determination process.

4.1.2 Extant Historical Records

Extant historical records are often used to determine the age of trees in the landscape. Commonly employed to reconstruct significant gardens, historical records can vary immensely in detail and therefore effectiveness in accurate tree age determination.

The level of detail originally recorded, combined with the availability of archival material are the two primary limitations encountered when using extant historical information to obtain tree ages, using non-destructive methods. Details can be omitted from historical records for various reasons, whether personal or political, or can be removed from collections at later periods and destroyed or simply never returned. Although uncommon, natural catastrophes can destroy entire collections of historical documents quickly, as can improper preservation techniques. Ultimately, the impractical nature of recording every detail of every event ever to have happened governs the quantity of extant information today. In addition, subsequent generations must find the archived material important or relevant, otherwise there will be a risk of records being discarded over time.

4.1.2.1. Archival Written Records

Written historical records are among some of the most common historical data of gardens and landscapes and their past. Archival written reports such as those retained by city councils on tree planting and removal work can be invaluable in determining tree ages. A research project by Attorre, Francesconi, Pepponi, Provantini, and Bruno (2003) used archival records to assist in the reconstruction of certain historic parks and gardens in Rome.[5] These archival records provided crucial information on Rome's tree planting and removal dates, along with reports of successful tree and plant species and changes to the vegetation over time. Australian research conducted by Banks, Brack and James (1999) on the management of urban trees in Canberra required tree ages as a determinate of maintenance requirements. In their research, 'city records' provided their tree planting dates.[6] Another research project conducted in Poland by Lukaszkiewicz *et al.* (2005) required tree ages for cross-comparison with developed growth models. Archival documents provided Lukaszkiewicz *et al.* (2005) with their tree planting dates also.[7] Peper, McPherson, and Mori (2001) also implemented the use of 'handwritten planting records' to verify tree ages in their database on street trees in California.[8] Research conducted by Pigott (1989a) followed the introduction of various *Tilia* species across England over time using historical documents to assist in determining tree age.[9]

The use of written archival documents, whether reports of work conducted or anecdotal records, can vary immensely in value to historic landscape research. The quality of information obtained for tree age determination is highly dependent upon the detail of the descriptions originally recorded and the subsequent ease of information translation onto the present landscapes. As trees are usually planted into landscapes when young, issues of mortality arise when interpreting written archival records. Young trees succumbing to transplantation or environmental shock may be replaced over subsequent years, potentially jeopardising accurate tree age determination. This inaccuracy aside, and if location descriptions are sufficient to enable current tree identification, written archival reports can prove most useful for tree age determination in the landscape.

4.1.2.2. Historical Maps, Plans, Lithographs and Paintings

Historical maps and diagrams are among the most popular of the available methods historians use for reconstructing previous landscapes and crosschecking the validity of other available extant historical records. The ability of drawings and lithographs to convey vast quantities of information within a limited space has made them valuable resources for the interpretation of past landscapes. Artists, landscape designers, monasterial inhabitants, architects, and engineers, among others, created images of landscapes in plan or perspective and many of these are used as historic landscape re-creation tools.

Boudon (1991) observed that historical cartography is essential to the reconstruction of a garden's history. As 'a paramount source' of information, historical cartography 'reveals a wealth of relevant documentation which leads inevitably to a method of investigation, analysis and explanation' when reconstructing past landscapes.[10] However, noted Boudon (1991), 'Not all cartographic images are of equal interest', as the quality contained in the imagery can vary considerably, depending upon the scale used, the date completed, and the intended purpose of the document.[11] Through layering or 'superimposition' of historical maps, various elements can be extracted and compared over a period of time to determine the history of a landscape. Although Boudon (1991) observed that these maps could indeed be contradictory, they can act as 'cross-checks, overlapping and complementing each other'.[12] Maps may also over or underestimate the maturity of features, such as trees on a landscape. If implemented as instruments of propaganda for the purpose of financial gain from a landscape, maps have the potential to reflect desired, as opposed to real, landscapes.[13]

In addition to written historical reports containing planting dates, Attorre *et al.* (2003) used historic maps of gardens and parks in Rome to reconstruct landscapes and vegetation patterns. After computer scanning to digitise the maps, they were inserted into geographical information systems software. The resulting 'spatio-temporal analysis' developed provided a spatial understanding of landscape changes, including changes to vegetation patterns and tree plantings through a direct comparison with subsequent maps. Identifying this method as 'laborious' and 'complex' with the risk of producing 'approximations' in changes, Attorre *et al.* (2003) confirmed the significance of the task by noting it 'is essential in order to follow the evolution of garden forms'.[14] Crucially, Attorre *et al.* (2003) observed the importance of 'accurate knowledge' of landscape changes that have influenced the present landscape, thereby creating 'the basis of future management and planning' for the landscape.[15]

Ultimately, the level of accuracy and detail in historical cartography is greatly dependent upon both the skill of the creator, and the intended final purpose of the document. Unless located within an allée, along a carriageway, or as a champion extant specimen, trees were often drawn as groups, with exact locations and quantities of trees estimated, as opposed to precise tree positioning within group settings. This level of detail can have a direct impact upon the usefulness and subsequent value of historical maps in tree age determination. Due to a lack in detail, historic cartographic records are often of more use in the broad scale restoration of historic gardens and landscapes than of identifying ages of individual trees within that location.

Research by Clare and Bunce (2006) proposed that by mapping existing tree species, new historic cultural landscape patterns were made visible within the English Lake District. Although not specifically targeting individual tree ages, the study combined tree species with known periods of tree species planting preferences, and identified topographical cultural areas to develop an enhanced understanding of the significance of the area. [16] The primary goal of Clare and Bunce's (2006) research was to discover new areas that required further investigative research, or the development of specific management plans, specifically using tree species as identifying features.[17] These 'historic landscape zones' would assist in understanding 'past land use', as well as future planning of the region under a potential world heritage listing.[18]

Paintings in both oil and watercolour may also be of some use in tree age determination. Unless created in an abstracted style, landscape artists historically represented the landscape they saw in their selected medium. Before photography became commonplace, images painted on canvas or paper were effectively the photographic equivalent, recording trees in landscapes and capturing particular moments in time, such as the landscapes painted by George French Angas during the 1840s in South Australia. Shown in Figure 4.1, an example of Angas' work titled *The City of Adelaide from Mr. Wilson's Section on the Torrens, June 1845* depicts particular vegetative features clearly in the landscape. The dynamic nature of cultural landscapes over time, however, could disguise such scenes in present-day landscapes, resulting in unreliable tree age determinations. This method of recording the landscape was time consuming, with artists or patrons generally selecting the particular scenes portrayed. For these reasons, determining accurate tree ages from such landscape paintings may become problematic.

Figure 4.1. The City of Adelaide from Mr. Wilson's Section on the Torrens, June 1845, by George French Angas.
(George French Angas, Britain/Australia, 1822 – 1886; The City of Adelaide from Mr. Wilson's Section on the Torrens, June 1845; 1845, Adelaide; watercolour on paper; 24.5 x 32.8 cm; Gift of Miss E.M. Johnson 1972; Art Gallery of South Australia, Adelaide; 721HP1).

4.1.2.3. Historical Photographs

The use of photography greatly improved the accuracy of historical landscape records. The level of detail captured using photographic equipment has made this historical medium useful in determining previously existing landscape plantings, and for reconstructing historic gardens. Their combination of aesthetic appearance and historic value ensured the preservation of historical photographs in many regions. The quality and subsequent value of old photographs in tree age determination typically depends upon the particular view or angle captured, the skill of the photographer, and the method of photograph preservation used over time. Examples of high quality historical photographs can be seen in Appendix 2, where historical photographs are compared to their contemporary equivalents. Unfortunately, as with historic paintings of landscapes, historic images depicted established trees, and determining precisely when they were established can be difficult from photographs.

4.1.2.4. Aerial Photographs

A more recent addition to landscape history interpretation, aerial photographs can assist in large-scale reconstructions of landscapes. The advent of flying assisted this photography process and as a result, an increase in the quantity of aerial photographs would have appeared concurrently with an increase in airflight. Before airflight, tall buildings or other high vantage points provided most historic aerial photographs, such as the panoramic photographs of Adelaide taken by Townsend Duryea from the newly constructed post office tower in 1865, shown in Figures 6.1 and 6.2 (pp. 127 and 140). However, photographs such as this may not capture adequate tree-planting detail, as the vantage point would need to be within close proximity to the landscape. The interpretation of historic aerial photographs can be hampered by a lack of detail usually associated with small-scale images, combined with poorer image quality, such as the 1936 aerial photograph of Park 17, shown in Appendix 2, Plate 9. As technology improved, better aerial photographs were able to be taken, providing higher levels of detail, as can be seen in the 2002 aerial photograph of Park 17, as shown in Appendix 2, Plate 10.

4.1.2.5. Plaques and Monuments

Trees planted in the landscape to recall or remember specific events or people are often accompanied by a plaque or commemorative sign. ‘Avenues of honour’ are one such example, reminding us of sacrifices made during war times. Trees planted to honour individuals during peace times can also provide specific planting dates for trees. Often within close proximity to individual specimens or avenues of trees, dated plaques can provide a very accurate method of determining tree age.

4.1.2.6 Historic Events

The occurrence of past events may lead to the age determination of trees in the landscape. Planned events such as Arbour Days, or unplanned catastrophes such as floods or storms may initiate sequences of tree planting, with these events often recorded and therefore datable. Research by Argent, McMahon, Bowler, and Finlayson (2004) involved the comparison of known germination dates to tree ring counts of River Red Gum (*Eucalyptus camaldulensis*) trees from the Barmah Forest in northern Victoria. Their germination date was known to correlate with 'specific flood events' in that portion of the River Murray floodplain.[19]

4.1.3 Tree Age Tables

Another useful method of determining tree age in a non-destructive manner is with 'tree age tables'. Among the earliest to devise and use these tables, Mitchell (1972) compiled a series of tabular tree data tables for the text *Conifers of the British Isles: A Descriptive Handbook*.[20] The tables contained the location of tree specimens collated into tree species, along with planting dates; measurements of trunk girth, tree height, and the dates of subsequent measurements. The value of these tables in determining tree age and growth rates of conifers in the British Isles should not be underestimated. Containing both planting dates along with subsequent measurements of the same specimen over time, tree age tables can easily be converted into mathematical formulae, enabling other trees of the same species growing in similar regions to be compared for growth patterns and age determination.

In White's (1998) guide to *Estimating the Age of Large and Veteran Trees in Britain*, tree age tables were proposed as a useful method for determining tree ages through non-invasive methods. As significant living trees should not be weakened through the process of extracting trunk core samples for tree ring counting, White (1998) suggested 'broken or cut' tree stumps or 'stem cavities' could instead provide some of this missing tree ring data for age determination.[21] Possessing a higher degree of accuracy, these compiled 'local site tables' could, for example, precede more generalised 'tree age tables' covering an entire country across multiple environments and climates.[22] The site or location of tree growth, according to White (1998), influenced tree growth parameters, therefore localised tables were important.

White (1998) proposed that the combination of existing tree age table data and extant non-invasive tree ring data could satisfactorily be used in comparisons to trees of unknown ages, specifically for their age determination.[23] Ultimately, White (1998) observed that,

> Age can only be estimated by external measurement and then by direct comparison with other trees of similar species, size, and known planting date on comparable sites elsewhere.[24]

The accuracy of such comparisons can only be verified if 'a considerable amount of data from a wide range of situations has been accumulated', and according to White (1998), a quantity of 'detective work' would then be required to place planting dates on these trees.[25] Tree growth information recorded in databases such as the Tree Register of the British Isles (TROBI) would assist in developing such tree age tables, as this particular database has decades of tree growth records.[26] Importantly, White (1998) noted that such databases contain 'hundreds of ring counts relative to stem diameter measurements' from broken or cut stumps, and from this data, 'tables of expected growth relative to stem size have been formulated for a number of commonly planted specimens'.[27]

Lukaszkiewicz *et al.* (2005) also investigated the validity of tree age tables in their tree age determination research. Finding White's (1998) method of combining site conditions with tree age tables produced 'notable discrepancies' in their results in Poland, Lukaszkiewicz *et al.* (2005) noted that such methods also require 'toilsome calculations'.[28] Lukaszkiewicz *et al.* (2005) added that 'the determination of tree age using tables is often error prone', with the primary weakness being 'insufficient correlation of tree age with dbh'.[29] Although perhaps the 'best known' of the non-invasive tree age determination methods, Lukaszkiewicz *et al.* (2005) noted tree age tables appear to lack precision.[30] Importantly, Lukaszkiewicz *et al.* (2005) also noted that despite their potential drawbacks, tree age tables continue in use.[31]

Similar in format to tree age tables, forestry log volume tables are used to calculate silvicultural production and tree growth. However, the use of log volume tables is unreliable for determining tree age in urban environments argue Lukaszkiewicz *et al.*

(2005), as they are not developed for trees in urban environments; 'They are prepared for trees growing in forest stands of high density and cannot be applied to urban forests'.[32]

4.1.4 Expert Estimation of Tree Age

Knowledge provided by experts in fields such as arboriculture and silviculture should be incorporated into methods where non-intrusive age determination of living trees is required. Such specialist knowledge is usually developed over a substantial period of time working within these, or other closely related occupations. Jacques (1987) noted that a 'common means' of tree age determination is to either 'ask an experienced silviculturalist to guess', with the second option being to count 'the rings once a tree is felled'.[33] Akeroyd, Leaney, Mathieson, Moloney, and Smith (2002) observed that,

> Estimates of relative tree age can be made from a comparison of individual trees within a stand by observing age-related morphological features such as bole size and crown form.[34]

This process, Akeroyd *et al.* (2002) note however, does not provide exact figures 'on the actual age' of the trees under examination.[35] Peper *et al.* (2001) interviewed 'city arborists' to assist in placing ages on their trees surveyed and in addition they interviewed local residents with knowledge on local planting dates.[36] Although not specifically experts in arboriculture or silviculture, local residents may provide historical tree planting information, as their memory permits. Worbes, Staschel, Roloff, and Junk (2003) also realised the practical value of local knowledge in determining tree age or planting dates. However, they also noted that the accuracy of such information would increase when 'correlated' with tree ring counts.[37] Provided as 'estimations' or 'expert knowledge', these tree ages can be used in conjunction with other techniques of tree age determination such as extant historical records or local resident knowledge. As a noted method of non-damaging tree age determination, expert estimations can prove invaluable when extant historical documents are not available to verify tree ages in the landscape.

4.1.5 Summary (Part I)

An understanding of tree histories and planting dates can provide valuable information on past landscapes, assist in landscape interpretation, and offer data to develop appropriate future management processes. There are many sources available to assist with determining tree ages in landscapes, and the detail they provide and subsequent value to this process varies immensely. Extant historical records such as written archival documents, paintings, maps, plans, and lithographs can all be used to determine tree ages. Additionally, historical and aerial photographs, plaques and monuments, and historic events can be employed with varying degrees of confidence. The level of detail captured, and the subsequent preservation of the records is dependent upon many factors. These include the skill level of the writer, artist, designer, or photographer, the purpose for conducting the work, and the desires and whims of subsequent generations to retain or destroy records of the past. Other resources that may provide valuable data on tree ages in landscapes are tree age tables, essentially containing collections of a tree's growth history over time, and the estimation of tree age by experts in tree-related fields such as arboriculture, horticulture, and silviculture. When available, extant or expert data can provide important information on tree ages in cultural landscapes, enabling both the reconstruction of the past, and management of the future.

Part II – Growth Modelling and Tree Mensuration

Other methods can be developed to assist in the age determination of living trees without causing damage to their structure. Investigated in Part 2 of this chapter are models of tree growth over time, and the possibility of using various parameters of tree growth to non-invasively determine the age of extant trees in cultural landscapes. Also investigated are projections of these growth models, their changes over time, and the possibility of determining future tree growth parameters from these growth models.

4.2.1 Growth Models in Tree Age Determination

Tree growth models are commonly used to calculate and predict tree growth patterns primarily within silvicultural and urban forestry areas of research and expertise. The investigation into their use for tree age determination is important since tree measurement data collected and implemented for modelling can be externally obtained and therefore non-intrusive. The modelling of forest growth, or ‘forest biometry’, generally involves taking measurements of standing trees and placing the figures into mathematical equations to obtain ‘models’ that display characteristics of the particular tree or forest’s growth.[38] Vanclay (1994) described a ‘model’ as ‘an abstraction, or a simplified representation, of some aspect of reality’.[39] Harvey (1969) observed this, stating that ‘In reality any system is infinitely complex and we can only analyse some system after we have abstracted from the real system’.[40] Sands (1988) agreed, noting that models are used for studying environmental systems, as they are ‘simpler than the original system’.[41] The complexity of environmental systems with innumerable complicated interactions can preclude model development at scales encompassing whole systems.

Vanclay (1994) described ‘growth models’ within forestry applications as typically referring ‘to a system of equations which can predict the growth and yield of a forest stand under a wide variety of conditions’. Importantly, Vanclay (1994) added that growth models can consist of ‘a series of mathematical equations’, the ‘numerical values’ within those equations, a logical link between the equations and the system being modelled, and coding and programming to enable model development on a computer.[42] Specifically, Vanclay (1994) defined ‘growth’ within a silvicultural context as ‘the increase in dimensions of one or more individuals in a forest stand over a given period of time’.[43] As important tools for foresters, Rayner and Turner (1990) noted that the quality of information obtained for use in growth models has a direct influence upon the quality of forest planning and subsequent decision-making processes.[44]

4.2.1.1 Growth Models as Predictive Tools

Much of the literature on tree and forest growth models stem from silvicultural practices where predictions of timber yield are important for forecasting future economic benefits. Vanclay (1988) observed growth models as being beneficial to the summary and communication of research results, the development of deeper understanding of tree growth and therefore forest stand dynamics, as well as informed decision-making processes stemming from yield prediction data.[45] Vanclay (1994) added to this the enhanced importance of growth models in making predictions, formulating prescriptions and guiding 'forest policy' when combined with 'resource and environmental data'. Sands (1988) observed that it is important to link model complexity and function; the focus of model development should consider both the end users and the proposed context, with these influencing the model's simplicity.[46] Vanclay (1994) noted the difference between forest growth 'models for understanding' and 'models for predicting'.[47] Models for understanding tend to 'link previously isolated bits of knowledge', and can locate 'gaps' where further work is required.[48] Models for predicting tend to 'sacrifice specific details of growth processes to achieve greater efficiency and accuracy', enabling suitable management decisions to take place.[49] The consideration of long-term vegetation changes and conditions over a substantiative period of time, according to Bettinger (2001), adds credibility to simulation models, and is of increasing importance in landscape simulation.[50]

Within forestry, Vanclay (1994) notes that perhaps 'the most powerful feature' of the growth model is its ability 'to assist managers to make reliable long-term forecasts' in tree growth and therefore timber yield.[51] Not all tree growth models, however, focus upon timber yield as the predictive outcome, with silviculture as the prospective consumers. Research by Jacques (1987) used growth models to predict the survival of Common Lime (*Tilia cordata*) trees within avenues in a statistical technique called 'cohort survival'. This process modelled the decline in avenue trees to enable the 'age composition' of the avenue's trees to be predicted from both original and replacement trees, potentially providing guidance in future discussions on the avenue's tree removal and replacement methods.[52] Research into tree growth modelling by Peper *et al.* (2001) observed that through predictive three-dimensional tree growth modelling in urban landscapes, the fourth dimension, time, could be utilised to display potential growth changes in urban trees.[53] Peper *et al.* (2001) added that the "growing" of these trees through computer visualisation could assist arborists, tree managers, and landscape architects in appropriate tree selection for specific planting locations.[54] Vanclay (1994) noted that the important factor in modelling is to create 'a good representation', using computers as tools to express potential future outcomes.[55]

In order to project future 'vegetation conditions' of 'forested landscapes', Bettinger (2001) stated that two 'basic elements' are required: 'forest inventory data and a forest growth-projection model'.[56] The forest inventory data usually describes various elements in the landscape, and can be general or very specific. When entered into 'growth-projection models', future forest conditions can be predicted. Ogden (1985) observed that reliable data on both 'age distribution and longevity' are a requirement for predictive modelling.[57]

Daily fluctuations in tree growth and environmental influences should not be the primary focus in long term growth modelling, according to Zeide (1993); instead, the emphasis should be placed on modelling 'long-term trends, such as aging'.[58] Zeide's (1993) focus here being the tree's 'entire lifespan as one wave' in a growth model, with this form of 'rigidity' being an 'asset' as opposed to a 'liability' in developing computer models.[59] Within Zeide's (1993) definition, equations are 'a means to achieve stability of parameters' with their accuracy intrinsically connected to the reliability of their parameters.[60] Zeide (1993) succinctly described growth equations as a method of bringing together 'age and size, to make explicit the hidden invariance that governs their relationship'.[61] This defines the original purpose for constructing tree growth models for landscapes.

4.2.1.2 Common Parameters in Tree Growth Models

In identifying parameters with the potential for use in growth models, Philip (1994) noted that 'Growth takes place simultaneously and independently in different parts of a tree'.[62] These changes in tree growth, according to Philip (1994), can be measured through tree height, trunk diameter, crown size, and bole volume.[63] Philip (1994) explicitly noted that 'four patterns' of tree growth 'on age', can 'provide a complete picture of the tree's development': trunk diameter at breast height, tree height, tree volume, and 'form factor'.[64]

While forest 'mensuration', or 'measurement' techniques have their origins embedded largely in silviculture, the inherent practices and experience gained thorough past silvicultural study has ensured a degree of robustness for their application to other associated fields, such as urban forestry. Many silvicultural mensuration processes employ non-intrusive methods of tree data collection for data input and subsequent modelling to achieve accurate economic forecasts of forest production. As the tree or forest age is regularly recorded at the time of planting, intrusive tree mensuration processes are generally not required in silviculture. Therefore, necessary measurements and calculations can be obtained externally, without damage to the tree. Due to 'age' being a known parameter, it is commonly used in tree or forest growth equations and models. The other parameters, therefore, become a major focus of silvicultural practices, and are commonly placed over 'age' for projection purposes. As almost all required parameters can be obtained without tree damage, methods of determining age from commonly used non-invasive silvicultural growth parameters are investigated.

4.2.1.3 Modelling Growth Rates and Changes

Many different models exist in various fields of tree growth prediction and management. In Vanclay's (1994) text, it was claimed that the sheer number of growth models in use made a review of each 'impossible'.[65] However, Rayner and Turner (1990) categorised growth and yield models as being in one of three general forms: tabular, graphical, or mathematical functions.[66]

There are a number of forms common to growth models within forestry applications. These are intrinsically linked to the parameters embedded in them, with the equation forming a reflection of the data collected and subsequently modelled. In a study on tree growth and age determination methods in landscapes, White (1998) observed that trees 'progress through three phases of growth: a formative period, middle age or the "mature state", and senescence'.[67] As tree changes occur through these stages, they can be recorded and expressed as a number of various equations. Zeide (1993) described growth equations as descriptions of changes in the 'size of an organism or a population with age'.[68] As noted previously, and observed again by Zeide (1993), the 'biological growth' of organisms consists of extremely 'complex processes'.[69] The growth or increase in size of a number of 'similar trees', when combined in an equation, will produce 'an ever smoother sigmoid curve', a common growth curve in biological organisms.[70] Zeide (1993) added that the early stages of tree growth when modelled produce a convex shape, later the shape turns concave as the tree ages and 'Although growth responds to environmental trends and fluctuations, this long-term pattern remains surprisingly stable'.[71] An example of a sigmoid growth curve is shown in Figure 4.2. Fritts (1976) also observed that 'When cumulative shoot growth is plotted as a function of tree age' it forms a sigmoid growth trend, with this described as:

> A brief period of increasing growth rate occurs during the seedling stage, a period of high growth rate occurs during the sapling stage, and a decreasing growth rate occurs as the tree matures and approaches old age.[72]

Of particular note, Fritts (1976) added that ‘for trees with long life spans’, the sigmoid curve becomes ‘stretched over a longer period of time’.[73] Those growing in stressful sites, observed Fritts (1976), have a rapid period of juvenile growth shorter in length than those growing in optimal environments, however, ‘the period of declining growth rate can be longer’.[74]

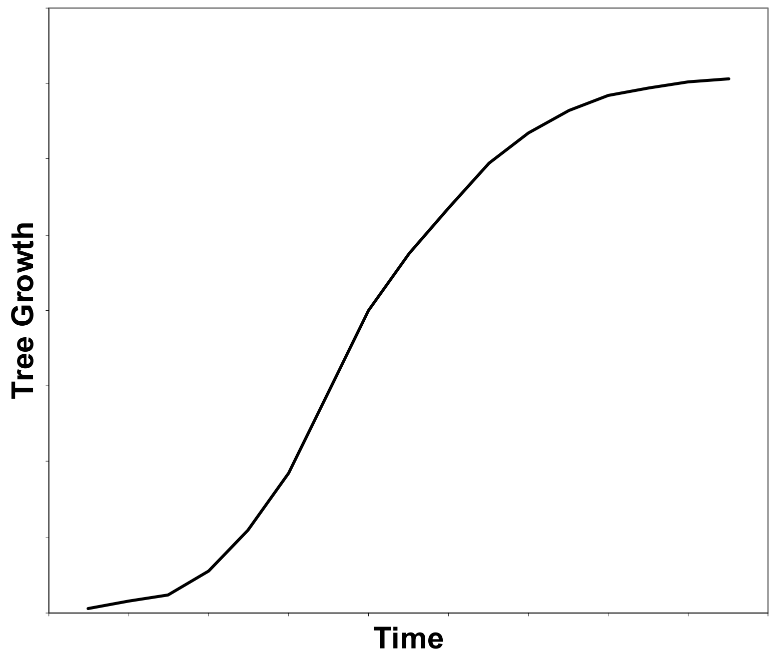

Figure 4.2. Representation of a sigmoid growth curve.

While sigmoid-shaped equations are a common representation of biological growth, other equations have also been used to express a change of size in relation to age. According to White (1998), the ‘early growth’ rate of trees can be ‘fairly predictable’ when compared to similar tree species on similar site types.[75] Jacques (1987) observed that upon reaching maturity, tree vigour ‘diminishes greatly’, with the tree entering into a slower, mature growth phase.[76] This transition is a gradual process, and Jacques (1987) noted that it is often reflected in a mathematical curve, such as a logarithmic curve, although ‘two straight lines, one for each growth rate, are sufficient for most purposes’ of tree growth modelling.[77]

The length of time taken to reach maturity varies according to both tree species and environmental influences. Hitchmough (1994b) noted the vast differences between the length of time trees spent in the ‘established-maturation phase’, comparing 15 years for certain *Acacia* species, to 200 years for various *Quercus* species.[78] Species aside, Moore (1990) observed that trees introduced to Australia have 'rates of growth' that are actually 'much greater' than their northern-hemisphere counterparts.[79] Moore (1990) added that this is primarily due to a much milder Australian climate with an extended 'growing season' and less severe winters.[80] Specifically, Moore (1990) observed that trees such as elms or oaks growing for 100 years in Australia may be of similar size to much older, related species in the northern hemisphere.[81]

4.2.1.4 Linear Regression Analysis in Modelling

The linear, or additive growth models investigated here generally undergo linear regression in order to fit appropriate equations to the data collected. Through the use of computers, equations can be fitted to data using 'ordinary least squares linear regression' to achieve the most appropriate fit.[82] In addition to providing suitable equations for use, the relationship and accuracy of the equation to the data can be calculated. Linear regression analysis relates data collected into a cohesive and purposeful trend, in the process providing details on the trendline accuracy and thus confidence levels on the data determined.

4.2.1.5 Extrapolation in Models

Issues of future projections or extrapolation will always persist in predictive growth modelling of living organisms such as trees and forests. Vanclay (1994) noted that 'Interpolation is safer than extrapolation' in growth models, and small quantities of reliable data at both the extremes and near the mean prove 'more useful than copious data clustered about the mean'.[83] A number of authors note the potential dangers or limitations of growth model extrapolation. Rayner and Turner (1990) note that 'strictly empirical regression formulations' will not produce sensible extrapolations when extended beyond the data available.[84] Zhang (1997) warned that extrapolation beyond the model data available has the potential to produce large errors.[85] Bettinger (2001) observed that planners should be aware of, and understand, the potential limitations associated with growth models, and the projections they generate, noting that growth models can project 'beyond the data collected'.[86] Nowak *et al.* (2004) noted that due to there being 'very limited data on urban forest change', projections created 'become more uncertain the farther the projection into the future'.[87] Also noted were potential factors influencing future urban tree natality and mortality such as storms, 'significant land-use change', and 'large-scale tree planting programs', with these having impacts upon tree growth projections.[88] Nowak *et al.* (2004) stated that,

> More long-term research is needed on urban forest growth, mortality and natality rates to provide more accurate estimates of future urban forest population totals and effects.[89]

Nowak *et al.* (2004) observed a 'high degree of uncertainty' associated with this lack of urban forest growth research, and therefore these projection models 'should be viewed with caution'.[90]

4.2.1.6 Accuracy of Tree Growth Models

The accuracy of a tree growth model correlates with the level of confidence of the model. According to Vanclay (1994), 'As in any application, the results are only as reliable as the inputs', and therefore, good 'growth and yield' estimates can only be obtained when the variables selected for use can be accurately determined.[91] Within a silvicultural context, Rayner and Turner (1990) noted that a limited amount of tree modelling has been undertaken in Australia, and therefore 'suitable data is presently lacking for many species'. In addition, they noted that the collection of the growth data and subsequent modelling is an expensive task, with the data collection 'requiring a comprehensive strategy' in order to ensure appropriate 'development of the next generation of models'.[92] Woolons and Wood (1992) explained that due to factors such as seasonal variation, mortality, and measurement errors, forest 'stand yield data' would always contain inaccuracies.[93]

The 'great number of factors' hindering tree growth, according to Zeide (1993), creates a 'growth path [that is] inherently imprecise'.[94] Zeide (1993) suggested we consider tree growth as a 'broad valley' as opposed to a 'single line' within a model.[95] While this may appear as loss of predictive accuracy, Zeide (1993) argues that through this understanding, we can 'dispense with a misleading precision read into growth equations', gaining knowledge into 'the actual variability' in growth processes and expressions.[96] The growth path shifts from a 'misleadingly precise line' to a wider band of growth that is more 'realistic', bringing 'clarity to our understanding of tree growth'.[97] Here, the loss of predictive accuracy is replaced with an enhanced understanding of tree growth patterns in the landscape.

4.2.1.7 Models as Simplified Systems

The modelling of tree growth can appear as a 'simplification' of a series of complex processes occurring in the landscape. This simplification of growth models in order to investigate the areas of direct significance to the research was investigated by a number of authors. Bunge (1963) stated that,

> All oversimplification should be avoided in science and in philosophy, except as a temporary methodological device enabling us to start work or to apply its results.[98]

Continuing with this thought, Bunge (1963) observed that simplicity could become 'dangerous' if it is considered the 'universal norm' in any quest for knowledge.[99] However, this 'loss of complexity' is present in most scientific formulations, according to Bunge (1963), as the real problem is often immensely rich in complexity, therefore transformation into a simpler scheme is necessary and, as a result, approximation or neglect of certain factors is required.[100] Although this may be 'an impoverishment relative to the actual situation', Bunge (1963) countered that 'Without such simplifications no research could start'.[101] Bunge (1963) also pertinently observed that,

> Science is not interested in simplicity by itself, but only in so far as simplicity may constitute a means for forming and checking our opinions. The ultimate goal of scientific research is not simplicity but truth.[102]

Sands (1988) agreed with Bunge's (1963) notions, adding that the simplicity of models needs to be considered within its own context: 'the simplest model that meets the objectives of a modelling project stands the best chance of gaining wide acceptance'.[103] Conversely, Sands (1988) added that there exists 'in science an underlying tension between simplicity and the quest for truth', and therefore the perception naturally follows that 'the simpler theory is the less truthful because more assumptions have been made'.[104] Writing on the advantageous nature of simplicity in complex natural models, Sands (1988) listed four important strengths to simple models:

a) easier to understand (i.e. transparent);

b) characterised by fewer parameters (i.e. parametrically efficient);

c) easier to test (i.e. refutable); and they

d) require fewer inputs and are easier to operate (i.e. less expensive to apply).[105]

Although outwardly simplistic in appearance, Sands (1988) noted that through an adherence 'to strict conventions' such as mathematics or 'structured programming techniques', representations or models of exceptionally complex systems can be constructed and understood. Sands (1988) also identified complex models impeding progress, by observing the wider acceptance of the simpler models as tools in management. 'Realism is not necessarily a virtue in a model,' observed Vanclay (1994), as 'it may be better to abstract just those aspects that are most relevant in each instance'.[106] Results gained from research by Hasenauer (1997) concurred, noting that 'for modelling purposes' the site influences could be neglected as they excessively complicated the formulations 'for a small gain in predictability' of future crown width or trunk diameter.[107] Sands (1988) noted that within the context of models for research, 'even seemingly grossly simplified models' could be implemented 'to gain important insights'.[108] Sands (1988) situated this observation within the wider context of 'management models', where the model best matching the required objective has the greatest chance of acceptance and use.[109] Interestingly, Vanclay (1988) noted that in plantations where the site is relatively 'uniform' and tree inventory data is of good quality, 'complex growth models [to predict yield] are appropriate'.[110] From these discussions, it would appear that the complexity of growth models directly links to their intended use and verification potential.

4.2.1.8 Model Testing

The testing of models following their development is an important aspect of model construction. Vanclay (1994) noted that it is important for data to be 'set aside' for thorough model testing. This process 'should not be neglected', and could 'provide a convincing demonstration of the adequacy of the model' in its intended use.[111] The data acquired for testing the model should not be used in the model development, and may be obtained from another population.[112] Vanclay (1994) stated that independent data is not always available, and for this reason data can be divided into 'two subsets', with one used for model development and the other for model testing.[113]

4.2.1.9 Forestry and Urban Forestry Models Compared

There is an apparent difference between growth models used in silvicultural applications and those used in urban forestry. Banks, Brack, and James (1999) noted that the modelling of growth in urban trees differed from models created for 'wood production'.[114] The important difference they observed was the urban focus upon individual trees, as opposed to whole stands in traditional silviculture.[115] The research project in Canberra by Banks, Brack, and James (1999) developed an urban tree management system, able to predict maintenance requirements and the costs associated with this, using urban tree growth models.[116] As they argued that bole size was of 'incidental importance', tree crown conditions and growth were the chief parameters of their focus.[117] Another important difference they noted between the forestry and urban forestry models was the necessity to cover many more tree species within an urban landscape.[118] For the 'purpose of predicting maintenance treatment', Banks *et al.* (1999) assumed the growth of park trees in their models to be the same as that of street grown specimens.[119]

Banks and Brack (2003), building upon their previous work in Canberra, noted the importance of modelling 'the projection of change and work requirements' formed as a direct result of both past and present tree planting in the urban forest.[120] A series of 'overlapping development periods', according to Banks and Brack (2003), has resulted in a very dynamic forest, 'with a diverse mixture of species, longevity and age classes' and as a result their management system addresses the trees at a 'forest level' as opposed to 'an individual tree or reactive level'.[121] Another important feature of the system developed by Banks and Brack (2003) was the ability to calculate the 'safe life' of trees from their maintenance requirements, identifying dangerous trees, and providing managers with time to instigate appropriate replacement plans in an 'aesthetically pleasing, ecologically sound and socially acceptable' manner.[122] The fact that many of Canberra's older trees are nearing the end of their safe life adds much strength to this urban tree management system:[123]

> Managers of the urban forest need to plan for its future well before the safe life of the existing trees are reached.[124]

Additionally, Banks and Brack's (2003) management system uses the growth models to predict tree species with particularly desirable characteristics for various urban landscapes. Although Canberra's urban forest is described as 'multi aged … comprising a large number of species', Banks and Brack (2003) noted that suburbs with predominately single-species trees of similar ages have the potential to 'reach the end of their safe life at approximately the same time'.[125] Banks and Brack (2003) warn that a situation such as this can result 'in a "lunar landscape, devoid of any majestic trees"'. The scheduling of tree replacements before they reach their 'maximum safe life' can prevent this problem.[126]

In addition to all this, Peper *et al.* (2001) identified general benefits to developing tree growth models for urban landscapes.[127] Urban forest managers, arborists, and researchers, among others, will benefit from the developed growth models, according to Peper *et al.* (2001), particularly if they can predict features such as trunk diameter, crown height, crown diameter, and leaf area[128]. Such models could assist in forecasting expenditure and benefits, examining 'alternative management scenarios', and establishing 'best management practices for sustainable urban forests'.[129] The potential for growth model use within urban forest research and management necessitates an examination of literature using various tree growth parameters in order to establish models suitable for urban application.

4.2.2 Parameters of Tree Growth for Modelling

Parameters such as trunk diameter, tree height, or canopy span are commonly used to measure tree growth over time. A review of the research analysing these parameters specifically for utility in tree age determination will establish growth mensuration suitable for further development in projection tree modelling in cultural landscapes.

4.2.2.1 Tree Girth and Diameter

The measurement of tree trunk or stem diameter or circumference is analysed to determine its validity in non-intrusive tree age determination. Obtained externally, these parameters cause no damage to the tree. Tree trunk circumference is often termed 'girth', with trunk diameter commonly referred to as 'diameter at breast height' or dbh.[130] The validity of these two parameters for non-invasive age determination lies in the ability to be able to accurately measure, and therefore predict tree growth over time.

Tree trunks grow in an additive fashion. This is fundamental to tree growth, as observed by Mitchell (1974):

> …the circumference of the bole of any tree must increase in some measure during every year of its life. The age of the tree is thus some function of the circumference alone.[131]

White (1998) also observed this trait stating that stem thickness 'is a constant non-reversible feature of tree growth', and the stem must increase every year of a tree's life.[132] The speed of this stem growth, described by White (1998), can be divided into three stages:

> First there is the rapid formative expansion period up to optimum crown development (core development). Second there is the more constant middle age period (the mature state). Finally, there is the period after crown decline (senescence).[133]

White (1998) described the increase in trunk size as a 'current annual increment of new wood' or CAI, the volume of which remains 'more or less constant'.[134] This new layer is spread 'over the entire under-bark surface of the tree', and therefore as the tree ages and increases in size, the layer is spread ever thinner. This process creates the 'annual rings' seen in some species, and 'are of the same cross-sectional area' as the previous years, even though they must 'progressively decline in width'.[135] Loehle (1988) also noted this process, stating that 'Absolute radial increment decreases' as the new 'wood must be spread over a greater surface area' and therefore reducing the diameter growth rate of the tree stem.[136] Chapman (1942) observed this change in dbh growth rate and warned that the use or 'assumption of straight-line projection' in tree diameter growth modelling was 'unsafe', and should therefore not be used.[137] Instead, Chapman (1942) suggested that 'curvilinear' equations provided forecasts of higher accuracy in trunk diameter modelling.[138]

An exception to the rule, palm trees do not increase in trunk diameter. Mitchell (1974) noted they have 'limited' trunk expansion due to the meristematic cells being at the top or growing tip of the plant.[139] Moore (1990) concurred, adding that 'This enables leaves to grow and the stem to elongate, but no increase in the girth of the trunk is possible'.[140] Moore (2008) added that palms do not have the cambium layer required for an increase in stem girth.[141] With this exception, tree trunk diameter appears a logical method of tree age determination, as it must increase in order for the tree to continue living. An examination into the use of this method from the available literature would determine its validity as a potential non-destructive age determination procedure.

4.2.2.1.1 Method for dbh Measurement

Tree dbh is most often recorded at 1.3 metres from the ground level on the uphill side of the tree, although this height has varied from one metre to 1.5 metres.[142] Measured with a tape, White (1998) observed that dbh taken at 1.3 metres 'is the single parameter which sums the infinite number of diameters in an irregular cross-section' of a tree.[143] Aside from being a 'convenient working height', Philip (1994) noted that this height is generally above 'root swell', and the measurements taken can be 'more regular'.[144] Swellings, buttresses, branches, deformities, and irregularities may affect the dbh reading, according to White (1998).[145] The solution to this provided by White (1998) was to measure the trunk at the narrowest point as near as practicable to the 1.3 metre height and the new height above ground level noted.[146] Pigott (1989b) measured dbh at the next available position above 1.3 metres 'at which bosses could be avoided'.[147]

While foresters often use the term 'diameter at breast height over bark' (dbhob), the term dbh is generally accepted in urban forestry to refer to the same measurement. Under-bark measurements are very silviculture-specific, often used for timber volume and production calculations. Trees with multiple trunks at breast height should have their details recorded separately, according to Vanclay (1994) and Philip (1994).[148] This is suggested within the context of silvicultural practices, to enable accurate timber volume calculations. 'Basal area' when used in silvicultural applications relates to the cross-sectional area of timber, usually at breast height, and is applied to volume calculations.

4.2.2.1.2 Tree Diameter in Age Determination

An examination into the available literature on relevant research projects would assist in analysing the validity of dbh as a technique for non-invasive tree age determination. A number of researchers have incorporated dbh into their tree age determination methods. While approaches vary and can incorporate methods ranging from simple calculations to complex equations, these projects share a common objective to determine tree age, and minimise tree damage in the process. Where tree damage occurs, the process appears to be a means to an end; the developed examples provide an established suite of useful tables, equations, or records.

One of the early researchers to publish a field guide for use in determining tree ages in the landscape, Mitchell (1974) noted that:

> It would seem that much calculation and many graphs would be needed to cope with the changes and increase in girth with advancing age, different species and differing individual vigour.[149]

Instead of this, Mitchell (1974) proposed that many trees 'conform to the simplest possible rule'.[150] This rule, according to Mitchell (1974), is that 'most trees with a full crown', when measured at a height of 1.5 metres from the ground level, grow approximately 2.5 centimetres in girth, or approximately 7.7mm in diameter each year.[151] Through this approximation, Mitchell (1974) proposed a tree with a girth of 2.44 metres, or a diameter of 77 centimetres, 'is usually about 100 years old'.[152] Trees of this measurement found growing 'in an avenue, or slightly hemmed in' may be approximately 150 years old, and those found growing 'in a wood' approximately 200 years in age.[153] Mitchell (1974) established these approximations in growth 'to be true of hundreds of specimens of almost every species'; although it was noted, that clarification of this growth rate was required.[154] Mitchell (1974) argued that a tree will spend 'much of its life' at this growth rate of 'near one inch for each year' alive, preceded by a period of faster growth in youth, and 'followed by a long period of a slower rate' in old age.[155] It should also be noted that Mitchell's (1974) observations of growth rate occurred across Britain and Northern Europe.

Investigating the use of tree girth as a non-invasive age determinate, Jacques (1983) disagreed with the notion of a 'constant' rate of growth, stating that Mitchell's (1974) 'straight-line relationship is a simplification, and can only be regarded as approximately correct for the initial 100 years of a tree's life'.[156] As a result, Mitchell's (1974) method could not be used to calculate the age of *Tilia* species 'probably planted in the late seventeenth century' in England.[157] Jacques (1983) subsequently devised an age-girth growth model incorporating known planting dates in order to calculate unknown planting dates for various tree species. Observed by Jacques (1983), the planting dates calculated from the model could only be considered 'very approximate', and added that individual trees 'cannot be dated accurately from this method', however, 'groups of trees could be dated with enough precision for analysing fashions for species' or for estimating the number of trees remaining 'from a particular period'.[158]

Extending this research beyond Hampton Court, Jacques (1987) investigated the potential of use of tree girthing for non-invasive age determination on a wider scale, incorporating examples of tree specimens across England. Proposing a 'sequence of operations' for investigating the history of landscape plantings through girthing, Jacques (1987) suggested the following process, in order:

> i) to assemble average girth versus age data, and to plot them onto a graph
>
> ii) to model the graph mathematically
>
> iii) to calculate notional ages for trees of unknown date
>
> iv) to plot notional ages onto a histogram and to examine it for planting activity at various periods.[159]

Jacques (1987) observed that trees of the same species, when found growing under the same conditions, 'have the same growth rate'.[160] This can provide a reference of age when compared to like trees of unknown age through tree girth, which Jacques (1987) measured at a height of one metre above ground level.[161]

Jacques (1987) noted that data for generating growth models indicative of tree age-girth are obtained from either: records of individual tree dimensions collected 'over a period of years', or from the archival records of a 'planting date of a group of trees'.[162] Jacques (1987) observed that the use of girth growth figures, when obtained from tree age tables, such as those prepared by Mitchell (1972) and discussed in Chapter 4.1.3, should be viewed with caution when applied to girth growth models.[163] The reason, according to Jacques (1987), is that tree age tables tend to contain records of individual remarkable or noteworthy specimens in growth, and the records of the one specimen over time may not provide an accurate representation of the growth of the average tree of the species.[164] The data contained in these tree age tables, however, should not be disregarded, and Jacques (1987) notes that it can be used to determine 'the likely shape of the graph' for the tree species under investigation.[165]

Using a combination of dendrochronology and extant historical records, Pigott (1989b) was able to compare *Tilia* species of known age, to those of unknown age, using diameter at breast height comparisons to calculate tree ages for 43 avenues in Britain. Through the development of least squares regression equations, Pigott (1989b) was able to establish a logarithmic relationship between dbh and tree age in the *Tilia* species examined, and revealed the possibility of inverting the equation in order to estimate tree age from trunk diameter.[166] In the results, Pigott (1989b) found that of a *Tilia* species avenue planted approximately in 1703, four of the dbh measurements were 'within 2.3 cm of each other even after 280 years', and it was added that 'trees in avenues are much more variable both morphologically and in trunk diameter'.[167] Although Pigott (1989b) employed dendrochronology, samples were only collected from *Tilia* species fallen during a storm in 1987. Through the combination of dendrochronological samples and extant historical records, Pigott (1989b) was able to establish dating periods and therefore propose 'a time-scale' for the introduction of various *Tilia* species clones into England.[168]

White (1998) specifically referred to the use of girth measurements recorded at 1.3 metres from ground level for estimating tree ages in Britain. With a particular focus upon 'large and veteran trees', White (1998) justified the use of trunk diameter as a method of non-intrusive age determination as it is readily comparable to existing records of similar tree species of equivalent trunk diameter.[169] The method proposed involved calculating the basal area or trunk cross-sectional area at breast height.[170] Using this, combined with dendrochronological records collected since 1952, the core or pre-maturity stage of tree growth is determined out of the basal area, and known annual ring widths in millimetres over the mature stage of the tree's life are calculated, thus providing an estimation of the tree's age.[171] Additionally, White (1998) expressed the need to record site notes. These would assist in determining the rate of tree growth from the table of known growing conditions according to species. Tables such as those compiled by White (1998) would prove most useful in estimating tree ages from their recorded growth rates, however, existing data collections such as the Tree Register of the British Isles, used by White (1998), are uncommon.

