URBAN & FORESTRY URBAN GREENING

Canberra's Urban Forest: Evolution and planning for future landscapes

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Abstract: Canberra, Australia's national capital, is a planned city established on grazing lands in the southern tablelands of New South Wales. Over the past nine decades it has grown into a garden city of 300,000 people. Landscaping was an early priority as much of the chosen site for the city was a treeless plain. Major tree planting began in the 1920's and today the urban forest on public lands contains 400,000 trees from over 200 species in streets and parklands. The species used have changed over time with exotic deciduous trees and conifers dominating early plantings. By the 1970's native species, mostly eucalypts, were planted. Today fewer species comprising an equal mix of native and exotics are used. Trees in the earlier plantings are now mature and given the harshness of the local climate many will come to the end of their 'safe life' in the early decades of this century. This provides new challenges for urban tree managers as to how to effect tree replacement that is aesthetically pleasing, ecologically sound and socially acceptable. To assist in this planning a tree data base and modeling system has been assembled. This system – Decision Information System for Managing Urban Trees or DISMUT – facilitates the development of forest-level management programs by allowing the projection of change and work requirements that the result from historical and current plantings over the entire urban forest.

Key words: Canberra's urban forest, garden city, bush capital, DISMUT, tree modeling

Introduction

Planning for Canberra's future urban landscapes began at the inception in 1911 of Australia's national capital – the Australian Capital Territory (ACT) – and has continued hand-in-hand with the expansion of the city through the decades of the last century producing a well-landscaped, aesthetically pleasing environment. At the time of federation in 1901 the need for a national capital was recognized and within the decade the city site was chosen, a city landscape plan selected from an international competition and preparations on the ground had begun. The site, located on grazing land in the southern tablelands of New South Wales (Fig. 1), was essentially a treeless, wind-swept and dusty valley divided by the Molonglo River, surrounded by forested hill crests and back-dropped with the Snowy Mountains. Out of this landscape a city of 20,000 people was initially planned to service the anticipated needs of the nation's capital. Today the National Capitol is a city of over 300,000 people living in a well-treed and spacious environment. The urban forest has undergone several distinct, but overlapping development periods, and today is a magnificent example of what can be achieved with holistic landscape planning. However, the resulting forest is very dynamic with a diverse mixture of species, longevity and age classes. This mixture means that the management of the urban forest must be

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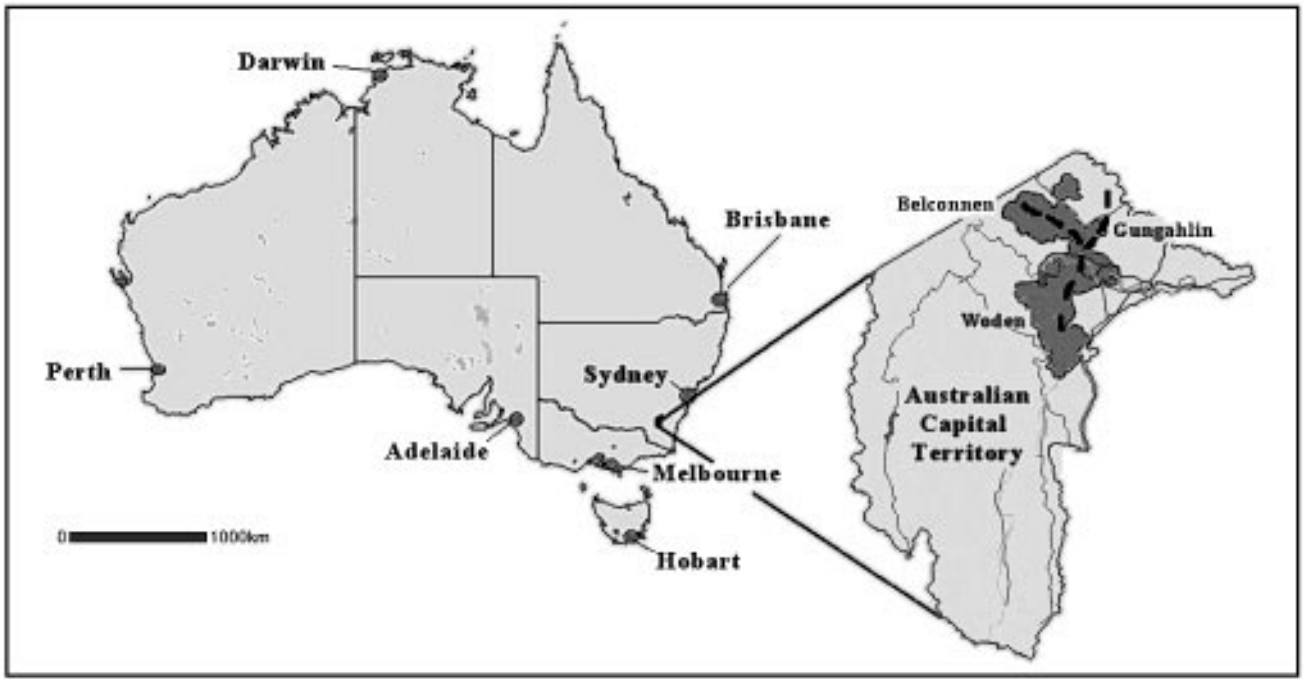

Fig. 1. Map showing the location of the Australian Capital Territory and highlighting the urban development (Canberra).

undertaken at a forest-level and not on an individual tree or reactive level.

This paper outlines the developmental phases of the Canberra's urban forest which have played an important role in achieving what is described today as a *city in a forest*. It discusses the use of an urban forest management information system developed to cope with the complexities of managing trees in a multi-aged urban forest comprising a large number of species. It also uses this information system to monitor tree species success and the timing and options for their eventual replacement.

Evolution of Canberra's urban forest

The city of Canberra is unusual in that the presence and importance of trees in the streets and parks was planned at its inception. Trees were seen as essential to ameliorate adverse environmental conditions like wind and dust as well as improve the barren landscape view. Walter Burley Griffin's winning design for Canberra drew on concepts of the American *city beautiful* movement celebrated at Chicago's 1883 World's Colombian Exposition. Griffin's vision was a city beautiful using the landscape to compliment an extravagant street layout arranged in circular, hexagonal or octagonal patterns around formal spaces and specialized centers (Clough 1982). Wide arterial roads reached out into suburbs serviced by curving streets such that street vistas ended in trees. Griffin's plans made provision for urban plantings in parks and gardens, and in particular for marking land axis (Gray 1999). He did not provide species preferences, but clearly saw the need to use native species for symbolic reasons (Gray 1999). Griffin's master plan was not adopted in its entirety - being modified by the Departmental Board Plan to incorporate material from other plans submitted to the competition (Reid 1996). This led to difficulties for Griffin who finally resigned and left the Canberra scene in 1921.

Planning and establishment of the urban forest was the province of Charles Weston, an English trained horticulturist, who had spent time at the Sydney Botanical Gardens working under the eminent botanist Joseph Maiden. On arriving in Canberra in 1913 Weston set about to develop a garden city. He was challenged by poor soils and a difficult climate for growing trees with hot summers and cold winters serviced by often-erratic rainfall. His aims can be summed up in six objectives:

- to establish a nursery
- to raise suitable plants for the area
- to ameliorate Canberra's harsh environment
- to establish an arboretum to test new species
- to beautify the landscape using both exotic and native plants
- to undertake conservation and afforestation activities on surrounding hills.

Weston's success in greening Canberra was in part due to his considerable confidence in handling large numbers of trees and shrubs in many different situations (Gray 1999). His major planting configurations consisted of formal arrangements emphasizing the beauty of individual species, a reflection of his 'gardenesque' training during the Victorian garden era in Britain (Fig. 2a). Weston carried out major conservation activities on adjacent hills, Mt. Ainslie, Mt. Majura and Mt. Mugga, using local species to recreate tree cover largely removed during the grazing era. Outside the city on Mt. Stromlo he established afforestation trials using *Pinus radiata* and *Pinus canariensis,* and nearby a small cork oak plantation using *Quercus suber* to test the potential of this species in the local environment. 'Cypress Hill', an important hill on the east-west axis, was densely planted to *Cupressus sempervirens* var *stricta,* and on river flats at Piallago a Californian redwood trial (*Sequioadenderon giganteum*) was established. During Weston's time in Canberra, over 2.0 million trees were planted out to lay the foundations for the garden city and begin the era of Canberra as a 'city amongst the trees'. Weston departed Canberra in 1926. In summary his major achievements were:

- street plantings in the first suburbs
- establishing Telopea and Haig Parks
- reafforestation with native trees on the surrounding hills
- a redwood forest of a quarter of a million trees at Pialligo
- trials of Cork Oak, Canary Island and Monterey Pines and Atlantic Cedar
- began Westbourne Woods arboretum adjacent to Yarralumla nursery.