Research by Peper *et al.* (2001) investigated the relationship between age and dbh, with age used as a parameter to calculate future dbh measurements in urban trees. Conducted in the San Joaquin Valley in Modesto, California, the sample of 341 trees across 12 species investigated the potential of dbh as a parameter for determining the validity of future parameter prediction in other facets of urban tree growth. The purpose of this work was to use age to determine future dbh measurements using regression equations, and then to develop further regression equations to predict future tree height, crown width, crown height, and leaf area based upon dbh measurements.[172] The research discovered that logarithmic equations provided the best fit for all data sets, except for leaf area.[173] When dbh was regressed on age, Peper *et al.* (2001) found that the correlation coefficient varied from r^2=0.40 to r^2=0.94, with an average r-squared value of 0.69.[174] Other parameters such as tree height, crown diameter, and crown height when regressed on dbh revealed higher average correlation coefficients of 0.78, 0.85, and 0.70 respectively across all 12 tree species surveyed.[175] Peper *et al.* (2001) noted the value of this research for arborists and urban tree managers to enable cost benefit analysis, develop alternative management scenarios, and instigate best practices in tree management.[176]

The study by Lukaszkiewicz *et al.* (2005) investigated the potential of using dbh to determine the age of common lime (*Tilia cordata*) trees in urban parks and streets of Poland. They collected both dbh data and extant planting dates for groups of trees and then developed a regression model outlining their growth over time.[177] Results of this model showed a distinct relationship, with a correlation coefficient of r^2 = 0.962, and when this model was applied to unrelated trees of known age, the difference between the actual age and the model-predicted age was less than ten percent.[178] The 'exponential character' shown in the growth curve when age was plotted over dbh expressed the 'gradual decrease in the dbh growth in proportion to the age' of trees surveyed.[179] This 'progressive reduction' in diameter growth 'in proportion to age', they observed, is 'a phenomenon related to tree growth'.[180] The accuracy of the developed growth model was then compared to tree ring counts collected with a Resistograph, with the 'results being highly concordant'.[181]

Lukaszkiewicz *et al.* (2005) noted that their model was not intended for use in determining individual specimen tree age; rather, the intended use was for calculating ages of groups of common lime trees found along roadways and alleys.[182] Lukaszkiewicz *et al.* (2005) also specified that all trees used in the research were growing in 'uniform climatic conditions', with measurements collected from 195 specimens for the project.[183] The non-invasive portion of their method, they concluded, allows for age determination where there is some data on their 'origin', but their age is 'unknown', and the invasive component would be more suitable for age determination of individual specimens.[184] Additionally, Lukaszkiewicz *et al.* (2005) stated that the growth model could be adapted for field use simply by straightening the exponential curve.[185]

From the literature investigated, modelling of tree growth, and in particular tree diameter, does not form a straight line. The accuracy provided by a curvilinear equation should be considered in equations determining tree age from trunk diameter, and appropriate linear regression analysis applied.

4.2.2.2 Tree Height and Canopy Span

The concept of trees as 'generating systems' through the process of adding new cells to their form in order to continue living has been discussed in Chapter 3.4. As variables of tree growth following in this 'generating' or addition of cells pattern of growth, tree height and canopy span are investigated for their potential as externally mensurable tree age determinates. While trunk diameter may appear an arguably appropriate method of non-destructive tree age determination, the importance of tree height and canopy span may add weight to externally mensurable tree age determination processes, and to provide the potential for various palm species age mensuration in tree growth models.

Banks *et al.* (1999) incorporated tree height into their tree management and maintenance prediction software, as a variable to determine future maintenance tasks required. Used in their logarithmic growth equations, the height of the tree is shown as ever increasing, in order to enable the prediction of tree works.[186] In the case of Banks *et al.* (1999), a logarithmic equation for predicting tree height was found appropriate, as trees reducing in top height may have indicated elements of structural unsoundness, or possibly the onset of senescence. For urban areas, such as the streets and parks of Canberra, the liability risk of retaining unsafe trees would effect their removal prior to encountering downward trends in their top height. The use of a logarithmic growth equation for modelling tree height appears supported by observations by Clark and Matheny (1991): mature trees experience 'reduced shoot elongation' when 'close to maximum height', the crown at this point loses apical dominance resulting in a 'rounded crown'.[187]

Adding details to their project, Banks and Brack (2003) specified that along with top height, other external mensuration features they were able to predict ‘at any nominated age’ and for any species included ‘maximum crown width and height of the maximum crown’.[188] They also incorporated other statistical formulae to predict the probability of each tree surviving ‘one more year without showing signs of stress or poor health’, the consequence of which could result in the instigation of various maintenance procedures, or tree removal.[189] Importantly, Banks and Brack (2003) noted that their statistical models were intended for use across large groups of trees; they could not therefore ‘be reliably applied to individual trees’ in Canberra’s urban landscape.[190] As a result, ‘the basic modelling unit’ in Banks and Brack’s (2003) project for predicting tree growth and maintenance costs over their ‘safe life’ were ‘taxa within a street or park’.[191]

Within South Australia, Leech (1984) found that the relationship between tree crown diameter and dbh for ‘open grown’ radiata pine trees (*Pinus radiata*) was ‘approximately linear’.[192] Although the research by Leech (1984) had a silvicultural focus with the objective to determine a model for defining ‘a crown competition factor’ for use in ‘growth and yield studies of radiata pine’, the study clearly showed the relationship between the two parameters of trunk diameter and crown diameter for this species.[193] The models developed by Peper *et al.* (2001) also investigated the possibility of predicting tree height, crown diameter, crown height, and leaf area for various tree species in Santa Monica streets, as discussed in Chapter 4.2.2.1.2.[194]

4.2.3 Accuracy of Size-Age Relationships in Trees

When size is regressed on age, or vice-versa, the accuracy of the relationship will be called into question. Specifically addressing the accuracy of tree age determination, Norton and Ogden (1990) correctly observed that ‘A minimum requirement of any study presenting tree-age estimates is to acknowledge the possibility of errors in the estimates.’[195] Fritts (1976) observed that ‘The rate of [tree] growth can be expressed as a function of increasing age’, and while this may be true for most tree measurements, the accuracy of either parameter for age determination will vary depending upon many factors. Harper (1977) succinctly noted that:

> It is wholly unrealistic and very dangerous to assume any relationship between the size of trees and their age, other than the vague principle that the largest trees in a canopy are likely to be old. However, it cannot be argued conversely that small trees are likely to be young: they may be as old as the main occupants of the canopy. If a tree is very young it is likely to be small, but if it is small it may be of any age.[196]

Therefore, in order to determine tree age from tree mensuration data collected, methods of model calibration must be employed to facilitate age size classes; as a minimum level of accuracy for interpretation of trees ages in cultural landscapes.

4.2.3.1 Accuracy of Diameter-Age Relationships in Trees

From the literature reviewed on tree growth, there appears a general agreement in the existence of a correlation between growth in trunk diameter and age, with the exception of various palm species. Due to this association, dbh appears a suitable non-invasive tree mensuration procedure, with the potential to reflect tree age. Some authors, however, advise of the dangers associated with trunk diameter when used expressly for age determination.

Although Jacques' (1987) girth-age method for dating trees may appear 'simple in theory', Jacques (1987) warned of three main 'limitations' to this age determination method.[197] Firstly, there may be difficulty 'in obtaining the true measure of girth' due to coppicing, low branches and a lack of 'Conformity with the ideal, the perfectly cylindrical tree'.[198] Secondly, the dating of trees 'used as controls' can vary in accuracy.[199] The planting dates of trees in groups or avenues may be located, along with planting dates of replacement trees. However, distinguishing between the two 'can be problematic' potentially placing incorrect dates to tree measurements collected.[200] Jacques (1987) also noted problems arising over the accuracy of 'annual growth rings', as discussed in Chapter 5.1 under the subject of invasive methods of determining tree age.[201] The third limitation to data accuracy noted by Jacques (1987) was attributed to 'genetic factors', human intervention through tree maintenance procedures, and environmental influences such as light and water availability, bark damage, and disease.[202]

Detailing additional inaccuracies, (Jacques, 1987) noted the possible differences between trees situated within a group, and how important it is 'to be aware of the range' of growth rates of trees.[203] Trees in a forest or group, with the same planting date, management histories, in the same growing conditions, may 'have a range of girths of ± 35 per cent around the average'.[204] This accuracy may be altered further by larger than average trees, Jacques (1987) noted, up to '+ 50 per cent to – 35 per cent' from the average.[205] According to Jacques (1987), trees found growing in different conditions or environments 'can be far greater' in difference than these percentages.[206]

Using dbh to determine age, Pigott (1989b) discovered that while trunk diameters could be used to estimate ages of common lime trees in avenues, the errors were 'disappointingly large'.[207] Even though trees in an avenue may appear uniform in diameter, Pigott (1989b) warned 'that average diameter provides a very poor estimate of age for older avenues', specifically those planted before 1740.[208] For specimens 'up to 240 years old, a reasonable estimate is obtained from the average of a sample of 10 or 20 of the largest trees'.[209] The results from ring counts obtained from the trunks, however, revealed accuracies to 'within a few percent' up to the age of 240 years.[210] Past this age, Pigott (1989b) observed that 'errors increase', finding that trees with a dbh 'greater than one metre indicate little more than that the trees are old'.[211]

Ogden (1985) noted that the actual dbh mensuration process itself could cause substantial error in age-diameter modelling due to 'large irregular boles', and;

> A consequence of these errors is that most age-diameter scatter diagrams contain more variance than is apparent; each point floats in a drop of uncertainty which increases with tree diameter.[212]

Adding to this, Ogden (1985) observed that small samples containing 'inaccurately aged trees from widely separated class sizes' could provide apparently "significant" correlations in age-diameter relationships, although they may, however, 'obscure a multiple cohort structure' containing a number of 'distinct and more or less even-aged waves of generation'.

Research conducted by Welch (1994) on comparisons between street and park trees in Boston revealed that dbh was 'not a reliable predictor of individual tree age', largely due to varying growth rates 'both within and among species'.[213] Instead, Welch (1994) proposed the use of 'size classes', as these 'represent general age structure' of urban forests.[214] From these age groups, 'size class diversity' can be determined, allowing for analysis of age structure across an urban forest.[215] Providing planners with age classes, according to Welch (1994), would allow insight into whether species populations are increasing, decreasing, or remaining stable.[216]

Norton and Ogden (1990) identified a number of inaccuracies associated with age-diameter relationships. Within studies of forest tree dynamics, they identified the widespread procedure of aging a sample of trees, and applying the resultant age-diameter trend to trees of unknown age. Due to 'considerable uncertainties' associated with age determination of individual trees used for model development, 'an unavoidable error is built into the age-diameter model', and 'The magnitude of this error is usually unknown'.[217] Norton and Ogden (1990) continued, proposing that 'In many cases age and diameter are not closely related', due to competition between certain trees with this altering growth rates.[218] They provided the illustration of even-aged silvicultural forest stands, where variances between the individuals can be measured, therefore claiming 'there are very real limitations in the use of size class data to determine age structures'.[219] For these reasons, Norton and Ogden (1990) believed even if an age-diameter relationship was proved statistically significant, 'predicting diameter from age, due to the large variances 'in age for any diameter class' would be misleading.[220]

Research published on mixed eucalypt forests in south-western Australia by Rayner (1992) discovered that there was 'a strong linear relationship' between tree age and trunk diameter in the 'dominant seed trees sampled'.[221] Rayner (1992) added that each 'block', or forest, returned different relationships between tree age and diameter.[222] For this reason, determining forest age from the diameters of the largest extant trees was an 'imprecise' method, and according to Rayner (1992), detailed site quality data and further tree sampling would be required to determine the accuracy of the diameter at breast height over bark-age (dbhob-age) relationship.[223] Within forest dynamics, Pearson and Searson (2002) observed that:

> Girth is often a reasonable approximation of a tree's age so measurement of circumference is a useful first description of forest processes that can be obtained quickly once the relationship between girth and age is proven in specific situations.[224]

From dendroecological-based research conducted by Argent *et al.* (2004) on River Red Gums (*Eucalyptus camaldulensis*) in Victoria, it was found that trees of a particular dbh 'can vary considerably in age due to different site conditions'.[225] From the results, Argent *et al.* (2004) revealed that individual specimens with ages of 66 and 28 years had 'similar diameters' when compared. Other trees with ages close to 28 years had dbh values varying 'by at least 50' per cent.[226]

In 'natural' tropical forest stands in Cameroon, a study by Worbes *et al.* (2003) discovered that tree diameter 'is dependent on its age'. However, from the trees sampled, 'The correlation between diameter and age is weak' providing a correlation coefficient of r^2=0.37.[227] Of the trees sampled, Worbes *et al.* (2003) claimed that 'Trees of the same age can have a diameter of 10 or 120cm'.[228] Unfortunately, this comparison did not differentiate between the tree species encountered, with all species plotted on the one scattergram.[229] Only tree height regressed on tree age was displayed for six individual species.[230]

Of the many methods for determining tree age in the landscape, trunk diameter 'has great limitation' according to Jacques (1987), however, it was conceded that 'in it lies the best available general method for the historical analysis of planting'.[231] If data could be collected on both tree survival and growth rates for a variety of conditions and species, Jacques (1987) argued, this method of dating could become much more effective and therefore more widely accepted for use.[232] Eventually, proposed Jacques (1987), data may be accumulated to acknowledge environmental conditions such as soil type and shading, various management techniques, or other factors that influence tree growth.[233] 'In the meantime', warned Jacques (1987), 'considerable care must be used in assembling the data and interpreting the graphs.'[234]

4.2.3.2 Accuracy of Height-Age and Canopy Span-Age Relationships in Trees

Tree height and canopy span can be affected by adverse site conditions, according to Fritts (1976). As previously noted, trees growing on stressful sites can have a shorter juvenile period. Fritts (1976) proposed that as a result, maximum tree height is reached sooner, and height increments reduce as maturity sets in. Due to this, trees growing in adverse conditions do not become as tall, and typically display a 'more spherical and flattened' shaped crown.[235]

From the projects investigated, a number of researchers expressed their concerns with the parameters of tree height and canopy span for accurate expressions of tree growth. Banks (1997) observed a 'curvilinear relationship' between tree height and 'bole girth' on Yellow box (*Eucalyptus melliodora*).[236] The observation noted that at some point tree height reached a 'ceiling', while the bole continued to expand over the life of the tree, 'although at a diminishing rate'.[237] Mitchell (1974) also wrote that at some point, both tree height and canopy span 'reach a maximum size', following which they 'start to decrease as senility sets in'.[238] For this reason, Mitchell (1974) stated that height and canopy span cannot be used to estimate tree age 'except in young trees'.[239] Supporting this, White (1998) noted that 'after middle age' tree height and canopy span are 'unrealistic' guides to tree age. Declining to provide the potential 'spread' of a tree species' canopy, Mitchell (1974) argued that, 'It is greatly dependent on surroundings and is nearly meaningless'.[240]

Jacques (1987) observed that determining tree age from mensuration 'usually relied upon the girth of the clear bole', with this having 'a more predictable growth rate' when compared to either height or canopy span.[241] Within the tropical forests of Cameroon, Worbes *et al.* (2003) deduced from their results that tree height 'correlates very weakly' with age.[242] Within 'uneven aged' forests, Philip (1994) observed that the growth rate of tree height can accelerate significantly once 'the tree is released from overhead shade'. [243] In their research on *Eucalyptus globulus* height and diameter growth in Portugal, Reed, Jones, Tomé, and Araújo (2003) noted that models developed using inventory data for tree height might not accurately reflect the species, as the plantation trees measured may not have reached their 'maximum growth potential'.[244]

There also appear potential errors in data obtained for growth modelling and testing developed growth models. Philip (1994) noted that human error could include failure to correctly identify the top of the tree, resulting in either under or over estimation of tree height.[245] Other possible errors in height measurements noted by Philip (1994) include 'wind sway' and 'lean', both of which can alter actual tree height data.[246] Additionally, past management techniques such as tree pollarding or coppicing can alter tree height and canopy span parameters, as can tree pruning or branch breakage. While there appears to be a number of reservations regarding the use of tree height or canopy span parameters to determine tree age, Jacques (1983) observed that determining age from trunk girth could provide predictions of canopy dimensions ‘at future dates’, possibly enabling these parameters to be estimated for future landscapes.[247]

4.2.4 Summary (Part II)

Tree growth models can be used to display growth trends over a period of time. Using ‘time’ as one parameter, other parameters of tree growth can be plotted and compared for growth trends and develop likely scenarios for predictive modelling. By modelling trees of recognized age and dimension, and comparing the trends to trees of similar species and growing conditions, age determination may be possible. Through simplified or model systems, a certain abstraction from reality must occur. Therefore, certain degrees of error may be inbuilt into such growth models. By selecting those parameters most accurately reflecting macro scale tree growth with age such as trunk diameter, tree height, and to a much lesser extent, canopy span, estimates of tree age may be provided for use in cultural landscape interpretation.

Chapter 4 Notes

[1] Jacques (1987) p. 193.
[2] Lukaszkiewicz *et al.* (2005) p. 280.
[3] Woodgate *et al.* (1994) p. 211.
[4] Woodgate *et al.* (1994) p. 56.
[5] Attorre *et al.* (2003) p. 293.
[6] Banks *et al.* (1999) p. 36.
[7] Lukaszkiewicz *et al.* (2005) p. 281.
[8] Peper *et al.* (2001) p. 307.
[9] Pigott (1989a)
[10] Boudon (1991) p. 125.
[11] Boudon (1991) p. 125.
[12] Boudon (1991) pp. 127-128.
[13] Pollock-Ellwand (2007) (Pers. comm.)
[14] Attorre *et al.* (2003) p. 293.
[15] Attorre *et al.* (2003) p. 293.
[16] Clare and Bunce (2006) p. 34.
[17] Clare and Bunce (2006) p. 34.
[18] Clare and Bunce (2006) p. 35.
[19] Argent *et al.* (2004) p. 90.
[20] Mitchell (1972)
[21] White (1998) p. 1.
[22] White (1998) p. 3.
[23] White (1998) p. 1.
[24] White (1998) p. 1.
[25] White (1998) p. 1.
[26] White (1998) p. 1.
[27] White (1998) p. 1.
[28] Lukaszkiewicz *et al.* (2005) p. 280.
[29] Lukaszkiewicz *et al.* (2005) p. 280.
[30] Lukaszkiewicz *et al.* (2005) p. 280.
[31] Lukaszkiewicz *et al.* (2005) p. 280.
[32] Lukaszkiewicz *et al.* (2005) p. 280.
[33] Jacques (1987) p. 193.
[34] Akeroyd *et al.* (2002) p. 265.
[35] Akeroyd *et al*. (2002) p. 265.
[36] Peper *et al.* (2001) p. 308.
[37] Worbes *et al.* (2003) p. 111.
[38] Pienaar and Turnbull (1973) p. 2.
[39] Vanclay (1994) p. 4.
[40] Harvey (1969) p. 448.
[41] Sands (1988) p. 20.
[42] Vanclay (1994) p. 4.
[43] Vanclay (1994) p. 4.
[44] Rayner and Turner (1990) p. 225.
[45] Vanclay (1988) p. 94.
[46] Sands (1988) p. 20.
[47] Vanclay (1994) p. 6.
[48] Vanclay (1994) p. 6.
[49] Vanclay (1994) p. 6.
[50] Bettinger (2001) p. 123.
[51] Vanclay (1994) p. 12.
[52] Jacques (1987) pp. 203-205.
[53] Peper *et al.* (2001) pp. 314-315.
[54] Peper *et al.* (2001) p. 315.
[55] Vanclay (1994) p. 4.

[56] Bettinger (2001) p. 109.
[57] Ogden (1985) p. 5.
[58] Zeide (1993) p. 596.
[59] Zeide (1993) p. 596.
[60] Zeide (1993) p. 596.
[61] Zeide (1993) p. 596.
[62] Philip (1994) p. 89.
[63] Philip (1994) p. 89.
[64] Philip (1994) p. 106.
[65] Vanclay (1994) p. 5.
[66] Rayner and Turner (1990) p. 224.
[67] White (1998) p. 1.
[68] Zeide (1993) p. 594.
[69] Zeide (1993) p. 594.
[70] Zeide (1993) p. 594.
[71] Zeide (1993) p. 594.
[72] Fritts (1976) p. 73.
[73] Fritts (1976) p. 73.
[74] Fritts (1976) pp. 73-74.
[75] White (1998) p. 3.
[76] Jacques (1987) pp. 199-200.
[77] Jacques (1987) p. 200.
[78] Hitchmough (1994b) p. 103.
[79] Moore (1990) p. 25.
[80] Moore (1990) p. 25.
[81] Moore (1990) p. 25.
[82] Vanclay (1994) p. 118.
[83] Vanclay (1994) pp. 82-83.
[84] Rayner and Turner (1990) p. 223.
[85] Zhang (1997) p. 251.
[86] Bettinger (2001) p. 118.
[87] Nowak *et al.* (2004) p. 146.
[88] Nowak *et al.* (2004) p. 146.
[89] Nowak *et al.* (2004) p. 146.
[90] Nowak *et al.* (2004) p. 146.
[91] Vanclay (1994) p. 105.
[92] Rayner and Turner (1990) p. 238.
[93] Woolons and Wood (1992) p. 71.
[94] Zeide (1993) p. 613.
[95] Zeide (1993) p. 613.
[96] Zeide (1993) p. 613.
[97] Zeide (1993) pp. 613-614.
[98] Bunge (1963) p. vi.
[99] Bunge (1963) p. vi.
[100] Bunge (1963) p. 90.
[101] Bunge (1963) p. 90.
[102] Bunge (1963) p. 96.
[103] Sands (1988) p. 20.
[104] Sands (1988) p. 21.
[105] Sands (1988) p. 21.
[106] Vanclay (1994) p. 6.
[107] Hasenauer (1997) p. 205.
[108] Sands (1988) p. 32.
[109] Sands (1988) p. 32.
[110] Vanclay (1988) p. 95.
[111] Vanclay (1994) p. 82.
[112] Vanclay (1994) p. 83.
[113] Vanclay (1994) p. 83.
[114] Banks *et al.* (1999) p. 37.

[115] Banks *et al.* (1999) p. 37.
[116] Banks *et al.* (1999) p. 35.
[117] Banks *et al.* (1999) p. 37.
[118] Banks *et al.* (1999) p. 37.
[119] Banks *et al.* (1999) p. 39.
[120] Banks and Brack (2003) p. 151.
[121] Banks and Brack (2003) p. 151.
[122] Banks and Brack (2003) p. 151.
[123] Banks and Brack (2003) p. 152.
[124] Banks and Brack (2003) p. 159.
[125] Banks and Brack (2003) pp. 152, 159.
[126] Banks and Brack (2003) p. 159.
[127] Peper *et al.* (2001) p. 306.
[128] Peper *et al.* (2001) p. 306.
[129] Peper *et al.* (2001) p. 306.
[130] For discussion on heights commonly used for dbh mensuration, see Section 4.2.2.1.1.
[131] Mitchell (1974) p. 25.
[132] White (1998) p. 2.
[133] White (1998) p. 3.
[134] White (1998) p. 2.
[135] White (1998) p. 2.
[136] Loehle (1988) p. 211.
[137] Chapman (1942) p. 806.
[138] Chapman (1942) p. 806.
[139] Mitchell (1974) p. 21.
[140] Moore (1990) p. 51.
[141] Moore (2008) p. 3.
[142] Vanclay (1994) p. 94; Philip (1994) p. 19; White (1998) pp. 2-3.
[143] White (1998) p. 2.
[144] Philip (1994) p. 19.
[145] White (1998) p. 3.
[146] White (1998) p. 3.
[147] Pigott (1989b) p. 290.
[148] Vanclay (1994) p. 93; Philip (1994) p. 20.
[149] Mitchell (1974) p. 25.
[150] Mitchell (1974) p. 25.
[151] Mitchell (1974) p. 25.
[152] Mitchell (1974) p. 25.
[153] Mitchell (1974) p. 25.
[154] Mitchell (1974) p. 25.
[155] Mitchell (1974) p. 25.
[156] Jacques (1983) p. 59.
[157] Jacques (1983) p. 59.
[158] Jacques (1983) p. 59.
[159] Jacques (1987) p. 198.
[160] Jacques (1987) p. 195.
[161] Jacques (1987) p. 195.
[162] Jacques (1987) p. 198.
[163] Jacques (1987) p. 198.
[164] Jacques (1987) p. 198.
[165] Jacques (1987) p. 198.
[166] Pigott (1989b) pp. 295-296.
[167] Pigott (1989b) p. 291.
[168] Pigott (1989b) p. 290.
[169] White (1998) p. 1.
[170] White (1998) p. 6.
[171] White (1998) p. 6.
[172] Peper *et al.* (2001) p. 306.
[173] Peper *et al.* (2001) p. 306.

[174] Peper *et al.* (2001) p. 311.
[175] Peper *et al.* (2001) p. 311.
[176] Peper *et al.* (2001) p. 306.
[177] Lukaszkiewicz *et al.* (2005) p. 280.
[178] Lukaszkiewicz *et al.* (2005) p. 280.
[179] Lukaszkiewicz *et al.* (2005) p. 281.
[180] Lukaszkiewicz *et al.* (2005) p. 281.
[181] Lukaszkiewicz *et al.* (2005) p. 280.
[182] Lukaszkiewicz *et al.* (2005) p. 280.
[183] Lukaszkiewicz *et al.* (2005) pp. 280-281.
[184] Lukaszkiewicz *et al.* (2005) pp. 282-283.
[185] Lukaszkiewicz *et al.* (2005) p. 282.
[186] Banks *et al.* (1999) p. 37.
[187] Clark and Matheny (1991) p. 178.
[188] Banks and Brack (2003) p. 155.
[189] Banks and Brack (2003) p. 155.
[190] Banks and Brack (2003) p. 155.
[191] Banks and Brack (2003) p. 155.
[192] Leech (1984) p. 335.
[193] Leech (1984) p. 337.
[194] Peper *et al.* (2001) p. 307; See Chapter 4.2.2.1.2.
[195] Norton and Ogden (1990) p. 288.
[196] Harper (1977) p. 634.
[197] Jacques (1987) p. 195.
[198] Jacques (1987) p. 195.
[199] Jacques (1987) p. 195.
[200] Jacques (1987) p. 195.
[201] Jacques (1987) p. 195; See Chapter 5.1. Dendrochronology.
[202] Jacques (1987) pp. 195-196.
[203] Jacques (1987) p. 196.
[204] Jacques (1987) p. 197.
[205] Jacques (1987) p. 197.
[206] Jacques (1987) p. 197.
[207] Pigott (1989b) p. 301.
[208] Pigott (1989b) pp. 297-298.
[209] Pigott (1989b) p. 301.
[210] Pigott (1989b) p. 301.
[211] Pigott (1989b) p. 301.
[212] Ogden (1985) pp. 4-5.
[213] Welch (1994) p. 136.
[214] Welch (1994) p. 136.
[215] Welch (1994) p. 136.
[216] Welch (1994) p. 136.
[217] Norton and Ogden (1990) p. 287.
[218] Norton and Ogden (1990) p. 287.
[219] Norton and Ogden (1990) p. 287.
[220] Norton and Ogden (1990) p. 287.
[221] Rayner (1992) p. 8.
[222] Rayner (1992) p. 8.
[223] Rayner (1992) p. 8.
[224] Pearson and Searson (2002) p. 433.
[225] Argent *et al.* (2004) p. 101.
[226] Argent *et al.* (2004) p. 101.
[227] Worbes *et al.* (2003) p. 113.
[228] Worbes *et al.* (2003) p. 113.
[229] Worbes *et al.* (2003) p. 115.
[230] Worbes *et al.* (2003) p. 118.
[231] Jacques (1987) p. 207.
[232] Jacques (1987) p. 207.

[233] Jacques (1987) p. 207.
[234] Jacques (1987) p. 207.
[235] Fritts (1976) pp. 73-74.
[236] Banks (1997) p. 38.
[237] Banks (1997) p. 38.
[238] Mitchell (1974) p. 25.
[239] Mitchell (1974) p. 25.
[240] Mitchell (1974) p. 13.
[241] Jacques (1987) pp. 194-195.
[242] Worbes *et al.* (2003) p. 105.
[243] Philip (1994) p. 99.
[244] Reed *et al.* (2003) p. 195.
[245] Philip (1994) p. 37.
[246] Philip (1994) p. 35.
[247] Jacques (1983) p. 62.

Chapter Five: Invasive Methods of Tree Age Determination

In addition to reviewing non-invasive methods of determining tree age, invasive methods must also be reviewed to establish both the extent of damage carried out by each process, and the level of accuracy attainable with regard to accurate determination of tree age. Investigation will also focus upon the suitability of invasive methods of tree age determination within an Adelaide Plains context, in order to identify potential methods for use within the Adelaide Park Lands. The invasive methods reviewed here involve sampling internal tissues of trees to calculate tree age, damaging live tissues on living trees, and potentially resulting in tree death through the introduction of pathogens and subsequent structural failure, or through the removal of the tree itself to study entire trunk cross-sections.

5.1 Dendrochronology

Dendrochronology, or the study of tree chronologies from their growth rings, is investigated here for its potential use as a method of tree age determination. The nature of dendrochronology requires examination across layers of tree growth formed over time, and therefore some tissue destruction in living trees must occur in order to observe this development. For this specific reason it is included in this chapter on 'invasive' tree aging methods. Its validity as a method of tree age determination is investigated along with issues concerning its use within Australia, and use on indigenous Australian trees. From a review of the available literature on the subject, the worth of dendrochronology in Australia, and more specifically, in the Adelaide Plains region may be deduced.

5.1.1 Definitions of Dendrochronological Terms

The central tenet of dendrochronology is the study of tree and plant growth rings. Pearson and Searson (2002) defined dendrochronology as 'the science of 'using trees for temporal sequencing''.[1] Molisch (1938) observed the expediency of counting tree rings to provide 'a generally reliable means for determining age', as it 'represents the yearly increase of wood'.[2] Woodgate *et al.* (1994) expressed this layer of wood as consisting of both 'earlywood' and 'latewood'.[3] Formed early on during the growing period, the earlywood is generally of a lighter colour than the latewood, which forms towards the end of the growing period, the latter both darker in colour and density.[4] Pearson and Searson (2002) explained that these formations of longitudinal cells, or 'tracheids', reflect the tree's growth cycle, allowing dates to be applied to the rings, and growth season length to be measured.[5]

However, issues arise where seasonal tree growth is not necessarily annual, or climatic conditions temporarily inhibit tree growth. Woodgate *et al.* (1994) noted that the assumption of one season of latewood representing 'one growing season or year' may not be appropriate for all situations involving dendrochronology:

> Many Australian species … do not produce annual growth rings that correlate with distinctive annual seasons, and it is not always possible to estimate tree age by counting growth rings in these species.[6]

Ogden (1978) also noted this, and while confirming the potential of tree ring counting to estimate the age of a tree, warned that periods of severe climatic conditions can result in a partial or complete lack of tree ring formation for that growth season.[7] Estimation of age, Ogden (1978) observed, can be particularly useful for 'ecological investigations', however, an accurate determination of the tree's chronology cannot 'be constructed' until each ring has been 'precisely dated to its year of formation'.[8] Ogden (1978) therefore argued, tree rings should not be considered 'annual'.

Unless every tree ring can be dated exactly in this manner, 'annual rings', as both a term, and a concept, cannot be assumed. For these reasons, the term 'growth ring' is preferable in the present research context, as the ring is created during tree growth only. Akeroyd *et al.* (2002) stated that growth ring width might vary due to fluctuations in 'environmental conditions, such as rainfall and soil moisture'.[9] Discussed in Chapter 4.2.2.1 on the diameter growth trends of trees, and noted by Akeroyd *et al.* (2002), growth ring width can 'be expected to initially increase exponentially' during youth, followed by a decrease as the tree ages due to wood volume being spread over an increased surface area.[10] Due to this combination of environmental and physiological changes over time, tree ring widths can be expected to vary. However, as discussed in Chapter 4.2.2.1 and noted by Mitchell (1974), trees must add new growth in order to continue living, therefore where and when produced, growth rings may still provide an interpretation of tree ages in the landscape.[11]

5.1.2 Purpose of Dendrochronology

A large quantity of research into dendrochronology focuses upon accuracy in counting and subsequent dating of growth rings in trees. For this research, a wider application of dendrochronological-based studies must be investigated to determine the validity of its use in cultural landscape tree dating. Research by Rayner (1992) on age determination of Australian karri (*Eucalyptus diversicolor*) forests involved dendrochronological study to assist in the 'interpretation of the forest' and to understand the forest's past.[12] Rayner (1992) added that,

> Dendrochronology and stem analysis provide efficient, cost effective means of gathering growth data and of reconstructing stand histories.[13]

In Cameroon, Worbes *et al.* (2003) analysed tropical forest tree rings in order to reveal the 'stand history and growth dynamics of important timber species', and therefore facilitate the development of appropriate management techniques for tropical forests.[14] On interpreting the history of tree avenues in Europe, Couch (1992) observed that while trunk dimensions may provide an approximate guide to tree age, 'ring-counting may be the only way' to determine accurate tree ages.[15] Adding to the complexity of this area of expertise, dendroclimatology investigates past environmental conditions from the width and density of growth rings, providing important ecological information for landscape research.

5.1.3 Methods of Dendrochronology

As growth rings form in subsequent layers over the surface of the tree, examination of these layers requires a whole section or part thereof across the growth rings to permit ring counting for establishing chronologies. A number of methods for obtaining this cross-sectional view of the tree are commonly used, and all obligate some degree of damage to living trees. The two methods commonly employed are tree coring, and tree felling.

5.1.3.1 Tree Coring

The least invasive method of growth ring analysis over the life of the tree involves the extraction of a core of wood, extending from the outer bark through to the centre of the tree. The coring device consists of a hollow steel tube with a threaded bit on the end, and a handle used for driving the instrument into the tree. After the tube is inserted, the core is extracted from the tree. Generally between 0.5 and one centimetre in diameter depending on the coring instrument, the core is seasoned before being mounted for finishing. The sample is finished by planing and sanding with increasingly finer grades of sandpaper in order to reveal the growth rings. Often the sample is wetted and dried during the ring counting process to enhance ring visibility, and stereomicroscopes are employed to ensure rings are not missed. As the less invasive of the two common methods, tree coring is often applied when the tree is to be retained, and removal is not warranted. Dunwiddie and LaMarche (1980) noted that tree cores 'are easily transported, and the technique permits the sampling of a large number of trees'.[16]

5.1.3.2 Tree Felling

Dendrochronological studies of felled trees are generally considered to provide tree growth ring counts of higher accuracy than cored tree ring samples.[17] The process involves felling the entire tree and a full or part cross-section of the trunk, known as a disk, is removed for study. The sample is planed and then sanded along any number of radii, often two to four, and the rings are wetted, dried and observed through a stereomicroscope as for cored samples.

Occasionally, whole tree or cross-section samples can be obtained from trees that must be removed from a landscape for various reasons. Programmed tree replacement schemes frequently require the removal of old trees, and trees felled during extreme weather conditions are generally removed from urban landscapes also. Dead or dying trees from stress, old age, insect attack, or disease may require removal for safety reasons, and areas intended for development may necessitate tree removal on small to large scales. Tree stumps present in the landscape may also prove of use. When available, samples salvaged through these methods can provide valuable dendrochronological data without the need for felling healthy trees to obtain chronologies.

5.1.4 Accuracy of Dendrochronology

Dendrochronological procedures are considered reasonably accurate and verifiable methods of tree age determination or age estimation in cultural landscapes. Within the literature on dendrochronology, issues arise over the accuracy of tree coring compared to tree felling, and dendrochronology as an age determination method itself. A crucial observation by Schweingruber (1988) stated that:

> It is worthwhile bearing in mind that dendrochronology is an empirical rather than a mathematical discipline, even though it relies quite heavily on a number of mathematical operations. This means that, however carefully measurements are made and calculations carried out, mistakes in dating can never be completely ruled out.[18]

Moreover, Norton and Ogden (1990) identified three primary 'sources of error' within age estimation of individual trees using dendrochronology:

- The existence of 'Anomalous growth rings'
- The 'Extrapolation of tree ages from partial cores'; and
- The 'Estimation of the time it takes a tree to grow to sampling height.'[19]

5.1.4.1 Cavities in Trunk Sections

The quality of samples collected can present problems for accurate ring counting. The centre or heartwood of a tree may have decayed over time, resulting in a loss of growth ring data. Extant on old or veteran trees, Russell *et al.* (2006) noted that most trees over 500 years in age would have hollow sections inside their trunk.[20] Pigott (1989a) observed that common lime (*Tilia cordata*) trees older than 250 years tended to be hollow.[21] When encountered, the missing 'portion of the chronology' of the tree can be estimated in order to establish tree age, however, Rayner (1992) emphasised the diminished accuracy in the application of such methods.[22] Pigott (1989a) noted that 'Direct determinations by counting rings have only a limited application' for old lime trees, as few 'retain their original stem'.[23] Pigott (1989a) also noted that hollow lime tree trunks occasionally contain tree roots growing into the earth.[24]

5.1.4.2 Slow Growth Rate Associated with Age

Aside from samples collected from decayed or hollow trunks, other factors can influence the accuracy attainable using dendrochronology. Jacques (1987) noted that as trees age, their growth slows and therefore growth rings may become indistinguishable from one another, as the number of cells added in subsequent growing seasons becomes very small.[25] Molisch (1938) also observed this slow rate of growth, in particular towards the northern-most growing regions on Earth, with some growth rings being only several cells thick, and difficult to observe even with a microscope.[26]

5.1.4.3 'False' and 'Missing' Rings

Due to various contributing factors, trees may not lay down regular growth rings. Intra-annual or 'false' rings may develop through intra-seasonal changes in the environment. The subsequent optimal growing conditions initiate a second growth ring sequence within a single growing season. Norton and Ogden (1990) observed that 'extreme environmental conditions' such as cold temperatures or drought during the growing season, can 'cause the formation of diffuse bands of smaller thick-walled cells (resembling latewood) in the middle of the growth ring', with this forming the false ring [27]

Norton and Ogden (1990) also warned that the 'Failure to recognize false rings' might result in 'substantial overestimations of tree age' for both individual specimens and entire forest chronologies.[28] Conversely, suboptimal growing conditions can 'check' or reduce growth rings over one or more growing seasons, depending upon the tree species and environmental conditions, appearing as a series of 'missing' rings. Fritts (1976) noted that although trees 'may produce an annual growth layer', variations in climate may not be sufficient to actually 'limit processes affecting growth', the result being little difference between one ring and the next, and appearing as a single growth season.[29]

A description of the phenomenon known as 'ring wedging' was provided by Norton and Ogden (1990), where 'rapid radial growth' takes place over a number of years 'in certain segments of the tree's circumference', and may be either absent or very slow in other segments. Causes of such patterns include the death or development of major branches and the consequential changes in 'food and growth regulator supplies'.[30] Pigott (1989b) possibly encountered ring wedging in the common lime cross sections studied, where the highest ring counts returned from the longest trunk radius, and different ring counts were obtained from a single tree.[31] Pigott (1989b) therefore raised concern over possible variances from samples taken using increment borers from the one tree. The solution to this 'within-tree variability', proposed Ogden (1978) was to remove more than one core sample and compare the rings for obvious correlations. [32] According to Philip (1994), identifying ‘annual rings’ and subsequent diameter growth increments from cored samples obtained in the field was generally not a ‘simple’ process.[33] Ultimately, argued Norton and Ogden (1990), the examination of entire cross sections of trees appears justified, allowing ring wedging issues to be addressed.[34]

5.1.4.4 Cross-dating Growth Rings

Cross-dating is the most commonly used method to counteract growth ring anomalies, allowing accurate chronologies to be calculated, and to identify ‘missing’ or false rings within chronological sequences.[35] Through the process of collecting and analysing a quantity of cores or cross sections from a number of trees in a region, ‘signature years’ can be identified and tree chronologies calculated with higher levels of accuracy.[36] The affects of insect attack, site climate, or disturbance may occur across ‘all trees in a single area’, according to Dunwiddie and LaMarche (1980), producing synchronous ‘patterns of wide and narrow rings’ over all trees, enabling cross-dating to take place.[37] This cross-dating, according to Leal, Pereira, Grabner, and Wimmer (2004), compares the ‘identifiable characteristics of rings in two or more trees’ in order to assign dates to the growth rings, and thus determine the year of formation.[38] Fritts (1976) noted that once accurate cross-dating has taken place, the year of formation for both the innermost, and outermost rings can be determined, allowing accurate tree ages to be calculated.[39]

Ogden (1978) further noted that once the samples have been cross-dated, and the data averaged, ‘master chronologies’ can be developed.[40] Rayner (1992) also observed an increase in chronological accuracy through the identification of overlapping growth ring patterns. This enabled easier dating of the less distinguishable outer rings on the old, slow-growing trees examined.[41] Identification of the overlapping patterns in tree ring series between individual specimens from within a particular region can also assist both dendroclimatological and dendroecological studies aimed at past environmental reconstruction. Norton and Ogden (1990) observed that,

> Accurate ages in many cases can be obtained only from complete cross sections, and even then only through cross-dating ring-width sequences between trees. Annual ring counts made from cut stumps in the field, or from improperly prepared cross sections and cores are likely to be inaccurate.[42]

Continuing with this view, they maintained that without the implementation of 'cross-dating techniques', differences would be present between actual age and estimated age, and the use of cross dating would 'greatly increase the accuracy of the age estimates'.

5.1.4.5 Estimates of Ring Counts in Cultural Landscapes

Precise chronologies of tree rings from landscapes are not a critical precondition of all research incorporating tree ring counts. A study on silvertop ash (*Eucalyptus sieberi*) by Woodgate *et al.* (1994) involved the counting of visible tree rings, 'based on the assumption that tree growth was seasonal', and where old trees possessed hollow centres, estimates of missing rings were made.[43] While acknowledging the existence of both indistinct and incomplete zones of rings, Woodgate *et al.* (1994) justified that for research into forest ecology, 'absolute chronologies are not always essential' and therefore estimates of tree age were still able to 'provide useful tree age data'.[44] In their data analysis, Woodgate *et al.* (1994) noted that their estimates were likely to be underestimates for both 'mature and senescent trees', and that improvements in accuracy could be obtained with larger numbers of samples to enable cross-dating and identification of missing rings. Pearson and Searson (2002) observed that for ecological research into dendrochronology, 'measurements need only be as precise as the comparison that is planned', with dbh or 'quick ring counts' a satisfactory resolution of detail without the need to 'fully resolve' cross-dating problems.[45] In a historical-based research project by Podger, Bird, and Brown (1988) for the Hogsback Plain region in Tasmania, complete accuracy of dendrochronology was not paramount. Instead, the discovery of *Eucalyptus obliqua* tree stumps felled in 1911, and containing 'up to 410 years' of ring counts, provided important historical information on past old growth forests.[46]

5.1.5 Indigenous Australian Trees and Dendrochronology

The review of literature now turns toward the various arguments supporting, or disputing, the validity of indigenous Australian trees for dendrochronological study. The popular belief that the genus *Eucalyptus*, in particular, has limited dendrochronological value has been reported by a number of authors, and Pearson and Searson (2002) acknowledged that these early publications 'discouraged research' for much of the 20-year period between

1980 and 2000.[47] Ogden (1978) was one of the early authors to collate the available Australian dendrochronological research projects and analyse them specifically for practicality of methodologies and to establish the extent of tree growth ring formation in indigenous Australian tree species. Among the findings by Ogden (1978) were the general observations that,

> …due to lack of clearly defined annual rings, numerous intra-annual bands, short life spans and the almost total absence of preserved dead wood, the genus *Eucalyptus* may be of limited potential in dendrochronology.[48]

Adding to this, Ogden (1978) observed that within the genera *Acacia* and *Eucalyptus*, 'The most abundant' of these species 'appear to be generally unsuitable for standard dendrochronological methods aimed at climatic reconstruction', however, Ogden (1978) noted that 'there are some exceptions'.[49] With a focus upon determining the dendrochronological potential within the genus *Eucalyptus*, Brookhouse (2006) disagreed with Ogden's (1978) conclusions, stating that 'annual rings are reliably formed in some regions', for some eucalypts.[50] Pearson and Searson (2002) provided yet another perspective through their observation that 'annual ring formation appears less reliable' in Australia than on other continents, as *Eucalyptus* and *Acacia* taxa 'respond opportunistically to unpredictable rainfall, and temperature rarely constrains growth'.[51]

A review by Gill (1971) on the history of radiocarbon dating in Victoria stated that 'The rings of eucalyptus are not laid down regularly and so cannot be used for determining the age of a tree'.[52] However, research contrary to Gill's (1971) observations have since been published. A study by Mucha (1979), revealed that,

> The growth rings of many eucalypts in Australia are neither distinct nor annual. It is only in climates which provide a regular and defined growing season each year that eucalypts tend to produce clear annual rings.[53]

Mucha's (1979) observation followed from results on comparisons between known age and growth ring counts on three *Eucalyptus* species grown near Darwin, Northern Territory. Mucha (1979) found that diameter growth for the three *Eucalyptus* species, *E. tetrodonta, E. nesophilia,* and *E. miniata*, was in fact seasonal, and the resultant rings reflected tree age, however, they were 'difficult to interpret'. Mucha's (1979) research also found that trees for study need to be selected carefully, and experience in ring counting would be advantageous.

Research conducted by Akeroyd *et al.* (2002) on the dendrochronological potential of spotted gum (*Corymbia citriodora*) in south-eastern Queensland, also noted that the majority of dendrochronological research in both Australia and abroad had been conducted primarily in cold climates.[54] In these cold climates seasonal changes were most evident, producing the distinct 'early and late wood' bands that engender comprehensible dendrochronological results.[55] As Akeroyd *et al.* (2002) noted that sub-tropical eucalypts were typically perceived to have a 'lack of distinct, annual growth rings' their merit for dendrochronological study was also questioned.[56] The results reported by Akeroyd *et al.* (2002) provided evidence that spotted gum in south-eastern Queensland produced seasonal growth rings. Burrows, Ward and Robinson (1995) concurred with the widespread belief that,

> The growth rings of many Australian Eucalypts are indistinct and not always annual, but where the climate is such that trees experience a regular and defined growing season, eucalypts (and other species) tend to produce clear annual growth rings.[57]

In their research on jarrah (*Eucalyptus marginata*) forests in southwest Western Australia, Burrows *et al.* (1995) observed that due to the region's climatic conditions consisting of 'a strong Mediterranean-type climate' typified by 'warm dry summers and cool wet winters', stem growth was limited 'to a single growing season each year'.[58] Brookhouse (2006) also observed this phenomenon of tree growth, explaining that formation of tree rings was 'dependent on periodic cambial growth quiescence'.[59] Therefore, Brookhouse (2006) argued, growth rings in eucalypts rely upon 'strong seasonal variation' in either temperature or moisture levels to form the 'annual cessation in diameter growth', producing visible 'latewood' bands.[60]

Philip (1994) also observed that tree growth rings in general might not appear annually; instead, they are 'associated with seasonality in the climate and patterns of growth'.[61] Rayner (1992) noted that the use of dendrochronology to determine tree age required growth patterns that are seasonal and therefore annual. This seasonal change in girth was detected in Rayner's (1992) research on karri forests.[62] Woodgate *et al.* (1994) confirmed the importance of dendrochronological studies for determining both tree age and 'past forest disturbances', but acknowledged the fact that tree species must 'lay down recognisable seasonal tree rings' in order for this to occur.[63] Adding to this, Woodgate *et al.* (1994) observed that trees such as deciduous hardwoods and conifers 'from cold climates typically possess such rings', and these are both well defined and 'dateable'.[64]

From this, Woodgate *et al.* (1994) deduced that evergreen hardwoods such as eucalypts may well produce 'datable tree rings' in locations where both 'growing conditions and growth rhythms are seasonal'.[65]

From the literature Ogden (1978) reviewed on indigenous Australian trees, it was revealed that conifers from Tasmania provided both 'the most suitable ring characteristics', and the longevity required for detailed dendrochronological study. This presents an interesting connection to Woodgate *et al.*'s (1994) observation that both deciduous and coniferous trees from areas with colder climates produced well-defined and easily dateable rings.[66] Dunwiddie and LaMarche (1980) noted that amongst the eucalypts, those located in colder regions have a tendency to produce clear rings:

> A few high altitude species in Victoria and Tasmania (*E. coccifera, E. pauciflora, E. stellulata*) have clear, annual rings that crossdate.[67]

In the research conducted on yellow box (*Eucalyptus melliodora*) in the Australian Capital Territory region, Banks (1997) discovered 'indistinct' tree rings caused by very slow growth rate, therefore reducing the chronological accuracy of the yellow box samples obtained.[68] One yellow box specimen returned an estimated ring count age of 160 years, however, subsequent radiocarbon dating provided an age more than double this figure.[69] Banks (1997) noted that a large part of this discrepancy was due to the outer 1.5 cm of trunk containing approximately 100 growth rings, and these were not part of the original ring count of 160. Banks (1997) did however point out that for tree species, including eucalypts, where growth rates were 'moderately fast', estimations of age from ring growth counts would be possible.[70]

The genus *Callitris* has also been reviewed for its dendrochronological potential on the Australian mainland. Research by Lange (1965) discovered discernable ring growth in *Callitris columellaris* near Woomera, South Australia, with the samples providing an estimation of tree age. The ring growth of the species displayed a distinct correlation with past rainfall records, with 'about one ring per year' produced, however, there was evidence of both intra-annual and missing rings for various years.[71] Authors such as Dunwiddie and LaMarche (1980) noted the 'promising' potential of the genus *Callitris* on the Australian mainland, and Pearson and Searson (2002) reported on the 'proven' capability of the genus for dendrochronological study.[72]

Research conducted by Leal *et al.* (2004) on the comparison between actual age and tree growth rings of *Eucalyptus globulus* in Portugal found that 'annual rings are not well defined', with earlywood and latewood bands visible from the cross sections possessing 'poor correspondence with the growing seasons'.[73] They also noted that dendrochronological data on eucalypts was 'rare', and was almost exclusively restricted to Australia.[74] Leal *et al.* (2004) stated that the,

> Formation of tree-rings is governed by genetic components as well as by environmental conditions prevalent during tree growth.[75]

Schweingruber, Kairiukstis and Shiyatov (1990) observed that a tree or shrub could be used for dendrochronological study if:

- It produces distinguishable rings for most years
- It possesses ring features that can be cross-dated dendrochronologically
- It attains sufficient age to provide the time control required for a particular investigation[76]

In their research on the suitability of river red gum (*Eucalyptus camaldulensis*) for dendroecological study in the Barmah Forest region of northern Victoria, Argent, McMahon, Bowler, and Finlayson (2004) found that due to unclear ring boundaries in the species, 'good sample preparation is very important'.[77] By polishing the samples to a fine level, they discovered that typically obscured ring characteristics became visible for the species. Their research indicated,

> …that *E. camaldulensis* can exhibit both a response and a sensitivity to climate influences. However, the ring patterns have a high variability from tree to tree, and unclear ring boundaries and obscure ring characteristics are common.[78]

Within this region of the Murray River floodplains, they discovered that the growth patterns of river red gums are 'strongly linked to available moisture' and the species is 'able to respond rapidly to periods of flooding or extensive rainfall events'.[79] From their findings, Argent *et al.* (2004) reflected that,

> The initial step in examining these types of species is to accept that whereas *ring chronology* building may be difficult or impossible, much is possible in the areas of ring matching and average pattern construction.[80]

Their findings provided argument towards the re-examination 'of previously rejected species', and added that through the incorporation of radiocarbon-based studies, dating accuracy would be increased.[81]

Brookhouse (2006) observed that the 'high degree of variability in intra-seasonal rainfall and low variation in inter-seasonal temperature' excluded a large number of Australia's eucalypt forests from accurate dendrochronological research.[82] From the literature reviewed, Brookhouse (2006) discovered that within Australia 'only the temperate south-east, monsoonal tropical north, humid central-east and the Mediterranean south-west appear suited to eucalypt dendrochronology'.[83] Adding to this, Brookhouse (2006) observed that due to land clearing for urban development and agriculture following European settlement, many areas suitable to eucalypt forest dendrochronology are no longer available for study within the 'suitable climate zones'.[84] As a direct result, dendrochronological research on eucalypts has been 'limited'.[85] From gaps in the available research, Brookhouse (2006) recommended that further studies in 'non-width-based tree-ring properties' of various eucalypt species across a range of sites be undertaken, to overcome confusion in the interpretation of results from different methodologies used.[86]

Although it is apparent from the research projects that dendrochronological studies can be conducted on a number of indigenous Australian tree species in a variety of climates, both Ogden (1978) and Brookhouse (2006) agree that research in this particular field 'is still in its infancy'.[87] Pearson and Searson (2002) also observed this, stating this was particularly obvious when compared to research on dendrochronology conducted in Europe, Russia, and North America.[88] Ogden (1978) noted that 'Only a tiny proportion of Australia's varied tree flora has been investigated dendrochronologically' and Brookhouse (2006) suggested that this might be partly due to the preconceived notion that eucalypts possess 'limited dendrochronological potential'.[89] Dunwiddie and LaMarche (1980) observed that 'Much work remains to be done in establishing dated chronologies in mainland Australia'.[90]

5.1.6 Suitability of the Adelaide Plains for Dendrochronological Study

The previous review of existing literature established that the occurrence of growth rings depends both upon genetic elements of the tree, and the climate within which it is growing. From the literature, Brookhouse (2006) revealed that no projects involving dendrochronological research on eucalypts have been conducted in South Australia. Lange (1965) identified *Callitris columellaris* specimens found growing in arid regions of South Australia as having dendrochronological potential. Aside from these examples, there appears to be a distinct lack of dendrochronological research undertaken in South Australia, and in particular from the Adelaide Plains region. The climate of Adelaide appears to have dendrochronological potential. The Köeppen classification system places Adelaide in a 'temperate' climate zone, specifically with a 'distinctly dry (and warm) summer'.[91] The Australian Government Bureau of Meteorology describes Adelaide as having a 'warm summer' with 'low summer rainfall', and a 'cold' and 'wet winter'.[92] Brookhouse (2006) described Adelaide as having a 'mild to warm summer, cold winter', and a 'uniform/winter dominated precipitation', which, according to Brookhouse (2006), are the required conditions for seasonal formation of growth rings.[93] Brookhouse (2006) therefore deduced that Adelaide falls within the category suitable for the dendrochronological study of eucalypts.[94] Due to a lack of published literature on other genera, the suitability of Adelaide for chronological study of tree rings remains unconfirmed.

5.1.7 Summary of Dendrochronology

The suitability of many indigenous Australian tree species from diverse climates within Australia has caused degrees of uncertainty and debate amongst researchers in the field of dendrochronology. Debates have arisen over not only issues of accuracy, but also the potential of dendrochronological study in Australia. New research creating high accuracy dendrochronological data sequences in Australia would be useful for reconstructing forest and landscape histories in areas not previously examined. While methods of dendrochronology have achieved highly refined levels, actual data collected for the reconstruction of long-term chronologies in Australia, such as those in existence in Europe, presently remain limited to regions of Tasmania.

From the literature on dendrochronological methods used, dendrochronologists have established whole cross-section sampling to be of higher accuracy than tree coring. Whole disk collection, however, is inherently more damaging to living trees. Therefore, the clear solution to obtaining a growth ring count with the highest level of accuracy from a living tree would be to fell the specimen, remove a cross-sectional disk, and count the rings in laboratory conditions. The reality, however, is not so simple. Unless salvaged from dead, dying, or unwanted trees in the landscape, this method of obtaining ring counts must be considered extremely injurious or fatal to the tree. Unless whole-tree removal is warranted, tree coring must be considered the preferred method of invasive tree age determination when dendrochronological study is undertaken on living trees.

Regardless of the number of cores removed, or the belief that tree coring is 'non-destructive', the process is invasive to the fabric of the tree. Although the tree itself is not felled during the coring process, the procedure has the potential to expose the structure of the tree to pathogen attack. Introduction of fungus spores on the borer tool, or prior to sealing the cored hole places the tree at risk of wood decay, inducing structural failure and possibly resulting in tree death.

5.2 Radiocarbon Dating

Radiocarbon dating of trees is incorporated into this section on invasive age determination methods, as it requires the removal of tissue from the tree to establish a germination date or to calibrate growth ring counts. In order to determine tree age using this method, wood from the core of the tree must be extracted for testing to determine the oldest part of the specimen.

5.2.1 Process of Radiocarbon Dating

Radiocarbon dating of trees involves the removal of tree tissue for analysis in a laboratory. The theory of cosmic radiation producing unstable radioactive carbon (^{14}C) isotopes, 'which was assimilated by plants in the process of photosynthesis and incorporated in organic compounds' was proved by Willard Frank Libby during the 1940s.[95] Akeroyd *et al.* (2002) noted that these 'isotopes are incorporated into wood cellulose in the same ratio as they occur in the atmosphere', and would 'in theory' allow ages to be assigned to trees that may not produce 'distinct annual rings'.[96] As explained by Akeroyd *et al.* (2002):

> If the wood is more than 200 y old, its age can be determined by measuring the decay of ^{14}C assuming a constant or near-constant concentration of ^{14}C in atmospheric CO_2. Samples are taken from the tree and dated through the analysis of ^{14}C levels in the cellulose.[97]

This is considered the conventional method of radiocarbon dating. Gill (1971) described this process of calculating the age of organic compounds using a radiocarbon dating machine:

> When a radiocarbon atom changes back to nitrogen it emits an electron, and a radiocarbon dating machine counts the flow of these electrons. The number per minute per gram of carbon allows the age to be calculated.[98]

The method of sampling to obtain heartwood for radiocarbon dating is injurious to the tree. Samples are either removed using an increment borer, or through felling the tree.

5.2.2 Accuracy of Radiocarbon Dating

The accuracy of dating trees using radiocarbon dating has been debated since Libby proved the theory during the mid-20th century. Trees established after the beginning of the Industrial Revolution appear to return inaccurate dates, due primarily to the burning of fossil fuels.[99] Schweingruber (1988) described the post-Industrial Revolution changes:

> By burning organic material, millions of years old, radio inactive carbon is released into the atmosphere which then mixes with active carbon already present, so that the ^{14}C level sinks.[100]

Schweingruber (1988) reported that Libby 'calculated the half-life of ^{14}C to be 5568 years', and therefore human-influenced changes to the ^{14}C levels affect the accuracy of tree establishment dates following the Industrial Revolution.[101] Pearson and Searson (2002) concurred with the consensus of radiocarbon dating providing 'very poor resolution for the last 300 years', due to the release of fossil carbon during the Industrial Revolution.[102] They added that although 'radiocarbon dating has helped build chronologies' for trees, it 'generally does not have the precision to cross-date annual rings in samples'.[103]

Another human-induced anomaly reported from samples tested was the very large increase of ^{14}C levels during the period of hydrogen bomb testing between the mid 1950s and early 1960s. Pearson and Searson (2002), among others, described this as a 'bomb pulse', with 'a steady decline after the 1963 test bans'.[104] Akeroyd *et al.* (2002) used this 'spike' in ^{14}C levels to 'successfully' age their spotted gum (*Corymbia maculata*) specimen in south-eastern Queensland, and to determine that growth rings formed concurrently with age for the specimen.[105] They added that:

> The ^{14}C dating technique could potentially be used to date the age structure of entire mixed-aged forests in south-eastern Queensland. This information would improve our understanding of forest processes and growth over time, and undoubtedly contribute to more efficient measures of forest growth.[106]

For trees established before the industrial revolution, radiocarbon dating appears to provide some degree of accuracy. A specimen of yellow box (*Eucalyptus melliodora*) radiocarbon dated by Banks to be '354+/-30 years' appeared to represent good accuracy, and 'was double the estimated ring count age' of 160 years, as previously discussed.[107] Akeroyd *et al.* (2002) noted the standard deviation for trees aged between 'a few hundred to several thousand years old' using radiocarbon dating procedures was between <1 and 25 per cent.[108] Research conducted by McPhail, Barbetti, Francey, Bird, and Dolezal (1983) on Huon pine (*Lagarostrobos franklinii*) and celery-top pine (*Phyllocladus aspeniifolius*) displayed their potential for ^{14}C dating in Tasmania. Data from stumps collected from trees felled prior to 1945 and from preserved logs found, provided chronologies that could be dated back to 7100 years BP ('Before Present' date of 1983) for Huon pine and back to 12000 BP for celery-top pines.[109] Lange, Barbetti and Donahue (2002) noted that due to the ability of Huon pine to exceed 2,000 years in age, combined with decay-resistant oils present in its wood, they are a most suitable species for 'calendar age calibration' enabling ^{14}C ages to be related to calendar ages.[110] McPhail *et al.* (1983) also observed:

> The presence of well-defined annual rings in both Huon and celery-top pines and coupling between variations in xylem growth and microclimate permit cross-dating and construction of long chronologies of ring-width series anchored in the present. Since their annual rings may be chemically treated so that only material assimilated in the year of growth remains, they can provide a long, accurate record of atmospheric variations in ^{14}C for the southern hemisphere.[111]

Research by Barbetti, Bird, Dolezal, Taylor, Francey, Cook, and Peterson in (1992) established the existence of Huon pine growth ring chronologies extending back to 273 BC, this being concordant with the observation by McPhail *et al.* (1983) that growth rings are reliably produced on the species.[112] Later, radiocarbon dating of Huon pine logs by Barbetti, Hua, Zoppi, Fink, Zhao and Thomson (2004) salvaged from floodplains dating to the Holocene period were able to be compared to ^{14}C levels obtained from the well-established Holocene oak chronologies of Germany.[113]

Aside from the ability to calibrate accurate radiocarbon dates from samples, Pilcher (1990) noted that samples for radiocarbon dating may not be available due to ‘missing rings’ or decayed heartwood, potentially hindering accurate age determination.[114]

5.3 Miscellaneous Methods of Invasive Tree Age Determination

Other methods exist that require invasive techniques to determine tree age. Studies of tree rings through fluorescence, scanning electron microscopy, and X-ray densiometry (radiodensiometry) require the removal of samples from the tree for study in specialised laboratory environments.[115] Used to determine both the existence of tree rings and climate from tree rings, these methods are primarily intra-ring based. Schweingruber (1990) observed that radiodensiometry traces ‘density variations within annual rings’, primarily for studies in climatic reconstruction.[116] Schweingruber (1990) also noted the unsuitable nature of hardwoods for densimetric study, as the uneven ‘distributions of pores (vessels) and rays distort the general density pattern of the wood’.[117]

Dendrometers and dendrographs are used to measure changes in tree stem growth over specific periods of time. The level of detail captured by these instruments can vary from ‘gross stem size’ measured seasonally, through to graphed recordings of daily changes to provide ‘information about chronological growth rhythm’.[118] These devices are generally mounted onto the tree stem, secured into the wood. Dendrometers and dendrographs provide data on tree growth over the period tested, and cannot be used to determine accurate past tree growth or tree age due to fluctuations between ring growth periods over the life of the tree.

5.4 Damage from Invasive Techniques

The processes involved in obtaining internal samples of tree tissue are inherently injurious to the trees studied. Obtaining whole disks of cross-sections are obviously far more injurious than samples taken using increment borers, the latter potentially causing latent damage to the internal structure of the tree. Pearson and Searson (2002) stated that,

> Tree rings cut to show the transverse section of the trunk are often the preferred source of tree-ring data because they allow the tracing of incomplete rings and the identification of fire scars around the full circumference.[119]

They also acknowledged the destructive nature of the procedure, and added that disks can be awkward to work with and prepare for examination. Interestingly, Pearson and Searson (2002) observed that disks tend to be collected from the landscape when tree stumps are the focus of an investigation.

Woodgate *et al.* (1994) noted that core samples removed from a tree are generally smaller than one centimetre in diameter, and following core extraction 'the tree is preserved'.[120] Harris (1992) also observes the utility of increment borers, noting that they are 'useful for measuring tree growth over a period of years', however Harris (1992) also cautioned that such samples should only be taken 'when necessary' as the method 'is time-consuming and injures the trunk'.[121] Woodgate *et al.* (1994) also noted that both tree coring and cross-section removal for analysis 'are slow and time consuming' procedures, and allow 'only a very small number of samples to be taken'.[122] For their investigation into tree growth rates of Australian forests over time, Booth, Serra and Wells (1988) required data on past growth rates to test their models and stated that: 'Core sampling and ring measurement are the only practical, non-destructive ways of gathering such data relatively quickly.'[123] With their particular focus upon climate and rainfall over a 44-year period, Booth *et al.* (1988) found easy justification for the tree coring technique.

Jacques (1987) maintained that the removal of tree cores was a sensible solution to counting growth rings without the need to fell the tree, however, the largest commercially available coring instruments in Britain could only extract cores 40 cm in length.[124] Trees larger than 80 cm in diameter therefore could not be sampled using this method, and according to Jacques (1987), trees in Britain obtained these dimensions 'in under a century'.[125] Importantly, White (1998) noted that veteran 'trees of historical or conservation significance' in the landscape 'cannot be cut down or weakened in any way by boring holes in them to count annual rings'. Lukaszkiewicz *et al.* (2005) concurred, stating that tree coring is invasive and damages the trunk, and added that age determination using 'invasive methods are time consuming and expensive'.[126]

The risks to the trees involved in core sampling has been observed by Schweingruber (1988), Schweingruber *et al.* (1990), and Fritts (1976). Mechanical damage can result from the corer itself, through physiological reactions by the tree, or pathologically through the introduction of foreign organisms.[127] Schweingruber *et al.* (1990) noted 'coring injures the tree', and no matter how careful the work, a bore hole is created.[128] They added that trees tend to seal the wound 'within a few years', observing that treatment for coniferous trees 'is seldom necessary'.[129] Conversely, broadleaf trees tend to 'react physiologically', resulting in 'radial disk-shaped discolorations in the wood surrounding the bore hole', often followed by fungal infection.[130] Plugging the hole with wax may reduce opportunities for pathogen entry; however, Schweingruber *et al.* (1990) noted that the 'opinions on the effectiveness' of such remedial treatments vary.[131] Fritts (1976) also advised on sealing the cored hole, but added the possible use of disinfectant, or simply avoiding coring during periods of high fungal activity to minimise internal tree damage.[132] More recently, Moore (2008) noted that 'placing a dowel back in the core hole' can reduce the risk of infection, particularly if the dowel is soaked in an anti-fungicide solution.[133]

5.5 Summary

Dendrochronology requires an investigation across the growth rings of a tree in order to develop its chronology of growth. Samples can be obtained using an increment corer, or by felling the tree and removing a cross-sectional disk. The accuracy of dendrochronology in establishing tree age depends on the ability of the investigator to recreate the complete chronology of the tree over time. Problems with growth ring clarity such as 'false' or 'missing' rings, extremely slow growth rates, or decayed sections of the trunk can all affect accurate chronological reconstructions aimed at establishing the date of germination. Cross-sectional disks are considered to provide higher accuracy in chronological reconstruction, and therefore tree age determination, than samples obtained from tree cores. Cross-dating growth rings with those of known dates increases the accuracy of formation dates when rings are clearly discernable. Estimating tree ages from either full or partial chronologies of growth rings also provides useful data for cultural landscape interpretation.

Many indigenous Australian tree species were believed to be of minimal dendrochronological use due to indistinct growth rings, and the opportunistic nature of growth in many species. Many were found to produce growth rings during periods of optimal growth conditions, often irrespective of seasonal climatic variations. From the research conducted in Australia, development of growth rings within the genera *Eucalyptus* and *Acacia* appears to vary according to both the species, and the climate. There is also a distinct lack of dendrochronological data for Australia. For this reason, new dendrochronological study must be undertaken for each tree species in each climatic region if dendrochronological data is required. From the climatological data gathered, the Adelaide Plains appears a suitable region for future dendrochronological study.

Radiocarbon dating can also be used to determine tree age, although issues arise over its accuracy. All radiocarbon dates obtained possess levels of confidence, these varying due to the accuracy of the test data collected, and the particular sample used. Trees established prior to the Industrial Revolution are suitable for radiocarbon dating, as are those established during the 'bomb pulse' period of hydrogen bomb testing, between 1955 and 1963. Trees outside these dates return radiocarbon ages with higher levels of inaccuracy. Trees with missing heartwood due to decay may also provide inaccuracies in radiocarbon dates obtained.

Radiodensiometry, fluorescence, and scanning electron microscopy also require samples to be extracted for testing. Most of the data obtained through these processes is intra-ring based, in large scales, and high in detail. Within tree ring studies and tree aging, they are primarily used for climatic reconstructions. Dendrometers and dendrographs measure changes in radial trunk growth over specific periods of time. Their use in tree aging is mostly restricted to determining recent tree growth trends and patterns.

In dendrochronological study, cross-sectional disks provide the opportunity to observe past anomalies in growth ring patterns over whole tree circumferences. In radiocarbon dating, whole disks ensure heartwood tissue is collected for analysis. The collection of cross-sectional disks must be considered extremely injurious to a living tree, and its subsequent death a very likely scenario. Tree cores extracted from living specimens may not necessarily cause tree death, however, the tree's structural wood may be exposed to pathogen attack, and internal decay can result.

Chapter 5 Notes

---

[1] Pearson and Searson (2002) p. 431.
[2] Molisch (1938) p. 39.
[3] Woodgate *et al.* (1994) p. 56.
[4] Woodgate *et al.* (1994) p. 56.
[5] Pearson and Searson (2002) p. 432.
[6] Woodgate *et al.* (1994) p. 56.
[7] Ogden (1978) p. 340.
[8] Ogden (1978) p. 340.
[9] Akeroyd *et al.* (2002) p, 266.
[10] Akeroyd *et al.* (2002) p, 266; See Chapter 4.2.1.2, White (1998) p. 2.
[11] Mitchell (1974) p. 25.
[12] Rayner (1992) p. 1.
[13] Rayner (1992) p. 14.
[14] Worbes *et al.* (2003) p. 106.
[15] Couch (1992) p. 45.
[16] Dunwiddie and LaMarche (1980) p. 125.
[17] Woodgate *et al.* (1994) p. 56; Pigott (1989b) p. 293.
[18] Schweingruber (1988) p. 77.
[19] Norton and Ogden (1990) p. 284.
[20] Russell *et al.* (2006) p. 18.
[21] Pigott (1989a) p. 117.
[22] Rayner (1992) p. 7.
[23] Pigott (1989a) p. 120.
[24] Pigott (1989a) pp. 117-118.
[25] Jacques (1987) p. 193.
[26] Molisch (1938) p. 39.
[27] Norton and Ogden (1990) p. 284.
[28] Norton and Ogden (1990) p. 284.
[29] Fritts (1976) p. 13.
[30] Norton and Ogden (1990) p. 284.
[31] Pigott (1989b) p. 293.
[32] Ogden (1978) p. 341.
[33] Philip (1994) p. 94.
[34] Norton and Ogden (1990) p. 284.
[35] Ogden (1978) p. 341.
[36] Ogden (1978) p. 341.
[37] Dunwiddie and LaMarche (1980) p. 125.
[38] Leal *et al.* (2004) p. 140.
[39] Fritts (1976) p. 2.
[40] Ogden (1978) p. 341.
[41] Rayner (1992) p. 7.
[42] Norton and Ogden (1990) p. 285.
[43] Woodgate *et al.* (1994) p. 58.
[44] Woodgate *et al.* (1994) p. 204.
[45] Pearson and Searson (2002) p. 431.
[46] Podger *et al.* (1988) p. 129.
[47] Gill (1971) p. 79; Ogden (1978) p. 345; Pearson and Searson (2002) p. 435.
[48] Ogden (1978) p. 345.
[49] Ogden (1978) p. 339.
[50] Brookhouse (2006) p. 443.
[51] Pearson and Searson (2002) p. 432.
[52] Gill (1971) p. 79.
[53] Mucha (1979) p. 13.
[54] Akeroyd *et al.* (2002) p. 265.
[55] Akeroyd *et al.* (2002) p. 265.
[56] Akeroyd *et al.* (2002) p. 265.

[57] Burrows *et al.* (1995) p. 7.
[58] Burrows *et al.* (1995) p. 7.
[59] Brookhouse (2006) p. 438.
[60] Brookhouse (2006) p. 438.
[61] Philip (1994) p. 99.
[62] Rayner (1992) p. 2.
[63] Woodgate *et al.* (1994) p. 204.
[64] Woodgate *et al.* (1994) p. 204.
[65] Woodgate *et al.* (1994) p. 204.
[66] Woodgate *et al.* (1994) p. 204.
[67] Dunwiddie and LaMarche (1980) p. 134.
[68] Banks (1997) p. 46.
[69] Banks (1997) p. 38.
[70] Banks (1997) p. 46.
[71] Lange (1965) p. 133.
[72] Dunwiddie and LaMarche (1980) p. 134; Pearson and Searson (2002) p. 436.
[73] Leal *et al.* (2004) p. 140.
[74] Leal *et al.* (2004) p. 140.
[75] Leal *et al.* (2004) p. 140.
[76] Schweingruber *et al.* (1990) p. 26.
[77] Argent *et al.* (2004) p. 93.
[78] Argent *et al.* (2004) p. 101.
[79] Argent *et al.* (2004) p. 99.
[80] Argent *et al.* (2004) p. 101.
[81] Argent *et al.* (2004) p. 101.
[82] Brookhouse (2006) p. 442.
[83] Brookhouse (2006) p. 442.
[84] Brookhouse (2006) p. 442.
[85] Brookhouse (2006) p. 442.
[86] Brookhouse (2006) p. 435.
[87] Ogden (1978) p. 339, Brookhouse (2006) p. 443.
[88] Pearson and Searson (2002) p. 435.
[89] Ogden (1978) pp. 342-343; Brookhouse (2006) p. 443.
[90] Dunwiddie and LaMarche (1980) p. 134.
[91] Bureau of Meteorology (2007c) <http://bom.gov.au/climate/environ/other/kpn_all.shtml> accessed 20/06/07.
[92] Bureau of Meteorology (2007a) <http://bom.gov.au/cgi-bin/climate/cgi_bin_scripts/clim_classification.cgi> accessed 20/06/07.
[93] Brookhouse (2006) p. 439.
[94] Brookhouse (2006) p. 439.
[95] Schweingruber (1988) p. 248.
[96] Akeroyd *et al.* (2002) p. 265.
[97] Akeroyd *et al.* (2002) p. 265.
[98] Gill (1971) p. 71.
[99] Schweingruber (1988) p. 250; Gill (1971) p. 71.
[100] Schweingruber (1988) p. 250.
[101] Schweingruber (1988) p. 248.
[102] Pearson and Searson (2002) p. 432.
[103] Pearson and Searson (2002) p. 432.
[104] Pearson and Searson (2002) p. 432.
[105] Akeroyd *et al.* (2002) p. 267.
[106] Akeroyd *et al.* (2002) p. 267.
[107] Banks (1997) p. 38.
[108] Akeroyd *et al.* (2002) p. 265.
[109] McPhail *et al.* (1983) p. 797.
[110] Lange *et al.* (2002) p. 449.
[111] McPhail *et al.* (1983) p. 797.
[112] Barbetti *et al.* (1992) p. 806; McPhail *et al.* (1983) p. 797.
[113] Barbetti *et al.* (2004) p. 806.

[114] Pilcher (1990) p. 94.
[115] Pearson and Searson (2002) p. 433.
[116] Schweingruber (1990) p. 55.
[117] Schweingruber (1990) p. 61.
[118] Fritts (1976) p. 75; Schweingruber (1988) p. 237.
[119] Pearson and Searson (2002) p. 434.
[120] Woodgate *et al.* (1994) p. 56.
[121] Harris (1992) pp. 525-526.
[122] Woodgate *et al.* (1994) p. 56.
[123] Booth *et al.* (1988) pp. 162-163.
[124] Jacques (1987) p. 194.
[125] Jacques (1987) p. 194.
[126] Lukaszkiewicz *et al.* (2005) p. 280.
[127] Schweingruber (1988) p. 44.
[128] Schweingruber *et al.* (1990) p. 28.
[129] Schweingruber *et al.* (1990) p. 28.
[130] Schweingruber *et al.* (1990) p. 28.
[131] Schweingruber *et al.* (1990) p. 28.
[132] Fritts (1976) pp. 29-30.
[133] Moore (2008) p. 3.

Chapter Six: Vegetation Changes in the Adelaide Park Lands

The significance of the Park Lands to the City of Adelaide is inherent in both its design origins and subsequent cultural history. A review of extant records detailing planting dates will establish the quantity of data available for determining tree age in the Adelaide Park Lands, and in particular, planting records for Tuttangga/Park 17 (Park 17) within those Park Lands. Additional benefits from this review of historical data reflect planting preferences and changes to those preferences over time.

6.1 Pre-European Vegetation of the Adelaide Park Lands

Prior to the arrival of European colonists to the Adelaide plains region, the area was inhabited by indigenous people who most commonly referred to themselves collectively as the Kaurna.[1] Their methods of controlled burning of indigenous flora would have influenced the floristic content of the plants inhabiting the Plains, and the appearance of the landscape upon the arrival of the early European settlers.[2] Kraehenbuehl (1996) perceived that these practices,

> …over many centuries would inevitably have had an impact upon the ground storey plant species, even perhaps converting some woodland areas and forest to tall shrubland and grassland.[3]

Regular controlled burning of the flora and landscape would certainly have influenced the appearance of the land. Complex ecosystems containing areas of open forest, woodlands, shrublands and heaths, grasslands and sedgelands would have been predominant over the Adelaide plains region, with these ecosystems containing many species of indigenous flora. The region now termed the Adelaide Park Lands, according to Kraehenbuehl (1996), would have been dominated by areas of South Australian Blue Gum (*Eucalyptus leucoxylon* subsp. *leucoxylon*), River Red Gum (*E. camaldulensis* var. *camaldulensis*), Grey Box (*E. microcarpa*), and Mallee Box (*E. porosa*) woodlands, along with their vegetation associations. The boundaries of these 'pre-European vegetation communities' were further refined by Long (2003) in *A Biodiversity Survey of the Adelaide Park Lands*.[4] Kraehenbuehl's (1996) research reconstructed extensive pre-European plant association species lists, providing the basis for Long's (2003) clarifications.

According to Long (2003), the River Torrens area would have contained predominately River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*) woodland near the river itself, possibly mixed with South Australian Blue Gums (*E. leucoxylon* subsp. *leucoxylon*) along the alluvial flats. Other tree species such as Silky Tea Tree (*Leptospermum lanigerum*) and River Bottlebrush (*Callistemon sieberi*) may have been present closer to the river, with Drooping Sheoak (*Allocasuarina verticillata*), Golden Wattle (*Acacia pycnantha*), and Southern Cypress Pine (*Callitris gracilis*) scattered along the alluvial flats.[5]

Mallee Box woodlands would have dominated much of the northern and western Park Lands. Upper storey plants associated with this Mallee woodland would have included Drooping Sheoak (*Allocasuarina verticillata*), Golden Wattle (*Acacia pycnantha*), Black Cypress Pine (*Callitris preissii*), Beaked Red Mallee (*Eucalyptus socialis*), Wreath Wattle (*Acacia acinacea*), Umbrella Bush (*A. ligulata*), Willow Wattle (*A. salicina*), Native Apricot (*Pittosporum angustifolium*) and Quandong (*Santalum acuminatum*), among others.[6]

Much of the southern Park Lands would have been covered with Grey Box-South Australian Blue Gum mixed forest, and was termed the “Black Forest” by early settlers. Associated trees and large shrubs included Drooping Sheoak (*Allocasuarina verticillata*), Golden Wattle (*Acacia pycnantha*), Wreath Wattle (*Acacia acinacea*), Kangaroo Thorn (*Acacia paradoxa*), Sweet Bursaria (*Bursaria spinosa* subsp. *spinosa*), and Yacca (*Xanthorrhoea semiplana* subsp. *semiplana*).[7]

The eastern areas of the Adelaide Park Lands would have contained predominately South Australian Blue Gum-River Red Gum mixed forest. Larger shrubs and trees associated with this forest type included Drooping Sheoak (*Allocasuarina verticillata*), Golden Wattle (*Acacia pycnantha*), and Native Cherry (*Exocarpos cupressiformis*).[8]

6.2 Origins of the Adelaide Park Lands Design

The formation of the South Australian Association in 1834 saw the beginning of plans to create the city of Adelaide. Langmead (1994) observed that:

> Their purpose was "to found a colony, under Royal Charter, and without convict labour, at or near Spencer's Gulph, [*sic*] on the South Coast of Australia, a tract of country far removed from the existing penal settlements." [9]

The concept behind the settlement of a colony in South Australia was that of 'concentration'. A single town was to be surveyed and the land divided into lots for sale to voluntary, free settlers. The lands surrounding the town would be progressively surveyed and sold as the town grew, enabling the expansion of the city from the centre outwards. In this manner, efforts establishing the town could be concentrated, optimising the time and labour of the settlers. The money raised from the land sold would fund the passage of new settlers in a 'Land and Emigration Fund'.[10] The South Australian Commission was formed in early 1835, and the process of appointing various colonial positions began. The employment of a number of surveyors and engineers was required, with Colonel William Light appointed Surveyor General, and George Kingston appointed Deputy Surveyor.

By September 1836, two ships, *Rapid* and *Cygnet* had arrived at the shores of South Australia and the surveyors aboard both spent the next three months examining Spencer Gulf for an opportune location to establish the colony's capital. Settling upon Holdfast Bay, expeditions into the landscape began to locate a suitable site for a town. By the end of December 1836, HMS *Buffalo* arrived with Governor John Hindmarsh, and on the 28th of December, the Governor conducted the ceremony for the proclamation of South Australia.

The belief that Colonel Light discovered and subsequently surveyed the site for the city of Adelaide is popular among historians; however, Langmead (1994) proposed that his Deputy, Kingston, actually undertook the majority of this work. Regardless of this historical disagreement, the actual survey of the city began in early January 1837. Pegged out over the next months and years, the plan for the town took shape.

The reasons behind Colonel Light's design of a city within a parkland setting do not survive as historical records, and can only be surmised. Daly (1987) observed the potential influence within his design of Classical Mediterranean cities, Roman military camp plans studied during his military years or perhaps popular parks such as the Tuileries in Paris, St. James Park, Hyde Park, or Kensington Gardens in London within his design.[11] Light may have been influenced through his military career to create a tract of land between the colonial settlers and any possible attacks from Aboriginal people in the surrounding land.

The most likely influence on Light's design, proposed Daly (1987), was the establishment of a 'new town' with regular streets, squares, and parks planned for the inhabitants.[12] Daly (1987) also noted that Light's plan closely resembled the recommendations of Maslen's (1830) text on town planning:

> All the entrances to every town should be through a park that is to say, a belt of park about a mile or two in diameter should surround entirely every town, save and exception such sides as are washed by a river or lake. This would greatly contribute to the health of the inhabitants in more ways than one, as well as pleasure … it would render the surrounding prospects beautiful, and give a magnificent appearance to the town from whatever quarter viewed.[13]

During the Industrial Revolution, the benefit of open or green spaces within cities would have been obvious. As noted by Daly (1987) during this period, 'there was a growing awareness of the health values from parks and gardens as the "lungs of the city".[14] The earliest plans of the city of Adelaide, published by Colonel Light, displayed a number of government and community buildings and facilities planned for construction within the Park Lands, known as 'Reserves'. During the ensuing period of development, a number of these institutions were built, including a Parliamentary building, hospital, school, and cemetery. Of these, the cemetery and Parliament House remain; however, a new school, hospital, university, zoological gardens, and railway station were added to the Park Lands, amongst other buildings. The comprehensive research text by Daly (1987) chronicled the many buildings and structures, both past and present that resulted in large areas being alienated from Adelaide Park Land public open space.[15]

6.3 Early Colonial Changes to Park Lands Vegetation

Following the arrival of European settlers on the Adelaide plains, further changes were effectively made to the vegetation patterns in the landscape. The early colonists, Ellis (1976) noted, would have been concerned over the Kaurna practice of deliberately lit fires consuming the landscape during the dry summer months. Animals overcome by smoke from these fires provided food for the Kaurna tribespeople, as did the animals encouraged to forage on the fresh new plant growth.[16] Ellis (1976) added that the descriptions of 'open grasslands' provided by the early colonists to the Adelaide Plains 'were a direct product of such "fire-stick farming"'.[17] The earliest European settlers would have pitched tents of sorts while they cleared various parcels of land in preparation for building construction.

Shrubs and grasslands would have been slashed, and many trees felled to provide timber for both construction and firewood. Materials such as timber, kindling, or thatch gathered from the landscape would have proved useful for these purposes.

6.4 Tree Planting in the Adelaide Park Lands

An early Council was formed for the City of Adelaide, however, following the Council's collapse in 1843, strict control over the use of the Park Lands collapsed with it. Whitelock (2000) described the Park Lands surrounding the city as being 'stripped of trees, heaped with rubbish and offal, and were scarred by clay and lime pits and squatters' shacks' immediately following this period.[18] With the reformation of a new Council in 1849, the Park Lands came under the supervision and care of The Corporation of the City of Adelaide.[19] The ultimate damage caused by the destruction of large tracts of indigenous vegetation and the removal of trees for timber in the Adelaide Park Lands since European colonisation was provided by Kraehenbuehl's (1996) contemporary observation:

> Indeed, this destruction was so complete that hardly any vestiges of the native plants remain today in the parklands surrounding the city, and not one single example of Grey box trees (*Eucalyptus microcarpa*) remains within the city mile.[20]

Uncontrolled grazing of the Park Lands surrounding the city also instigated change to their floristic composition. The combination of introduced fodder plant species and the pasturing practices of Europe initiated in the new ecosystem encouraged the demise of many indigenous understorey plant species. Riddle (1992) noted that the grazing on indigenous grasses occurred at 'inopportune periods', effectively halting plant regeneration, and creating tracts of 'bare land'.[21]

The reformation of the Council greatly kerbed uncontrolled grazing, tree removal, and land damage in the Park Lands. A Park Lands Ranger was appointed and effectively instigated the construction and maintenance of fences and the control of livestock on the areas of Park Lands leased out. The first gardener for the city's gardens, squares, and Park Lands was appointed in 1854 and placed under the supervision of the City Surveyor, where this position remained until 1900. Although the first jobs undertaken by the gardener were the improvement of the city squares through planting, by 1857 various trees were being selected and planted predominately along city streets, and some perimeters of the Park Lands. The Mayor's Report in late 1857 recorded:

> The very great improvements which [have] taken place in consequence of fencing and planting portions of the Park Lands [have,] I apprehend[,] given general satisfaction, and I would certainly advise a continuance of the same during the ensuing year, by which these lands will become what they were originally intended for; pleasure grounds for the citizens.[22]

The city Council, however, undertook its share of tree removal, and obtained income from the timber sold. Daly (1987) noted that the Council obtained income from the sale of dead trees for firewood until 1868.[23]

The damage caused by ringbarking, firewood collecting, and livestock grazing also hastened the need for fence construction in many areas of the Park Lands. During 1858, some 800 trees were planted in the Park Lands, and an additional £528 spent creating post and plant tree guards for them.[24] During 1863, the *Mayor's Report* recorded that 'more than 5,000 new trees [were] planted, which are now in a healthy condition'.[25] Numbers of trees planted increased substantially the following year, according to the *Mayor's Report* of the gardener's activities for 1864:

> The City Gardener informs me that he has during the last winter planted in and around the city the following trees – namely, 1025 blue gums [*Eucalyptus* spp.], 350 olives [*Olea* spp.], 6,700 red gums [*Eucalyptus* spp.], 3,000 willow slips [*Salix* spp.], 1,000 rose cuttings [*Rosea* spp.], 160 cork oaks [*Quercus suber*], 160 Moreton Bay figs [*Ficus macrophylla*], and 12 sheoaks [*Casuarina* or *Allocasuarina* spp.], and nearly all are doing well.[26]

Descriptions of planting locations and spatial arrangements were generalised during most of this early period, with city squares, streets, and Park Lands often described as a whole city unit. Even with the planting of various trees, by 1865 the Adelaide Park Lands were quite denuded of trees, as can be seen in Townsend Duryea's well-known panoramic photographs of that year. One of these 16 photographs taken by Duryea clearly showing the denuded Park Lands is displayed in Figure 6.1. Riddle (1992) observed that the practice of leasing areas of the Park Lands for livestock grazing continued well into the 20th century, the benefits of which included a source of income for the Council, a reduction in the need for mowing open spaces, and as a deliberate 'fire retention practice'.[27] Where livestock were not used for this method of 'fire retention', the grasses were mown and the hay removed.[28] Riddle (1992) also noted that by 1864 portions of the Park Lands were leased out to individuals for sowing and harvesting crops such as barley. The *Mayor's Report* at the time observed that "good crops now abound where for years not a blade of grass has grown".[29]

Figure 6.1. Section of Townsend Duryea's 1865 panorama looking into the South Park Lands. Note the large tracts of treeless Park Land behind the city's buildings. (© History Trust of South Australia)

During 1865, the Corporation planted 8,369 trees including 2,875 'blue' and 'red gums' (*Eucalyptus* spp.), 5,375 'olives' (*Olea europaea*), 103 Moreton Bay Figs (*Ficus macrophylla*), and 16 'plantains'.[30] The following year, tree planting consisted of 4,200 'gum trees' (*Eucalyptus* spp.), 370 'native pines', 521 'Ficus microfilia' (*Ficus microphylla*), 29 cypresses, and four 'Auricaria Cookii' (*Araucaria columnaris*).[31] With the appointment of new City Gardener William Pengilly in 1867, tree planting increased, with the *Mayor's Report* in *The South Australian Advertiser* recording:

> The number of trees and shrubs planted during the past season is extremely large, and consists of indigenous and foreign plants as follows:– 4,450 gums, 1,705 native pines, 24 cypresses, 10,600 olives, 105 Moreton Bay figs, 280 English oaks, 50 ash, 1,260 European trees, and about 4,000 shrubs.[32]

While precise locations for every tree were not provided, the plant selection provides an interesting insight into the species understood to survive in the Park Lands at the time.

Figures 6.1 and 6.2
Images from Townsend Duryea's 1865 panorama of the City of Adelaide

Permission to include images from the panorama in this thesis given by
The History Trust of South Australia.