After World War Two and until 1958 the planning of Canberra's landscape was in the hands of Lindsay Pryor. During this time he quickly renewed the planting program along the lines of Weston's interpretation of the garden city theme. His approach was to plant extensively in mass amounts in informal arrangements and to work on these plantings later (Hince 1992). These massed plantings were designed to fill spaces between major buildings thus ensuring tree dominance of the landscape e.g. the Australian National University. Pryor greatly expanded the species palette that remained dominated by exotic species. In this respect, the approach of using streets and urban green areas as trial planting areas was similar to that practiced in some European cities like Copenhagen, Berlin, Freiburg, Brno and St. Petersburg (Konijnendijk 1999). Weston's command of the expanding array of species may be likened to an artist painting landscapes with 'living pencils' of green in summer and bright flashes of reds and yellows in autumn. Major developments during this period were:

- building on the garden city concept
- increased tree diversity to over 100 species
- maintained single species in suburban streets (Fig. 2b)
- massed infill plantings to draw the city together in an urban forest
- trialing of new species in arboreta and as street trees
- National Botanic Gardens, devoted to native flora, established

The Bush Capitol

During the period 1958–2002, the urban forest rapidly expanded as Canberra's population increased ten-fold to over 300,000. In order to maintain a low population density Canberra expanded into adjacent valleys following the *Y-plan* (Reid 2002). This expansion was overseen by the newly formed National Capital Development Commission (NCDC), specifically established to integrate city development combining town planning, engineering, building architecture, design, construction, roads and services, and landscape architecture.

Fundamental changes occurred during this time, in landscape design and preferred tree species. Firstly, the colonnades of single species neatly demarcating public nature strips from householder's front gardens, which had been the hallmark of earlier landscape planning were progressively changed to multiple species per street, and where possible with these arranged in random patterns to give a sense of informality (Fig. 2c). Secondly, the horticultural use of Australian native species increased dramatically during this period. Landscapes in Woden Valley (tail of the Y-plan – see Fig. 1) were changed from the dominance of exotic species to native species. In one arm of the Y-plan (the Belconnen town center) where development began later in the 1960's, native species, almost exclusively eucalypts, were used as street and parkland trees with the very limited use of exotics around shopping centers (Fig. 2d). The second arm of the Y-plan (Gungahlin) is still being developed, but here plantings have swung back towards a more even mixture of exotic and native species. The dominance of eucalypts in the new towns ensured the planted tree cover blended with the adjacent hill top eucalypt forests which are now part of the Canberra Nature Park. This intensive use of native trees gave an Australian bush flavor to the urban forest giving birth to the term 'The Bush Capital'.

This brief period saw:

- rapid and major expansion of the National Capital and its urban forest
- almost exclusive use of native species in new public plantings
- introduction of many new species to horticulture

- loss of tree density and species planted in the newest suburbs
- field operations increasingly undertaken by contract labour
- research arm of urban forestry closed down
- reduction in the species palette
- plant material increasingly sourced from private nurseries
- use of the term 'bush capital' (Fig. 2d)
- and the need for a new approach to managing the complex urban forest.

Canberra's streets and parks – its urban forest – now exceeded 150 species and 400,000 trees, i.e. almost 4 trees for every 3 residents, ranging from saplings to mature trees. This density is more than double the 0.4 to 0.5 trees per capita estimated for the US in the 1980's–1990's (Kielbaso & Cotrone 1989; McPherson & Rowntree 1986). The estimated total crown area of the trees planted in Canberra is more than 23×10^6 m^2 (Brack 2002) or 75 m^2 per capita. European cities that report significantly higher levels of forest cover (e.g. Joensuu, Arnhem and Freiburg) include large municipal blocks of forest that surround the urban areas (Konijnendijk 1999).