The Duryea Panorama is available from
http://ww3.fusion.com.au/duryea/

During 1868 and 1869, tree-planting activities temporarily subsided, with the Mayor's *Report* acknowledging that 'the planting of the Park Lands has not been carried to the extent which former years have seen', however 'improvements' such as trenching, 'manuring', and 'planting' occurred in the northern Park Lands and along West Terrace, to increase the success of tree establishment and subsequent growth.[33]

Over the following three years, tree planting again increased significantly. In 1870, '2,000 ornamental trees and 1,852 gums' were planted in unspecified city and Park Land locations, with 'about 9,000' trees planted during 1871.[34] Quantities of trees reported planted in 1872 dropped to 5,542, and consisted 'of 2,357 olives, 950 gums, and 2,235 various ornamental trees and plants suitable for the climate'.[35] For the following two years, tree planting was not recorded; however, in 1875, 3,712 trees of various taxa were planted, including the following listed as 'gifts' from donors:

> 105 shrubs, 200 Ficus, 100 Ash, 249 Pines, 12 Sterculius, 15 Pittosporums, 24 Acacias, 1760 Gums, 73 Poplars, 26 Tamarisks, 20 Buddleas, 428 Olives, 500 Jarrah, 100 White cedars, 100 Brachychitan [*sic*] [36]

During 1876 over 5,000 trees were planted, including 1,301 across the six squares of the city, and 3,951 in the city streets and Park Lands.[37] The Mayor was duly impressed: 'I am informed by the City Gardener that there are now no less than 30,100 trees growing in the Squares and Plantations throughout the city.'[38] Over the next decade, the quantity of trees growing within the city and its Park Lands would more than double. In the planting season of 1877, 3710 trees were planted across Council lands, including 555 Olive trees, 1,733 'gums', and 1,422 'various kinds' of trees, bringing the city's tree count to 33,264.[39] Although acts of vandalism towards Council property were not uncommon in the Park Lands, two consecutive reports by the City Gardener convey a distinct sense of frustration towards the situation in 1877:

> The destruction of the number of young trees just after planting is discouraging in the extreme, and has given me much anxiety; this destruction is not accidental, but deliberate and wanton…[40]

During 1878 a further 446 'young trees were deliberately pulled up' or otherwise destroyed.[41] These events did not deter the gardeners, for during the 1879 planting season 3,700 trees were planted across the city's lands.[42]

Even with these extensive planting engagements, Morton (1996) noted that by the late 1870s, 'Dead and dying trees were everywhere', and large areas of the Park Lands were subject to misuse and to neglect.[43] The primary reason for this, Morton (1996) observed, was a lack of money, possibly combined with the Council's reluctance to use it for Park Land embellishment.[44] Until the late 1880s, and probably later, according to Morton (1996), the Council generally believed that self-supporting Park Lands were the solution, and ratepayers were not to be charged for improvements or maintenance.[45] Much of the early income obtained through pastoral Park Land leases, for example, went into repairing old fences and constructing new ones.

Towards the end of the 1870s, the City Council engaged the Conservator of Forests, John Ednie Brown, to commission a series of recommendations, plans, and guidelines for the planting of the Adelaide Park Lands. In 1880, Brown submitted his *Report on a System of Planting the Adelaide Park Lands, Illustrated by Plans and Sketches*. A comprehensive and influential master plan at the time, Brown's report contained plans for the various areas of the Adelaide Park Lands, along with planting diagrams for establishing young trees, recommended taxa for soil types, drainage observations, aesthetic landscaping techniques to produce ornamental gardens, and most importantly, the recommendation of the employment of a specific Curator of Park Lands. With due consideration for the future, Brown (1880) observed that:

> …the planting operations in the Park Lands of this city are not a thing of expediency for the present time only, but affect their pictorial beauty for all time to come, and that the proper ornamentation of the grounds has an intimate connection with the pleasure of thousands of people every day…[46]

By the time Brown was engaged to compile his report there would have been a wide diversity of tree taxa within the Park Lands. Many benefactors gave trees to the Corporation, and there was no control over the species received or subsequently planted. Owing to a distinct lack of funding for the aftercare of the trees, many of the specimens unsuited to Adelaide's harsh summer would have perished. Those that survived would have provided Brown with an unusual scenario. There were distinct differences between tree species previously planted, and those specified by Brown (1880):

> The Gums as a rule are not very ornamental trees, and besides, those in the Park Lands have a very unhealthy appearance and show evident signs of early decay. Under these circumstances the fact must be looked in the face now, that if the Parks are to be beautified in the manner and to the extent to which they are capable, the present plantations will, as a rule, have to give place to others of a more suitable character.[47]

The consideration of tree taxa selection was paramount to Brown's (1880) Park Land plan. Trees needed to be suited to the soil and location they were planted in, and Brown's (1880) document duly pointed this out:

> In taking up any part of the Park Lands for the improvement by planting, the first consideration ought to be as to what kinds of trees will grow best upon it. This is undoubtedly the most important matter of all for the future success of the plantations and too much care and judgement cannot therefore be shown in its proper discernment. I may here remark that this is a subject which has not been sufficiently considered in the planting operations of the Corporation hitherto, and that consequently much of the unhealthy appearance of the existing plantations in the Park Lands is attributable to its neglect in the first instance.[48]

The design of the planting layouts was crucial to Brown's (1880) landscape concept. This design philosophy for Adelaide was to create a 'park-like' landscape; with tree plantings arranged accordingly 'to make the whole scene as natural as possible'.[49] Brown (1880) attempted to work with existing tree plantings, however, in areas considered unsuitable for certain taxa, their existence was ignored and removal was recommended. Sweeping changes causing degraded swathes of land was not an option, according to the report. Brown (1880) stated that 'It will be found that, if my suggestions are adopted, much that has been done will have again to be undone', however, this was to be undertaken sensitively, in 'a gradual manner', so as to avoid 'temporary disfigurement' to the landscape.[50]

Brown (1880) also pressed the Council to appoint a Park Lands Curator. As 'It can be readily understood that ornamental planting is a specialty', noted Brown (1880), the appropriate person for the position should be 'properly-qualified' to carry out the recommended landscape changes; and to 'ensure success', the person should have 'had special training in the various detail operations of Landscape Gardening'.[51]

There was no doubt Brown's (1880) report had an immediate effect on the City Gardener's actions at the time. Aside from the 1,900 and 1,228 trees planted in the Park Lands and city squares respectively, the *Mayor's Report* echoed Brown's (1880) words:

> The Gums as a rule are not very ornamental trees, and besides, those in the Park Lands have a very unhealthy appearance and show evident signs of early decay.[52]

Despite the Corporation's apparent dislike of the '*Eucalypti*', the total number of trees reportedly growing in and around the city, including eucalypts, was 38,796 by the end of 1880.[53] Brown's (1880) report appeared to fill the Council with a distinct sense of pride over the Park Lands of which they were custodians. The *Mayor's Report* of 1881 reflected this, along with the announcement of 11,914 trees planted that year:

> The great glory of Adelaide is the surrounding park, across which avenued [*sic*] roads and paths extend in devious ways, and divide the whole into many irregular and diversified parts. These parts are now being planted – thus developing their varied beauties – in accordance with the plans proposed by the Conservator of Forests…. It affords me great pleasure to be able to inform you that there are now 50,710 trees growing in the various plantations, and I am informed by the Park Lands Gardener that they are looking remarkably well.[54]

During 1882 tree mortality obligated the replacement of 1,000 Park Land trees. In addition to this, 400 new trees were planted in the city squares, and 12,000 were planted in the Park Lands.[55] 1883 also proved to be another busy year, with 11,309 trees planted, bringing a reported total number of trees growing across the city streets, squares, gardens, and Park Lands of 71,830.[56] During 1882 Brown was appointed 'Supervisor of the Plantations' to manage tree planting operations in the Park Lands. Relations between the City Gardener and the Supervisor of the Plantations were not agreeable, with both soon parting from the Corporation. Pengilly ended his career with the Corporation in 1883, and during his 16 years as City Gardener planted over 74,500 trees in the squares and Park Lands.

During 1884 some '2,000 trees and shrubs' were planted, and the new City Gardener reported that 'with few exceptions, these trees are growing well'.[57] No new plantings were recorded for 1885, and tree planting during 1886 consisted of 392 trees, mostly obtained as gifts to the Corporation including 'cork elms', cedars, poplars, pines, and cypresses.[58] Within the planting season of 1887, the trees planted and quantities of each were recorded as follows:

> Ulmus suberosa [*Quercus suber*]… 168
> Populus fastigata … 84
> Populus canescens … 48
> Eucalyptus cornuta … 24
> Eucalyptus corynocalyx [*Eucalyptus cladocalyx*]… 138
> Eucalyptus diversicolor … 10
> Eucalyptus gomphocephala … 24
> Pinus halepensis … 330
> Pinus insignis [*Pinus radiata*]… 96

> Pinus pinaster … 38
> Tamarix gallica … 30
> Schinus molle [*Schinus areria*]… 125
> Melia azedarach [*Melia azedarach* var. *australasica*]… 60
> Phoenix dactylifera … 9 [59]

This list provides some insight into tree taxa planted at the time. Between 1888 and 1890 no new 'plantations' were established and only trees that had 'failed' or those that had 'been torn up by mischievous persons' were replaced.[60] In 1891, the City Gardener appeared perplexed over acts of vandalism or 'wilful mischief' towards new trees in the Park Lands:

> It is difficult to understand what can be the motive of the perpetrators of such contemptible mischief, and especially in a country where the foliage of trees is so much required, both as pleasantly relieving the eye from the glare of the bright sunshine and as conducing to the freshness and coolness of the atmosphere.[61]

1892 saw the planting of 284 trees, including 138 palms. The tree list included 12 *Ulmus suberosa* (*Quercus suber*), 50 *Eucalyptus corynocalyx* (*Eucalyptus cladocalyx*), 20 *Eucalyptus leucoxylon*, 20 *Eucalyptus ficifolia* (*Corymbia ficifolia*), 20 *Pinus halepensis*, 12 *Ceratonia siliqua*, and 12 *Populus fastigiata*.[62] Tree plantings for 1893 were not recorded, and only the replacing of dead trees was undertaken during 1894. In 1895 a number of trees in the Park Lands appear to have been removed, according to the Park Lands Ranger: 'a great many old gum trees have been grubbed … from which I have made 520 good substantial posts'.[63] The City Gardener also reported on removing 'the worst of the dead trees' from the 'plantations' within the Park Lands, in addition to adding 131 unspecified 'trees and shrubs' donated by the Conservator of Forests.[64] Between 1896 and 1899 a reported lack of rain described as 'three successive bad years' curtailed tree planting and only maintenance operations were carried out across the Park Lands.[65] Again, during this period, the Park Lands Ranger reported grubbing 'many trees', from which at least 770 posts were made.[66]

In 1899, the Corporation appointed August Wilhelm Pelzer as City Gardener. The following 33 years of Pelzer's landscape management direction were to have another lasting influence upon the Park Lands. The Corporation nurseries originally recommended by Brown were promptly supported by Pelzer, and were to be constructed over the ensuing years for the purpose of growing annuals, shrubs and trees for the benefit of the various city parks and gardens. Pelzer obviously wasted no time, and by the end of 1900 had planted approximately 750 trees across the city. Trees planted during that year included

250 Plane trees, 200 Elm trees, 50 White Acacias (*Robinia pseudoacacia*), 200 White Cedars (*Melia azedarach* var. *australasica*), 25 Spreading Poplars (*Populus monilifera*), and 25 Upright Poplars (*Populus alba* 'fastigiata').[67]

Pelzer planted 208 trees during 1901, and had by this stage developed planting philosophies akin to Brown's, as observed in *The City Gardener's Report* for the year, on reflection of both past actions and future directions:

> In my opinion a tremendous mistake has been made in planting too many gum trees; the majority of trees about the park lands consist of gum trees, and most of them are decaying and dying. Gum trees about the plains of Adelaide will, in time to come, be trees of the past. The Eucalypts will not submit to cultivation and civilization, and it is my candid belief that with the progress of Arboriculture gum trees will have to make room for Oriental, Mediterranean, and South American species.[68]

Pelzer's philosophy was to follow this trend away from planting eucalypts, with few exceptions, for the next three decades. There were 250 new and 82 replacement trees planted during 1902, and 1,002 trees and 24 'palms' planted during 1903, along with a refined species list in the *Annual Report* for 1903:

> Elms [*Ulmus* spp.], Planes [*Platanus* spp.], Peppers [*Schinus areria*], Sugar Gums [*Eucalyptus cladocalyx*] Ash [*Fraxinus* spp.], White Cedars [*Melia azedarach* var. *australasica*], Ailanthus [*Ailanthus altissima*], Aleppo [*Pinus halepensis*], and Canary Island Pines [*Pinus canariensis*], Cypress [*Cupressus* spp.], Spreading, Upright, and Silver Poplars [*Populus* spp.], Tamarisks [*Tamarix* spp.], Lagunarias [*Lagunaria patersonii*], [and] White Acacias [*Robinia pseudoacacia*].[69]

Palm taxa planted in 1903 included *Pritchardia filamentosa*, *Phoenix reclinata*, *Phoenix dactylifera*, and *Chamaerops excelsa*. Pelzer's planting palette reflected the majority of these taxa for the next decade, with additions as species proved successful. Between 1904 and 1906 Willows (*Salix* spp.) were added to areas around the River Torrens, and by 1906 'camphor' (*Cinnamomum camphora*), 'sterculia' (*Brachychiton acerifolius*), and 'sophora' (*Sophora* spp.) were added to the planting palette.[70] In 1907 'gleditschias' (*Gleditsia triacanthos*), 'sheaoaks' [sic] (*Allocasuarina* spp.), and one Spanish Oak (*Quercus falcata*) were planted, and in 1908 Pelzer added Jacarandas (*Jacaranda mimosifolia*).[71] Between 1904 and 1910, Pelzer had planted at least 2,982 trees.

The City Gardener was possibly testing previously untried tree species, with two 'Wattles' (*Acacia* spp.) and one 'Rolrenteria' (*Koelreuteria paniculata*; Golden Rain Tree) recorded planted during 1911. By 1913, Judas Trees (*Cercis siliquastrum*) were being planted and in 1914 'Flowering Peach', Hawthorn (*Crataegus* spp.), and Coral Trees (*Erythrina indica*) were planted in the 'gardens' of the city.[72] The planting of even more trial taxa continued in 1915, with the addition of two Maidenhair Trees (*Ginkgo biloba*), one 'Queensland Nut Tree' (*Macadamia* spp.), one 'Silky Oak Tree' (*Grevillea robusta*) one 'Fire Tree' (*Stenocarpus sinuatus*), seven 'Double-flowering plum trees' (*Prunus* spp.), two 'Queensland Chestnut Trees' (*Castanospermum australe*), two 'Rawrie Trees' (Syn. *Dammara* spp.), two 'Native Myrtle Trees (Myoporum)' and two 'Strawberry Trees' (*Arbutus unedo*).[73] Pelzer added to this planting list in 1916 with at least five new taxa including one each of 'Kauri Gum' (*Agathis* spp.), Box Elder (*Acer negundo*), 'Harpulea' (*Harpullia* spp.), Podocarpus (*Podocarpus* spp.), 'Variegated Fig Tree' (*Ficus* spp.) and two 'Parksonia' (*Parkinsonia* spp.) Additionally of note, during 1915 and 1916, Pelzer planted 66 'various' 'Gum trees' however unfortunately the species were not recorded.[74]

During 1917, a number of previously unmentioned tree taxa were reported to have been planted by the City Gardener, including Bottle Brush (*Callistemon* spp.), Lilly Pilly ('Eugenia' or *Syzygium* spp.), Pittosporum, 'Box Tree' (*Lophostemon confertus*), Cabbage Tree, (*Cordyline australis*), 'Kingston Oak' ('Casuarina' or *Allocasuarina* spp.), New Zealand Christmas Tree (*Metrosideros excelsa*), 'Ti-Tree' (*Melaleuca* spp.), Maple (*Acer* spp.), 'Kolrenteria' (*Koelreuteria paniculata*), and 'Flowering Apple' (*Pyrus* or *Malus* spp.).[75] In 1918 the City Gardener added that Alder (*Alnus* spp.) and Birch (*Betula* spp.) trees were planted.[76] In the years between 1910 and 1920, Pelzer had planted over 3,520 trees and palms of various taxa.

Pelzer's tree planting trials continued again briefly with Norfolk Island Pines (*Araucaria heterophylla*) in 1921, and Walnut trees (*Juglans nigra*), 'Nettle trees' (*Celtis occidentalis*), 'Oak trees' (*Quercus* spp.), 'Kaffir Bean trees' (*Schotia* spp.) in 1922.[77] The survival rate of all trees planted remains unclear, however, taxa selection for subsequent planting may have reflected the most robust and suitable tree species for Adelaide's climate and soils. From 1921 to Pelzer's retirement in 1932, a palette of successful tree taxa predominated Park Land, street, and garden planting schemes. These included Elm (*Ulmus* spp.), Gum (*Eucalyptus* spp.), White Cedar (*Melia azedarach* var. *australasica*), Wattle (*Acacia* spp.), Plane (*Platanus* spp.), Ash (*Fraxinus* spp.), Robinia (*Robinia pseudoacacia*), Poplar (*Populus* spp.), Pine (*Pinus* spp.), Kurrajong (*Brachychiton* spp.) and Pepper tree (*Schinus areria*). Many of these tree taxa were recurrent over Pelzer's three-decade career of planting in the city of Adelaide. Between the 1921 to 1932 period specifically, Pelzer planted over 6,700 trees. During Pelzer's time as City Gardener, over 15,000 trees were planted across the Park Lands, gardens and squares in the City of Adelaide.

Following Pelzer's retirement, the City Gardener and staff were placed under the management of the City Engineer. Believing too many staff were employed for the various jobs, the City Engineer reduced staff numbers significantly, resulting in the prompt resignation of the next two head gardeners over several years. From 1932 to 1935 no tree plantings were recorded, but upon the recommencement of planting in 1936, a familiar palette returned. The use of Ash (*Fraxinus* spp.), Elm (*Ulmus* spp.), Nettle tree (*Celtis* spp.), Poplar (*Populus* spp.), Koelreuteria (*Koelreuteria* spp.), and Jacaranda (*Jacaranda* spp.) appeared again, influenced either by previous years' successful plantings, or through the 4,470 trees reportedly growing in the Corporation nurseries at the time, most likely left over from Pelzer's management.[78] The City Gardener in 1936 also reported removing 'About 100 old gums and pines', noting that they 'will be replaced by others of a more ornamental nature'.[79] From 1937 to 1939, the City Gardeners removed 467 trees from the squares, gardens, and Park Lands, reporting them to be 'principally of peppers and pines, which had become unsightly'.[80] During this same three-year period, at least 1,513 new trees were planted; unfortunately with no further taxa details provided.

Benjamin J. E. Bone was appointed Curator of Parks and Gardens in 1939 and tree planting activities during the period of the Second World War were not specified in detail. The next significant tree planting stage began during the 1947 financial year with the establishment of 575 trees, consisting of sugar gums (*Eucalyptus cladocalyx*), Aleppo, Monterey, and Canary Island pines (*Pinus halepensis*, *P. radiata*, and *P. canariensis* respectively), Southern Nettle Tree (*Celtis australis*), Athol Tree (*Tamarix articulata*), 'Eucalyptus leucoxylon Rosea (Pink-flowering Ironbark Gum)', and 'Assorted Poplars and Willows' (*Populus* and *Salix* spp.).[81] Between this period and 1949, no plantings were recorded within the city or its Park Lands, however this changed by 1950 with the establishment of 525 trees, and the following planting list detailed by the Director of Parks and Gardens in the *Annual Report* for the year records:

> Eucalyptus Corynocalyx [*Eucalyptus cladocalyx*] (Sugar Gum), Eucalyptus Ficifolia [*Corymbia ficifolia*] (Red Flowering Gum), Eucalyptus Diversicolor [*Eucalyptus diversicolor*] (Karri Gum), Eucalyptus Citrodora [*Corymbia citriodora*] (Lemon Scented Gum), Eucalyptus Rostrata (*Eucalyptus camaldulensis*] (Red Gum), Eucalyptus Globulus [*Eucalyptus globulus*] (Blue Gum), Jacaranda Mimosaefolia [*Jacaranda mimosifolia*], Tristania Conferta [*Lophostemon confertus*] (Queensland Box), Pinus Canariensis [*Pinus canariensis*] (Canary Island Pine), Pinus Insignis [*Pinus radiata*] (Monterey Pine), Erythrina Indica [*Erythrina indica*] (Coral Tree), Ficus Macrophylla [*Ficus macrophylla*] (Moreton Bay Fig), Tamarix Aphylla [*Tamarix aphylla*] (Athol Tree), Araucaria Excelsa [*Araucaria heterophylla*] (Norfolk Island Pine), Casuarina Stricta [*Allocasuarina verticillata*] (She Oak), Casuarina Cunninghamiana [*Casuarina cunninghamiana*] (River She Oak), Sterculia Acerifolia [*Brachychiton acerifolius*] (Flame Tree), Sterculia Alba [*Brachychiton populneus*], Lagunaria Petersoni [*Lagunaria patersonii*], Quercus Ilex [*Quercus ilex*] (Holly Oak), Populus Alba [*Populus alba*] (Silver Poplar), Populus Monilifera [*Populus monilifera*] (Spreading Poplar), Paulownia Fortunii [*Paulownia fortunei*], Harpephyllum Caffra [*Harpephyllum caffrum*] (Kaffir Plum).[82]

The following year a further 865 trees were planted, using a very similar palette, with the addition of ‘Populus Bolleana Alba’, Lombardy Poplar (*Populus nigra* ‘Italica’), English Elm (*Ulmus procera*), Silky Oak (*Grevillia robusta*), and Black Walnut (*Juglans nigra*).[83] Tree planting continued in 1952 with 441 trees established, and a further 621 in 1953.[84] The planting list for 1953 reflected that of the 1950 list, with the addition of *Eucalyptus sideroxylon* var. *rosea* (Red-Flowered Ironbark), *E. leucoxylon* (South Australian Blue Gum), *Arbutus unedo* (Strawberry Tree), ‘Sterculia Hybrida’ (*Brachychiton* spp. hybrid), *Cinnamomum camphora* (Camphor Laurel), *Acacia dealbata* (Silver Wattle), *A. decora*, *A. decurrens* (Early Black Wattle), *A. elata* (Cedar Wattle), *A. longifolia* (Sallow Wattle), *A. pycnantha* (Golden Wattle), *A. sophora*, *Pittosporum undulatum* (Sweet Pittosporum), and *Celtis sinensis* (Chinese Nettle Tree) planted during that year.[85]

A planting list provided for the 1954 *Annual Report* also reflected many taxa from the 1950 list, along with interesting additions such as Spotted Gum (*Corymbia maculata*), Marri (*C. calophylla*), Southern Mahogany (*E. botryoides*), Carob Tree (*Ceratonia siliqua*), English Oak (*Quercus robur*), Hoop Pine (*Araucaria cunninghamii*), Cape Chestnut (*Calodendron capensis*) Oriental Plane (*Platanus orientalis*), Chinese Pistachio (*Pistacia chinensis*), Bald Cypress (*Taxodium distichum*), Liquidambar (*Liquidambar styraciflua*), and Claret Ash (*Fraxinus angustifolia* subsp. *oxycarpa* 'Raywood').[86] Again in 1956, the taxa list increased in variety with the planting of Sydney Red Gum (*Angophora costata* subsp. *costata* Syn. Angophora Lanceolata), Native Frangipani (*Hymenosporum flavum*), Brush Cherry (*Syzygium paniculatum* Syn. Eugenia Myrtifolia), Karo

(*Pittosporum crassifolium*), and Hill's Weeping Fig (*Ficus microcarpa* var. *hillii* (syn. Ficus Hilli)).[87]

During 1957, 'Podocarpus' (*Podocarpus* spp.), Eastern Cottonwood (*Populus deltoides*), Bunya Pine (*Araucaria bidwilli*), 'Hakeas' (*Hakea* spp.), and 'flowering Eucalypts of seven varieties' including Yellow Box (*Eucalyptus melliodora*) were planted by the gardeners in various locations, in addition to previously successful taxa from the early 1950s.[88] Between 1954 and 1958 over 1,670 trees were planted. The *Annual Report* for 1958 contained the following list of tree taxa planted:

> Brachychiton Acerifolia [*Brachychiton acerifolius*], Sterculia Alba [*Brachychiton populneus*], Jacaranda Mimosaefolia [*Jacaranda mimosifolia*], Araucaria Cunninghami [*Araucaria cunninghamii*], Melaleuca Pubescens [*Melaleuca pubescens*], Erythrina Indica [*Erythrina indica*], Angophora Intermedia [*Corymbia intermedia*], Callistemon Viminalis [*Callistemon viminalis*], Camphora Officinalis [*Cinnamomum camphora*], Calodendron Capensis [*Calodendron capensis*], Euginia Myrtifolia [*Syzygium paniculatum*], Virgilia Capensis [*Virgilia capensis*], Callistris Cupressiformis [*Exocarpos cupressiformis*], Pittosporums, [and] 'many varieties of Eucalypts'.[89]

Following this inclusion, records of planting lists ceased to be included in subsequent *Annual Reports*. Indistinct descriptions such as 'Tree planting consisted of many species of both ornamental and utility value including native trees in variety, flowering and shade trees' predominated in the ensuing years.[90] Although tree planting continued, as reflected in the 3,940 trees recorded as having been established between 1959 and 1965, specific details were generally deficient. Following Bone's retirement in late 1966, Mr. Val Bertram Harold Ellis became the Director of Parks and Gardens.[91] The number of trees planted during Bone's 27-year management period had exceeded 10,880, and averaged over 400 trees per year.

Tree planting over the next several decades again appeared to reflect social preferences of popular taxa of the time. While comprehensive taxa lists were not provided, the 1971 *Annual Report* described plantings of 'gum [*Eucalyptus* spp.], pine [*Pinus* spp.], wattle [*Acacia* spp.], sheoak [*Casuarina* or *Allocasuarina* spp.], silky oak [*Grevillia robusta*] and honey myrtle [*Melaleuca* spp.]' for that year.[92] By 1977 're-afforestation' of the Park Lands was occurring.[93] Trees selected were predominately 'tall', and provided with 'shrubby undergrowth to create a "village green" effect'.[94] Records for 1985 expressed that:

> A heavy emphasis has been placed on the selection of Australian native trees, although introduced species have been planted in the North Adelaide area to further complement the English style gardens in the area.[95]

Within these 'Australian native trees' were 'many species of Eucalypts and Casuarina'.[96] Between 1967 and 1980, at least 10,100 trees were planted. Between 1981 and 1990 over 7,800 trees were additionally planted. During 1991 alone, over 22,000 trees were planted across the Park Lands and these most likely consisted of *Eucalypt*, *Acacia* and *Allocasuarina* species, along with introduced street tree plantings and replacements. By 1998 'revegetation' of the Park Lands was predominate, and various indigenous tree and shrub species were established. Revegetation may have occurred more extensively prior to this date, however records are lacking. The 1990s saw a significant increase in tree planting. Over 53,000 trees of various sorts were planted across the city in the years between 1991 and 2000. During 1996, a reported 95 per cent of the 10,000 trees planted were 'Australian natives'.[97] In 2000 the Council celebrated the planting of its '20 millionth tree', among the 12,000 others for the year.[98] Replanting of Kadlitpinna/Park 13, Ityamaiitpinna/Park 15, and Tulya Wodli/Park 27 of the Park Lands with 'native vegetation' occurred in 2005, although further details were also absent.[99]

From approximately 1970 onwards, there was a general shift from planting introduced tree species, with the exception of the many squares, gardens and streets, towards Australian tree taxa. By the late 1990s this shifted again towards tree taxa more specifically indigenous to the various areas of the Park Lands themselves. Introduced tree taxa were still being established, however they were typically restricted to tree replacements along streets and gardens where indigenous trees were not deemed suitable. This preference towards indigenous tree taxa continued to the present, where increased watering restrictions encouraged both low maintenance and low water usage trees in the landscape.

6.5 Tuttangga/Park 17 Extant Tree Planting History

An understanding of past changes to vegetation patterns created over time through cultural influences may assist in comprehension of previous landscapes, and emphasize potential vegetation changes of the future. Here, an understanding of the vegetation changes over time that occurred specifically in Park 17, within the Adelaide Park Lands, will highlight extant historical data, and determine the quantity of information available for potential use in tree age determination in the landscape.

6.5.1 Pre-European Vegetation of the South Park Lands

Prior to European settlement, the area of the Adelaide Park Lands currently known as Park 17 contained a wide variety of indigenous plant taxa. Crompton (1998) developed a floristic reconstruction of the South Park Lands for the Patawalonga Catchment Water Management Board. Crompton's (1998) *South Parklands Wetland Feasibility Project: Native Vegetation Survey* reconstructed the Pre-European South Park Land environment based upon the tree and plant species believed to exist in the area, and created a 'walking' visual description of the landscape one would expect to have encountered at the time:

> To an observer in 1836, walking in what is now Park 19, the scene would have been dominated by the dark trunks and dark foliage of Grey Box [*Eucalyptus microcarpa*], Sheoak (*Allocasuarina verticillata*) and Native Pine (*Callitris preissii*). The pale trunks of the S.A. Blue Gum [*Eucalyptus leucoxylon*] would have provided an attractive contrast. In some parts, the woodland would have presented an open character and in others there would have been thickets of Golden Wattle (*Acacia pycnantha*) and Round-leaved Wattle (*Acacia acinacea*) flowering yellow in winter. There would also have been scattered patches of the large shrub *Bursaria spinosa* with profuse white flowers in early summer.
>
> The most obvious feature of the ground-flora would have been the many kinds of grasses. The spring flowering season would have revealed a great diversity of other small plants from a range of different plant families including Lilies, Daisies, Orchids, Legumes and Goodenias. It would have been easy to walk through the Black Forest. Vegetation would have been kept open by wildlife activity and by the Aboriginal management practice of patchwork burning.
>
> Walking towards Glen Osmond Creek, the trees would have increased in stature and River Red Gum [*Eucalyptus camaldulensis*] would have become dominant. The creek would have been broad and shallow with some deeper pools. The vegetation would have been thicker with a range of sedges and rushes and with River Bottlebrush (*Callistemon sieberi*). Following Glen Osmond Creek downstream to where it now crosses Unley Rd, the watercourse would have spread out to form a sedgeland swamp under a forest of River Red Gum.[100]

These visual descriptions provide an insight into the South Park Land area and nearby Park 17 landscape, as it may have presented prior to 1836.

6.5.2 Post-Colonial Tree Planting in Tuttangga/Park 17

The early colonists stripped much of the Adelaide Park Lands of their vegetation and tree cover, and Park 17 would not have been an exception. Early efforts at tree planting in Park 17 remain both unclear, and unsubstantiated. By 1860 much of the Adelaide Park Lands, including Park 17, had the majority of the original trees removed, as shown in the Park 17 section of Duryea's panoramic photograph from 1865 (Figure 6.2) where very few trees can be seen. Jones (2007), writing upon the cultural history of Park 17 among the Park Lands, noted that between the 1850s and the late 1870s, Park 17 'was used for grazing, fire wood collection, and agistment'.[101] The combination of these three land uses would have resulted in a relatively open landscape, with a cropped understorey of plants from grazing.

Figure 6.2. Image from Duryea's 1865 panorama overlooking the south-east corner of the Adelaide Park Lands. Park 17 is highlighted in orange. (© History Trust of South Australia)

Early direct references towards tree planting in the area now known as Park 17 were often indistinct and lacking in detail. References to locations were often generalised to include larger areas, such as the planting of 630 trees in the 'South Park Lands' in 1876.[102] The composition of trees extant within Park 17 at the time of Brown's 1880 design proposal is unclear. Brown's 1880 plan for Park 17 contained a planting philosophy, adopted in part by Pelzer, with tree planting an influential part of the report:

> For its improvement I make the following recommendations:-
> These comprise two Carriage Drives, one to enter at the corner of the grounds opposite Hutt-street, and sweep east and south through the Park; and the other, with entrance at corner opposite the junction of Mount Barker and Unley-roads, and bending with a graceful curve to the eastward through the grounds until the two meet opposite the southern entrance of proposed Drive round the Race-course, where they will open into Beaumont Road. The Drive first described, to be planted with an Avenue of Pinus Insignis [*Pinus radiata*], and the other drive to run through an Avenue of Ficus Macrophylla [*Ficus macrophylla*] trees. In both cases the trees to stand fifty feet [15.24m] apart in the lines.[103]

An important aspect of Brown's recommendations was the matching of certain taxa to their appropriate soil types. The taxa list specified as suitable for Park 17 by Brown (1880) are shown in Table 6.1. Justifying the planting design and parkland layout itself, Brown (1880) specified that:

> In laying out the plantations and clumps of trees on the past under notice, the principle idea has been to make the block as Park-like as possible: hence the broken-up appearance which the design has on the Plan.[104]

The planting plan for Park 17, shown in Figure 6.3, shows the distinct intersecting 'Carriage Drives', with the clumping of trees to create the 'Park-like' appearance desired.

In the *Mayor's Report* of 1883, Pengilly reported that 721 'various kinds of trees' had been planted in 'The South Park Lands between the Glen Osmond-road on the west, and Greenhill-road on the North-east road'.[105] During 1904, Pelzer reported the planting of '21 planes' and '37 elms' along 'South Terrace', with no precise locations defined.[106] In 1907 Pelzer planted '36 elms' along 'South Terrace East', and again in 1908 planted '31 various trees' at the 'Beaumont Road Plantation'.[107] Alongside Beaumont Road again in 1909 two 'sheoaks' were planted.[108] During 1913, '386 Sugar Gum' and '179 Wattle' were planted, with the 'South Park' described for the generic location.[109] The 'Bowling Club Ground', now known as the South Terrace Croquet Club, had 17 trees established in its vicinity in 1915, a further 17 trees were planted in 'Park 17' during 1916, and another nine during 1918.[110] Details of genera for these plantings were absent.

Recommended Planting List Brown (1880) p23	Current Nomenclature Jones (2007) p269	Current Common Name Jones (2007) p269
Abies Albertiana		
Abies Douglasii	*Pseudotsuga menziesii*	Douglas Fir
Abies Excelsa	*Abies magnifica*	Californian Red Fir
Araucaria Excelsa (&c., &c.)	*Araucaria heterophylla*	Norfolk Island Pine
Cedrus Atlantica	*Cedrus atlantica*	Atlas Cedar
Cedrus Deodara	*Cedrus deodara*	Deodar Cedar, Himalayan Cedar
Cupressus Lawsoniana	*Chamaecyparis lawsoniana*	Lawson Cypress, Port Orford Cedar
Cupressus Torulosa	*Cupressus torulosa*	Himalayan Cypress, Bhutan Cypress
Cupressus Uhdeana	*Cupressus lusitanica*	Mexican Cypress
Ficus Macrophylla	*Ficus macrophylla*	Moreton Bay Fig
Fraxinus Americana	*Fraxinus americana*	White Ash
Fraxinus Excelsior	*Fraxinus excelsior*	English Ash
Juniperus Virginiana	*Juniperus virginiana*	Pencil Cedar, Eastern Red Cedar
Legunaria Patersonii	*Lagunaria patersonii*	Norfolk Island Hibiscus
Melia Azedarach	*Melia azedarach* var. *australasica*	White Cedar
Picea Grandis	*Abies grandis*	Giant Fir
Picea Nobilis		
Picea Normanniana	*Picea nordmanniana*	Caucasian Fir
Pinus Banthamiana		
Pinus Canariensis	*Pinus canariensis*	Canary Island Pine
Pinus Cembra	*Pinus cembra*	Swiss Pine
Pinus Excelsa	*Pinus wallichiana*	Bhutan Pine
Pinus Gerardiana	*Pinus gerardiana*	Chilgoza Pine
Pinus Halepensis	*Pinus halepensis*	Aleppo Pine
Pinus Insignis	*Pinus radiata*	Monterey Pine
Pinus Lambertiana	*Pinus lambertiana*	Sugar Pine
Pinus Laricio	*Pinus nigra* var. *maritima*	Corsican Pine
Pinus Longifolia	*Pinus palustris*	Longleaf Pine
Pinus Pinaster	*Pinus pinaster*	Maritime Pine, Cluster Pine
Platanus acerifolia	*Platanus* x *acerifolia*	London Plane
Populus Alba	*Populus alba*	White Poplar, Silver Poplar
Populus Canescens	*Populus canescens*	Grey Poplar
Populus dilatata	*Populus nigra* 'Italica'	Lombardy Poplar
Populus Macrophylla	*Populus tacamahaca*	Balsam Poplar
Populus nigra	*Populus nigra*	Black Poplar
Populus Temula	*Populus tremula*	European Ash
Quercus Ilex	*Quercus ilex*	Holm Oak, Holly Oak
Quercus Pedunculata	*Quercus robur*	English Oak, Common Oak
Quercus Sessiliflora	*Quercus petraea*	Durmast Oak
Sterculia heterophylla	*Brachychiton acerifolius*	Illawarra Flame Tree
Thuja Lobii	*Thuja plicata*	Giant Thuja, Western Red Cedar
Thuja Menziesii		
Ulmus Campestris	*Ulmus procera*	English Elm
Ulmus Montana	*Ulmus glabra*	Scotch Elm, Wych Elm
Ulmus Suberosa	*Quercus suber*	Cork Oak

Table 6.1. Recommended Tree Planting List from Brown (1880).

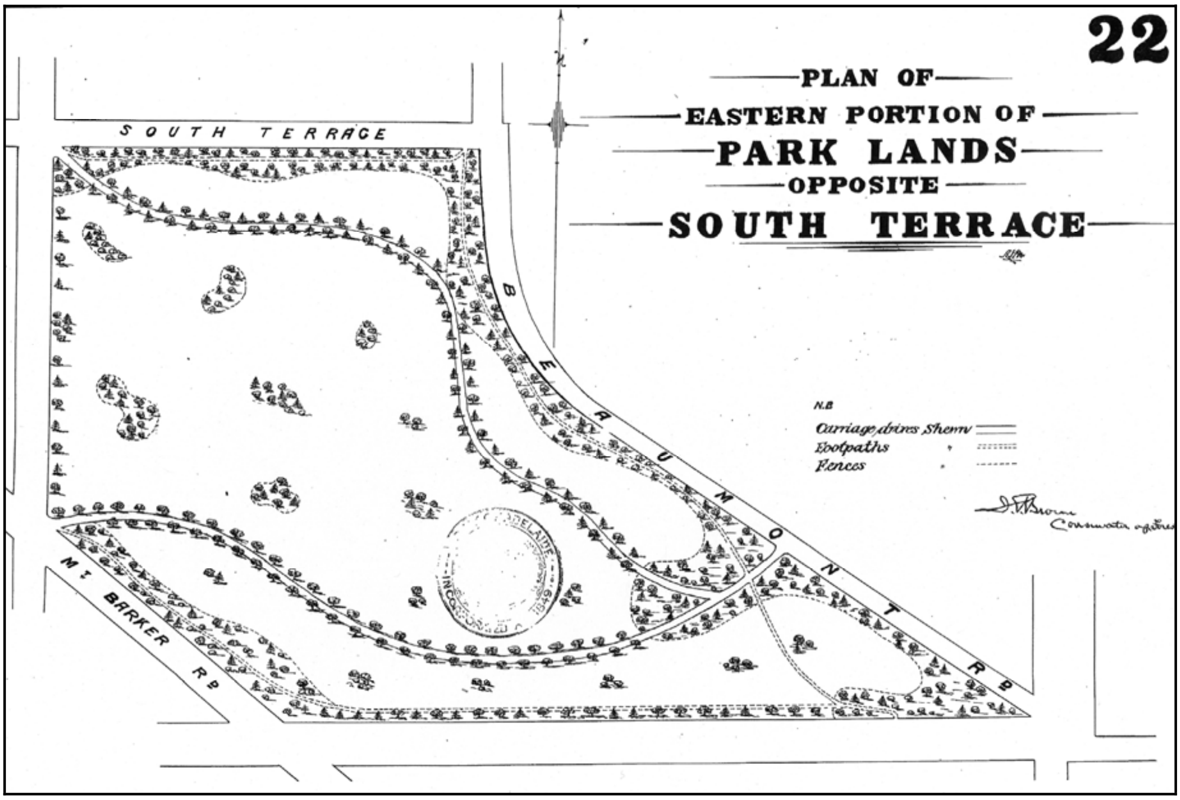

Figure 6.3. John Ednie Brown's (1880) Planting Plan for Park 17 (© The Corporation of the City of Adelaide Archives, Accession 0001, Item 0002).

In 'Park No. 17 (along pathway from South Terrace to Park Terrace [Goodwood Road]) … 128 Ash [*Fraxinus angustifolia* subsp. *angustifolia*] Trees' were planted in 1921, with the majority of this Ash tree avenue existing today.[111] In 1930 the Council approved Pelzer's recommendation,

> …that 114 ashtrees [*sic*] should be planted in Park No. 17 (South Park Lands), from the corner of South Terrace and Hutt Road to Park Terrace, opposite Birken Street, Eastwood, at an estimated cost of £260.[112]

The exact location of this planting is unclear, as there is no evidence of an Ash (*Fraxinus angustifolia* subsp. *angustifolia*) tree avenue extending between these two locations. The trees may have instead been added to the established 1921 Ash avenue previously detailed, or may have resulted in the present-day carriage-drive avenue in Park 17, consisting of English Elms (*Ulmus procera*). Within Parks '17, 18 and 19' there were '12 elm' trees planted in 1936.[113] The next specific mention of tree planting in Park 17 occurred in the *Annual Report* for 1954, with '105 trees' having been planted.[114] During the late 1990s volunteers associated with Bush For Life located indigenous remnant plant species growing in an area of Park 17, in the area described in Chapter 2.4.2. Through the removal of non-indigenous plant and weed species, remnant indigenous plants flourished, and natural regeneration was encouraged.

From 1954 onwards, Park 17 was included amongst generalised tree planting descriptions in the Adelaide Park Lands. As outlined in section 6.3, tree-planting descriptions following this period became much broader, encompassing larger areas and generalised taxonomic data. Historical records containing lists of genera planted during particular years can provide planting trends over time, indicating periods where certain taxa were preferred over others.

6.5.3 Tuttangga/Park 17 Extant Photographic Records

Photographic evidence of tree planting in Park 17 is limited. Historic photographs from the early 1900s can be compared to current landscapes to determine the extent of surviving trees, however, obtaining precise planting dates from these images is inherently problematic. Landscapes can, however, be compared using this technique, and changes over time noted. Five archival landscape photographs and one aerial photograph, along with their contemporaries are included in Appendix 2, Plates 1 through 10. Planting dates for the trees shown in the photographs may only be surmised from their apparent age at the time of photograph capture.

6.5.4 Summary of Tuttangga/Park 17 Tree Planting Records

Precise tree planting details for Park 17 appear limited. While quantities of trees planted within numbered Parks or the Park Lands generally may be provided, specific details pertaining to taxa selection and precise quantities are often absent. Records of tree planting in the Adelaide Park Lands appear to follow streets, avenues, or other well-known landscape features such as creeks or buildings. Photographic records may provide clues to past landscapes and planting schemes, however, they rarely provide details on tree planting dates. Records kept through observations of tree planting from the present day onwards would increase the quantity of existing tree planting knowledge, and therefore tree ages in the Adelaide Park Lands.

6.6 Summary of Extant Historical Data

From the review of extant records on tree planting in the Adelaide Park Lands, and specifically Park 17, there appears a general lack of detailed planting data in the form of tree species selection, planting dates, and planting locations. Descriptions such as 'various trees planted' appear often, and cannot be used to determine accurate taxonomic lists. Quantities of trees planted may be generalised to encompass the entire city area and are therefore not of use in determining tree ages in the Adelaide Park Lands. In addition, mortality details of young trees are broad, and replacements of trees not specified accurately. Therefore, replacement trees in an avenue planted at a later date may not reflect accurate tree ages across the avenue.

Chapter 6 Notes

[1] Ellis (1976) p. 113.
[2] Ellis (1976) p. 113.
[3] Kraehenbuehl (1996) p. 1.
[4] Long (2003) p. 25.
[5] Long (2003) pp. 26-27; Kraehenbuehl (1996) p. 81.
[6] Long (2003) pp. 28-29; Kraehenbuehl (1996) pp. 135, 139.
[7] Long (2003) p. 26; Kraehenbuehl (1996) p. 69.
[8] Long (2003) p. 26; Kraehenbuehl (1996) p. 90.
[9] Prospectus of the South Australian Association, (No Date) p. 1, In: Langmead (1994) p. 19.
[10] Langmead (1994) p. 21-22.
[11] Daly (1987) p. 11.
[12] Daly (1987) pp. 14-15.
[13] Maslen (1830) p. 263, In: Daly (1987) p. 15.
[14] South Australian Government *Gazette* (1839), 17th October, In: Daly (1987) p. 27.
[15] Daly (1987)
[16] Ellis (1976) p. 113.
[17] Ellis (1976) p. 113.
[18] Whitelock (2000) p. 237.
[19] Whitelock (2000) p. 237.
[20] Kraehenbuehl (1996) p. 5.
[21] Riddle (1992) p. 110.
[22] *Mayor's Report* (1857) December.
[23] Daly (1987) p. 121.
[24] *Register* (1858) 24th September, In: Riddle (1992) p. 109.
[25] *Mayor's Report* (1863) December.
[26] *Mayor's Report* (1864) December.
[27] Riddle (1992) p. 115; pp. 109-110.
[28] Riddle (1992) p. 115.
[29] *Mayor's Report* (1864) 28th November, In: Riddle (1992) pp. 109-110.
[30] *Mayor's Report* (1865) November.
[31] *Mayor's Report* (1866) In: *The South Australian Advertiser*, 27 November 1866.
[32] *Mayor's Report* (1867) In: *The South Australian Advertiser*, 30 November 1867.
[33] *Mayor's Report* (1869) In: *The South Australian Advertiser*, 3 December 1869.
[34] *Mayor's Report* (1870) In: *The South Australian Advertiser*, 29 November 1870; *Mayor's Report* (1871) In: *The South Australian Advertiser*, 30 November 1871.
[35] *Mayor's Report* (1872) In: *The Adelaide Observer*, 14 December 1872.
[36] *Mayor's Report* (1875) pp. 2-3.
[37] *Mayor's Report* (1876) pp. 3-4.
[38] *Mayor's Report* (1876) p. 4.
[39] *Mayor's Report* (1877) p. 11.
[40] *Mayor's Report* (1877) p. 11.
[41] *Mayor's Report* (1878) p. 53.
[42] *Mayor's Report* (1879) p. 80.
[43] Morton (1996) p. 157.
[44] Morton (1996) p. 157.
[45] Morton (1996) p. 157.
[46] Brown (1880) p. 6.
[47] Brown (1880) p. 3.
[48] Brown (1880) p. 8.
[49] Brown (1880) p. 8.
[50] Brown (1880) p. 3.
[51] Brown (1880) p. 6.
[52] *Mayor's Report* (1880) pp. 102-103.
[53] *Mayor's Report* (1880) p. 103.
[54] *Mayor's Report* (1881) pp. 108-109.