Planning for the future landscapes

The population of the ACT increased ten-fold over the past 50 years to over 300,000 – well in excess of any vision by Griffin, Weston or the other early planners. As the above section summarises, this increase in population led to a significantly larger area of residential development and also resulted in the progressive addition of new tree plantings and landscape modification. Major urban forest issues in this period were largely centered on species selection. However, as the oldest planted trees in the urban areas now approach 100 years, the major urban forest issues tend towards maintenance of mature trees and planning for their eventual

Fig. 2. Examples of different streetscapes in suburbs of Canberra.
a: A formal garden with "specimen" trees (Turner)
b: Single species streetscape (Forrest)
c: More informal streetscape with Australian natives (Duffy)
d: 60,000 residents in the "bush" established around the Belconnen town center (view from Mt Painter)

replacement. The future of the streetscape will depend on the efficient management and maintenance of existing trees and decisions on their eventual replacement. To assist in the resolution of these issues, Canberra's Urban Parks and Places contracted the Department of Forestry, Australian National University to develop an appropriate decision information tool.

DISMUT: a Decision Information System for Managing Urban Forests

DISMUT is composed of three components: a database of trees; a modeling system; and a reporting and analysis system. The design philosophy of DISMUT holds more in common with the management information systems of commercial plantations like MISPLN or RADHOP (Brack 1985) and SILMOD or STANDPAK (Maclaren 2000; West 1995) than with asset register-based systems. These commercial plantation information systems do not record individual trees, but instead use planning units (e.g. compartments or crop types) that often exceed hundreds of trees, all of which take on the characteristics of the mean tree as predicted by statistical-based models. Asset register systems record individual trees and the work that has been carried out on that individual. For example, *Tree Manager™ for Windows* advertises its capabilities as '…store detailed work histories, track expenses, review worload accomplishments, and maintain service requests' (http://www.artinc.com/tree_mgr.html). Initial collection of individual tree data to populate an asset register would be extremely time consuming and would not add significantly to the power of the system to project future needs and work schedules.

The DISMUT database was populated from a tree census undertaken between 1995–1999 by the Department of Forestry, Australian National University. The data collected included the species, age, and health for all trees planted on public land in streets and parks. Health classification was based on a visual assessment of the worst or most urgent problem apparent. These problems included one or more branches dead, epicormic shoots or dieback, fungus, wounds or death. Trees that were causing access problems or potentially dangerous crown structure (e.g. high angle branching) were also identified. Trees were only allocated to their worst class as it was assumed that any maintenance work to ameliorate this condition would also remove lesser problems.

The modeling system incorporates a series of growth and yield equations that predict the total height, maximum crown width and height of the maximum crown for each species group (Taxa) at any nominated age. The probability that any tree in a Taxa will survive one more year without showing signs of stress or poor health is also included. The model parameters were derived from samples across the range ages and of important Taxa (Banks et al. 1999). These statistical models are useful for relatively large groups of trees, but cannot be reliably applied to individual trees. Thus, the basic modeling unit within DISMUT is a Taxa within a street or park.

The Reporting and Analysis system allows the data to be summarised in a variety of ways, e.g. a "snapshot" of the health of the entire urban forest (Fig. 3). This system was also designed to assist in planning the management of the urban forest and is directed towards proactive management. The models predict the expected mean growth and expected health or condition of each street and park for each year in the planning horizon. Once nominated conditions are exceeded, resources (labour and equipment) are allocated to maintain tree shape (e.g. lifting crowns and pruning), correct problems (e.g. by removing dead branches from the crown) or removing and replanting trees. The cost of each treatment is estimated from the number of hours that are predicted as required and their user-defined cost/hour.

DISMUT is not ideally suited to reactive management (i.e. predicting daily work schedules and the immediate priority and location of individual trees marked for urgent maintenance), although it can be adapted to store such information. Other modeling systems can be developed to improve daily work orders and crew assignment once the type and frequency of work and resource needs are known (e.g. McCabe 2002). DISMUT is more fully described in Brack et al. (1999) and James et al. (1997).