[55] *Mayor's Report* (1882) pp. 137-138.
[56] *Mayor's Report* (1883) pp. 135-136.
[57] *Mayor's Report* (1884) p. 116.
[58] *Mayor's Report* (1886) p. 112.
[59] *Mayor's Report* (1887) p. 70.
[60] *Mayor's Report* (1888) p. 41; *Mayor's Report* (1890) p. 77.
[61] *Mayor's Report* (1891) pp. 85-86.
[62] *Mayor's Report* (1892) p. 65.
[63] *Mayor's Report* (1895) p. 107.
[64] *Mayor's Report* (1895) pp. 64-65.
[65] *Mayor's Report* (1898) p. 90.
[66] *Mayor's Report* (1896) p. 96; *Mayor's Report* (1897) p. 110.
[67] *Mayor's Report* (1900) p. 296.
[68] *Annual Report* (1903) pp. 41-42.
[69] *Annual Report* (1903) p. 44.
[70] *Annual Report* (1904) p. 63; *Annual Report* (1905) p. 54; *Annual Report* (1906) p. 63.
[71] *Annual Report* (1907) pp. 71-72 ; *Annual Report* (1908) p. 45.
[72] *Annual Report* (1913) p. 64; *Annual Report* (1914) pp. 81-82.
[73] *Annual Report* (1915) p. 68.
[74] *Annual Report* (1915) p. 68; *Annual Report* (1916) p. 45.
[75] *Annual Report* (1917) p. 43.
[76] *Annual Report* (1918) p. 34.
[77] *Annual Report* (1921) p. 38; *Annual Report* (1922) p. 28.
[78] *Annual Report* (1936) pp. 36-37.
[79] *Annual Report* (1936) p. 37.
[80] *Annual Report* (1937) p. 21; *Annual Report* (1938) p. 11; *Annual Report* (1939) p. 27.
[81] *Annual Report* (1947) p. 26.
[82] *Annual Report* (1950) p. 26.
[83] *Annual Report* (1951) pp. 25-26.
[84] *Annual Report* (1952) p. 26; *Annual Report* (1953) p. 27.
[85] *Annual Report* (1953) p. 27.
[86] *Annual Report* (1954) p. 34.
[87] *Annual Report* (1956) p. 28.
[88] *Annual Report* (1957) p. 26.
[89] *Annual Report* (1958) p. 31.
[90] *Annual Report* (1960) p. 60.
[91] *Annual Report* (1967) p. 26.
[92] *Annual Report* (1971) p. 26.
[93] *Annual Report* (1977) [no page number] p. 16 (approx).
[94] *Annual Report* (1977) [no page number] p. 16 (approx).
[95] *Annual Report* (1985) [no page number] p. 15 (approx).
[96] *Annual Report* (1985) [no page number] p. 15 (approx).
[97] *Annual Report* (1996) p. 17.
[98] *Annual Report* (2001) p. 16.
[99] *Annual Report* (2005) p. 23.
[100] Crompton (1998) p. 9.
[101] Jones (2007) p. 266.
[102] *Mayor's Report* (1876) p. 4.
[103] Brown (1880) p. 24.
[104] Brown (1880) p. 24.
[105] *Mayor's Report* (1883) p. 135.
[106] *Annual Report* (1904) p. 63.
[107] *Annual Report* (1907) p. 71; *Annual Report* (1908) p. 45.
[108] *Annual Report* (1909) p. 64.
[109] *Annual Report* (1913) p. 64.
[110] *Annual Report* (1915) p. 68; *Annual Report* (1916) p. 44; *Annual Report* (1918) p. 33.
[111] *Annual Report* (1921) p. 38.
[112] *Annual Report* (1930) p. 15.
[113] *Annual Report* (1936) p. 36.

---

114 *Annual Report* (1954) p. 34.

Chapter Seven: Method

7.1 Method Overview

This chapter outlines the method undertaken to obtain data for use in tree age determination and tree longevity modelling. A diagram outlining an overview of the method used, and the numbered order of method sequence, is presented in Figure 7.1.

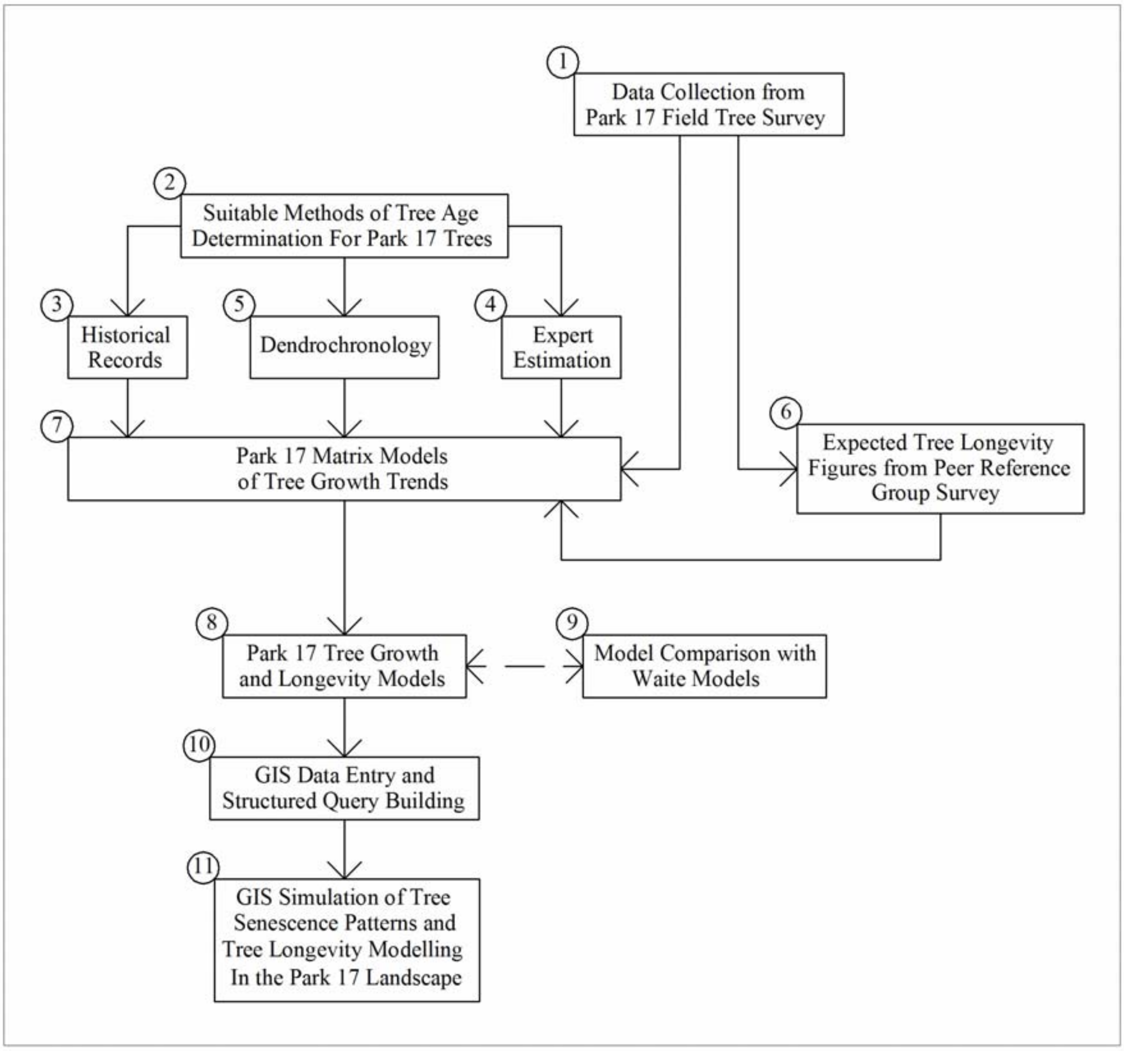

Figure 7.1. Diagram of method process used to model Park 17 trees.

Taxonomic details collected during the field survey formed a tree species list that was subsequently sent to a peer reference group, in the form of a self-administered survey. The purpose of this survey was to obtain tree longevity figures, or expected tree life spans, from experts on tree taxa within an Adelaide Park Lands context. Tree mensuration data recorded during the field survey of Park 17 trees combined with known tree ages of extant specimens formed matrix models indicating probable growth trends for the various taxa encountered. By applying the resulting functions to mensuration figures from trees with unknown ages, tree ages were calculated and subsequently combined with the peer reference group longevity figures to predict tree senescence in Park 17. The field data combined with the tree longevity figures were then modelled using GIS software, enabling future landscape scenarios and tree senescence patterns in Park 17 to be investigated.

7.2 Field Survey of Tuttangga/Park 17 Trees

A field survey was conducted within the Park 17 landscape to gather specific data on its tree population. The primary purpose of the field survey was to collect measurement (mensuration) details of the Park's tree specimens for use in conjunction with tree age information to develop tree age matrix models.

7.2.1 Tuttangga/Park 17 Site

Park 17 is situated in the southeast region of the Adelaide Park Lands (see Figure 2.2). An aerial photograph of Park 17 taken in 2002 is displayed in Figure 7.2. It is located centrally at 138.6166 decimal degrees Longitude and –34.9376 decimal degrees Latitude and comprises of 31.6 hectares. The majority of the Park 17 landscape is between 40 and 50 metres above sea level. The park is bounded by South Terrace on the north, Beaumont Road on the east, Greenhill Road on the south, and Hutt Road and Glen Osmond Road on the West. It contains a number of small amenity, sports, and maintenance buildings, with the majority of the land being public open space. Large sports fields are located near Greenhill Road in the south, and tennis courts, croquet lawns, and a dog obedience training area are located at various other positions in the park. Bush For Life maintains an area for the natural regeneration of indigenous plant species in the northern area, and an ephemeral creek runs through the interior of the park from east to west. The annual mean rainfall for the City of Adelaide, recorded by the Bureau of Meteorology at their Kent Town weather station for the 30-year period between 1977 and 2007 was 552mm. The climate statistics recorded for the Adelaide region from the Kent Town weather station, located 1.7km north of Park 17 are shown in Table 7.1.

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean maximum temperature (°C)	28.9	29.3	26.2	22.5	18.9	16.1	15.3	16.6	18.9	21.7	24.8	26.9	22.2	30

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean minimum temperature (°C)	17.0	17.1	15.1	12.3	10.1	8.2	7.4	8.2	9.6	11.4	13.8	15.5	12.1	30

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	20.6	13.2	25.5	39.4	59.8	82.7	75.2	67.9	62.9	47.0	32.1	27.6	552.4	30

Table 7.1. Climate Statistics for the City of Adelaide (Kent Town weather station) for the 30-year period between 1977 and 2007. Source: Bureau of Meteorology (2007b) <http://www.bom.gov.au/climate/averages/tables/cw_023090.shtml> (Accessed 03/07/2007).

Figure 7.2. Aerial Photograph of Park 17 taken in 2002. (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002)).

7.2.2 Permit to Undertake Scientific Research

In order to undertake fieldwork in the form of a tree survey in the Adelaide Park Lands, a Permit to Undertake Scientific Research was obtained. This was provided upon application to the Government of South Australia and was administered by the Department for Environment and Heritage: Science and Conservation Directorate, Research Permits Section. The permit allowed small samples of vegetation to be removed from the field for the purpose of taxonomic identification. The permit was number K24953_1 and was provided for the duration of the field survey, from the 8th of March 2005, to the 31st of March 2006 inclusive. Small vegetative samples were removed from the study area for the purpose of taxonomic identification on a number of occasions when confirmation of species was required with the assistance of external references. As a condition of the permit, vegetative samples were lodged with the State Herbarium of South Australia. A report outlining the data collected on the research under the permit was submitted to the Research Permit Section Director of National Parks and Wildlife within 28 days of the permit expiry date. This Permit to Undertake Scientific Research was required to be carried at all times while conducting the field survey research. A copy of this permit is included as Appendix 3.

7.2.3 Fieldwork Equipment

A variety of equipment was employed for the duration of the fieldwork, to assist with the measurement of tree parameters, such as dbh (DBH), tree height, and tree canopy span, and for data recording. Photographs of the important mensuration equipment used for the duration of the fieldwork are included along with the instrument descriptions in the relevant sections of this chapter.

7.2.3.1 Field Maps

The maps used in the field were sourced from an orthorectified aerial photograph (orthophotograph) of the Adelaide Park Lands. This was obtained from the South Australian Department for Environment and Heritage, and was Crown Copyright (2002). The orthophotograph was outlined as ‘Orthorectified colour image 'tiles' from the Digital

Image Data Base, radiometrically balanced and mosaicked, covering the greater metropolitan area of Adelaide.'[1] The orthophotograph, taken in October 2002, had a pixel resolution of 25cm, translating to one pixel on the orthophotograph representing 25cm x 25cm on the ground. The image represented an undistorted aerial view of the city of Adelaide, with a high level of detail. The entire orthophotograph was provided on two data compact discs, and together were over one gigabyte (Gb) in size.

Sections of the aerial orthophotograph containing Park 17 were formatted to A3 (42cm x 29.7cm) size and printed out in colour. They were then matt laminated to protect them from the weather for use in the field. These became the base maps upon which the spatial position of every tree encountered in the field was recorded.

7.2.3.2 Field Data Spreadsheets

Spreadsheet printouts were taken into the field and these enabled data to be recorded alongside each numbered tree in a legible format. Information recorded for each tree included the unique tree identification number, taxonomic data, diameter at breast height (DBH), height, canopy span, health status, and sample number, as detailed in sections 7.2.4.2 to 7.2.4.8, and any other relevant observations or notes as outlined in section 7.2.4.9. A sample of a blank fieldwork sheet is included as Appendix 4.

7.2.3.3 Diameter Tape

The tape used for the mensuration of trunk DBH in the field was a Lufkin Artisan Diameter Tree Tape with the Lufkin brand product code C106TPM.[2] The instrument consisted of a 10mm wide chrome clad steel tape with increments for measuring tree diameter on one side and circumference on the other. The tape was 650cm long, and capable of measuring trees up to 200cm in diameter. A winding drum on the side enabled tape retraction back into the case, and a chrome hook fastened the end of the tape to the tree as the measurement was taken. This piece of equipment was specifically designed for accurate tree trunk mensuration within silvicultural applications. An image of this instrument is shown in Figure 7.3.

7.2.3.4 Height Measuring Staff

The measuring staff, with the Brookeades label and design code of ‘AUST 54/561’, consisted of two one-metre lengths of aluminium tubing threaded together on a brass thread to form one staff two metres in total length. One end was constructed of solid steel formed into a point, with a foot peg on one side that enabled the user to push the staff into the soil. The staff was painted in 50cm long alternating red and white colours that enabled clear visibility when viewed from a distance. A piece of yellow tape placed on the staff at a height of 1.3m provided ease of height positioning for DBH mensuration. An image of this instrument is shown in Figure 7.4.

7.2.3.5 Field Data Recording Equipment

Various items were also used for recording data in the field. Pencils were used to record measurements onto the spreadsheets in the field, and also assisted in the measurement of tree height when used in conjunction with the measuring staff, as detailed in section 7.2.4.5. A ‘chinagraph’ pencil and permanent marker were used to record both spatial positions and unique tree numbers on the printed map, to enable the spatial data to correspond with mensuration data recorded on the field data spreadsheet. A piece of 5mm thick Medium Density Fibreboard (MDF) cut to size provided support for recording on the maps and spreadsheets, and steel binder clips held the sheets in position and were particularly useful when windy conditions prevailed.

7.2.3.6 Safety Equipment

A high-visibility (‘hi-visibility’) safety vest with reflective strips was worn while conducting the fieldwork survey. This piece of equipment enabled both council maintenance staff and other users of the park to identify the wearer in the field.

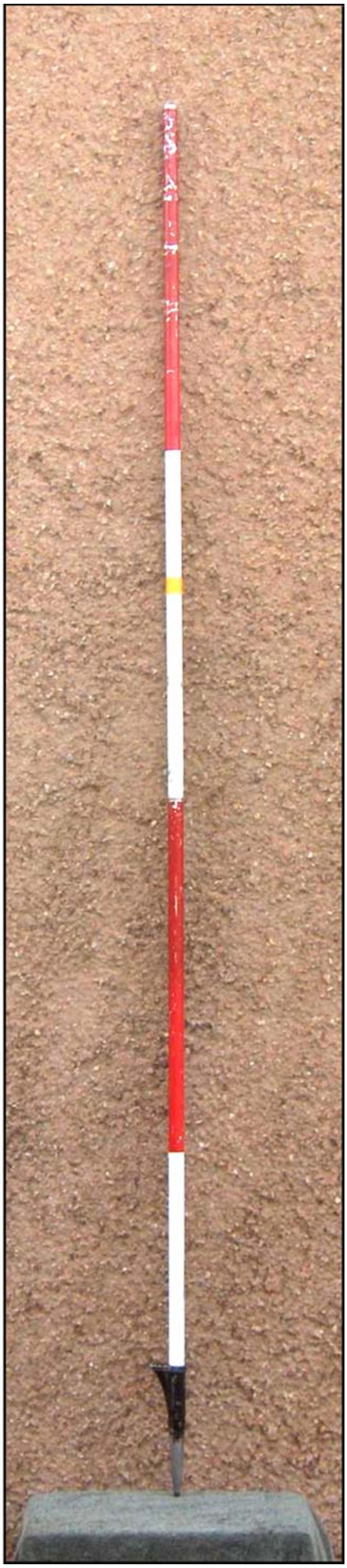

Figure 7.3. (Above) Lufkin Artisan Diameter Tape C106TPM. The Diameter Tape casing itself, shown here, is 8.5 cm in diameter.

Figure 7.4 (Right) Brookeades Tree Height Measuring Staff AUST 54/561
Note the 50cm sections of alternating red and white colouration to aid visibility, the yellow strip of tape to indicate DBH level, and foot peg for inserting the staff into the soil.

7.2.3.7 Vegetation Sample Collecting Equipment

A number of items were employed for the process of vegetation specimen collection in the field. A pair of sharp secateurs were used when a sample was required to be removed from a tree for identification purposes. Long-handled secateurs with a two-metre extension enabled samples to be retrieved from taller specimens. A fine-tipped permanent marker was used to clearly label vegetation samples taken, as this wrote on most surfaces including plastic bags and masking tape. Zip lock plastic bags of various sizes were used to enclose smaller samples, in particular the small fruit collected from eucalypts. Fresh fruit collected for identification could not be stored permanently in these bags until they were properly dried. Pieces of masking tape were used for labelling on small branches of samples taken from the field. A plant sample press was used to press and carry small samples in the field. It consisted of two galvanized steel mesh sheets, each 30cm x 45cm in size, and held together with an elasticised strap. Fresh labelled samples were collected and placed between pages of newspaper, and pressed between the steel sheets. The newspaper pages were replaced regularly until the fresh samples had dried.

7.2.4 Field Survey Data Capture

A number of various mensuration and data collection methods were used to detail the field notes and capture data for computation and analysis.

7.2.4.1 Locating Spatial Positions

The position of each tree surveyed in the Park 17 landscape was located and recorded. If the tree's location was not clearly visible on the orthophotograph, the tree was located using other visible landmarks concurrent with both the surrounding landscape and the orthophotograph. Once spatially located, the tree's position was marked on the laminated orthophotograph, and a unique number assigned. The spatial positioning of each tree was recorded for digital input into the Geographical Information System (GIS) software.

7.2.4.2 Unique Tree Identification Number

Each tree measured in the field was assigned a unique number. This enabled spatial data to be linked with data recorded on the field spreadsheets. All trees within Park 17 were assigned the prefix ‘17’, followed by five digits unique to each tree measured. The unique number for the first tree was 1700001, the second 1700002, and so on. This allowed up to 99,999 trees to be recorded for Park 17.

7.2.4.3 Taxonomic Data

Taxonomic data for each tree was recorded in the field. Where specimens were unidentifiable in the field, small samples were retrieved for later analysis or clarification using the necessary references (see section 7.2.5 on Sample Collection and Identification).

7.2.4.4 Diameter at Breast Height

Tree trunk DBH was recorded using the Lufkin Artisan Diameter Tree Tape. The height measuring staff was placed next to the tree and the position 1.3m from the ground level noted on the trunk. Where the ground was uneven or sloping, the higher soil level was used as the ground level benchmark. The diameter tape was placed around the trunk, at the 1.3 metre height, perpendicular to the stem, and the diameter recorded in centimetres, as shown in Figure 7.5. For specimens presenting more than one trunk per tree at the 1.3m breast height, all trunks at 1.3m high were measured individually, and then added together to form a single DBH recording for specimens with multiple trunks. Where bosses, irregularities, or very large branches occurred at the 1.3m mensuration height, the nearest unaffected part of the trunk closest to 1.3m from the ground level provided the DBH for the tree. All trees four metres in height or taller had their DBH recorded at 1.3m above ground level. For trees shorter than four metres in height, trunk diameter was recorded at 0.5m above ground level. DBH measurements were recorded to the nearest centimetre, and included the tree bark to avoid tree damage.

Figure 7.5. Measuring trunk DBH using the Lufkin Artisan Diameter Tree Tape. DBH was measured at 1.3m above ground level, as indicated by yellow tape on the height measuring staff. This specimen had a DBH recorded of 82cm.

7.2.4.5 Tree Height

Tree height was calculated using the height measuring staff. The sharp foot peg end of the staff was inserted upright into the soil close to the base of the tree, in a position that enabled the staff to be visible when viewed from a distance. The observer stood back from the tree far enough to clearly see both the length of the staff, and the top of the tree. Holding a pencil at arms-length, the observer noted the height of the measuring staff on the pencil, and counted the number of one or two metre increments from the ground level to the top of the tree to obtain the tree height. A diagram of this method is shown in Figure 7.6. Tree height, where possible, was measured to the nearest 0.5m.

Figure 7.6. Measuring tree height in the field using the height measuring staff. The two-metre staff has been highlighted in red, with two-metre height measurements highlighted in yellow.

7.2.4.6 Canopy Span

Tree canopy span was calculated using measured paces. The observer's paces were measured to obtain the distance covered per pace, and the canopy span paced out across the diameter of the canopy span, with the distance calculated as a mean value and recorded. Canopy span was measured to the nearest metre.

7.2.4.7 Health Status

The health of the tree was based primarily upon a visual inspection of the tree's canopy above ground, and the presence of dieback or dead branches noted as percentage categories. This was approximated into five health level categories: A, B, C, D and E, as outlined in Table 7.2.

Health Level	Description
A	Tree was a healthy specimen with less than ten per cent branch dieback present in the canopy. Overall the tree appeared to be in good health
B	Tree was reasonably healthy, with between ten and 40 per cent branch dieback present in the canopy. Overall the tree appeared to be in satisfactory health
C	Tree was not in particularly good condition, with more than 40 percent of branch dieback present in the canopy. Overall the tree appeared to be in a poor state of health
D	Tree was in extremely poor condition. Tree had no live foliage present, and upon detailed inspection using secateurs to examine the bark, no live cells were present in the cambium layer of tissue at any location on the tree. The tree was considered dead
E	Tree had been removed from the landscape subsequent to its details having been recorded during the 12-month survey period. This status was given in addition to the health level of either A, B, C, or D, as an indicator of tree health prior to tree removal from the landscape

Table 7.2. Tree health levels recorded in the Park 17 field survey

7.2.4.8 Sample Number/Notes

The unique number assigned to each tree provided the sample number when a sample was collected from the field. When a sample was collected it was noted in this column. Field notes were also recorded in this column and reflected observations considered influential to the mensuration data recorded, the health of the tree, potential impacts upon longevity, or various other tree-related issues potentially warranting a more detailed examination by an arborist at a later stage.

7.2.5 Sample Collection and Identification

A number of samples were removed from the field to enable positive identification using current scientific nomenclature.[3] These samples were provided with the tree's unique number to allow identified taxa to be located spatially in the field. Identification of specimens was conducted using a selection of reference books, and sample comparisons made to labelled living specimens located in either the Adelaide Botanic Gardens or in the Waite Arboretum. Taxa collected for identification purposes were lodged with the State Herbarium of South Australia as voucher specimens as per the requirements of the Permit to Undertake Scientific Research.

7.2.6 Field Survey Data Entry

Following all field survey data collection, all results were entered into Microsoft Excel, a computer-based software program with spreadsheet facilities. Each tree measured possessed its own row space horizontally, and columns, or 'fields' were established, each to contain one of the following specimen attributes outlined in Table 7.3. Data recorded as descriptive 'Notes/Comments' were sorted into categories and assigned numbers 1 to 21, as shown in Table 7.4. Each tree surveyed was assigned either a 'Yes', or a 'No', for each of these 21 descriptive attributes.

'Field' Name	'Field' Name Description
Tree_ID	Unique tree identification number (e.g. 1700603)
Family	Family (e.g. Myrtaceae)
Genus	Genus (e.g. Eucalyptus)
Specific	Denotes a hybrid where applicable (e.g. X)
Species	Species (e.g. camaldulensis)
Infraspf	Subspecies or Varietal type (e.g. var)
Infrasp	Subspecies or Varietal nomenclature (e.g. camaldulensis)
Cultivar	Cultivated variety
Common_Nme	Common name (e.g. River Red Gum)
DBH	Tree diameter at breast height in centimetres
Height	Tree height in metres
Canopy_Spn	Tree Canopy span in metres
Health	Health level A, B, C, D, or E
Removed	Date of specimen removal from Park 17

Table 7.3. List of 'fields' used as attributes to contain separated data for trees surveyed in Park 17.

Field Name	Description
1	Scratched bark (graffiti)
2	Spray paint on bark (graffiti)
3	Marker / brush paint / oil pastel on bark (graffiti)
4	Snapped branches (less than 2.5 metres above ground level)
5	Leader broken off at base (regrowth present)
6	Leader broken off at base (regrowth not present)
7	Vehicle collision scar(s)
8	Ringbarked
9	Main trunk(s) lopped at ground level (regrowth present)
10	Main trunk(s) lopped at ground level (regrowth not present)
11	Pollarded between ground level and 2 metres above ground level
12	Pollarded higher than 2 metres above ground level
13	Slash marks /bark damage on trunk near ground level
14	Leader slashed off at or near ground level
15	Concrete-filled trunk cavity
16	Bridging of ringbarking
17	Hollow in trunk
18	Trunk wound (unspecified)
19	Large lower limb(s) broken off
20	Borer/termite evidence
21	Defoliation (vertebrate or invertebrate)
22	Severe defoliation (vertebrate or invertebrate)
23	Axe marks/scars
24	Fire Damage

Table 7.4. List of 'field' names (coded numbers) used to describe tree attribute observations (notes/comments) recorded in Park 17 trees surveyed.

7.3 Tree Age Determination in Tuttangga/Park 17

Tree age determination of specimens extant in the Park 17 landscape was undertaken where data were available, and where reliable figures of tree age in years could be provided and linked to those specimens surveyed. Sources included extant historic planting records, expert estimations of tree ages, and tree ring counting when available. Tree ages were collected for use in the tree age matrix models described in section 7.5.1.

7.3.1 Extant Historical Tree Age Data

A number of trees surveyed in Park 17 correlated with historic planting records obtained from extant archival data. Where this data were available, and deemed reliable, certain trees within Park 17 were assigned planting dates or dates of establishment.

7.3.2 Expert Estimation Tree Age Data

A qualified arborist was engaged to identify individual tree specimens in the field, and provide estimated ages for the specimens encountered. The arborist was considered an expert in the field of arboriculture, and ages of trees were provided based upon experience gained by the expert within that field over a period of time. Tree ages were supplied in years, and were given in a 'walking lecture' format. Tree ages were recorded on adhesive tape, which was then attached to each tree for identification. Following the expert's estimations of tree age, unique tree numbers were obtained for the specified trees, and estimated ages were assigned to the identified age-determined specimens. Moore (2008) has noted that this method of determining tree age may provide inaccurate figures, however, the inherent value of assigning estimates of tree age to measured Park 17 field specimens for the purpose of tree modelling was considered important.[4]

7.3.3 Dendrochronology

The counting of tree rings was undertaken to obtain approximate tree specimen age in the Park 17 site. Trees were deemed suitable for this method of age determination if their external mensuration details had been obtained prior to the felling of the tree. Trees were felled once deemed dead or unsafe by the Adelaide City Council, and removal had been approved. One specimen in Park 17 fitted these criteria, and was inspected for tree ring analysis. Steel pins were inserted into the tree stump to indicate every fifth growth ring for ease of counting (see Figure 7.7). This figure was recorded as an approximation of the tree's age. Tree coring to obtain ring counts was not undertaken during either the Park 17 field survey or the age determination process.

Figure 7.7. Photograph of growth ring counting on felled tree stump in Park 17. Each steel pin denoted five growth rings, and are shown here to scale with a Commonwealth of Australia 50-cent piece.

7.4 Tree Longevity Figures from Peer Reference Group Survey

In order to obtain primary data on the expected longevity of trees within the Adelaide Park Lands, a peer reference group was assembled in March 2006. The purpose of this was to obtain primary data of expected tree longevities based upon expert opinions that reflected tree longevity figures for that point in time.

7.4.1 Assemblage of Peer Reference Group Respondent List

The peer reference group was assembled from experts with knowledge of tree longevities within an Adelaide context. An arborist based in Adelaide with an awareness of other experts who possessed knowledge on tree longevities, provided the population list of respondents for the peer reference group survey. Respondents in the peer reference group were contacted by means of telephone or through postal correspondence, and a list of respondents prepared to undertake the survey compiled.

7.4.2 Survey Design

The surveys received by the respondents were in a tabulated format with data provided in rows and columns. The survey comprised of data arranged in four vertical columns: ‘Taxa’, ‘Common Name’, ‘Predicted Life Span on Adelaide Plains (Specifically Adelaide Park Lands)’, and ‘Revised Life Span on Adelaide Plains (Specifically Adelaide Park Lands)’. The first three of these columns were filled, while the fourth was left blank for the respondent to submit their proposed tree longevity figures for each Taxon. The survey was produced in Microsoft Excel Worksheet format with the file extension ‘.xls’.

The first column, labelled ‘Taxa’ contained a list of all tree taxa located within the field survey area. Current scientific nomenclature was used to provide these data. The second column, labelled ‘Common Name’ contained a list of commonly used names for each of the taxa. The third column, labelled ‘Predicted Life Span on Adelaide Plains (Specifically Adelaide Park Lands)’ contained figures of tree longevity, in ‘years’, provided as personal estimates, by the interviewer. The fourth column, labelled ‘Revised Life Span on Adelaide Plains (Specifically Adelaide Park Lands)’ was left for the respondent to fill in with their own proposed tree longevity figures. The survey was designed as a self-administered survey. The survey was produced in Microsoft Excel format. A hard copy sample of the survey received by the respondents is included as Appendix 10.

In addition, two letters of introduction, outlining the rationale for conducting the peer reference group survey, accompanied the surveys. The letters assured confidentiality for each of the respondents, and the intended purpose of the figures provided by the respondents in the survey.

7.4.3 Method of Survey Distribution

The survey was conducted as a ‘self-administered survey’ during the six-month period between March and August in 2006. This form of survey, outlined by Walter (2006) occurs where the survey is undertaken away from the direct supervision of the interviewer.[5] Surveys were distributed either electronically or through conventional postal services, depending upon the availability of email services and the preferences of the respondent. Respondents received electronic surveys as three files attached to an email: two letters of introduction and the tree longevity survey itself provided in Microsoft Excel Worksheet format (.xls), as outlined in section 7.4.2. Respondents received hard copies through the post in the same format, with two letters of introduction and the survey printed in hardcopy laid out across five landscape-oriented pages, as shown in Appendix 10.

7.4.4 Tree Longevity Primary Data Collection and Analysis

Surveys returned as attachment files to emails were stored electronically. Surveys returned as hard copy printouts had their data entered into computer-based spreadsheets (Microsoft Excel Worksheets). One survey was completed and returned during a meeting to discuss the survey itself. All survey responses were entered into the Microsoft Excel Worksheets in the order returned. Following the completion period and return of all surveys, the data entered into the worksheet was analysed and computed to provide figures that accurately reflected the responses provided by the peer reference group respondents. The rate of response was 76 per cent, as detailed in Appendix 11.

7.4.5 Returning Primary Data Results to Respondents

Following the compilation of all primary data collected, respondents received copies of the tabulated figures. An explanation sheet accompanied the returned data, and outlined the following four data columns: 'Average Life Span on Adelaide Plains', 'Minimum to Maximum Life Spans from Averages', 'Standard Deviation from the Mean', and 'Number of Respondents Submitting an Age'.

'Average Life Span on Adelaide Plains' contained the mean tree longevity figure for each taxa, to the nearest year, from the tree longevity figures provided by the respondents. This was calculated as the sum of the longevity figures provided by the respondents, divided by the number of responses. 'Minimum to Maximum Life Spans from Averages' was the numerical range, in years, within which the majority (greater than 50 per cent) of the respondents submitted a tree longevity figure. 'Standard Deviation from the Mean' contained the average deviation of the respondent-provided tree longevities from the 'Average Life Span on Adelaide Plains' figure obtained in years. 'Number of Respondents Submitting an Age' contained, as a percentage, the number of respondents that provided a tree longevity figure for that taxon. All respondents to the survey received the tabulated figures as attachments to an email, or as hard copies sent through regular postal services, depending upon respondent preferences.

7.5 Tree Longevity Projections

Tree age matrix models combining tree mensuration parameters with determined tree ages in the landscape were created to discover growth trends for various tree species encountered during the field survey of Park 17. The resultant equations from these models were then applied to mensuration parameters from other Park 17 surveyed trees with identical taxa and unknown age. The tree ages obtained were then applied to longevity figures provided by the peer reference group for tree longevity projections. The study by Lukaszkiewicz *et al.* (2005) reviewed in Chapter 4.2.2.1.2, observed the exponential nature of tree growth in *Tilia* species in Poland, where tree age was regressed on DBH. This exponential model of tree growth provides a suitable study upon which to base the exponential nature of growth trends for Park 17 trees.

7.5.1 Tree Age Matrix Models

For the tree age growth models, trees of identified age, as determined using the process outlined in sections 7.3.1 to 7.3.3, were plotted against the tree mensuration data obtained from the field survey conducted in Park 17, outlined in section 7.2.4. This was to determine a growth trend for each tree taxa, for each of the following parameters reflective of tree growth: DBH, tree height, and canopy span. Using these growth trends, trees of unknown age could have their age determined based upon the most reliable growth parameters, and their life spans projected into the future based upon the combination of calculated age and potential tree longevity, as obtained from the peer reference group survey responses.

Using data separation by species, point matrix graphs were plotted with tree age regressed on tree DBH, tree age regressed on tree height, and tree age regressed on tree canopy span to create three distinct point matrices for each taxa. Each point on the matrix represented a Park 17 surveyed tree with age determined. A trendline was added to each matrix of points using the software program SPSS 13.0, and from this an exponential function was obtained as a reflection of the growth trend of each growth parameter within a taxon. From this exponential function, a correlation coefficient was obtained that indicated the relationship between the scattergram points, and the trendline itself, in turn reflected confidence levels for the exponential function when regressed to the point matrix data.

7.5.2 Point Matrix Model Construction Method

Example: Tree Age Regressed on Tree DBH for *Eucalyptus camaldulensis* var. *camaldulensis* (River Red Gum)

Only data for the one species, in this case *Eucalyptus camaldulensis* var. *camaldulensis* (River Red Gum), was used for the construction of each model, as specified by the separation of data by species, resulting in three unique models for each taxon, based upon either DBH, height, or canopy span. Additionally, only those field specimens with their age previously determined within the species specified were used for the model construction.

DBH, in centimetres, was plotted as the abscissa (independent variable) on the *x*-axis, and tree age, in years, was plotted as the ordinate (dependent variable) on the *y*-axis, forming a scatter of points. Each point reflected a known River Red Gum specimen in the field, with its proposed age determined previously, and DBH as measured during the field survey period. An exponential function was regressed on these parameters, forming an equation mathematically, and a trendline visually produced on the graph. This exponential function reflected the DBH growth trend in centimetres, over time in years, for the River Red Gum in this example. Correlation coefficients were obtained from the graph as a reflection of the relationship between the matrix of points and the exponential function, and as an indicator of confidence level for the growth function plotted, and therefore data reliability.

7.5.3 Matrix Model Testing Using Waite Datasets

In order to examine the growth models developed for growth trend analysis, a second dataset for a number of the taxa located in Park 17 was required for comparison. This data was obtained from both historical tree mensuration details recorded in the Waite Arboretum Archives, and from tree mensuration data collected during a 2006 field survey of the Arboretum. Situated approximately three kilometres south-southeast of Park 17 in the Adelaide suburb of Urrbrae, the Waite datasets provided mensuration details concurrent with those collected in the Park 17 field survey, for a number of Park Land taxa encountered.

Considered appropriate for comparison, the Waite datasets were taken from trees 'growing under natural annual rainfall of 626mm', and included planting dates and the dates of subsequent DBH and height mensuration procedures recorded over the life of the trees.[6] From these archival records at the Waite Arboretum, taxa common to both the arboretum, and Park 17 had their details collected for model testing and growth trend comparison. Tree age matrix models were then constructed from the Waite datasets using the procedure outlined in sections 7.5.1 and 7.5.2. Through a comparison of growth functions created from separate datasets of the same species, similarities and differences between the growth trends were correlated.

7.5.4 Matrix Models For Tree Age Determination

Using the exponential function obtained from the point matrix model outlined in the previous sections, a tree of unknown age was assigned an age, based upon its DBH parameter collected in the field survey. This assigned age was then subtracted from the expected tree longevity figure for that taxon, as supplied by the peer reference group, providing a future date at which that tree would be expected to reach senescence. This process was then repeated for all trees within the species, and the data prepared for spatial data entry as outlined in section 7.6.1.

7.6 GIS Model Construction

Following tree growth model construction and data input using the Microsoft Excel program, all field data combined with the growth model computation figures detailing tree ages were entered into a GIS software package known commercially as 'ArcInfo 9.0', released by software manufacturers ESRI. This program comprised a number of smaller software programs that included ArcMap, ArcCatalog, ArcToolbox, ArcScene, and

ArcView. The primary GIS program used for spatial map generation, data input, and analysis was ArcMap.

7.6.1 Creating the Georeferenced Base Map

In order to achieve georeferenced maps suitable for GIS model creation with the aim of accurate spatial data entry, a dataset containing the correct projection for the Adelaide region was required, and was obtained from the Corporation of the City of Adelaide. This dataset, labelled 'parksurf' was added into a new ArcMap program file as a new layer with a 'shapefile' format, and with the file extension '.shp'. This parksurf shapefile consisted of a series of 'polygons' that represented the property under the custodianship of the Adelaide City Council, and embedded within was the projected coordinate system required: GDA 1994 Transverse Mercator (GDA 1994).

The orthophotograph section of Park 17 was then added as a second layer in the ArcMap file in the form of a 40-megabyte (Mb) tiff format file with the extension '.tif'. The image was georeferenced using the 'Georeferencing' tools to align it spatially with the previously described shapefile labelled 'parksurf'. Once aligned, the new layer was labelled 'Park 17 Map', and this was to form the base for spatial positioning of the trees surveyed. Following this process, the parksurf layer was not required and was removed from the ArcMap interface.

7.6.2 Constructing the Field Data Shapefile

Using ArcCatalogue, a new shapefile labelled 'Park 17 Trees' was created based upon the spatial reference and projection data (GDA 1994) embedded in the parksurf shapefile. The new 'Park 17 Trees' shapefile was created as a 'point' shapefile, with each tree surveyed in the field represented by a 'point' on the ArcMap interface. Once created, this new shapefile, 'Park 17 Trees', was added into the ArcMap interface as a new layer.

7.6.3 GIS Data Entry

Using the newly created ‘Park 17 Trees’ layer, an ‘editing session’ was initiated. This enabled data in the form of spatially orientated ‘points’, in the form of trees surveyed in the landscape, to be manually added as individual items on the ArcMap ‘Park 17 Trees’ layer. Beginning with the first tree surveyed in Park 17, all trees were added as ‘points’ on the orthophotograph map in the positions determined in the field tree survey. Each point added a new ‘row’ to the shapefile’s attribute table, and corresponded to a tree surveyed in the landscape. Points were added in the exact order in which they were recorded in Park 17, to enable the exact matching sequence to the previously entered Microsoft Excel spreadsheet field survey records. Once all trees surveyed in Park 17 were added spatially as ‘points’ on the map, the blank attribute table could be populated with fieldwork survey columns to contain the recorded data. The attribute table at this point contained each surveyed tree as a unique number, but with no further details of tree attributes.

The next stage was to create a number of ‘fields’, or columns, within the new ‘Park 17 Trees’ layer, and these were to contain all of the tree survey fieldwork data collected in Park 17. This was to form the ‘attribute table’ linking spatially referenced points, representing actual trees surveyed in Park 17, to important data, such as tree species, DBH, and tree height. The content of each ‘field’ was specified, for example, text containing the common names required the column format ‘Text’, and the column containing DBH numeric figures required the format ‘Double’. The ‘fields’ created were concurrent with those in the Microsoft Excel spreadsheet containing the tree field survey data, enabling ease of data sharing between the two programs and for ease of attribute table population.

After commencing a new editing session in the ‘Park 17 Trees’ layer, data were copied from the Microsoft Excel spreadsheet containing the field survey data entered previously (see section 7.2.6), and pasted into the blank attribute table using ‘copy’ and ‘paste’ commands. The Microsoft Excel spreadsheet contents were copied as a single item, as the rows and columns in both were precisely concurrent. After this process, the populated Park 17 Trees layer was ready for both spatial and temporal analysis using structured queries in combinations.

7.6.4 GIS-Based Simulation

Following spatial model construction and data input, the Park 17 Trees layer combined with the aerial orthophotograph of Park 17, was equipped for use as a tool that enabled the projection of future tree senescence in the landscape. Using the 'Select By Attributes' tool embedded within the ArcMap program, structured queries were developed, in combination, to project future tree senescence patterns in Park 17.

7.7 Summary

Using the combination of field-gathered tree mensuration parameters, age-determined tree specimens, mathematical growth curves, and GIS modelling, simulations of tree longevity and senescence patterns were able to be created for trees within the Park 17 landscape. The ability to add or modify further data to these simulation models as they become available enable the mathematical growth models to be updated, creating simulations of higher accuracy and greater analytical capability. Results obtained from the method of modelling tree senescence proposed here are summarised in Chapter Eight.

Chapter 7 Notes

[1] South Australian Department for Environment and Heritage (2004) Metadata p. 1.
[2] Forestry Tools (2007) <http://www.forestry tools.com.au/Tapes.htm> (Accessed 14/08/2007).
[3] Texts sourced for current scientific nomenclature:
Spencer *et al.* (1997) *Horticultural Flora of South-Eastern Australia: Identification of Garden and Cultivated Plants*, Volumes 1-5, University of New South Wales Press, Sydney.
Brooker *et al.* (2002) *Euclid: Eucalypts of Southern Australia*, Multimedia CDROM, 2nd Edition, CSIRO Publishing.
[4] Moore (2008) p. 5.
[5] Walter (2006) p. 200.
[6] Waite Arboretum (2007) <http://waite.adelaide.edu.au/arboretum/> (Accessed 22/08/07)

Chapter Eight: Results

8.1 Results Overview

The results displayed in this Chapter reflect the many outcomes that arose from the methodology described in Chapter 7. This methodological process involved conducting a field survey of the trees contained within Park 17 and recording important mensuration parameters of each specimen such as trunk diameter at breast height (DBH), tree height, and canopy span, as well as taxonomic details. A list of Park 17 taxa, along with pre-emptive estimates of tree longevity, was sent out to a group of experts involved in horticulture and arboriculture (peer reference group) to obtain their estimates of tree longevities for each taxon within the Adelaide Park Lands environment (tree longevity survey). Results from the returned self-administered surveys were tabulated to obtain tree longevity figures for each taxon. Using available data obtained from historical records, expert opinion, and dendrochronological study, a number of Park 17 trees were assigned ages. Assigned tree ages, and collected field mensuration parameters, were plotted as x-y variables to form a matrix of points. These points reflected DBH, tree height, and canopy span as the independent variable (x), while the assigned tree age was the dependent variable (y), for each taxon. A 'best fit' exponential growth curve was then fitted to each set of matrix points to obtain growth trends that reflected each mensuration growth parameter with relation to age per taxa. Tree growth models were also compared to models created from data obtained at the Waite Arboretum from field and archival records. Following model comparison, the Park 17 growth equation parameters were then applied to Park 17 trees with known field mensuration parameters but unknown ages to obtain tree establishment dates. By adding tree longevities proposed by the peer reference group collected earlier, future dates of senescence were calculated and applied to each Park 17 tree. The tabulated taxonomic, mensuration, and age tree data was then modelled spatially using GIS, and future landscape scenarios obtained, through the use of structured queries.

Provided here as a separate Chapter, results are displayed in recorded numerical and statistical formats, with descriptions outlining the results shown. Tables, equations, models, and images, are included in the relevant Appendices. Both discussion and conclusions arising from these results are presented in Chapter 9.

8.2 Tuttangga/Park 17 Field Survey Results

The fieldwork, conducted over a period of twelve months, resulted in the collection of a large quantity of data reflecting various details of the Park 17 tree population at a particular point in time. This data may be considered as a 'snapshot' for Park 17 over the period between March 2005 and February 2006.