Using DISMUT to demonstrate streetscape changes

DISMUT data can be used to understand the history of the development of an urban forest and present some of

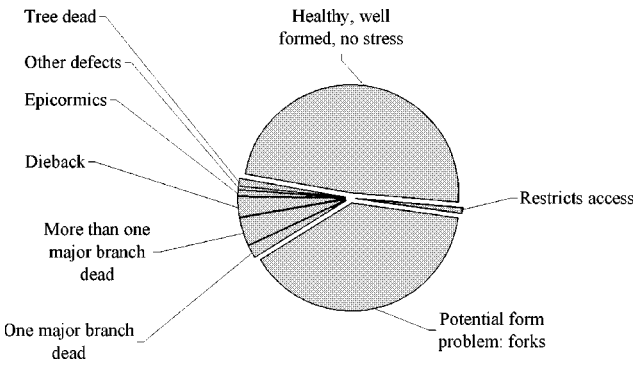

Fig. 3. Summary of health and problem status for 400,000 trees recorded during DISMUT census of the Canberra.

the important factors that will determine the best developments for that forest. The DISMUT census data is integrated with information about the streets and suburbs (e.g. establishment dates). Plotting the decade of establishment against the number of exotic and Australian endemic species provides a view of the dynamic nature of species selection (Fig. 4). From the 1920's to the early 1960's, the number of exotic species planted in the streets of Canberra far outnumbered the endemic species. In the late 1960's and 1970's the total number of exotic species planted was reduced while the endemic species remained relatively constant thus increasing the ratio of endemic to exotic species.

Species present in almost all periods of development include: *Celtis australis, Eucalyptus blakelyi, E. bridgesiana, E. cinerea, E. mannifera ssp maculosa, E. melliodora, E. pauciflora, E. polyanthemos, Fraxinus oxycarpa, F. oxycarpia 'Raywood', Liquidambar styraciflua, Pistacio chinensis, Prunus cerasifera* 'Nigra', *Quercus palustris, Sophora japonica,* and *Ulmus parvifolia*.

Species that were planted in the early decades but not since 1970 include: *Acer negundo, Crataegus* 'Smithiana', *E. bicostata, Juglans nigra, Populus nigra* 'Italica', *Prunus cerasifers* 'Moseri', *P. yedoensis, Quercus bicolor, Q. borealis, and Q. robur*, while new species introduced since the 1970's include: *E. moorei, E. nortonii, E. sideroxylon* 'Rosea' and *F. excelsior* 'Aurea'.

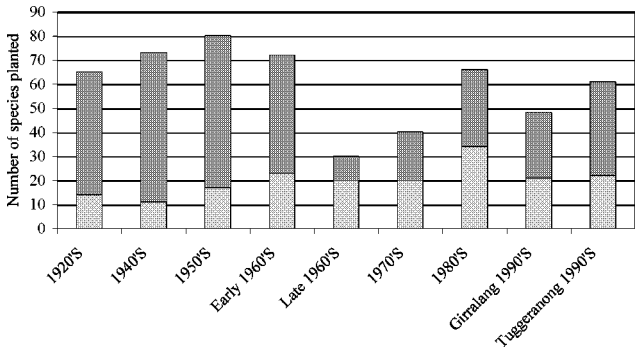

Fig. 4. Numbers of endemic Australian and exotic species planted in the streets of the Canberra by establishment period. ■ Endemic, ■ Exotic

Using DISMUT to identify potential problems

The length of the 'safe life' of urban trees is typically a multi-factorial process that includes the species, its location and site prevailing conditions. Figure 3 indicates that the street and park trees in Canberra are currently in relatively excellent condition with over 75% showing no external signs of stress or ill health, although over one third of these trees display evidence of potential problems with crown form. In contrast, Kielbaso & Cotone (1989) found that only 33.3% of urban street trees in the US were in an excellent condition.

However, the condition of the street trees in Canberra may be undergoing relatively rapid change as the earliest plantings are now around 80 years old. Some species are nearing the end of their safe life and consequently, tree thinning, removal and replacements are taking place. Tree removals approved under an interim tree preservation order for the first half of 2001 were not all due to poor health or stress – only 40% of the trees approved for removal were classified as stressed, diseased and/or posing an unacceptable risk to public or private safety. A further 40% were approved for removal as they were considered inappropriately large