A brief summary of the 2873 specimens surveyed in Park 17 can be seen in Tables 8.1 and 8.2. A list containing the Park 17 taxa, along with the quantities recorded both over and under 4m in height for modelling purposes, is included as Appendix 5. Statistical data reflecting the mensuration parameters of DBH, tree height, and canopy span across the Park 17 specimens is displayed as Appendix 6. The quantities of Park 17 specimens recorded at various health levels, and collated by taxa, are included as Appendix 7. Other miscellaneous field observations of note or further investigation from the surveyed can be seen in Table 8.3, with complete tables of these observations collated by taxa in Appendix 8.

Total Number of Trees, Shrubs, and Palms Surveyed in Park 17				
Shrubs	**Trees**	**Shrubs/Trees**	**Palms**	**Total**
19	2781	72	1	**2873**

Table 8.1. Total number of trees, shrubs and palms surveyed in Park 17.

Numbers of Tree, Shrub, and Palm Taxa Obtained from the Park 17 Field Survey				
Shrub	**Tree**	**Shrub/Tree**	**Palm**	**Total**
9	48	5	1	**63**

Table 8.2. Numbers of tree, shrub, and palm taxa obtained from the Park 17 Field Survey.

Park 17 Field Survey Results **Miscellaneous Field Observations of Interest**

Taxa	Observation Number Assigned																				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
	Quantity of Miscellaneous Field Observations Recorded Per Taxa																				
Acacia pycnantha				6											1			8			
Acacia spp.				2														1			
Allocasuarina luehmannii											2							1			
Allocasuarina verticillata				5						5	2										
Callitris gracilis				2																	
Celtis australis	2																				
Ceratonia siliqua								1				1					2				
Corymbia ficifolia																	1				
Corymbia maculata	1							1													
Cotoneaster spp.				1																	
Eucalyptus camaldulensis var. *camaldulensis*	24	4	3	30				1	2	7				3	5		9	658	20	3	2
Eucalyptus cladocalyx	28	3		1					3	2				2	5		6	3			
Eucalyptus largiflorens				5				1		1					1			63	2		
Eucalyptus leucoxylon subsp. *leucoxylon*	1			31						2						1		81	1		
Eucalyptus microcarpa				13						3					1			70	1		
Eucalyptus odorata															1		1	7			
Eucalyptus sideroxylon								1											4		
Eucalyptus spp.				1	6	1		1			1							64	1		
Eucalyptus torquata				1																	
Fraxinus angustifolia subsp. *angustifolia*	1	5							1					1		1					
Gleditzia triacanthos				1										1			1				
Melaleuca nesophila				1																	
Melia azedarach var. *australasica*														1		1					
Pinus canariensis							2						2								
Pinus halepensis		2					1		1				1								
Pinus pinea	1																				
Platanus X *acerifolia*								4						1							
Populus alba	1													2	1	1	1				
Populus X *canescens*	7																				
Schinus molle var. *areira*								1						4	2		1	1			
Ulmus procera		1												10		1				1	
Totals	66	15	3	100	6	7	3	11	7	20	5	1	3	25	17	5	22	957	29	4	2

Table 8.3. Park 17 field survey results: Miscellaneous field observations of interest. Observation number assigned correlates with data displayed in Table 7.4.

8.3 Tuttangga/Park 17 Tree Age Determination Results

From the 2873 specimens examined in the Park 17 field survey, 156 were assigned an age using the tree age determination methods outlined in Chapter 7.3. A summary of the quantities per taxa of the age determined specimens is shown in Table 8.4. A summary of age ranges and average age calculated by taxa for age determined Park 17 trees is shown in Table 8.5. Detailed tree age data at the individual tree level for these 156 trees are included as Appendix 9.

Summary of Tree Age Determination Methods Used Per Taxa			
	Quantity of Age Determined Specimens Obtained Per Method Used		
Taxa	Expert Estimation	Historical Record	Dendrochronology
Eucalyptus camaldulensis var. *camaldulensis*	26	0	0
Eucalyptus cladocalyx	11	0	0
Eucalyptus leucoxylon subsp. *leucoxylon*	14	0	0
Eucalyptus microcarpa	13	0	0
Fraxinus angustifolia subsp. *angustifolia*	7	81	0
Pinus halepensis	3	0	1
Totals:	74	81	1

Table 8.4. Summary of tree age determination methods used per taxa.

Summary of Tree Ages Determined From Park 17 Field Survey		
Taxa	Age Range Recorded (Years) (Years)	Average Age Recorded (Years)
Eucalyptus camaldulensis var. *camaldulensis*	7.5 - 155	68
Eucalyptus cladocalyx	30 - 105	52
Eucalyptus leucoxylon subsp. *leucoxylon*	15 - 175	34
Eucalyptus microcarpa	15 - 25	17
Fraxinus angustifolia subsp. *angustifolia*	65 - 135	85
Pinus halepensis	45 - 109	77

Table 8.5. Summary of tree ages determined per taxa.

8.4 Peer Reference Group Tree Longevity Survey Results

Statistical figures reflecting respondent survey data, such as response rate and refusal rate, are included as Appendix 11. Statistical figures obtained from the tree longevity survey of the peer reference group are included in Appendices 12 and 13. Tree longevity figures extracted from the surveys were tabled as Appendix 12, with longevity figures provided for each taxon separately. Standard deviations from the supplied longevity figures, along with response rates per taxa, are also provided in Appendix 12. Bar graphs displaying mean tree longevities arranged from longest lifespan to shortest are shown in Figures 8.1 to 8.5, and are also included as Appendix 13.

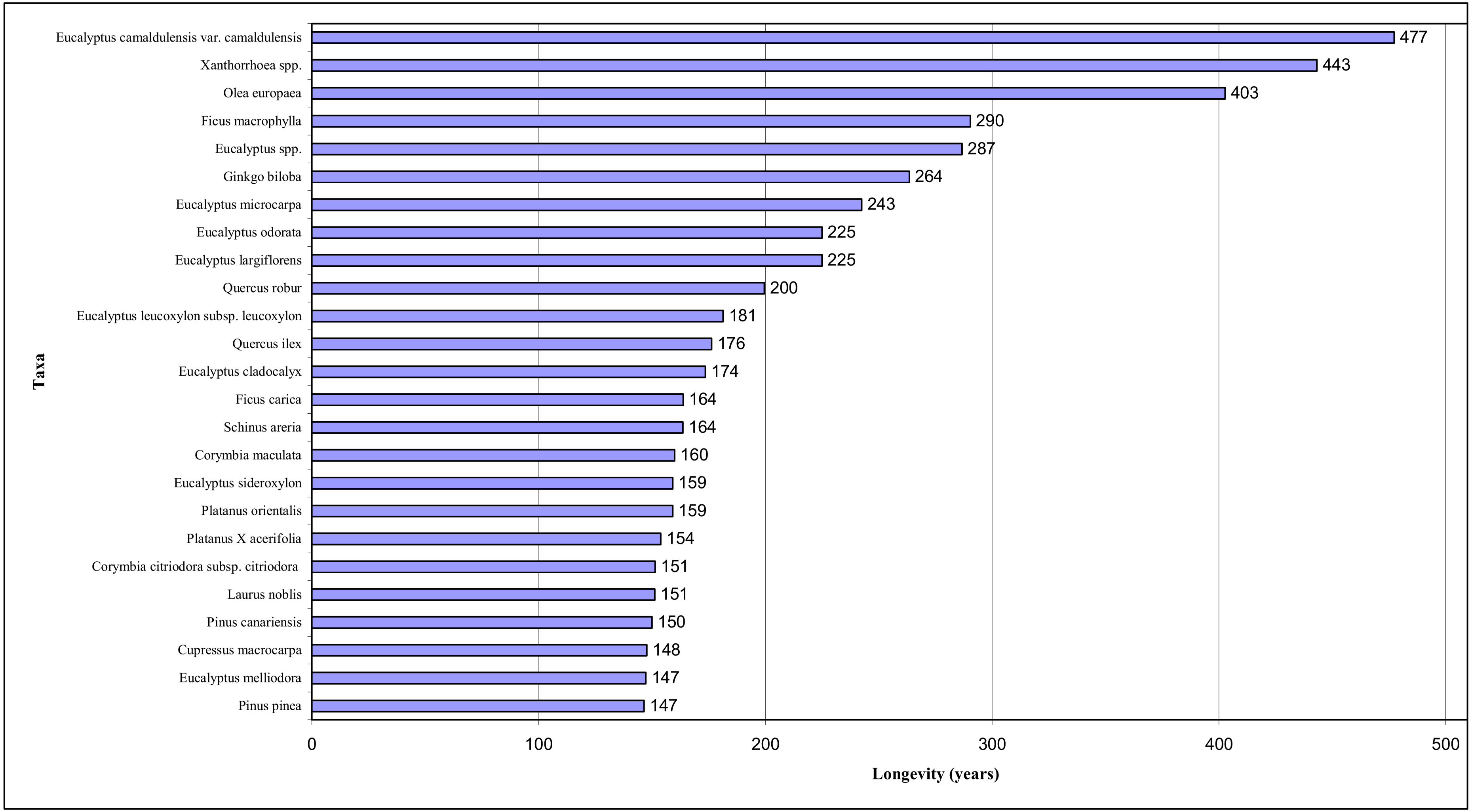

Figure 8.1. Bar Graph 1: Mean tree longevity figures arranged from longest to shortest.

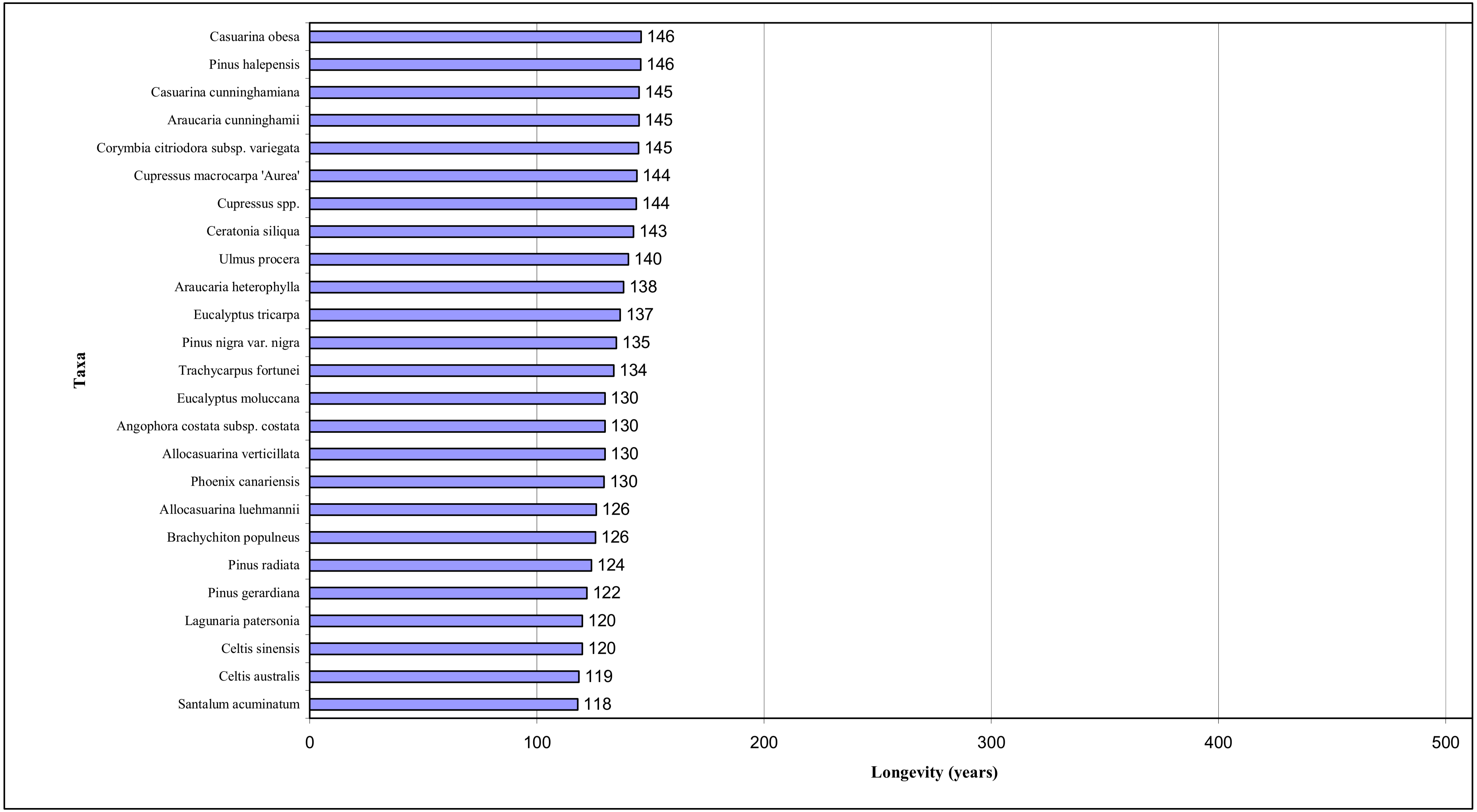

Figure 8.2. Bar Graph 2: Mean tree longevity figures arranged from longest to shortest.

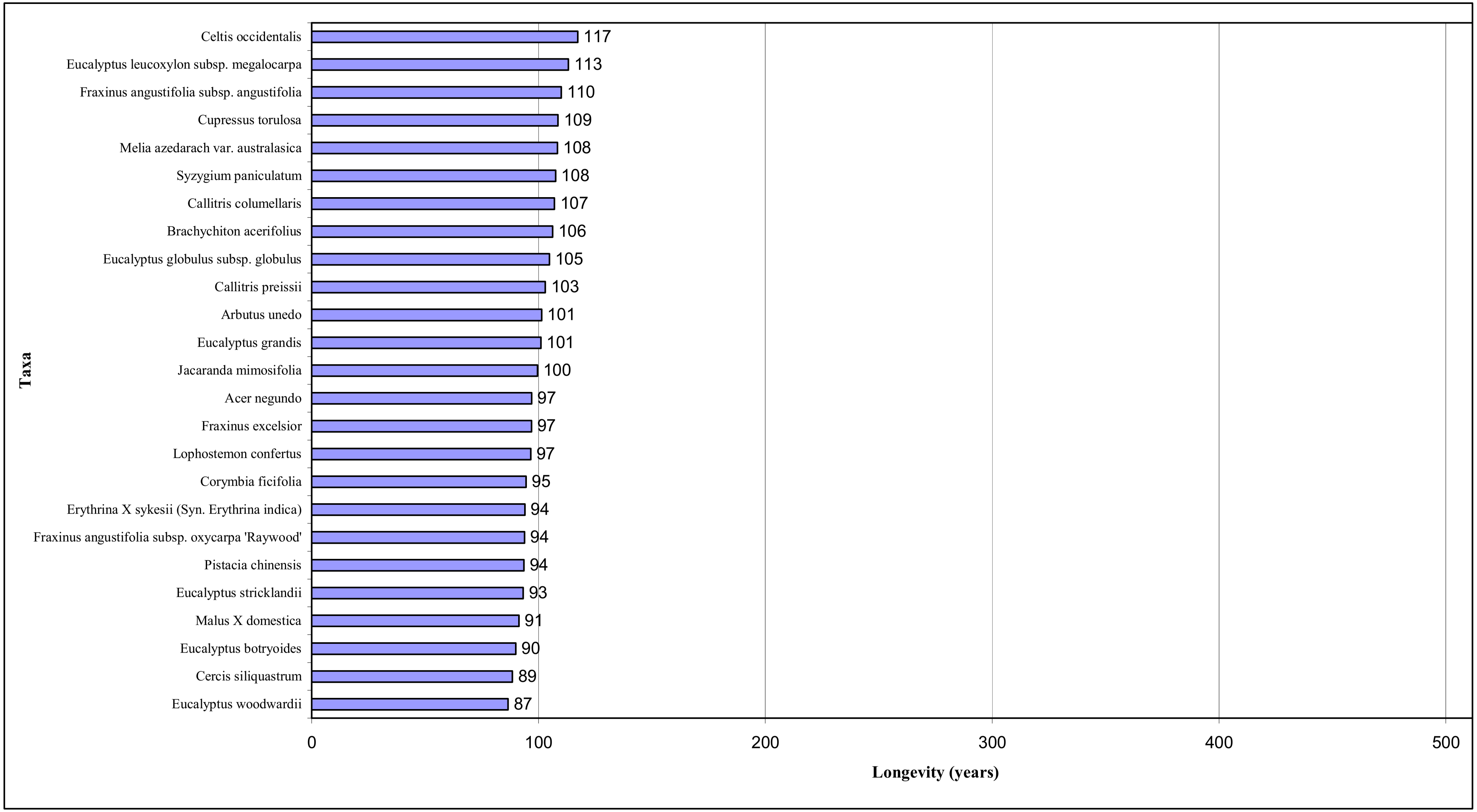

Figure 8.3. Bar Graph 3: Mean tree longevity figures arranged from longest to shortest.

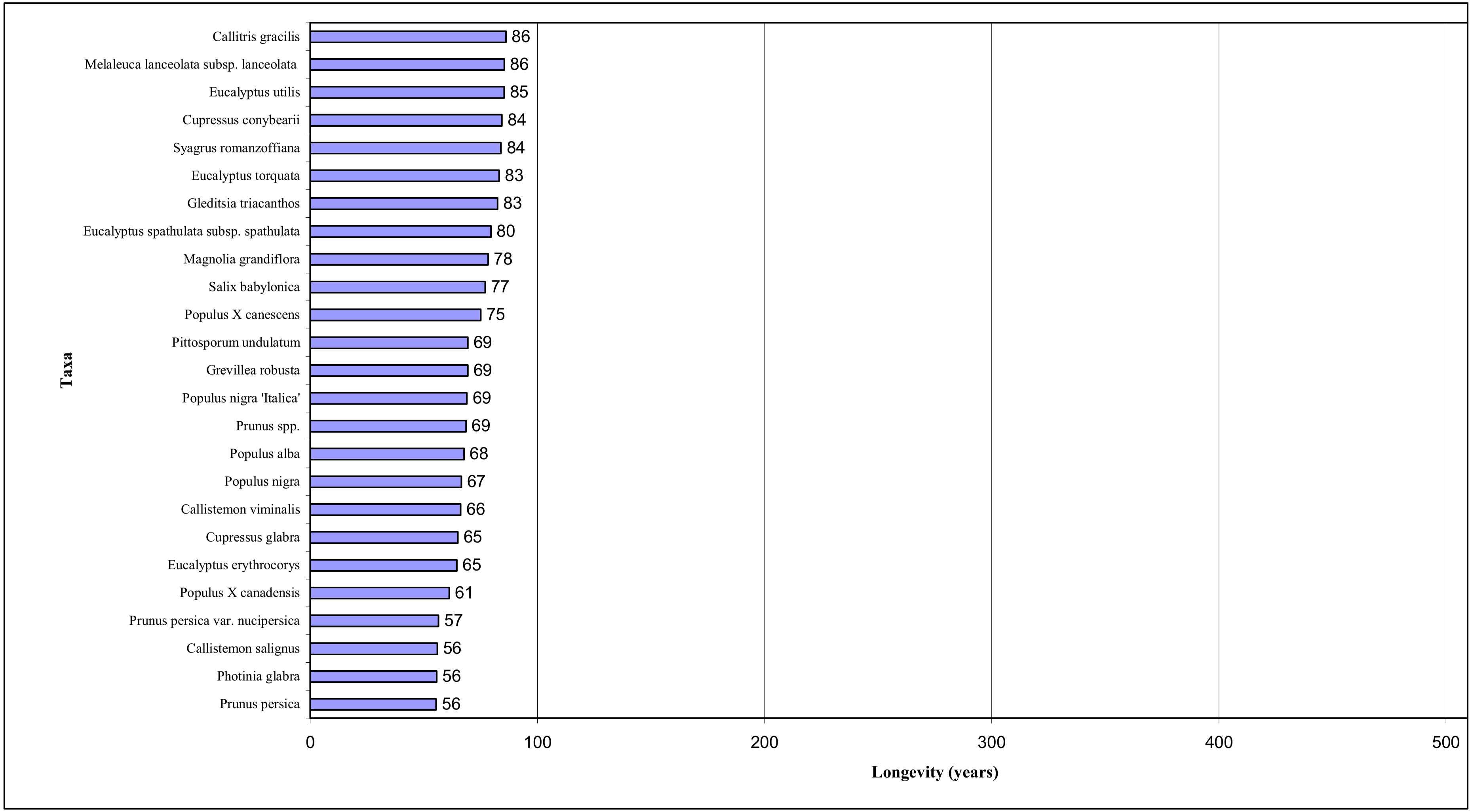

Figure 8.4. Bar Graph 4: Mean tree longevity figures arranged from longest to shortest.

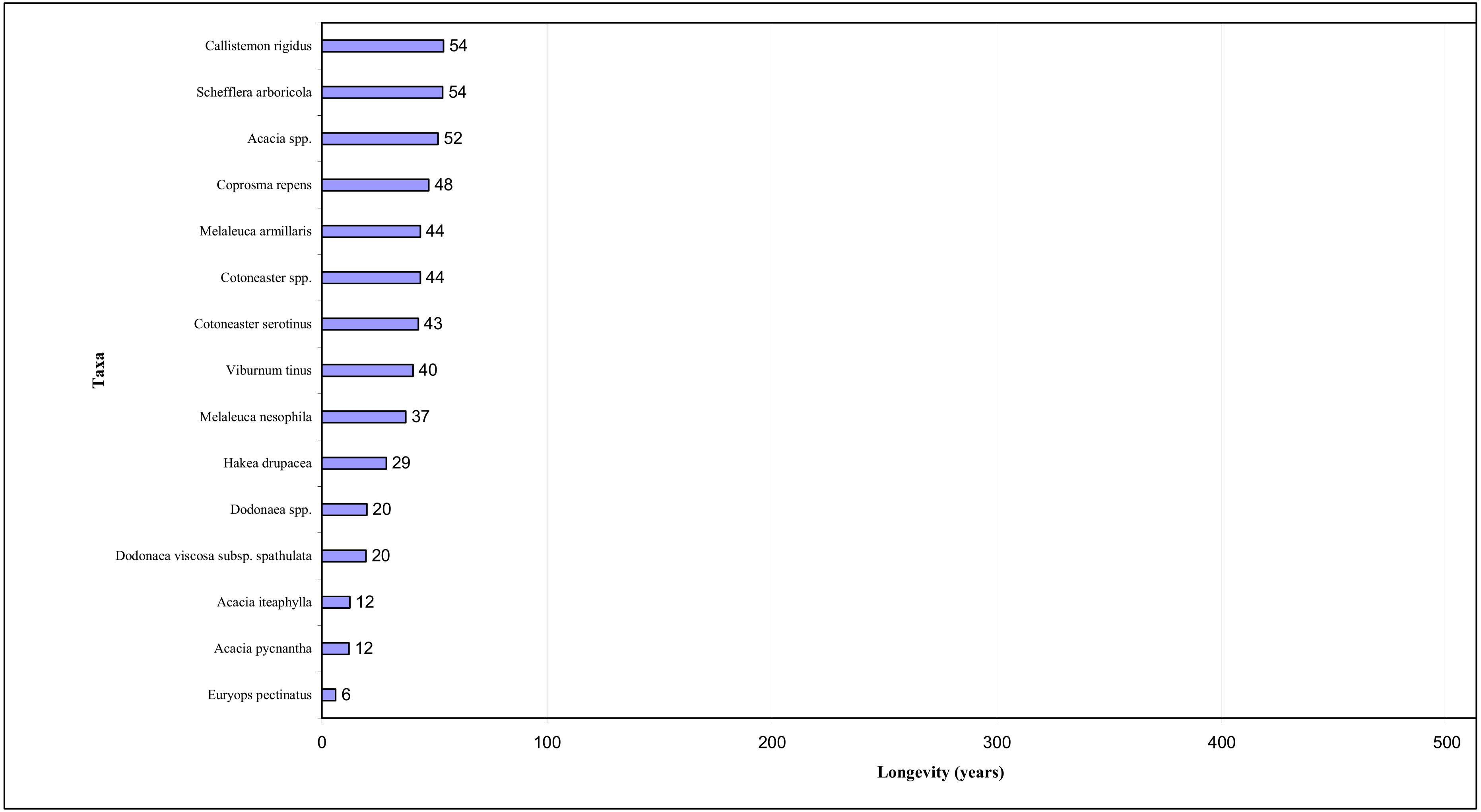

Figure 8.5. Bar Graph 5: Mean tree longevity figures arranged from longest to shortest.

8.5 Tree Growth Modelling and Longevity Projection Results

8.5.1 Tuttangga/Park 17 Models

Tree growth models were constructed using points plotted as *x-y* coordinates, as outlined in Chapter 7.5.2. An exponential equation was fitted to the matrix of points to provide a growth trend reflecting the growth parameters of DBH, height, and canopy span with relation to tree age for each of the six taxa modelled. The models created for each of these mensuration parameters per taxa, using Park 17 data only, are included as Appendix 14. An example of the exponential model graphed for *Eucalyptus camaldulensis* var. *camaldulensis* (River Red Gum) to determine tree age from DBH is shown in Figure 8.6. Summaries of the equation parameters used to create trend lines for these Park 17 taxa are included as Appendix 15.

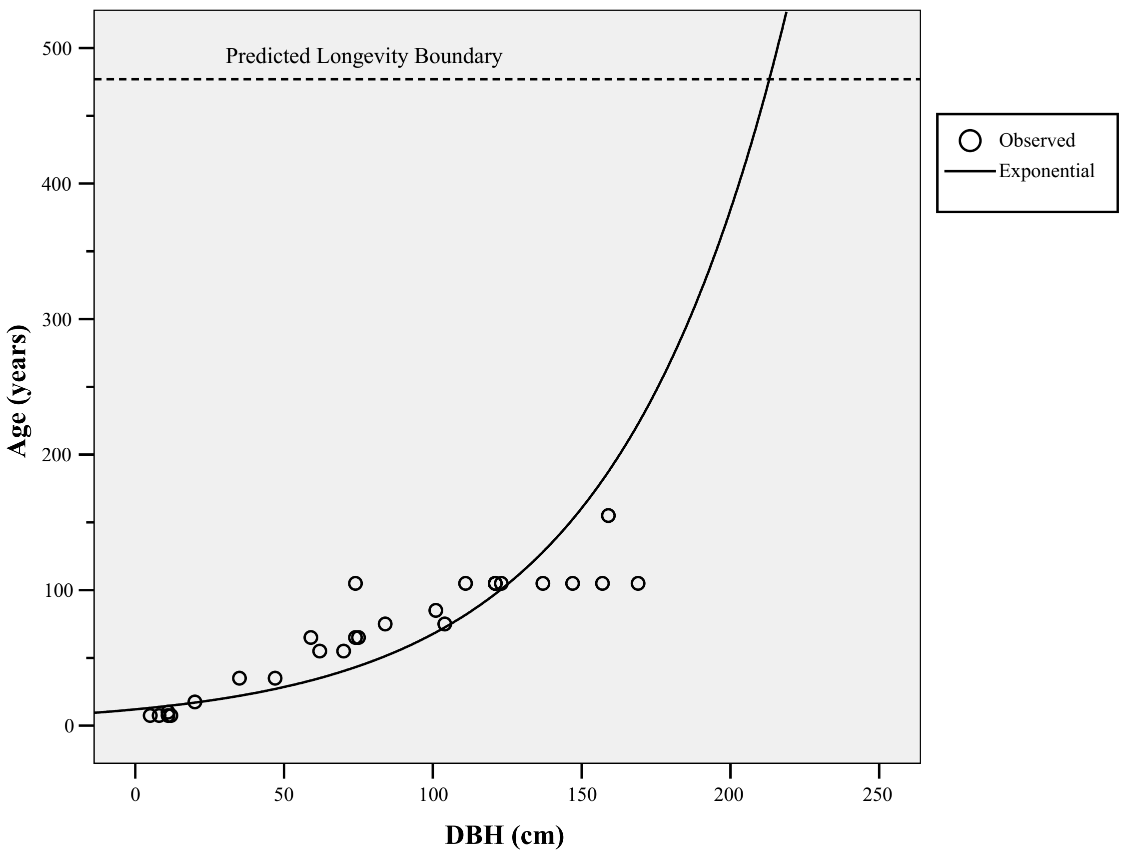

Figure 8.6. Graph of exponential model used to determine tree age from DBH for *Eucalyptus camaldulensis* var. *camaldulensis* (River Red Gum) in Park 17.

8.5.2 Waite Arboretum Models

A number of tree taxa located in Park 17 were discovered both in the Waite Arboretum archives and still extant in the Arboretum itself. Tree mensuration data, along with tree ages sourced from the Waite Arboretum for the purpose of model testing, are included as Appendix 16. Figures from the archive records included in Appendix 16 were converted from imperial figures to decimal numerals for ease of numerical comparison and for model development. Data was separated by taxa and plotted as *x-y* coordinates to form a matrix of points and an exponential curve fitted to the points as described in Chapter 7.5.1 Summaries of the equation parameters used to create trend lines for the Waite Arboretum data are included as Appendix 17.

8.5.3 Model Testing and Comparison

Equation parameters obtained from both the Park 17 and Waite Arboretum data sets are displayed together for comparison in Appendix 18. Correlation coefficients for both can be compared for their 'fit' to the data in the matrix models; values closer to 1 providing the better equation fit. Canopy Span data for the Waite Arboretum trees was not available, as displayed in Appendix 17, and therefore correlation coefficients for this parameter cannot be compared to those obtained from the Park 17 models. A list of the taxa surveyed in Park 17, along with the availability of data to enable model creation for each of those taxa, is included as Appendix 19.

Matrix models containing data from both Park 17 and the Waite Arboretum were also constructed in order to potentially increase the number of points used to fit the exponential curve. Equation parameters for these combined models are included as Appendix 20.

8.6 GIS Simulation

Using the process described in Chapter 7.6, a GIS model was constructed to contain the spatial and mensuration data collected in the Park 17 field survey. Using the exponential function and unique modelling parameters per taxa, tree establishment dates, and projected tree senescence dates, were created for each of the three field mensuration parameters:

DBH, height, and canopy span. Through this method, all Park 17 trees with these known field mensuration parameters from the six growth-modelled taxa were assigned dates of establishment, and, using the projected longevity figures obtained from the peer reference group tree longevity survey, dates of projected future senescence. Once these establishment dates and senescence dates were computed using Excel, the GIS model was formatted to contain this new predictive data. The attribute table embedded within the Park 17 Tree GIS layer was expanded to include six new fields: 'year of establishment', and 'year of senescence' for each of the mensuration parameters DBH, height, and canopy span respectively. Using this method, dates of tree planting and tree senescence were modelled for each of the primary field mensuration parameters separately. Results of the quantities of Park 17 taxa able to be age determined through this method are shown in Table 8.6.

Quantity of Park 17 Trees With Longevities Modelled in GIS (>=4m in height)		
Taxa	**Common Name**	**Quantity**
Eucalyptus camaldulensis var. *camaldulensis*	River Red Gum	887
Eucalyptus cladocalyx	Sugar Gum	174
Eucalyptus leucoxylon subsp. *leucoxylon*	South Australian Blue Gum	199
Eucalyptus microcarpa	Grey Box	139
Fraxinus angustifolia subsp. *angustifolia*	Desert Ash	109
Pinus halepensis	Aleppo Pine	21
	Trees (>=4m in height) Modelled with Longevities	1529
	Total Number of Park 17 Trees	2873
	Percentage of Park 17 Trees Modelled with Longevities	53.2

Table 8.6. Quantity of Park 17 Trees able to be modelled with both establishment and senescence dates from the entire Park 17 GIS modelled tree population.

Structured queries were then used to develop simulations of possible futures for the Park 17 tree population. Using the structured query process multiple results could be obtained, in any number of combinations, depending upon the information desired. The number of possible combinations from the structured query process prohibits comprehensive results in the form of tables or images as an Appendix. A list of the 'fields' available as inputs for structured query building is included as Appendix 21.

The interactive nature of the GIS simulations promotes hands-on use, inquiry, and interpretation. For these reasons, the many possible queries able to be constructed predicting tree longevity based upon DBH, tree height, and tree canopy span cannot simultaneously be presented here. Sample images displaying the capabilities of the ArcScene three-dimensional (perspective) views predicting tree senescence patterns in the Park 17 landscape are presented in Figures 8.7 to 8.10. Examples of the structured query process are included as Appendix 22, where DBH was used to model tree senescence in two-dimensions (map) using the ArcMap software. Further three-dimensional images of these structured query samples are included as Appendix 23, where ArcScene was used to render the images. Tables showing the quantities of GIS modelled trees attaining specific future dates are summarised in Appendix 24. Tables showing possible planting dates by taxa modelled using the structured query process and modelling in reverse to show the past based upon tree mensuration parameters are summarised in Appendix 25.

Figure 8.7. Modelled image from ArcScene representing the year 2006. Displayed here is a 3-dimensional rendering of all trees recorded in the Park 17 landscape. (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

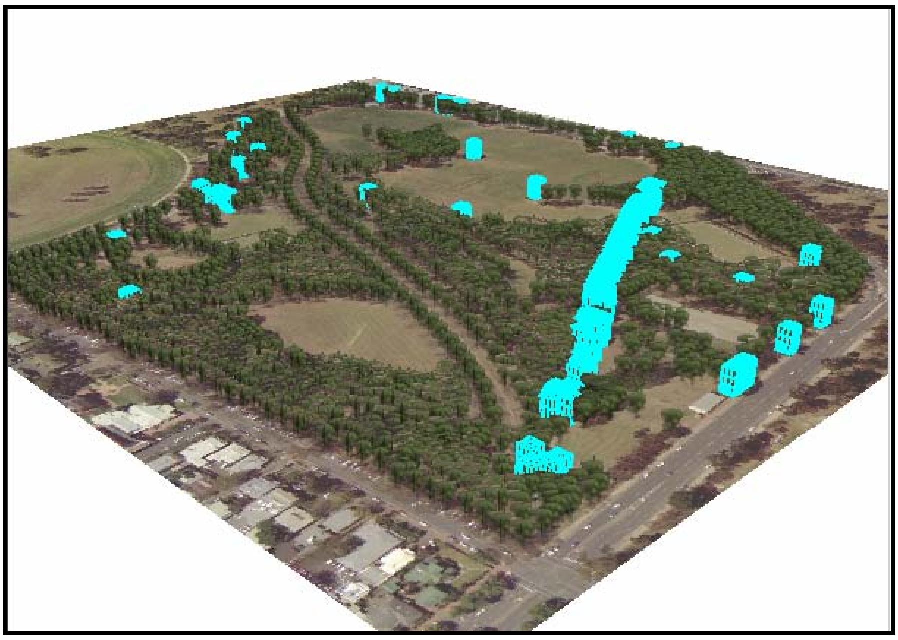

Figure 8.8. Modelled image from ArcScene representing the year 2050. Displayed here are extant Park 17 trees predicted to have reached the end of their life span by the year 2050 (highlighted). (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

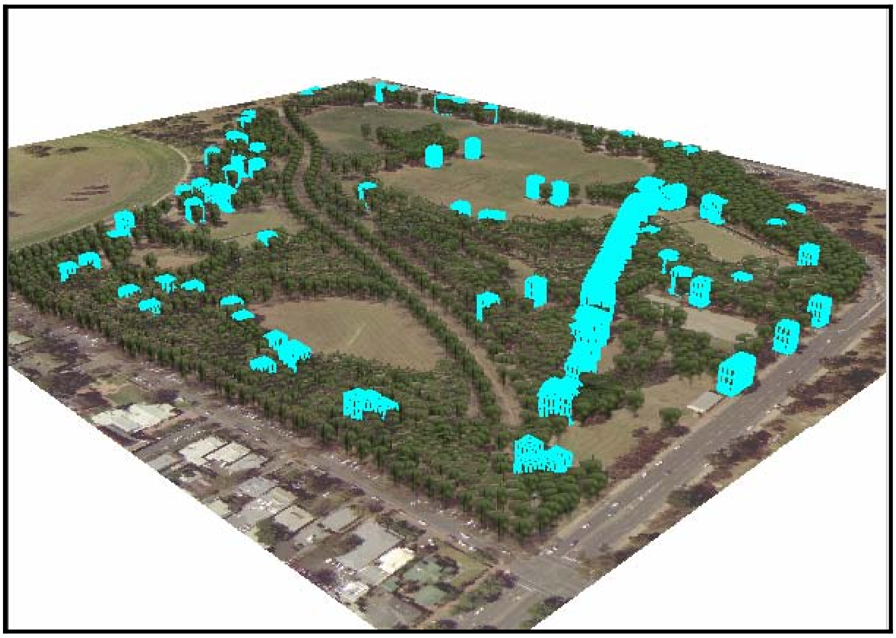

Figure 8.9. Modelled image from ArcScene representing the year 2100. Displayed here are extant Park 17 trees predicted to have reached the end of their life span by the year 2100 (highlighted). (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

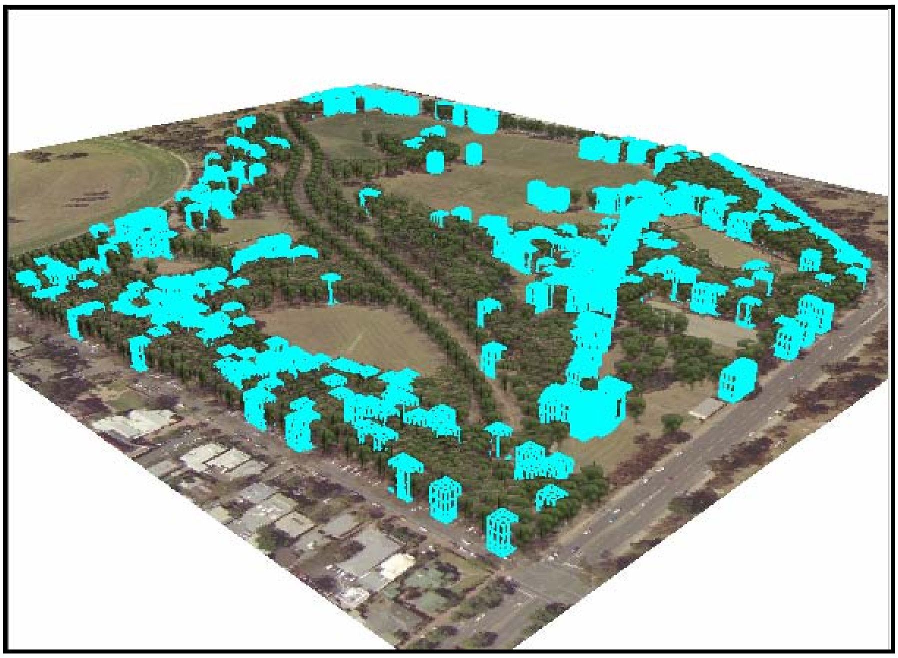

Figure 8.10. Modelled image from ArcScene representing the year 2200. Displayed here are extant Park 17 trees predicted to have reached the end of their life span by the year 2200 (highlighted). (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

8.7 Summary

Large quantities of data were obtained from the research method established previously in Chapter 7. A summation of these data, included in this chapter, provide an overview of these results. Embedded within the figures obtained from the peer reference group tree longevity survey are useful data for estimating future tree longevities within the Adelaide Park Lands, based upon data supplied at the time of the survey. A combination of these longevity figures, exponential growth models derived from age determined tree specimens, and field survey data collected and subsequently modelled within a GIS software package, provide insight into potential future landscape scenarios for trees within the Park 17 landscape. Issues arising from the method and results outlined in Chapters 7 and 8 are examined in further detail in Chapter 9.

Chapter Nine: Discussion and Conclusions

9.1 Introduction

The previous chapters outlining the methodology for modelling tree growth and senescence, and the results obtained from that methodology, have generated a number of issues that require discussion and elaboration in this chapter. These subjects necessitate further discussion in order to fully analyse the important aspects of the method proposed and results obtained from previous chapters, and to highlight possible areas of improvement in the method undertaken. In addition, conclusions arising from this research are outlined, along with potential areas of further research.

The tree longevity figures provided by the respondents in Appendices 12 and 13 present landscape designers, planners, and managers with valuable data on various tree longevities based upon Adelaide Park Land conditions as at 2006. For example, landscape designers wishing to create landscapes with trees that reach maturity and senescence quickly, and are therefore replaced faster, can select those taxa with shorter life spans. Designers wishing for longer-term stability in a landscape may choose to select trees with longer life spans, reducing the need for short-term tree replacement schedules. Landscape managers and planners may use these longevity figures to develop planning guidelines, or forecast maintenance procedures, based upon tree senescence programs and tree life expectancy.

9.2 Discussion of Tuttangga/Park 17 Field Survey

Arising from the Park 17 field survey were a number of topics that required further discussion or clarification. Included in this section, they provide supplementary information to Chapter 8.

9.2.1 Spatial Positioning of Trees

A Global Positioning System (GPS) was not employed for locating tree positions in the field. This was due to inaccuracies inherent within handheld GPS units available at the time the field survey was undertaken. Tests by Wing, Eklund, and Kellogg (2005) on GPS performance discovered that:

> …performance varied, in some cases considerably, among units and appeared to be influenced by canopy cover and satellite availability. Among the top GPS performers, we determined that users could expect positional accuracies within approximately 5 m of true position in open sky settings, 7 m in young forest conditions, and 10 m under closed canopies.[1]

As a number of trees in Park 17 were within close proximity to one another, spatial errors of up to 10m from a GPS would have formed inaccurate spatial tree locations. Trees were discovered requiring sub-metre spatial accuracy in Park 17, and therefore spatial errors from a GPS-produced tree map would not accurately match with actual Park 17 tree locations. As a result it would be difficult to locate specific GIS-highlighted tree specimens in the field. The spatial positioning method used to locate trees in the field, involved manually recording tree positions onto detailed orthophotographs, as outlined in Chapter 7.2.4.1. These were then digitally translated into the georeferenced orthophotograph embedded within a GIS layer, as outlined in Chapter 7.6.3. Future advances in GPS technology may overcome these issues, resulting in cheap, efficient, and most importantly, accurate spatial data collection for urban tree modelling purposes.

9.2.2 Park 17 Field Survey as a Taxonomic Inventory

The quantities of various taxa recorded in the Park 17 field survey reflect the site's tree and shrub population at the time of the survey. This data provides information that directly relates to past taxa selections used in various Park 17 plantings. Individual specimens from a single taxon may reflect extant survivors from past trial plantings, leftover stock from a different Park Land location or nursery, or a specimen sourced and planted by a member of the community that had associations to Park 17. Examples of the latter may be located within the South Terrace Croquet Club grounds, where four taxa representing the only four specimens from those taxa in the entire Park 17 landscape were recorded. In this example, people associated with the croquet club may have selected plants and established them within these grounds, providing an explanation as to why these particular taxa are not located outside the South Terrace Croquet Club.

9.2.3 Suitability of Park 17 Specimens for Tree Growth and Longevity Modelling

Taxa surveyed were arranged into ‘Shrub’, ‘Shrub/Tree’, ‘Tree’, or ‘Palm’, as outlined in Appendix 5. These factors were taken into consideration for the purpose of growth modelling, and the parameters related to these growth models. As discussed in Chapter 4.2.2.1, most palm taxa would be better suited to tree height modelling as opposed to DBH, as their trunk diameters do not, in many cases, increase with age. Multiple stems associated with many shrub taxa may also predispose them towards height modelling for age determination and longevity prediction.

The growth models used in this research to determine tree age and calculate tree longevity represent the upper boundary of tree growth, where growth rates in DBH, tree height, and canopy span, slow down as the tree reaches senescence. This upper boundary reflecting a deceleration in tree growth rate does not incorporate the lower end of a ‘sigmoidal’ growth curve, as discussed in Chapter 4.2.1.3, and therefore the period of slow growth rate reflected in very early tree growth is not modelled in this research. For this reason, trees less than 4m in height were excluded from the development of growth models, and subsequent GIS structured query analysis, to avoid any possible inclusion of trees still within this initial stage of growth. As the upper boundary of tree growth and longevity was the primary focus of this research, these younger specimens were therefore excluded from all modelling stages. The opportunity still exists to model these younger trees and the shorter shrubs from the data collected and embedded in the GIS Park_17_Trees layer, however the development of these models would need to reflect the early stages of accelerating growth in trees or shrubs.

9.2.4 Size Statistics of Tree Population

Extracted from the large quantity of data collected from the Park 17 Field Survey are summaries of mensuration parameters, by taxa, shown in Appendix 6. The minimum, maximum, and mean recorded DBH of each taxon greater than or equal to 4m in height are shown to give an indication of the tree populations by size. Mean figures are also provided for tree height and tree canopy span for each taxa surveyed in Park 17. These data provides information reflecting the average size of each taxon in Park 17, and summarises overall tree populations of Park 17 trees.

9.2.5 Health Statistics of Tree Population

The observed health levels of all tree specimens were recorded in the field, and these were tabled in Appendix 7. As noted by Parker (2004) 'Assessments of tree health are not often quantified, rather being subjective appraisals of the tree condition based on the experience of the assessor'.[2] As the assessor of Park 17 tree health did not possess formal arboricultural training, observations for the Park 17 trees should be assumed a preliminary assessment of tree health, with detailed evaluations pending arboricultural examination. In addition to this, tree health should not be considered static, as tree health status will be expected to change over time. Individual specimens may therefore require subsequent investigation. With these points of contention noted, the data included as Appendix 7 still provides a preliminary indication of tree health by taxa across the entire Park 17 tree population, at the time of the field survey. In addition, patterns of tree health can be identified spatially within the GIS construct and measures undertaken to investigate serious health issues further, or to implement contingency plans if they are available to landscape managers.

The data incorporated within Appendix 8 reflects a variety of other field observations that may or may not impact upon tree health at later stages. The irregularities observed varied from seemingly non-injurious, such as graffiti painted onto a tree's bark, to potentially life-threatening, such as the complete ringbarking of a tree's trunk. Often, the abnormalities to regular tree growth appeared to have been inflicted by human activities, however, the cause of many of these was difficult to determine precisely. The tabling of these field observations by taxa provides insight into possible health-related issues. In addition to the analysis of tree health by taxa, spatial mapping of these trends can also provide indications of problem areas, such as identifying the location of trees most exposed to graffiti attack.