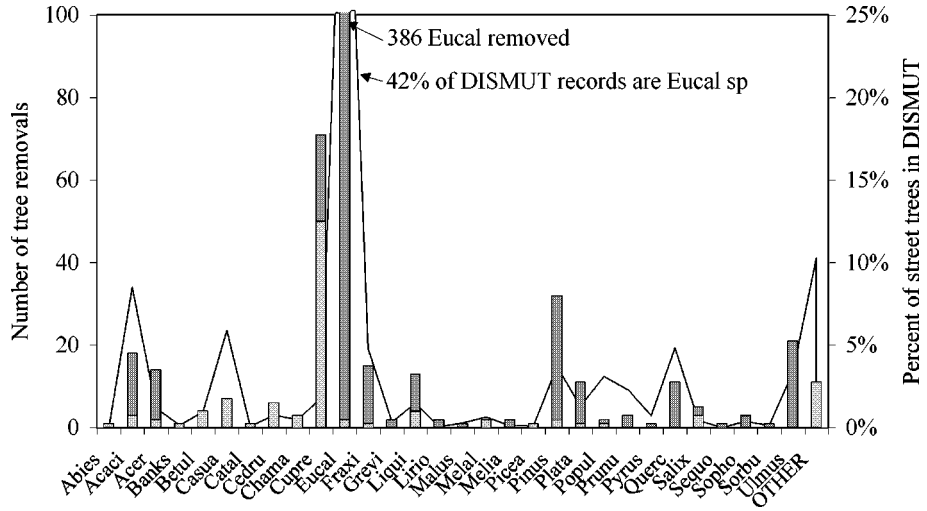

Fig. 5. Comparison of the number of trees removed with their proportion in the DISMUT database. Trees not in the official planting lists were not formally planted in streets or parks and may include private plantings on public or private land.

■ Excluded from lists, ■ Included in official planting lists

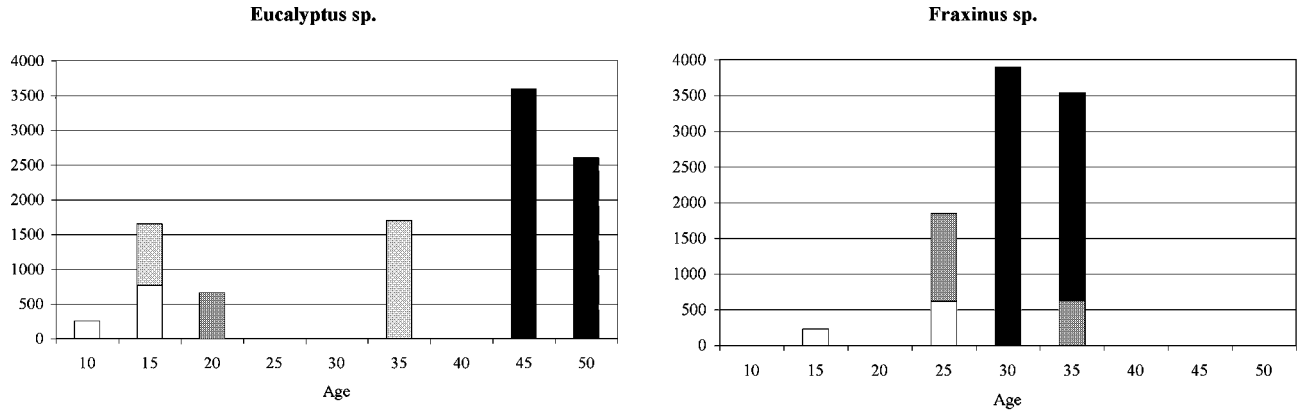

Fig. 6. Relative costs and timing of maintenance for a simulated single species street of 100 trees (nominal $/hour assumed). Form pruning, Lift pruning, Crown pruning and repairs, Thinning/removal

for the site where they were planted or were threatening to cause damage to substantial buildings, other structures and services. A comparison of the number and species of trees removed with the records in DISMUT indicated that, except for *Cupressus* species, the number of trees approved for removal was in proportion to the numbers planted (Fig. 5). Conifers are not as popular as they used to be and the disproportionate number of *Cupressus* species removed may reflect the relatively large number of earlier plantings, presumably by home owners, of *Cupressus* species that were not included in the regular street plantings.

The DISMUT growth and yield models predict the need for maintenance work (Banks et al. 1999) and can indicate which species are likely to be relatively expensive to maintain (Fig. 6). The maintenance requirements can be summarised to indicate which suburbs are likely to require significant work in upcoming periods and the relative amount of effort required (Fig. 7).

The growth and yield models can also be used to predict the possible benefits of urban trees. Brack (2002) used the DISMUT inventory and growth models to predict the value of the public street and park trees in pollution mitigation as between US$ 20–67 million for the period 2008 to 2012. Wee (1999), using models similar to DISMUT, predicted that the aesthetic, property and energy efficiency values of a eucalypt tree (in the appropriate location) might be as high as $ 16,000 over its useful life.