Tree defoliation through vertebrate or invertebrate attack was the most common observation across Park 17 tree population. Other insect damage was observed on a number of specimens, including evidence of borer attack and termite damage to the support tissue of some trees. A number of large trees bore evidence of having shed large limbs, and a quantity also possessed obvious cavities in their trunks. The majority of other damage evident on the Park 17 trees appeared to have been inflicted by various human activities. A large number of trees had smaller live branches within arm's reach snapped off, leaving green splintered stubs. Others displayed damage to their trunks caused by a sharp blow from an unidentified instrument. One specimen had its trunk cavity filled with concrete, reflecting procedures probably not practiced by recent Park 17 maintenance staff.

9.3 Discussion of Tree Age Determination Methods from Tuttangga/Park 17

The three methods used to determine the age of Park 17 tree specimens were outlined in Chapter 7.3. Here, a discussion of the issues arising from that process is engaged to identify positive and negative aspects of each age determination method used.

9.3.1 Extant Historical Tree Age Data Used

From the extant historical data available for determining tree ages of extant Park 17 specimens, only one group of trees could be identified and assigned ages for growth modelling purposes. This allée of 81 Desert Ash (*Fraxinus angustifolia* subsp. *angustifolia*) specimens were matched to planting records from The Corporation of the City of Adelaide Council *Annual Report* (1921) as reviewed in Chapter 6.5.2.[3] Each specimen in this allée was assigned the age of 85 years, as listed in Appendix 9, and used in the subsequent matrix growth model development for the Desert Ash taxon. There were, however, reservations regarding the accuracy of this historically assigned tree age, with these coming to light once growth models were developed for the taxon.

As shown in Appendix 14, the 81 historically age determined Desert Ash specimens significantly affected the three growth trends of DBH, height, and canopy span, fitted to the points for this taxon. This resulted in three poor correlation coefficients for these growth curves. When the growth curves were plotted a second time, as shown in Appendices 26 with one matrix point for each DBH, tree height, and canopy span model, the correlation coefficients improved significantly. On the growth curves displayed in Appendix 26, the location of the averaged allée trees are highlighted to display their relationship and position within the remainder of the points that regressed the growth curve. Several explanations are proposed to determine a possible reason why so many historically age-determined trees could adversely affect the growth curves presented in Appendix 14 for this taxon. One explanation could be that this allée of trees extant in Park 17 were in fact younger than the historically determined age of 85 years; new trees may have replaced unsuccessful specimens at various stages over a period of time, reflecting younger, smaller trees within this allée. For example, the largest DBH from this single-taxon-allée was recorded as 68cm, with the smallest recorded as 22cm, reflecting highly discordant rates of tree growth. The second explanation is that trees grown within close proximity to one another may have had to compete for sunlight, nutrients, and moisture over a period of time, potentially reducing overall tree growth and moving all of the allée specimens into lower positions along the *x*-axis of the growth models. The third explanation is that the remainder of the age determined Park 17 Desert Ash specimens provided by the expert estimations in the field and incorporated into the matrix models were incorrect.

Interestingly, when the Desert Ash specimen from this allée with the largest recorded DBH of 68cm was entered into the adjusted growth curve equation from Appendix 26, an estimated age, based upon DBH, of 74 years was calculated. This large specimen may be a remnant of the most original tree from the allée, if any were replaced over time. The growth models shown in Appendix 26 were not used to determine tree age and longevity in the GIS models presented in the main body of this research. When the mensuration parameters collected in the field were entered back into these adjusted growth models, it was discovered that the entire allée was in fact seriously underestimated in tree age for all parameters, and therefore the adjusted growth curves did not reflect the majority of the Desert Ash specimens in Park 17, represented by this allée of 81 trees. Regardless of whether or not the historically determined age of 85 years proposed for the allée specimens was correct, it cannot be assumed incorrect based upon these growth model results only, and assigned a lesser value as a method of tree age determination in this particular cultural landscape.

If accurate and reliable planting dates were to be collected and retained at the time of establishment, and subsequent replacement of specimens recorded also, historically age determined data for tree growth and longevity modelling would have the potential to become far more reliable, with this confidence reflected in the subsequent growth curve models. Importantly, detailed spatial records must also be retained in order to re-locate specimens and undertake further tree mensuration in subsequent years.

Historic photographs obtained from the Adelaide City Council Archives, and displayed in Appendix 2, provide interesting viewing when compared to contemporary scenes of the same locations. Unfortunately these particular historic photographs do not indicate tree planting or establishment dates, and therefore cannot provide accurate figures of tree age for use in these growth models. Historic photographs of 'Arbour Days', where celebrations of tree plantings were recorded, may provide more accurate details of tree establishment dates. Unfortunately, as with other historic records, tree replacement in subsequent years cannot be recorded in a single Arbour Day photograph, reducing the utility of historic photographs for determining tree establishment dates.

The determination of tree ages from the Waite Arboretum using historic archival records was a relatively straightforward process. Archival records of past tree mensuration data kept at the Arboretum also contained the year of establishment for each specimen. In addition to this, each specimen extant at the Arboretum had both the taxonomic details, and year of establishment attached to the tree itself. These details were collected during the 2006 field mensuration of extant specimens at the Waite Arboretum.

Extant historic records of tree plantings can vary in the level of detail originally recorded, the quantity of data subsequently retained over time, and the interpretation of those records as planting dates. The weighting assigned to historically age determined trees incorporated into tree growth models can impact upon the confidence levels of those models, however, this would be dependent upon the accuracy of the historical data used. Strict reliance upon such historic resources in large-scale landscape modelling projects could result in inaccurate future landscape predictions. Regular maintenance of tree planting and replacement records, combined with accurate spatial records would significantly increase the reliability of this extant data source for use in tree growth and longevity projection modelling.

9.3.2 Expert Estimation Tree Age Data Used

The data collected from the expert estimation of tree age provided 74 age determined tree specimens across six taxa. This determination of tree age was provided as an estimate, based upon the expert's experience, with figures provided as an 'age range'. These age ranges were provided within ten-year brackets, such as "80 to 90 years old", and each was subsequently averaged to a mean figure. In this particular example, an age of 85 years would have been recorded for this tree.

The issue of accuracy in expert opinion of tree age is important, and must be taken into consideration when developing growth models using tree age as one of the parameters. A large number of experts may provide a quantity of varying tree ages for the one specimen, and average figures would need to be considered also. The present dearth of extant historical data reflecting tree age in Park 17 requires alternative means of tree age determination methods to be employed in order to assign ages to extant Park 17 tree specimens for growth modelling. While inaccuracies may be inherent in expert estimations of tree age within a landscape, these estimations provide, at the very minimum, figures for growth model development. Without such data, simulation of possible future landscape scenarios reflecting tree longevity would not be possible for most Park 17 trees, unless proven invasive methods of tree age determination were to be employed.

It may also be argued that experts could be employed to determine the ages of every tree in a landscape. If the scale of the landscape permitted this method, then the result would be increased accuracy in forecasting tree senescence patterns. When incorporated into tree growth models, large volumes of data such as these have the potential to return strong correlation coefficients. Although errors may be inherent in any expert opinion of tree age, where other means of tree age determination are not available, they may present the best possible method of assigning ages to trees in cultural landscapes, using non-invasive age determination processes.

9.3.3 Dendrochronological Data Used

Of the 2873 trees surveyed in Park 17, only one specimen fits the criteria suitable for dendrochronological age determination study. This Aleppo Pine (*Pinus halepensis*) specimen had been measured for trunk DBH, tree height, and canopy span prior to its felling. As the tree presented visible growth rings, it was deemed suitable for this method of age determination. Following tree felling and timber removal, the stump was examined and growth rings counted to return a figure of 109 rings. This age determined figure, combined with the mensuration parameters of DBH, height, and canopy span previously collected, were incorporated into the matrix models for this taxon.

As discussed in Chapter 5, concerns surround the accurate use of dendrochronological procedures in determining the ages of some trees in certain climates. Detailed research on the subject of Aleppo Pine dendrochronology within the Adelaide region was not available at the time of the study. Research by Schweingruber (1993) on Aleppo Pines from the Mediterranean region determined that 'the tree-ring boundaries are very distinct', and the 'wood is suitable for chronological, ecological, as well as climatological purposes'.[4] However, Schweingruber (1993) also noted that 'early summer rains often result in the development of false rings' in Aleppo Pine wood.[5] As early summer rains may have occurred periodically in the Adelaide region over the life of this sampled Park 17 specimen, the potential of false ring presence may reduce the accuracy of the 109 years counted on the felled tree, possibly resulting in an overestimation of tree age based upon growth ring counts. As an approximation, however, the inclusion of this age determined tree into the Aleppo Pine matrix growth models was considered an important part of the model development process, incorporating various age determination methods for use in the models. The dendrochronologically determined point, shown as the furthest along the *y*-axis in the growth models from Appendix 14 (pp. 312-314), appeared to fit the curve reasonably well. Removing potential 'false rings' from this age calculation would lower the matrix point further along the *y*-axis, providing an even better fit to each of the three growth curves displayed.

9.4 Peer Reference Group Tree Longevity Survey Discussion

As previously outlined in Chapter 3, figures reflecting expected tree longevity in the Adelaide Park Land region were not present in the published tree longevity literature reviewed. As tree longevity figures were required for use in tree growth modelling and subsequent GIS tree senescence simulations, numerical values reflecting the expected longevity of various Park 17 taxa had to be sourced. This information was ascertained to be extant within the knowledge of experts in the fields of horticulture and arboriculture within the Adelaide region. Over a period of time, experts in these fields develop experience and knowledge of various tree species, gathering information and observations of considerable value in the area of tree longevity research. Collecting this longevity knowledge for use in the simulation of future landscape scenarios was considered a suitable method of determining Adelaide Plains tree longevities, and creating from this data patterns of possible tree senescence in the Park 17 landscape.

9.4.1 Survey Design

As outlined in Chapter 7.4.2, the Tree Longevity Survey was designed to collect unpublished figures reflecting expected tree longevities as of 2006, based upon knowledge collected by the experts over a period of time. Columns containing taxonomic details, common names for each taxa, along with preliminary estimates of tree longevity provided by the interviewer were followed by blank columns that invited respondents to submit their own tree longevity figures, as displayed in Appendix 10. The primary purpose of this survey was to obtain tree longevity figures across the target population, as they possessed expert knowledge for use in tree growth and senescence modelling. A column for additional comments was also provided on the survey, with the intention of collecting further longevity data, or any other information the respondents wished to provide. Discussion of these additional comments are included in section 9.4.5.

9.4.2 Assembling Peer Reference Group Respondent List

A list of peer reference group experts in the fields of horticulture and arboriculture was compiled with the assistance of an Adelaide-based arborist, as described in Chapter 7.4. Through the recommendations of individuals from this peer reference group of experts, two additional respondents were added to the original arborist-provided list of 26, to bring the target population to 28 potential respondents, as shown in Appendix 11. Four of these respondents could not be contacted and were therefore removed from the list of potential respondents. A further three potential respondents contacted refused to participate in the survey, resulting in a list of 21 interested respondents. With the target population identified, the self-administered surveys were sent out, and results awaited.

9.4.3 Response Rate of Tree Longevity Surveys

From the list of 21 interested respondents receiving a tree longevity survey, 16 surveys were returned, as shown in Appendix 11. Three of these 16 surveys returned were completed by pairs of experts; the original respondent in each of these three cases had selected the second individual of the pair to assist or provide additional information and complete the longevity survey as a two-person team. This resulted in 19 individual experts providing feedback across 16 tree longevity surveys. The 16 returned surveys reflected a response rate of 76 per cent. Marans (1987) noted that with the use of self-administered questionnaires sent through postal services for 'general population' surveys, a response rate of 10 per cent was 'not uncommon'.[6] Marans (1987) also observed that,

> If the topic is of sufficient interest and importance to the respondents, the response rate will be higher than if it is viewed as irrelevant or lacking in interest.[7]

The tree longevity survey conducted here was aimed at a target population of experts, a number of which may have embraced the survey as a topic of personal interest related to their particular horticultural or arboricultural expertise. This may provide an explanation for the high response rate. Walter (2006) considered a response rate of 70 per cent from self-administered surveys to be very good, with 50 per cent considered acceptable.[8] Marans (1987) also observed that self-administered surveys generally remove interviewer bias, returning candid responses.[9]

9.4.4 Tree Longevity Figures from the Surveys Returned

Tree longevity figures from the returned surveys were collected and tabulated as shown in Appendix 12. As the survey responses for tree longevity were provided in years, numerical interpretation of these answers was straightforward, reducing complexity in calculation and statistical analysis. Figures provided in each survey returned were numerical, with the majority being whole figures, such as '120', representing 120 years of expected life for the particular taxon, within the specified region of the Adelaide Park Lands on the Adelaide Plains. Other figures of tree longevity were provided as 'ranges', such as '120-150' years;

single figures accompanied by a 'less than' or 'greater than' symbol, such as '<120' or '>120'; or single figures accompanied by a 'plus' symbol, such as '120+' years, as tabled in Appendix 11. Where an age 'range' was encountered, the two figures were averaged to obtain a single mean figure of tree lifespan, for example, an answer of '120-150' years became '135' years for that taxon. Where 'less than', 'greater than', or 'plus' symbols were encountered, the figure was calculated without the symbol, for example '120+' years became '120' years. It was considered imperative to avoid interviewer bias in the provision of final longevity figures used for longevity prediction, as the objective of the survey was to gain knowledge from expert sources. As the upper limit intended beyond the '120+' figure was not provided by the respondent, the interviewer did not estimate it.

To obtain the mean longevity figure each taxon was expected to reach, the sum of all longevity figures provided for the taxon was divided by the number of responses, providing an arithmetic average for the taxon, as displayed in Appendix 12. The mean, or arithmetic average outlined by Neuman (2000) 'is the most widely used measure of central tendency'.[10] Using further statistical analysis, the standard deviation from the mean was also calculated. Neuman (2000) defined standard deviation as a figure that 'is based on the mean and gives an "average distance" between all scores and the mean'.[11] The standard deviation in this survey provided interesting data on longevity knowledge across the respondents for each taxon: the higher the standard deviation, the less agreement between longevity figures provided by the respondents. Mean longevity figures for each taxon were compiled, in order, from longest-lived to shortest-lived for ease of comparison, and displayed in Appendix 13.

9.4.5 Tree Longevity Responses and Comments from the Surveys

During the Tree Longevity Survey process, the respondents were assured anonymity, as outlined in the accompanying cover letter described in Chapter 7.4.2. The primary purpose of this was to ensure that respondent identities and associated longevity figures were withheld from their peers, and to obtain candid tree longevity figures from their responses, as discussed in section 9.4.6. With this issue duly considered, several anonymous comments returned by the respondents do, however, provide a valuable insight into the variety of tree longevity responses, and are important aspects of the peer reference group tree longevity survey discussion.

As outlined in Appendix 11, nine surveys were returned through emails, and seven were returned by traditional postal services. Contained within these 16 returned surveys were 240 written ‘comments’, generally included as short additions to the longevity figures provided by the respondents. These comments varied widely in their content, and included reflections such as ‘can live much longer’, ‘subject to borers’, or ‘don’t know’. Of these 240 comments, 159 came from the seven surveys returned by post, with the remaining 81 comments provided by the nine surveys that were returned through email. These brief comments are of general interest to the overall tree longevity survey, and are a good reflection of the wealth of knowledge possessed by respondents from the peer reference group, however, their qualitative features excluded them from quantitative numerical computation incorporating mathematical platforms to predict tree senescence. Additionally, the large variation in qualitative responses across the 240 comments rendered them unsuitable for quantitative coding into numerical figures reflecting tree longevity figures.

Several respondents provided important feedback to the tree longevity survey, and were supplied on separate written pages, in addition to tree longevity figures provided. One respondent stated that,

> Despite what other recipients of your letter may say, I believe there is no one who could give accurate answers to most of the species you have listed. How could we, in such a young country?[12]

This pertinent observation appears to highlight the need for conducting a tree longevity survey from a target population of experts, and gathering the information provided to use as a basis for expanding tree longevity knowledge. Out of the possible 1840 tree longevity figures submitted across the 16 surveys, respondents provided longevity figures for 1163, or 63.2 per cent. Whether these tree longevity figures were estimates, or observed occurrences, will remain uncertain, however the fact that 36.8 per cent of potential responses remained unanswered appears to suggest a general reluctance of respondents to assign longevities to taxa they are unfamiliar with. The overall quantity of tree longevity figures provided by the peer reference group appears to suggest a general interest by the respondents in the subject of this survey.

From the surveys returned, there appeared to be a quantity of additional tree longevity knowledge amongst the peer reference group respondents. Of the 16 surveys returned, five surveys contained a total of 27 new taxa, with 23 new longevity figures provided for those new taxa. This information, however, could not be incorporated into the tree longevity results due to a lack of additional longevity figures to substantiate the new taxa longevities. The knowledge possessed by the peer reference group, as reflected by the quantity of extra comments, taxa, and longevities provided, indicates a willingness to share their information where known, and to participate in a topic of interest.

9.4.6 Use of Self-Administered Surveys

The use of self-administered surveys to obtain tree longevity data from a target population of experts or peer reference group has both inherent advantages and disadvantages associated. Walter (2006) noted that self-administered surveys 'Provide a high level of respondent anonymity and may encourage more honest answers around sensitive topics'.[13] For example, the respondent quoted in section 9.4.5 openly questioned the validity of longevity figures provided by other respondents for most of the taxa in Australia. As a Peer Reference Group, respondents in these areas of expertise would almost certainly know other respondents within the Peer Reference Group from the Adelaide region, and by assuring anonymity, respondents were able to provide unbiased longevity figures for the survey, with the knowledge that their own longevity figures would not be disclosed to their peers for scrutiny.

There also appear disadvantages associated with self-administered surveys. The absence of an interviewer during the survey process could have an adverse affect upon results obtained, with Walter (2006) noting that the 'Researcher cannot be sure that the respondent has not misinterpreted the questions', and therefore provided answers based upon their own interpretations.[14] Walter (2006) also noted that self-administered surveys 'Tend to have more missing data', particularly where either detailed or open responses are required from the respondents.[15] This may provide another explanation for the nonresponse rate of 36.8 per cent, as discussed in section 9.4.5.

The inclusion of several unspecified taxa in the self-administered survey may have also had an influence upon the rate of nonresponse. As the peer reference group survey was conducted prior to confirmation of all taxa located in the Park 17 field survey, 'Acacia spp.' and 'Eucalyptus spp.' were incorporated into the tree longevity survey. As noted by several respondents, the genera *Acacia* and *Eucalyptus* both contain species with varying life spans, and therefore accurate answers to their longevities could not be provided. The low response rates of 18.8 per cent for both of these taxa appear to reflect this general reluctance in providing these with longevity figures.

The general use of surveys to gain information has both advantages and disadvantages, according to several authors. Marans (1987) observed that the purpose of conducting a survey is often related 'to a problem or set of problems', the main aim of which is to seek solutions contained within respondent answers.[16] As pointed out by Walter (2006), 'Survey data is conducive to statistical analysis techniques', with comparisons and relationships between the data able to 'be identified and analysed using robust and rigorous analysis techniques'.[17] The quantitative nature of the primary data collected from the peer reference group tree longevity survey represents 'precise measurement' in the form of numerical figures, according to Neuman (2000), the analysis of which is conducted through the use of 'statistics, tables, or charts', and followed by a discussion of the results.[18]

9.4.7 Changes in Tree Longevity Surveys

When implementing data obtained from survey results, concerns will often arise regarding the changing nature of values, opinions, and estimates provided by the respondents. Walter (2006) observed that data collected from surveys are generally a 'snapshot' and are not a constant reflection of the respondent views.[19] This is due to most data 'being collected at a specific time' and therefore 'reflective of this time rather than being a fixed phenomenon', according to Walter (2006).[20] Marans (1987) observed that,

> Cross-sectional surveys are designed to collect data at a single point in time from a population or a sample of that population. That is, the data are intended to describe or explain something about the population at the time the survey is conducted.[21]

If data collected from the peer reference group tree longevity survey are considered a reflection of expert opinion based upon their knowledge and experience at the time of the survey, it becomes even more purposeful when combined with field data collected at approximately the same time. The concept of change in environments must also be taken into consideration, with fluctuations in climate having the potential to impact upon tree longevities in the landscape. Without the ability to predict accurate future environmental conditions, estimates of future senescence patterns must therefore be based upon present conditions. In the case of modelling tree longevities in cultural landscapes, changes in environmental conditions and climate would be reflected in subsequent peer reference group tree longevity surveys undertaken periodically, in turn reflecting changing expert opinions of tree longevity over time.

9.5 Discussion of Tree Growth and Senescence Modelling

Following the review of models for determining tree growth, as discussed in Chapter 4, and the subsequent development of Park 17 growth models to determine tree age and senescence predictions for various Park 17 taxa, discussion of the results obtained from these methods is required.

9.5.1 Tree Growth Models and Curve Fitting

As discussed in Chapter 4.2.1.7, complete environmental systems are infinitely complex and therefore some degree of simplification must occur in order to create models for use in tree longevity projections. As argued by Sands (1988), 'even seemingly grossly oversimplified models' can provide us with 'important insights' otherwise not available.[22]

As observed in Chapter 4.2.1.3, a 'sigmoid' or 'S' curve reflects the growth pattern of many biological organisms. Focusing upon tree growth patterns in particular, Zeide (1993) identified a period of slow initial growth, followed by a period of accelerated growth, followed again by another period of slow growth as the tree ages, eventually reaching senescence.[23] Outlined in Section 9.2, tree longevity and senescence modelling reflects the latter stages of tree growth, with the models displaying slower rates of growth for all parameters.

Although tree growth may be plotted as a straight-line relationship between tree age and any of the growth parameters, both Chapman (1942) and Jacques (1983) warned against such oversimplification when representing tree growth in models.[24] A number of authors presented growth models reflecting the latter stages of tree growth, where the relationship between tree age, and a growth parameter such as height or DBH, were shown plotted on a graph using *x-y* coordinates, and a curve fitted to the points. Lukaszkiewicz *et al.* (2005) plotted exponential functions to determine tree ages in *Tilia* avenues from trunk diameters in Poland; Peper *et al.* (2001) created logarithmic curves reflecting a trunk diameter-age relationship in Californian street trees; and Pigott (1989b) plotted logarithmic curves to represent DBH-age relationships for *Tilia* species in England.[25] Similarly, Banks *et al.* (1999) used logarithmic equations to represent tree height-age relationships in Canberra's street trees to predict maintenance schedules, and Clark and Matheny (1991) observed reduced rates of tree growth and branch elongation when trees appeared close to their 'maximum height'.[26]

When creating the tree growth models for use in Park 17, it was noted that the field gathered tree mensuration parameters of DBH, height, and canopy span would be used to determine tree age for senescence modelling of Park 17 trees. For this reason, the age determined tree data used to create the growth models were plotted with tree age as the dependent variable (*y*-axis), and the tree mensuration parameters as the independent variable (*x*-axis). The calculation of tree age for the remainder of the Park 17 tree specimens was therefore reliant upon the independent variable collected during the field survey. When plotted in this manner to determine tree age from a known mensuration parameter, the curve providing the best fit to the matrix of points, was an exponential equation. These curves, as displayed in Appendix 14, reflected a decrease in tree growth rate as tree age increases, for all mensuration parameters. The equation and an explanation of the equation parameters are as follows:

<u>EXAMPLE: Equation to Calculate Tree Age (years) from DBH (cm)</u>

$\boldsymbol{y = ce^{bx}}$ Exponential Equation

Where:

$\boldsymbol{y}$ = tree age in years (dependent variable);

$\boldsymbol{x}$ = trunk diameter at breast height or DBH (independent variable);

$\boldsymbol{e}$ = 2.718 Transcendental Number; and

c and ***b*** are constants derived from the curve fitted to the matrix of points.

9.5.2 Regression and Correlation in Matrix Models

When plotted using mathematical or statistical software computer programs, curves regressed to a series of points return mathematical calculations that are a direct reflection of the relationship between the curve, and the points used to develop the curve. This correlation coefficient, or *R*-square value, according to Moroney (1965) 'cannot exceed +1 or be less than –1 in value', and depends upon whether the relationship is positive or negative.[27] Moroney (1965), clarified this *r* value further explaining that,

> A value of +1 denotes perfect functional relationship between *x* and *y*, an increasing *x* being associated with an increasing *y*. When *r* is equal to –1, we again have a perfect functional relationship, but this time an increasing *x* is associated with a decreasing *y*. When *r*=0, there is no relation at all between *x* and *y*.[28]

Research of tree growth modelling by Peper *et al.* (2001) also defined R^2 values as ' a direct measure of the strength of association between variables' plotted on an *x-y* axes.[29] From the R-square values tabled in Appendix 15, it can be noted that no equations returned correlation coefficients of +1. As a perfect correlation of +1 would have been an unlikely occurrence, we must therefore assume that each tree age calculated, using the equations obtained from these growth curve models, would return a figure that was an imprecise reflection of tree age. The correlation coefficient provides us with an indication of how imprecise the calculated tree age could be. Therefore, the correlation coefficient affords us a figure that reflects the level of confidence we can assign to the equation in providing us with a reliable figure of tree age, based upon the relationship between the matrix points plotted, and the curve fitted to those points. To avoid inaccuracies inherent in such models calculating tree age from tree DBH, Zeide (1993) suggested that growth curves represent a 'broad valley', or a wider band of growth instead of a single line equation, as discussed in Chapter 4.2.1.6.[30] While this broad valley may indeed reflect the majority of trees represented, for the purpose of determining tree age for senescence modelling, equations were required for the calculation of numerical figures of tree age. When combined with knowledge of the correlation coefficient, tree age can be determined, and confidence levels to those figures assigned.

Although poor correlation in the form of low positive R-square values represent trend lines with a weaker relationship to the matrix points plotted, they can also indicate a lack of available data for growth modelling purposes. Consistently poor correlation coefficients returned for the Grey Box (*Eucalyptus microcarpa*) models summarised in Appendix 15, for example, are a reflection of the lack of matrix point data, as displayed in Appendix 14 (pp. 306-308). The points plotted in these models represent a small cross-section of tree ages for the taxa. Unfortunately, older specimens of the taxa were not extant in Park 17, with the resultant growth models reflecting a poor spread of points across the age-mensuration parameter matrix.

Similarly, a quantity of points close to the lower end of the growth curve with few points towards the upper end can result in large extrapolations, examples of which can also be seen in Appendix 14. Again, Appendix 14 (pp. 306-308) displaying the Grey Box growth models, provide good examples of large extrapolations. In addition, the River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*) models shown in Appendix 14 (pp. 297-299) also show extrapolation of the growth curve into potentially unknown growth parameters. The primary reason for both of these appear to be a significant lack of data representing extant Park 17 tree specimens from much older age brackets, toward the upper extent of the growth curves. This lack of data, combined with lengthy tree longevities provided by the peer reference group tree longevity survey, resulted in large extrapolations for these two taxa. Although the River Red Gum models returned fairly good correlation coefficients for all three mensuration parameters with relation to tree age, the extrapolation required to extend the curve past the predicted longevity for the taxon clearly identifies a lack of available tree age-size data. Due to this limitation of data for these two taxa, either proving or disproving the shape of these growth curves as they reach their predicted longevity boundaries could remain somewhat problematic, and the issue may not be fully resolved until subsequent measurements are recorded in the distant future for these plotted Park 17 specimens.

9.5.3 Possibility of Trees Surviving Beyond Predicted Longevity

Even though tree longevity modelling may predict tree senescence in the landscape, the possibility of individual specimens surviving beyond the predicted senescence date must be considered. A potential example provided here can be seen in Appendix 14 (pp. 309-311), where one Desert Ash specimen has been determined to have an age exceeding the predicted longevity boundary. If the age determination provided by the expert estimation was correct, this specimen at the time of the survey had lived 25 years past its predicted maximum longevity of 110 years, as provided by the peer reference group tree longevity survey. Three possible explanations for this occurrence are therefore proposed. Firstly, the estimation of tree age provided by the expert in the field may have been incorrect, and the tree was actually younger than estimated. Secondly, the tree age estimated by the expert may have indeed been correct, and the tree reflected an exemplar specimen of the taxon growing under conditions conducive to tree health and therefore extended longevity. Thirdly, the peer reference group had underestimated the potential longevity of this taxon, or did not predict such extensive tree longevities for this taxon in the future. Interestingly, this tree indeed appears larger than the remainder of the plotted specimens in all three growth parameters, as can be noted on each of the three growth models. Whether or not this specimen is older than 110 years, provision should be made for the eventuality of individual tree specimens reaching beyond their predicted longevity boundary.

9.5.4 Possibility of Trees Not Reaching Predicted Longevity

Conversely, the potential exists for trees to senesce before their predicted time. A number of environmental factors can impact upon tree growth and tree parameter mensuration for age determination, and subsequent senescence modelling in cultural landscapes. Each topic is worthy of individual research to determine their impact upon tree growth and senescence modelling, however, the scope of this research project prohibits detailed investigation into each. Although not a comprehensive list, the following may influence the growth rate and senescence of trees in cultural landscapes:

- Variations in soil types and profiles
- Storm damage
- Root competition from other plants or trees
- Fertiliser usage
- Landscape topography
- Salinity of groundwater

- Subsurface watertable levels
- Overhead shading
- Tree lopping or excessive pruning
- Climate change
- Air Pollutant Levels
- Pathogen attack
- Vertebrate or invertebrate damage
- Vandalism
- Soil compaction
- Above or belowground infrastructure
- Drought

Provision should therefore be made for tree specimens not reaching their predicted date of senescence.

9.5.5 Model Testing and Tree Growth Comparisons with Waite Data

The use of tree mensuration and tree age data collected from the Waite Arboretum was of importance to the testing stage of model development. The list of specimens modelled, along with mensuration parameters and ages are displayed in Appendix 16. Of this list, only those taxa representing four of more separate matrix points were used for modelling. This was considered the minimum required, as two points only would always return a perfect R-square value of +1, or 1.0. Through this method, the use of growth models with insufficient quantities of data were avoided.

From the model parameter figures presented in Appendix 17, it can be observed that data representing the River Red Gum taxon were not available for growth modelling from the Waite Arboretum. In addition, tree canopy spans were also not available from the Waite Arboretum archives, and therefore not able to be modelled for comparison or testing purposes.

Data obtained from the Waite Arboretum Archives were mensuration details of tree height and trunk diameter recorded during either 1968 or 1973. While these records are extremely valuable in tree growth modelling applications, curves fitted to points separated by five years only will very often return poor correlation coefficients, as shown by the R square values of the Kurrajong (*Brachychiton populneus*), White Cedar (*Melia azedarach* var. *australasica*), and Chinese Pistachio (*Pistacia chinensis*) models summarised in Appendices 17. If the correlation coefficients returned were poor, the extrapolation resulting from extending the curve towards the predicted longevity boundary may prove equally unreliable. Examples of the White Cedar models displaying unreliable extrapolation for both trunk diameter and tree height are included as Appendix 27.

As a topic of further interest, the separate tree modelling datasets from Park 17 (Appendix 10) and the Waite Arboretum (Appendix 16) were integrated to create combined growth models for each of the available Park 17 taxa. Plotted according to taxa, the resultant equation parameters and correlation coefficients are displayed in Appendix 20 as combined Park 17 and Waite Arboretum models. There were two primary reasons for this amalgamation of datasets. The first was to fit a new growth curve to an increased number of matrix points per taxa, with the potential of returning better R-square values and therefore increasing the confidence in each model. The second was to construct tree growth trend models within a broader Adelaide Plains context, by considering the two datasets together holistically to represent a wider geographic region. Interestingly, the only taxa to return better R-square values from the combined dataset models were Grey Box (*Eucalyptus microcarpa*) for both DBH and tree height.

9.6 Discussion of GIS in Tuttangga/Park 17 Tree Senescence Modelling

The use of a Geographical Information System (GIS) software package in this research was crucial to obtaining outcomes based upon the spatial layout of extant trees in the Park 17 landscape. Non-spatial electronic databases can produce similar structured queries to those described in Chapter 7.6.4, however, structured query results produced visually on maps such as those shown in Appendices 22 and 23, provide more versatile application of field data for landscape planers, managers, and designers. Burrough (1986) defined GIS as ‘a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes’.[31] Both Hanna (1998), and Prastacos and Diamandakis (2000), noted that GIS are database management systems (DBMS) for spatial data, and Prastacos and Diamandakis (2000) added that the data is typically georeferenced within the system.[32] The ability of GIS software to incorporate 'time', or changes over time has been examined in detail by Langran (1992), where 'temporal' GIS processes were identified. The six major functions of a temporal GIS outlined by Langran (1992) include inventory, analysis, updates, quality control, scheduling, and display.[33]

9.6.1 Representation of Change in GIS Modelling

A discussion of how geographical information systems incorporate time into their software is important for the representation and modelling of continually changing landscapes. Langran (1992) noted that temporal GISs can 'trace the changing state of a study area', and store both past and 'anticipated geographic states' as required.[34] Identifying this potential, Langran (1992) noted that responses could be obtained for queries such as:

> Where and when did change occur?
> What types of change occurred?
> What is the rate of change?
> What is the periodicity of change? [35]

By incorporating this data, according to Langran (1992), GIS software may subsequently evaluate 'whether temporal patterns exist', 'what trends are apparent', or 'what processes underlie the change' in the landscape.[36] These evaluations, Langran (1992) argued, could assist us in 'understanding the causes of change, leading to a better understanding of the processes at work in a region'.[37] For the modelling of tree longevity in landscapes such as Park 17, these concepts are important, as results from structured queries can highlight underlying processes at work in the landscape that potentially influence tree longevity.

In order to model time or change in a temporal GIS, there is a crucial need to establish a 'base state' or 'artificial present'.[38] This point in time, according to Langran (1992), does not necessarily need to coincide 'with the real-world present'; the base state instead provides a point from which changes are modelled.[39] For the Park 17 GIS models developed in this research, the artificial present was the year 2006. Projections both forward and backward through time in the Park 17 models used this point as the base state, identified here by Langran (1992).

Changes to GIS landscapes modelled, Stead (1998) observed, are most often represented as 'snapshots' at specified points in the past or future, recorded for display and interpretation.[40] These snapshots or 'time slices', Stead (1998) noted, can be incorporated as 'interpretive backcloths', with the 'hypothetical landscape … constructed using the data currently available to estimate the shape and form of the landscape'.[41] Advancing this concept further, Stead (1998) noted that these time-slice snapshots of temporal geographic information system models,

> … are like movie cameras: they present a series of images, which if sliced fine enough, give the illusion of temporal movement or change. In effect, one is dealing with state changes.

The problem identified by both Langran (1992) and Stead (1998) was that these methods of 'time-slicing' poorly represent the events that effect change between one slice and the next.[42] Stead (1998) noted that the outcome displayed for interpretation tends to represent the result of the process of change, not the actual process of change itself. Langran (1992) noted that sequent snapshot creation tends to record images at regular intervals, and therefore 'if several events occur between snapshots, they go unnoted'.[43] An example of this can be seen in Appendix 22 (pp. 337-345), where structured queries were entered into the Park 17 model developed, in order to determine the quantity and location of Desert ash trees expected to be alive at 2030 and 2050. Modelled on tree DBH, the two state changes do not show details of senescence pattern changes for the intervening years between 2031 and 2049.

9.6.2 Purpose for Modelling in GIS

As discussed in Chapter 4, modelling environmental systems can simplify complex interactions between multiple ecological processes. Mathematical growth curves, combined with GIS modelling using structured queries that are linked to spatially referenced data, can produce predictions of possible tree senescence patterns in complex environments. Brady and Whysong (1999) noted that 'models simplify the systems they are intended to represent', and while not exact representations, they tend to 'share significant features', making them suitable for 'addressing a rather limited, although perhaps very important, set of questions'.[44] Green (1999) observed that 'Models simplify the world by reducing information to those variables most critically affecting the decisions to be made.'[45] If the focus of the decision-making, or planning process involved tree longevities in studied cultural landscapes, then the simplification of complex landscape systems would be justified in order to extract important tree longevity data for that landscape. While also considering landscape simulation within a GIS context, Bell (1999) specifically noted that:

> Modelling incorporates the use of GIS data, together with assumptions and design rules about processes at work over time, to produce possible patterns in the landscape, either in the past or in the future.[46]

Ferrand (2000) also observed the use of simulation in GIS-based landscapes to analyse 'spatial patterns' and 'for studying dynamic processes' modelled.[47] Mathian, Mikula, and Sanders (2000) noted the importance of 'dynamic modelling' in GIS 'to help identify the processes behind change, analyse the spatial structure of change and predict future patterns and organisations'.[48] The prediction of future patterns in parkland landscapes, particularly those within close proximity to urbanised spaces, is of importance to informed decision-making processes. The modelling of future landscape scenarios to provide information on potential changes to that landscape is valuable for appropriate planning, design, and management processes to take place. As trees senesce in the Australian landscape, methods to predict, and therefore incorporate their inevitable decline into future planning, would prove a useful tool.

9.6.3 Practical Applications for Models Developed

Continuing with this concept of practical applications for modelling GIS across timeframes of the cultural landscape, the use of GIS as an inventorial system for the management of trees over time provides a connection between digital storage and analysis of data and the spatial identification of trees. Smiley and Baker (1988) noted the importance of urban tree inventories as tools for providing both information and education, reflecting the significance of 'well managed trees' to the wider community.[49] They warned, however, against the use of identifying 'hazardous trees', as this can 'increase liability problems' for managers of urban trees.[50] Importantly, Smiley and Baker (1988) observed that collecting details 'on existing tree injuries or damage' is valuable, as it may be used 'to predict tree decline or to define the cause of future tree problems' in the landscape.[51]

While spatially referenced relational databases such as these GIS examples are of significant importance to those involved in future landscape planning, Innes and Simpson

(1993) stressed that we 'must go beyond' these 'dry, technical definitions' and move towards image creation using GIS.[52] This important visual capability of most GIS processes, they argue, should be used to produce future projection 'imagery that can capture the imagination of planners and agency managers'.[53] Research by Challinor (1998) observed that the geographical information embedded in GIS maps can 'reveal site conditions', 'determine suitable land use', and 'identify opportunities and constraints', fostering the development of informed land management decisions based upon knowledge.[54] Challinor (1998) also noted, however, that skilled interpretation of the information extracted from these GIS resources is 'the key to sound land management decisions'.[55] This is important, as unskilled interpretation of tree senescence patterns may adversely affect the management of mature trees in a landscape. With this noted, Challinor (1998) observes,

> It is also important that organizations have the confidence to keep pushing into the unknown. Computer technology is a tool, an extension of the user's ability. It will not replace creativity and professional skills, but it can make work more efficient, and presentation more accessible and powerful.

These suggestions noted by Challinor (1998) would enhance the value of three-dimensional imaging in order to convey concepts, ideas, or predictions of future landscapes across wider communities. Consultation with the wider community, based upon specific scenarios presented, may also provide important feedback for planners, designers, and managers of landscapes. Of increasing importance, community consultation can also influence decision-making processes, such as the publicised tree removal and subsequent ring barking scenario presented in Chapter 2.4.2. Research by Tulloch (2000) suggested that 'Geospatial technologies … have often empowered their users with analysis-driven map products that provide leverage which can be used to alter public decisions'.[56] This observation provides us with an important insight into the capability and potential influence of science-based data computation combined with visual analysis output products within community-wide applications. Future enhancements in GIS-driven three-dimensional technologies would only advance this potentially powerful and influential decision-making instrument.

Science-based mathematical modelling combined with GIS spatial analysis may provide us with insights into past tree planting and future tree senescence patterns not previously visible in urban landscapes. The use of structured queries in ArcMap, such as those displayed in Appendix 22, disclose details of Park 17 tree growth and senescence patterns suitable for use in the investigation of tree senescence on even larger scales. When viewed through three-dimensional outputs, such as those created by ArcScene and shown in Appendix 23, the visual applications of the software become evident, as realism increases in the form of three-dimensional trees spatially arranged in a landscape.

9.6.4 Short and Long Term Modelled Changes to Park 17

From the tree growth and senescence models developed in this research, it would appear that the majority of Desert Ash (*Fraxinus angustifolia* subsp. *angustifolia*) trees in Park 17 are reaching the latter stages of their lifespan. These trees would be the most likely to reach senescence first, with the entire population predicted to be dead prior to 2056. The taxon least likely to be affected in the near future, as observed from the models developed here, appears to be the River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*) tree population. Aside from having extant specimens representing some of the oldest through to the youngest Park 17 trees, they were also believed to be the longest-lived Park 17 taxon from the peer reference group tree longevity survey results.

9.6.5 Omissions from Park 17 Models

An additional point of interest in this research is the projected senescence of tree specimens not modelled due to a lack of age determination data available for certain taxa. As can be seen in Figures 8.2 to 8.4, a number of trees are highlighted, indicating specimens predicted to have reached the end of their life span at particular points in the future. These predictions were based upon the method described in Chapter 7. Age determination data for a number of taxa was not available, resulting in their omission from the predictive modelling process. Included in Figures 9.1 to 9.3 are images depicting estimated senescence patterns, based upon probable tree ages and longevities by taxa, in future landscape scenarios. It should be noted that these latter images are expressly based upon tree ages estimated by the researcher, and not by any other means. Large tracts of tree senescence can clearly be seen in the three-dimensional renderings presented in these images. Further research into tree age determination and longevity modelling may fill such gaps in these Park 17 models.

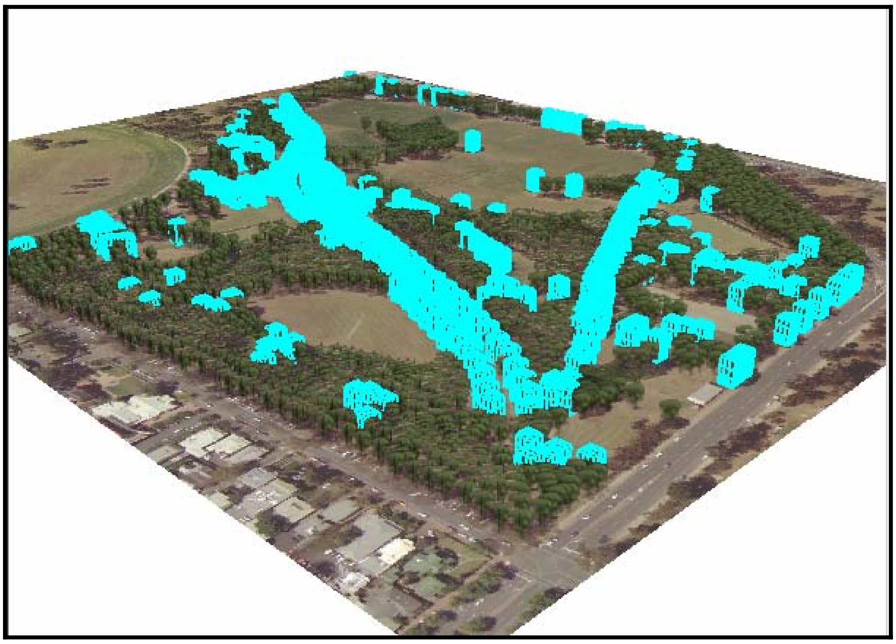

Figure 9.1. Hypothetical image from ArcScene representing the year 2050. Displayed here is the possible scenario of the year 2050, with highlighted trees estimated to have exceeded their predicted life span. (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

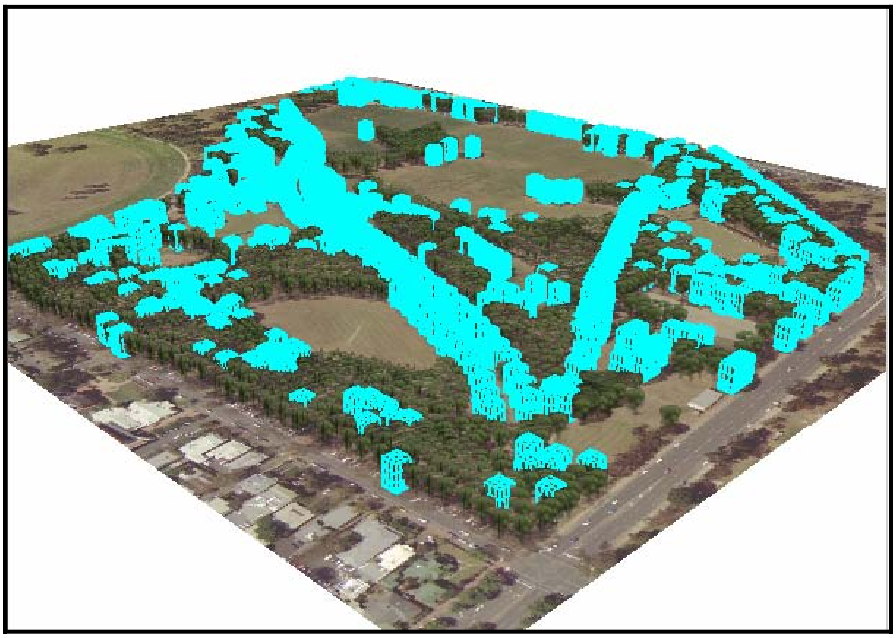

Figure 9.2. Hypothetical image from ArcScene representing the year 2100. Displayed here is the possible scenario of the year 2100, with highlighted trees estimated to have exceeded their predicted life span. (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

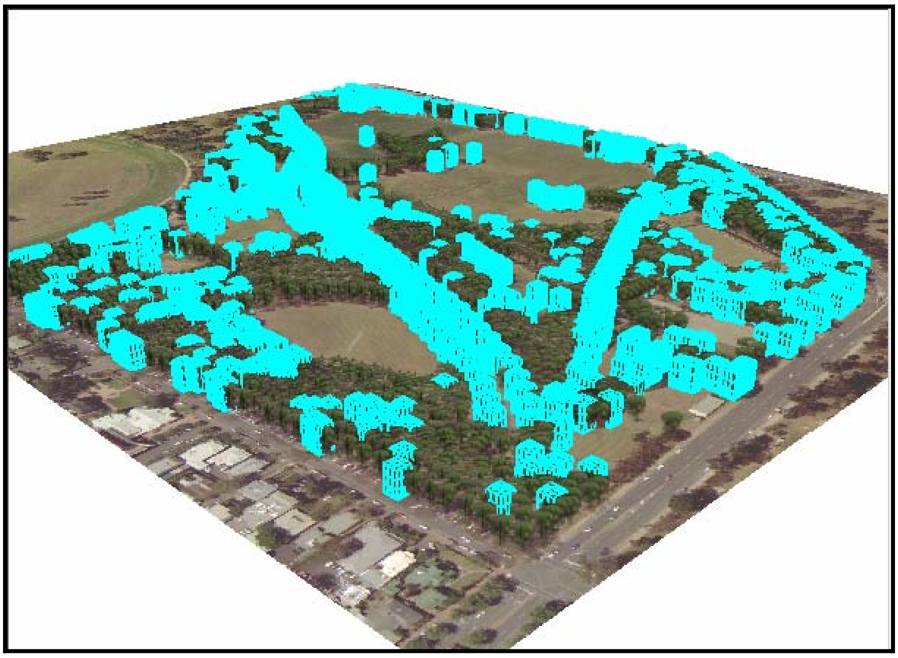

Figure 9.3. Hypothetical image from ArcScene representing the year 2200. Displayed here is the possible scenario of the year 2200, with highlighted trees estimated to have exceeded their predicted life span. (Aerial Photograph of Park 17 Copyright © MAPLAND, Information, Science and Technology: Department for Environment and Heritage (2002))

9.7 Conclusions

The research undertaken and presented in this thesis has investigated and analysed tree longevity and senescence modelling in cultural landscapes. With a particular focus upon Park 17 within the Adelaide Park Lands, models depicting tree senescence based upon knowledge gathered from relevant sources were developed and presented. The intention was to provide methods for predicting tree senescence patterns suitable for use in landscape planning, management, and design applications. From the research gathered and presented here, a number of conclusions emerged, and can be brought forward at this point in the research discussion:

- Cultural landscapes are dynamic, ever-changing environments that are shaped through human influence.
- Change in cultural landscapes is inevitable. Through an understanding of those changes taking place in the landscape, change can be managed, planned for, and embraced.

- Knowledge of potential future changes to cultural landscapes can result in informed decision-making, and strategy planning for those changes.
- All individual tree specimens can be expected to reach senescence at some point in their life. These changes are irreversible.
- Published figures representing expected tree longevities for the Adelaide Plains region are nonexistent from the literature reviewed on tree longevities.
- Surveys conducted to obtain expected tree longevity figures from targeted experts in the fields of arboriculture and horticulture provided valuable primary knowledge on tree longevities for specific taxa on the Adelaide Plains.
- Expert opinion of tree longevity figures would be expected to change as global environmental conditions and local climates change. Subsequent surveys of experts would provide up-to-date tree longevity figures for the future.
- Determining tree age from extant historical resources should be viewed with some degree of caution; exceptions to these would be in the form of appropriate record keeping techniques, or through the accurate verification of extant tree specimen-documentation relationships.
- Extant historic records displaying detailed tree planting dates for the Park 17 region of the Adelaide Park Lands are limited.
- Expert estimates of tree age may provide valuable data for tree growth modelling in cultural landscapes. The accuracy of the age estimates may vary depending upon expert knowledge.
- In order to avoid potential errors from any one resource, multiple methods of tree age determination should be incorporated into tree growth models.
- Reliance upon a single source for tree age determination data should be considered as a last resort option, to avoid possible errors from any one source.
- Although considered an invasive method of tree age determination, dendrochronology may have the potential to provide estimates of tree age in the Adelaide Plains region.
- As an invasive method of tree age determination, radiocarbon dating may only provide accurate tree ages for the period between the mid-1950s to the mid-1960s, and prior to the Industrial Revolution.
- Based upon statistical evidence, tree DBH provides, for the majority of taxa, the most accurate non-reversible, non-invasive method of modelling tree growth over time. Tree height should be considered second, and canopy span considered the least accurate of the three methods.

- From the correlation coefficients provided by the growth models in this research, DBH provides the best expression of tree growth over time, for the majority of the Park 17 tree taxa modelled.
- Tree growth modelling has the potential to predict future growth parameters of extant trees in cultural landscapes, however, extrapolations past known mensuration parameters for DBH, tree height, and canopy span, towards predicted senescence boundaries may provide unreliable long-term growth parameter prediction.
- Where possible, extrapolations of growth trends may be avoided by locating age determined specimens closer to the predicted longevity maximum for the taxa, indicating the growth trend direction towards senescence.
- The use of tree growth models to determine tree age from growth parameters can provide valuable data on projected tree senescence patterns in the Park 17 landscape. Although predicted tree senescence patterns cannot be proven in the immediate future, they can indicate tree populations at risk of senescence.
- Tree senescence modelling using interactive spatial technology such as GIS may indicate tree senescence patterns not visible through hard-copy mapping techniques.
- In addition to predicting senescence trends, GIS-based models may operate in reverse, providing details of past planting patterns or dates of tree establishment.
- GIS provides a practical spatial platform upon which possible scenarios of future landscapes can be modelled, analysed, and interpreted for use in landscape-related studies.
- From the tree senescence models developed for Park 17, the majority of Desert Ash (*Fraxinus angustifolia* subsp. *angustifolia*) specimens appear to be close to reaching their expected longevity boundary. Tree Replacement schedules, if available and appropriate for these specimens, should be implemented in the near future.
- From the senescence models developed for Park 17, the River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*) specimens appear the least at risk of senescence in the near future. In addition to possessing a broad spectrum of tree age classes within Park 17, it was determined to be the longest-lived taxon from the results of the peer reference group tree longevity survey.

9.8 Further Research

Arising from this research project are a number of specific research areas that would assist in the enhancement of accurate tree growth and senescence models for use in predicting future landscape scenarios for the Adelaide Park Lands landscape:

- Although considered invasive, dendrochronology and radiocarbon dating may represent accurate methods of determining tree age in cultural landscapes, however, more research in these fields need to be conducted to determine the validity of their use as methods of tree age determination on the Adelaide Plains.
- Accurate records of tree planting and replacement schedules in parkland landscapes, and in particular the Adelaide Park Lands, need to be detailed and retained to increase the accuracy of future tree growth and senescence modelling.
- Regular surveys of experts from the Adelaide region in the fields of arboriculture and horticulture will provide updated figures reflecting the life span we may expect from future trees in the Adelaide Park Lands, directly reflecting climate change scenarios.
- Further research into the accurate prediction of future climate change may improve the accuracy of tree senescence models through the forecasting of expected environmental trends influencing both tree growth patterns and tree longevity.
- Recording growth parameters from tree specimens over a period of many years would assist in developing tree growth models and therefore increase confidence levels for those models.
- The development of diverse tree growth models over the Adelaide Plains region would assist in determining approximated tree growth trends for the entire Adelaide Plains.
- Tree growth and senescence modelling will need to be undertaken for the majority of non-indigenous plant taxa across the Adelaide Park Lands. Ageing tree populations from the taxa not modelled in this research may be at risk of senescence in the near future.
- The tree growth models developed in this research project require further age-determined specimens to fill gaps in the growth curves modelled by extrapolation only.
- Visual analysis research into tree senescence modelling using GIS-based three-dimensional graphic representations may assist landscape planners, managers, and designers to ascertain community acceptance levels of change in cultural landscapes.

- Research into community consultation using the tree senescence models proposed in this project could assist planning strategies incorporating community-based feedback. This may also assist in providing information to community groups on change in cultural landscapes.

Chapter 9 Notes

[1] Wing *et al*. (2005) p. 169.
[2] Parker (2004) p. 117.
[3] *Annual Report* (1921) p. 38.
[4] Schweingruber (1993) pp. 125, 128.
[5] Schweingruber (1993) p. 128.
[6] Marans (1987) p. 68.
[7] Marans (1987) p. 68.
[8] Walter (2006) p. 202.
[9] Marans (1987) p. 68.
[10] Neuman (2000) p. 319.
[11] Neuman (2000) p. 320.
[12] Anonymous Peer Reference Group Respondent (2006)
[13] Walter (2006) p. 201.
[14] Walter (2006) p. 201.
[15] Walter (2006) p. 201.
[16] Marans (1987) p. 52.
[17] Walter (2006) p. 190.
[18] Neuman (2000) p. 123.
[19] Walter (2006) p. 190.
[20] Walter (2006) p. 190.
[21] Marans (1987) p. 48.
[22] Sands (1988) p. 32.
[23] Zeide (1993) p. 594.
[24] Chapman (1942) p. 806; Jacques (1983) p. 59.
[25] Lukaszkiewicz *et al*. (2005) p. 280; Peper *et al.* (2001) p. 306; Pigott (1989b) pp. 295-296.
[26] Banks *et al.* (1999) p. 37; Clark and Matheny (1991) p. 178.
[27] Moroney (1965) p. 287.
[28] Moroney (1965) p. 287-288.
[29] Peper *et al.* (2001) p. 310.
[30] Zeide (1993) p. 613.
[31] Burrough (1986) p. 6.
[32] Hanna (1998) p. 33; Prastacos and Diamandakis (2000) p. 223.
[33] Langran (1992) p. 5.
[34] Langran (1992) p. 4.
[35] Langran (1992) p. 4.
[36] Langran (1992) p. 4.
[37] Langran (1992) p. 5.
[38] Langran (1992) p. 30.
[39] Langran (1992) p. 30.
[40] Stead (1998) p. 215.
[41] Stead (1998) p. 215.
[42] Langran (1992) p. 39; Stead (1998) p. 215.
[43] Langran (1992) p. 57.
[44] Brady and Whysong (1999) p. 297.
[45] Green (1999) p. 6.
[46] Bell (1999) pp. 112-113.
[47] Ferrand (2000) p. 176.
[48] Mathian *et al.* (2000) p. 203.
[49] Smiley and Baker (1988) p. 37.
[50] Smiley and Baker (1988) p. 37.
[51] Smiley and Baker (1988) p. 39.
[52] Innes and Simpson (1993) p. 234.
[53] Innes and Simpson (1993) p. 234.
[54] Challinor (1998) pp. 114-115.
[55] Challinor (1998) p. 115.

[56] Tulloch (2000) p. 211.

References

Akeroyd, M.D., Leaney, F.W., Mathieson, M., Molonel, D. & Smith, G.C. 2002, Dating Spotted gum (*Corymbia citriodora*) tree rings in south-eastern Queensland using ^{14}C measurements of cellulose, *Australian Forestry* 65(4), pp. 265-267.

Ambrose, J.G. 1982, *An Ecological and Behavioural Study of Vertebrates Using Hollows in Eucalypt Branches*, PhD Thesis, School of Biological Sciences, Department of Zoology, La Trobe University, Melbourne, Australia.

Andrews, L., Harris, B. & Skipper, R. 2000, *The Horticulture and Management of Melbourne's Southern Conifers*, Melbourne, Horticultural project report (Undergrad) Institute of Land and Food Resources, University of Melbourne, Australia.

Anonymous, 2005, Tree Doomed, In *The City Messenger*, February 3rd, Adelaide, Australia, p. 5.

Antrop, M. 2005, Why landscapes of the past are important for the future, *Landscape and Urban Planning*, 70(1-2), pp. 21-34.

Annual Report, years: 1900-2006, Corporation of the City of Adelaide, Adelaide, Australia.

Apostle, H.G. 1969 *Aristotle's Physics: Translated with Commentaries and Glossary*, Indiana University Press, Bloomington, Indiana, U.S.A.

Argent, R.M., McMahon, T.A., Bowler, J.M. & Finlayson, B.L. 2004, The dendroecological potential of *Eucalyptus camaldulensis* Dehnhardt (River Red Gum) from the Barmah Forest, Victoria, Australia, *Australian Geographical Studies*, 43(1), pp. 89-102.

Attorre, F., Francesconi, F., Pepponi, L., Provantini, R. & Bruno, F. 2003, Spatio-temporal analyses of parks and gardens of Rome, *Studies in the History of Gardens and Designed Landscapes*, 23(3), pp. 293-306.

Australian Heritage Council, 2007, Commonwealth of Australia, Australian Government, viewed 2 January 2007, <http://www.ahc.gov.au/register/index.html>

Australia ICOMOS, 1999, *The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance*, Australia ICOMOS Incorporated.

Banks, J.C., Brack, C.L. & James, R.N. 1999, Modelling changes in dimensions, health status, and arboricultural implications for urban trees, *Urban Ecosystems*, 3(1), pp. 35-43.

Banks, J.C.G. 1982, *The Use of Dendrochronology in the Interpretation of the Dynamics of the Snow Gum Forest*, PhD Thesis, Australian National University, Canberra, Australia.

Banks, J.C.G. 1993, *Tree-ring Analysis of Two Mountain Ash Trees, Eucalyptus regnans F.Muell. from the Watts and O'Shannassy Catchments, Central Highlands, Victoria: A Report to the Central Highlands Old Growth Forest Project*, Australian National University, Canberra, Australia.

Banks, J.C.G. 1997, Tree Ages and Ageing in Yellow Box, *Australia's Ever-Changing Forests III: Proceedings of the Third National Conference on Australian Forest History*, J. Dargavel (Ed.), Centre for Resource and Environmental Studies, Canberra, Australia, pp. 17-28.

Banks, J.C.G. & Brack, C.L. 2003, Canberra's urban forest: evolution and planning for future landscapes. *Urban Forestry and Urban Greening* 1(3), pp. 151-160.

Barbetti, M., Bird, T., Dolezal, G., Taylor, G., Francey, R., Cook, E. & Peterson, M. 1992, Radiocarbon variations from Tasmanian conifers: first results from late Pleistocene and Holocene logs, *Radiocarbon*, 34(3), pp. 806-817.

Bell, S. 1999, *Landscape: Pattern, Perception and Process*, E & FN Spon, London, England.

Bell, S. 2001, Landscape pattern, perception and visualisation in the visual management of forests, *Landscape and Urban Planning*, 54(1-4), pp. 201-211.

Bettinger, P. 2001, Challenges and opportunities for linking the modeling of forest vegetation dynamics with landscape planning models, *Landscape and Urban Planning*, 56 (3-4), pp. 107-124.

Blaut, J.M. 1961, Space and process, *The Professional Geographer*, 13(4), pp. 1-7.

Booth, T.H., Serra, R.G. & Wells, K.F. 1988, Tree Ring Measurement and Growth Modelling, *Modelling Trees, Stands and Forests: Bulletin No. 5 of the School of Forestry, The University of Melbourne*, J.W. Leech, R.E. McMurtrie, P.W. West, R.D. Spencer, & B.M. Spencer (Eds.), The University of Melbourne, Melbourne, Victoria, pp. 161-172.

Boudon, F. 1991, Garden History and Cartography, *The History of Garden Design: The Western Tradition from the Renaissance to the Present Day*, M. Mosser, & G. Teyssot (Eds.), Thames and Hudson, London, England, pp. 125-134.

Brady, W.W. & Whysong, G. L. 1999, Modeling, *GIS Solutions in Natural Resource Management: Balancing the Technical-Political Equation*, S. Morain (Ed.), OnWord Press, Santa Fe, California, U.S.A., pp. 293-324.

Brooker, M.I.H., Slee, A.V., Connors, J.R. & Duffy, S.M. 2002, *Euclid: Eucalypts of Southern Australia*, 2nd edn. Multimedia CD-ROM, CSIRO Publishing, Australia.

Brookhouse, M. 2006, Eucalypt dendrochronology: past, present and potential, *Australian Journal of Botany*, 54, pp. 435-449.

Brown, J.E. 1880, *Report on a System of Planting the Adelaide Park Lands, Illustrated by Plans and Sketches*, R.K. Thomas (Publisher), Adelaide, South Australia.

Bunge, M. 1963, *The Myth of Simplicity: Problems of Scientific Philosophy*, Prentice-Hall, Englewood Cliffs, New Jersey, U.S.A.

Bureau of Meteorology, 2007a, Commonwealth of Australia, Australian Government, viewed 20 June 2007, <http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/clim_classification.cgi>

Bureau of Meteorology, 2007b, Commonwealth of Australia, Australian Government, viewed 3 June 2007, <http://www.bom.gov.au/climate/averages/tables/cw_023090.shtml>

Bureau of Meteorology, 2007c, Commonwealth of Australia, Australian Government, viewed 20 June 2007, <http://www.bom.gov.au/climate/environ/other/kpn_all.shtml>

Burrough, P.A. 1986, *Principles of Geographical Information Systems for Land Resources Assessment*, Clarendon Press, Oxfordshire, England.

Burrows, N.D., Ward, B. & Robinson, A.D. 1995, Jarrah forest fire history from stem analysis and anthropological evidence, *Australian Forestry*, 58(1), pp. 7-16.

Challinor, C. 1998, Computer technology: an extension of our abilities? *Landscape Australia*, 20(2), pp. 111-116.

Chapman, H.H. 1942, The problem of forecasting timber growth in irregular stands, *Journal of Forestry*, 40, pp. 805-806.

Clare, T. & Bunce, R.G.H. 2006, The potential for using trees to help define historic landscape zones: a case study in the English Lake District, *Landscape and Urban Planning*, 74(1), pp. 34-45.

Clark, J.R. 1983, Age-related changes in trees, *Journal of Arboriculture*, 9(8), pp. 201-205.

Clark, J.R. & Matheny, N. 1991, Management of mature trees, *Journal of Arboriculture*, 17(7), pp. 173-184.

Cobham, R. 1990, *Amenity Landscape Management: A Resources Handbook*, E & FN Spon, London, England.

Couch, S. 1992, Trees in line for conservation, *Landscape Design*, 214, pp. 43-46.

Crisp, M.D. & Lange, R.T. 1976, Age structure, distribution and survival under grazing of the arid-zone shrub, *Acacia burkittii*, *Oikos*, 27(1), pp. 86-92.

Crompton, A.W. 1998, *South Parklands Wetland Feasibility Project: Native Vegetation Survey*, Prepared for the Patawolonga Catchment Water Management Board, Adelaide, Australia.

Daly, J.W. 1987, *Decisions and Disasters: Alienation of the Adelaide Parklands*, Bland House, Adelaide, Australia.

Day, C. 2006, 100-Year-Old Pines Saved, In *The City Messenger*, Adelaide, Australia, p. 5.

Dragicevic, S., Marceau, D.J. & Marois, C. 2001, Space, time, and dynamics modelling in historical GIS databases: a fuzzy logic approach, *Environment and Planing B: Planning and Design*, 28(4), pp. 545-562.

Dunwiddie, P.W. & LaMarche, V.C. 1980, Dendrochronological characteristics of some native Australian trees, *Australian Forestry*, 43(2), pp. 124-135.

Ellis, R.W. 1976, The Aboriginal Inhabitants and their Environment, *Natural History of the Adelaide Region*, C.R. Twidale, M.J. Tyler, B.P. Webb (Eds.), Royal Society of South Australia, Adelaide, Australia. pp. 113-120.

Eyring, S. 1999, Vegetation management in large cultural landscapes: techniques for preserving historic fields and vistas, *APT Bulletin*, 30(1), pp. 21-27.

Fakes, J. 2006, Whole of life tree management, *Landscape Contractor*, 2(1), pp. 16-21.

Felix, R. & Shigo, A.L. 1977, Rots and rods, *Journal of Arboriculture*, 3(10), pp. 187-190.

Ferrand, N. 2000, Multi-reactive Agents Paradigm for Spatial Modelling, *Spatial Models and GIS: New Potential and New Models*, A.S. Fotheringham & M. Wegener (Eds.), Taylor & Francis, New York, U.S.A., pp. 167-184.

Forestry Tools, 2007, viewed 14 August 2007, <http://www.forestrytools.com.au/Tapes.htm>

Frank, A.U. 1998. Different Types of "Times" in GIS. *Spatial and Temporal Reasoning in Geographic Information Systems*. M.J. Egenhofer, R.G. Golledge (Eds.), Oxford University Press, New York, U.S.A., pp. 40-62.

Frawley, K.J. 1989, 'Cultural landscapes' and National Parks: philosophical and planning issues, *Australian Parks and Recreation*, 25(3), pp. 16-23.

Fritts, H.C. 1976, *Tree Rings and Climate*, Academic Press, London, New York.

Funnell, K. 1992, Managing the future, *Landscape Design*, (214), pp. 34-37.

Gilbert, J.M. 1959, Forest Succession in the Florentine Valley, Tasmania, *Papers and Proceedings of the Royal Society of Tasmania*, 93, pp. 121-151.

Gill, E.D. 1971, Applications of radiocarbon dating in Victoria, Australia, *Proceedings of the Royal Society of Victoria*, 84(1), pp. 71-85.

Goulty, S.M. 1993, *Heritage Gardens: Care, Conservation and Management*, Routledge, London, England.

Graham, E. 2005, Botonist Deems Ringbarked Pine Tree 'Effectively Dead' [sic], In *The City Messenger*, Adelaide, Australia, p. 9.

Green, K. 1999, Development of the Spatial Domain in Resource Management, *GIS Solutions in Natural Resource Management: Balancing the Technical-Political Equation*, S. Morain (Ed.), OnWord Press, Santa Fe, California, U.S.A., pp. 5-15.

Grey, G.W. & Deneke, F.J. 1992, *Urban Forestry*, 2nd edn, Krieger Publishing, Malabar, Florida, U.S.A.,

Hanna, K.C. & Culpepper, R.B. 1998, *GIS in Site Design: New Tools for Design Professionals*, Wiley, New York, U.S.A.

Hannah, B.L. & Yau, D.P. 1993, *Avenues and Boulevards: A Guide to their Tree Management*, Royal Australian Institute of Parks and Recreation, Carlton South, Victoria, Australia.

Harper, J.L. 1977, *Population Biology of Plants*, Academic Press, London, England.

Harris, R.W. 1992, *Arboriculture: Integrated Management of Landscape Trees, Shrubs and Vines*, 2nd edn., Prentice Hall, Englewood Cliffs, New Jersey, U.S.A.

Harrison, R.P. 1992, *Forests: The Shadow of Civilization*, University of Chicago Press, Chicago, Illinois, U.S.A.

Harvey, D. 1969, *Explanation in Geography*, Edward Arnold Ltd, London, England.

Hasenauer, H. 1997, Dimensional relationships of open-grown trees in Austria, *Forest Ecology and Management*, 96(3), pp. 197-206.

Heathcote, R. 1995, Rippon Lea revealed: an approach for restoring a major historic garden, *Australian Garden History*, 7(3), pp. 11-16.

Helms, A.D. 1945, A giant eucalypt (*Eucalyptus regnans*), *Australian Forestry*, 9, pp. 25-28.

Heyer, H. 1976, Shifting meanings in a garden landscape, *Landscape Architecture*, 66(3), pp. 240-247.

Hitchmough, J.D. 1990, Principles and Practice of Tree Replacement in Historic Gardens, *Open to View: Historic Gardens and the Public, Proceedings of the Ninth Annual Conference of the Australian Garden History Society*, D. Missingham (Ed.), Australian Garden History Society, Melbourne, Australia, pp. 17-20.

Hitchmough, J.D. 1994a, An Overview of Urban Landscape Management, *Urban Landscape Management*, J.D. Hitchmough (Ed.), Inkata Press, Sydney, Australia, pp. 1-19.

Hitchmough, J.D. 1994b, The Principles Underlying the Management of Urban Vegetation, *Urban Landscape Management*, J.D. Hitchmough (Ed.), Inkata Press, Sydney, Australia, pp. 81-111.

Hitchmough, J.D. 1994c, The Management of Trees in the Urban Landscape, *Urban Landscape Management*, J.D. Hitchmough (Ed.), Inkata Press, Sydney, Australia, pp. 267-300.

Hodge, S.J. 1992, The natural choice, *Landscape Design*, 214, pp. 30-33.

Holland, P.G. 1967, *Biomass and Pattern in the Ecology of Mallee Vegetation.* PhD Thesis, Australian National University, Canberra, Australia.

Innes, J.E. & Simpson, D.M. 1993, Implementing GIS for planning: lessons from the history of technological innovation, *Journal of the American Planning Association*, 59(2), pp. 230-236.

Isard, W. 1970, On notions and models of time, *Papers of the Regional Science Association*, 25, pp. 7-32.

Jackson, J.B. 1958, Southeast to Turkey, *Landscape: Magazine of Human Geography*, 7(3), pp. 17-22.

Jacques, D. 1983, Hampton Court: Analysis of Tree Surveys Aided by Computer Plotted Mapping, *Computerisation of Tree Inventories*, C.J. Bickmore & T.H.R. Hall (Eds.), A. B. Academic Publishers, Bichester, U.K., pp. 53-62.

Jacques, D. 1987, Girth growth analysis in historical survey, *Arboricultural Journal*, 11, pp. 193-207.

Jim, C.Y. 2000, The Urban Forestry Programme in the heavily built-up milieu of Hong Kong, *Cities*, 17(4), pp. 271-283.

Johnston, C. 1992, *What is Social Value? A Discussion Paper*, Government Publishing Service, Canberra, Australia.

Jones, D. 2007, *Adelaide Park Lands and Squares Cultural Landscape Assessment Study*, Prepared for the Corporation of the City of Adelaide, Adelaide Research & Innovation Ltd, University of Adelaide, Australia, pp. 265-273, 745-756.

Jönsson, A. & Gustavsson, R. 2002, Management styles and knowledge cultures, past, present and future, related to multiple-use and urban woodlands, *Urban Forestry and Urban Greening*, 1(1), pp. 39-47.

Kerr, J.S. 1990, *The Conservation Plan: A guide to the preparation of conservation plans for places of European cultural significance*, Sydney, The National Trust of Australia (NSW).

Kraehenbuehl, D.N. 1996, *Pre-European Vegetation of Adelaide: A Survey From the Gawler River to Hallett Cove*, Nature Conservation Society of South Australia Inc., Adelaide, Australia.

Lacey, C.J. 1973, *Silvicultural Characteristics of White Cypress Pine, Research Note Number 26*, Forestry Commission of New South Wales, Sydney, Australia.

Lange, R.T. 1965, Growth ring characteristics in an arid zone conifer, *Transactions, Royal Society of South Australia*, 89, pp. 133-137.

Lange, T., Barbetti, M. & Donahue, J.D. 2002, Radiocarbon measurements of tree rings from 14 ka Huon pine, *Radiocarbon*, 43(2A), pp. 449-452.

Langmead, D. 1994, *Accidental Architect: The Life and Times of George Strickland Kingston*, Crossing Press, Darlinghurst, N.S.W., Australia.

Langran, G. 1992, *Time in Geographic Information Systems*, Taylor and Francis, London, England.

Latreille, A. 1985, Introduction. *Design for Change: Community Renewal after the 1983 Bushfires*, R. Green, J. Schapper, I. Bishop & M. McCarthy (Eds.), School of Environmental Planning, University of Melbourne, Melbourne, Australia, pp. 1-7.

Lawrence, H.W. 1993, The Neoclassical origins of modern urban forests, *Forest and Conservation History*, 37(1), pp. 26-36.

Leal, S., Pereira, H., Grabner, M. & Wimmer, R. 2004, Tree-ring structure and climatic effects in young Eucalyptus globulus Labill. grown at two Portuguese sites: preliminary results, *Dendrochronologia*, 21(3), pp. 139-146.

Leech, J.W. 1984, Estimating crown width from diameter at breast height for open-grown Radiata pine trees in South Australia, *Australian Forest Research*, 14(4), pp. 333-337.

Leopold, A.C. 1980, Aging and Senescence in Plant Development, *Senescence in Plants*, K. V. Thimann (Ed.). CRC Press, Boca Raton, Florida, U.S.A., pp. 1-12.

Loehle, C. 1988, Tree life history strategies: the role of defenses, *Canadian Journal of Forest Research*, 18, pp. 209-222.

Long, M. 2003, *A Biodiversity Survey of the Adelaide Park Lands, South Australia in 2003*, Department for Environment and Heritage, Adelaide, Australia.

Lowenthal, D. 1975, Past time, present place: landscape and memory, *The Geographical Review*, 65(1), pp. 1-36.

Lowenthal, D. 1979, Age and Artifact: Dilemmas of Appreciation, *The Interpretation of Ordinary Landscapes*, D.W. Meinig (Ed.), Oxford University Press, New York, U.S.A., pp. 103-128.

Lowenthal, D. 1985, *The Past is a Foreign Country*, Cambridge University Press, Cambridge, England.

Lukaszkiewicz, J., Kosmala, M., Chrapka, M. & Borowski, J. 2005, Determining the age of streetside Tilia cordata trees with a dbh-based model, *Journal of Arboriculture*, 31(6), pp. 280-283.

Lynch, K. 1985, *What Time is this Place?* Massachusetts Institute of Technology Press, Cambridge, Massechusetts, U.S.A.

Marans, R.W. 1987, Survey Research, *Methods in Environmental and Behavioral Research*, R.B. Bechtel, R.W. Marans & W. Michelson (Eds.), Van Nostrand Reinhold Co., New York, U.S.A., pp. 41-81.

Maslen, J.T. 1830, *The Friend of Australia - A Plan for Exploring the Interior and for Carrying out a Survey of the Whole Continent of Australia*, Hurst, Chance and Co., London, England.

Mathian, H., Mikula, B. & Sanders, L. 2000, Modelling the Dynamics of Spatial Systems within a GIS: Problems and Perspectives, *Spatial Models and GIS: New Potential and New Models*, A.S. Fotheringham & M. Wegener (Eds.), Taylor & Francis, New York, U.S.A., pp. 203-221.

Mayne-Wilson, W. 2001, Understanding and managing cultural landscapes, *Landscape Australia*, 23(1), pp. 10-16.

Mayor's Report, years: 1857-1899, Corporation of the City of Adelaide, Adelaide, Australia.

McPhail, S., Barbetti, M., Francey, R., Bird, T. & Dolezal, J. 1983, ^{14}C variations from Tasmanian trees - preliminary results, *Radiocarbon*, 25(3), pp. 797-802.

McPhee, C. 1999, Historic landscape management: making the leap from assessment to action, *Australian Garden History*, 10(4), pp. 4-8.

Meinig, D.W. 1979, Reading the Landscape: An Appreciation of W.G. Hoskins and J.B. Jackson, *The Interpretation of Ordinary Landscapes*, D.W. Meinig (Ed.), Oxford University Press, New York, U.S.A., pp. 195-244.

Melnick, R.Z. 1981, Capturing the cultural landscape, *Landscape Architecture*, 71(1), pp. 56-61.

Melnick, R.Z. 1983, Protecting rural cultural landscapes: finding value in the countryside, *Landscape Journal*, 2(2), pp. 85-96.

Milbank, Z. 2004a, Parkland Pines are Closer to Getting the Axe, In *The Advertiser*, 14th April, Adelaide, Australia, p. 2.

Milbank, Z. 2004b, Opposition Grows to Parkland Tree Removal: Pressure to Save Pines, In *The Advertiser*, 15th April, Adelaide, Australia, p. 22.

Mitchell, A. 1974, *A Field Guide to the Trees of Britain and Northern Europe*, Collins, London, England.

Mitchell, A.F. 1972, *Conifers in the British Isles: A Descriptive Handbook*, Her Majesty's Stationary Office, London, England.

Molisch, H. 1938, *The Longevity of Plants*, Science Press, New York, U.S.A.

Moore, G.M. 1990, *Tree Care for the Home Gardener*, Lothian Publishing, Melbourne, Australia.

Moore, G.M. 2008, *Darren Peter PhD Thesis*, Personal Communication, 14th May, 2008.

Moroney, M.J. 1965, *Facts From Figures*, 3rd edn., Penguin Books, Ringwood, Victoria, Australia.

Morton, P. 1996, *After Light: a History of the City of Adelaide and its Council 1878-1928*, Wakefield Press, Kent Town, South Australia, Australia.

Mucha, S.B. 1979, Estimation of tree ages from growth rings of eucalypts in northern Australia, *Australian Forestry*, 42(1), pp. 13-16.

Neuman, W.L. 2000, *Social Research Methods: Qualitative and Quantitative Approaches*, 4th edn., Allyn and Bacon, Boston, Massechusetts, U.S.A.

Noodén, L.D. 1980, Senescence in the Whole Plant, *Senescence in Plants*, K. V. Thimann (Ed.), CRC Press, Boca Raton, Florida, U.S.A., pp. 219-245.

Noodén, L.D. 1988, The Phenomena of Senescence and Aging, *Senescence and Aging in Plants*, L.D. Noodén & A.C. Leopold (Eds.), Academic Press, San Diego, California, U.S.A.

Norton, D.A. & Ogden, J. 1990, Problems with the use of tree rings in the study of forest population dynamics, *Methods of Dendrochronology: Applications in the Environmental Sciences*, E.R. Cook & L.A. Kairiukstis (Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 284-288.

Nowak, D.J., Kuroda, M. & Crane, D.E. 2004, Tree mortality rates and tree population projections in Baltimore, Maryland, U.S.A., *Urban Forestry and Urban Greening*, 2(3), pp. 139-147.

Ogden, J. 1978, On the dendrochronological potential of Australian trees, *Australian Journal of Ecology*, 3(4), pp. 339-356.

Ogden, J. 1985, Past, Present, and Future: Studies on Population Dynamics of Some Long-lived Trees, *Studies on Plant Demography: A Festschrift for John L. Harper*, J. White (Ed.), Academic Press, London, England, pp. 3-16.

Olwig, H.R. 2005, Liminality, seasonality and landscape, *Landscape Research*, 30(2), pp. 259-271.

Parker, M. 2004, *The Management of Tree Replacement in Mature Urban Landscapes*, PhD Thesis, Institute of Land and Food Resources, University of Melbourne, Melbourne, Australia.

Patrick, J. 1988, The Management of the Tree Resource, *The proceedings of Trees in the Environment Current and Future Conference, April 13-15th 1988*, T. Arthur & D. Aldous (Eds.), Royal Australian Institute of Parks and Recreation, Springvale, Victoria, Australia, pp. 251-254.

Patrick, J. 1994, The Management of Culturally Significant Landscapes, *Urban Landscape Management*, J.D. Hitchmough (Ed.), Inkata Press, Sydney, Australia, pp. 471-491.

Pearson, S. G. & Searson, M. J. 2002, High-resolution data from Australian trees, *Australian Journal of Botany*, 50(4), pp. 431-439.

Peper, P.J., McPherson, E.G. & Mori, S.M. 2001, Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees, *Journal of Arboriculture*, 27(6), pp. 306-316.

Pescott, R.T.M. 1968, Life Expectancy and Planned Replacement, *Proceedings of the Symposium on Street Trees*, *conducted by the Victorian Division, Australian Institute of Parks and Recreation, at La Trobe University, Bundoora, Saturday, 8th June, 1968.* A.E. Wilkie (Ed.), Australian Institute of Parks and Recreation, Victoria Division, Melbourne, Australia, pp. 53-59.

Philip, M.S. 1994, *Measuring Trees and Forests*, CAB International, Wallingford, UK,

Pienaar, L.V. & Turnbull, K.J. 1973, The Chapman-Richards generalization of Von Bertalanffy's growth model for basal area growth in even-aged stands, *Forest Science*, 19, pp. 2-22.

Pigott, C.D. 1989a, Factors controlling the distribution of Tilia cordata (Mill) at the northern limits of its geographical range, IV. Estimated ages of the trees, *New Phytologist*, 112(1), pp. 117-121.

Pigott, C.D. 1989b, Estimation of the age of Lime-trees (Tilia spp.) in parklands from stem diameter and ring counts, *Arboricultural Journal*, 13, pp. 289-302.

Pilcher, J.R. 1990, Radioactive Isotopes in Wood, *Methods of Dendrochronology: Applications in the Environmental Sciences*, E.R. Cook & L.A. Kairiukstis (Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 93-96.

Pippos, C. 2004, Vandals Kill Pines: Century-Old Trees Ringbarked at Night, In *Sunday Mail*, Adelaide, Australia. p. 16.

Podger, F.D., Bird, T. & Brown, M.J. 1989, Human Activity, Fire and Change in the Forest at Hogsback Plain, Southern Tasmania, *Australia's Ever-Changing Forests: Proceedings of the First National Conference on Australian Forest History, Canberra, 9-11 May, 1988*, K.J. Frawley & N.M. Semple (Eds.), Department of Geography and Oceanography, Australian defence Force Academy, Canberra, Australia, pp. 119-140.

Pollak, L. 1997, Pieces of the world: nature-object and nature-space, *Daidalos*, 65, pp. 28-41.

Prastacos, P. & Diamandakis, M. 2000, Applying GIS Technology in Operational Urban Models. *Spatial Models and GIS: New Potential and New Models*, A.S. Fotheringham & M. Wegener (Eds.), Taylor & Francis, New York, U.S.A., pp. 223-234.

Rayner, M.E. 1992, *Application of Dendrochronology, Stem Analysis and Inventory Data in the Estimation of Tree and Stand Ages in Karri Forest, Technical Report No. 27*, M. Lewis (Ed.), Department of Conservation and Land Management, Como, Western Australia, Australia.

Rayner, M.E. & Turner, B.J. 1990, Growth and yield modelling of Australian eucalypt forests: I. Historical development, *Australian Forestry*, 53(4), pp. 224-237.

Reed, D.D., Jones, E.A., Tomé, M. & Araújo, M.C. 2003, Models of potential height and diameter for Eucalyptus globulus in Portugal, *Forest Ecology and Management*, 172(1-3), pp. 191-198.

Richards, N.A. 1983, Diversity and stability in a street tree population, *Urban Ecology*, 7(2), pp. 159-171.

Riddle, A. 1992, Adelaide's Parklands, *William Shakespeare's Adelaide 1860-1930*, B. Dickey (Ed.), Association of Professional Historians, Adelaide, Australia, pp. 106-125.

Roberts, J., Jackson, N. & Smith, M. 2006, *Tree Roots in the Built Environment*, TSO, London, England.

Rose, J.C. 1939, Plant forms and space: materials create volume by definition of space, *Pencil Points*, 20(5), pp. 227-230.

Russell, T., Cutler, C. & Walters, M. 2006, *Trees of the World: An Illustrated Encyclopedia and Identifier*, Hermes House, London, England.

Sales, D.J. 1975, The role of the National Trust in garden conservation and restoration, *Garden History*, 3(4), pp. 50-61.

Sales, J. 1990, Active Management of Gardens, *Open to View: Historic Gardens and the Public, Proceedings of the Ninth Annual Conference of the Australian Garden History Society*, D. Missingham (Ed.), Australian Garden History Society, Melbourne, Australia, pp. 32-36.

Salisbury, F.B. & Ross, C.W. 1992, *Plant Physiology*, 4th edn, Wadsworth Publishing Co., Belmont, California, U.S.A.

Sands, P. 1988, Is Small Beautiful? Pros and Cons of Simple, Appropriate Models, *Modelling Trees, Stands and Forests: Bulletin No. 5 of the School of Forestry, The University of Melbourne*, J.W. Leech, R.E. McMurtrie, P.W. West, R.D. Spencer & B.M. Spencer (Eds.), School of Forestry, The University of Melbourne, Melbourne, Australia, pp. 20-33.

Sauer, C.O. 1927, Recent Developments in Cultural Geography, *Recent Developments in the Social Sciences*, E. C. Hayes (Ed.), J. B. Lippincott Co., Philadelphia, Pennsylvania, U.S.A.

Schapper, J. 1990, Planning and Managing Historic Gardens, *Open to View: Historic Gardens and the Public, Proceedings of the Ninth Annual Conference of the Australian Garden History Society*, D. Missingham (Ed.), Australian Garden History Society, Melbourne, Australia, pp. 21-26.

Schapper, J. 1993, Criteria for the evaluation of landscape as heritage, *Landscape Australia*, 15(4), pp. 344-347.

Schweingruber, F.H. 1988, *Tree Rings: Basics and Applications of Dendrochronology*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Schweingruber, F.H. 1990, Radiodensiometry, *Methods of Dendrochronology: Applications in the Environmental Sciences*, E.R. Cook & L.A. Kairiukstis (Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 55-63.

Schweingruber, F.H. 1993, *Trees and Wood in Dendrochronology: Morphological, Anatomical, and Tree-Ring Analytical Characteristics of Trees Frequently Used in Dendrochronology*, Springer-Verlag, Berlin, Germany.

Schweingruber, F.H., Kairiukstis, L. & Shiyatov, S. 1990, Sample Selection. *Methods of Dendrochronology: Applications in the Environmental Sciences*, E.R. Cook & L.A. Kairiukstis (Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 23-35.

Semple, K. 1994, *A History of a Dry Sclerophyll Forest Stand at Mulloon Creek, Southern Tablelands, NSW*. BSc(Honours) Thesis, Australian National University, Canberra, Australia.

Shigo, A.L. 1982, Tree: What is it and How it Survives After Injury and Infection, Section Two, *Trees and Their Environment*, Rivett Enterprises, Malvern East, Victoria, Australia.

Shigo, A.L. 1989, *Tree Pruning: A Worldwide Photo Guide*, Shigo and Trees Associates, New Hampshire, U.S.A.

Simpson, J.A. & Weiner, E.S.C 1989. *Oxford English Dictionary,* 2nd edn., Volume XVIII, Oxford, Oxford University Press, U.K.

Smiley, E.T. & Baker, F.A. 1988, Options in street tree inventories, *Journal of Arboriculture*, 14(2), pp. 36-42.

Spencer, R., Barley, A., Pearson, S. & Turzac, P. 1997, *Horticultural Flora of South-eastern Australia: The Identification of Garden and Cultivated Plants*, Volumes 1-5, University of New South Wales Press, Sydney, Australia.

Spencer, R.D., Beetham, J.W. & Lumley, P.F. 1981, Table of Trees Suitable for Street Planting in Victoria, *Street Tree Directory*, T.E. Arthur & S.D. Martin (Eds.), Royal Australian Institute of Parks and Recreation, Tullamarine, Victoria, Australia.

Stead, S.D. 1998, Temporal Dynamics and Geographic Information Systems, *Spatial and Temporal Reasoning in Geographic Information Systems*, M.J. Egenhofer & R G. Golledge (Eds.), Oxford University Press, New York, U.S.A., pp. 214-219.

Taylor, K., 1983, Rural cultural landscapes: A case for heritage interpretation, conservation and mangement; Lanyon, A.C.T., a role model, *Landscape Australia*, 89(1), pp. 28-32, 34.

Tulloch, D.L. 2000, Data shaping the landscape: GIS and stewardship, *Landscape Journal*, 19(1-2), pp. 211-219.

Vanclay, J.K. 1988, Precision in Modelling Native Forests, *Modelling Trees, Stands and Forests: Bulletin No. 5 of the School of Forestry, The University of Melbourne*, J.W. Leech, R.E. McMurtrie, P.W. West, R.D. Spencer & B.M. Spencer (Eds.), The School of Forestry, University of Melbourne, Melbourne, Australia, pp. 94-97.

Vanclay, J.K. 1994, *Modelling Forest Growth and Yield: Applications to Mixed Tropical Forests*, CAB International, Wallingford, U.K.

Waite Arboretum, 2007, The University of Adelaide, viewed 22 August 2007, <http://www.waite.adelaide.edu.au/arboretum/>

Walter, M. 2006, Surveys and Sampling, *Social Research Methods: An Australian Perspective*, M. Walter (Ed.), Oxford University Press, Melbourne, Australia, pp. 187-222.

Wegener, M. 2000, Spatial Models and GIS, *Spatial Models and GIS: New Potential and New Models*, A.S. Fotheringham & M. Wegener (Eds.), Taylor & Francis, New York, U.S.A., pp. 3-20.

Welch, J.M. 1994, Street and park trees of Boston: a comparison of urban forest structure, *Landscape and Urban Planning* 29, pp. 131-143.

White, J. 1998, *Estimating the Age of Large and Veteran Trees in Britain*, Information Note Issued by Forestry Practice, Edinburgh, UK, Forestry Commission, viewed on 6 November 2006, <http://www.forestry.gov.uk/pdf/fcin12.pdf/$FILE/fcin12.pdf>

Whitelock, D. 2000, *Adelaide: A Sense of Difference*, 3rd edn., Arcadia, Kew, Victoria, Australia.

Wing, M.G., Eklund, A. & Kellogg, L. D. 2005, Consumer-grade Global Positioning System (GPS) accuracy and reliability, *Journal of Forestry*, 103(4), pp. 169-173.

Wood, R. & Handley, J. 2001, Landscape dynamics and the management of change, *Landscape Research*, 26(1), pp. 45-54.

Woodgate, P.W., Peel, W.D., Ritman, K.T., Coram, J.E., Brady, A., Rule, A.J. & Banks, J.C.G. 1994, *A Study of the Old-Growth Forests of East Gippsland*, Department of Conservation and Natural Resources, East Melbourne, Victoria, Australia.

Woolons, R.C. & Wood, G.R. 1992, Utility and Performance of Five Sigmoid Yield-Age Functions, Fitted to Stand Growth Data, *Integrating Forest Information Over Space and Time: IUFRO Conference 13-17 January 1992 Canberra, Australia*, G. Wood & B. Turner (Eds.), ANUTECH, Canberra, Australia, pp. 71-79.

Worbes, M., Staschel, R., Roloff, A & Junk, W.J. 2003, Tree ring analysis reveals age structure, dynamics and wood production of a natural forest stand in Cameroon, *Forest Ecology and Management*, 173(1-3), pp. 105-123.

Workman, J. 1991, Trees in gardens: some notes, *Journal of Garden History*, 11(3), pp. 173-176.

Worster, D. 1993, *The Wealth of Nature: Environmental History and the Ecological Imagination*, Oxford University Press, New York, U.S.A.

Zeide, B. 1993, Analysis of growth equations, *Forest Science*, 39(3), pp. 594-616.

Zhang, L. 1997, Cross-validation of non-linear growth functions for modelling tree height-diameter relationships, *Annals of Botany*, 79(3), pp. 251-257.