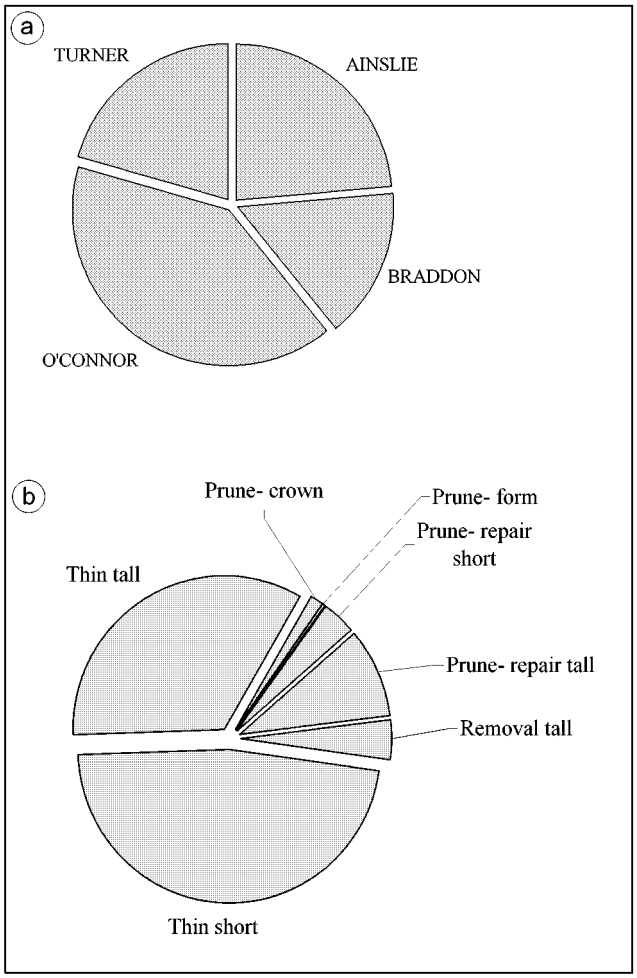

Fig. 7. a: Relative workloads for selected Suburbs in Canberra's inner north during 2001–2020. **b:** Relative cost of maintenance activities in selected Suburbs during 2001–2020. Short and tall refers to the tree heights when different machinery and techniques are required for work.

Discussion

The diversity and numbers of species used in Canberra's streetscapes reflects the various influences that have waxed and waned in importance over the past nine decades. In the beginning, 1913–1926, TCG West-

on's landscape vision and his policies and principles strongly influenced the development of Canberra's urban forest. His aims were to ameliorate the harsh climate and strong dusty winds of that time; to achieve seasonal effects and beautify the landscape with trees locally indigenous and others most likely to produce good results; and to experiment with trees likely to be successful. Exotics dominated the species used, in a ratio of 49 to 13, and the majority of the indigenous species were eucalypts. There was little planting in the years immediately following and it was only after WWII that renewed planting was to take place. During this time LD Pryor, 1944–1958, was instrumental in introducing a wide range of new species and sometimes using actual streets for trial plantings, *e.g. Phellodendron amurense* in Jervois Street, Deakin and *Quercus lobata*, Lobelia Street, O'Connor. Exotic species continued to dominate, 65 to 18. Pryor's species mix continued for some time after his departure although the number of species planted began to decline.

The extended and severe drought of the mid-1960's resulted in many tree losses, particularly exotics, and this in part brought about a policy change to include more indigenous species and fewer exotics in the planting program. In 1972 the NCDC, National Capital Development Commission, now in control of landscape policy, issued stated aims to preserve and enhance the natural environment where possible and to integrate the natural environment as far as possible. These aims were in sympathy at the time with growing community attitudes to the Australian environment and the use of native flora in landscaping. These policies were first applied in Belconnen and are reflected in the dominance of Australian species that were planted in the ratio of 2:1. Some suburbs e.g. Aranda were planted exclusively to Australian species.

Williams (2002) however concludes that residents may not have any overall preference for native species in the urban forests of Melbourne – another Australian capital city. She found that there were significant preferences for different types of crown structure and leaf shape, but also differences of preference with demographic characteristics like age and education. Fraser & Kenney (2000) also conclude that the cultural background of the residents will result in different preferences for species in the streetscape. Thus, attracting residents of different demographics and hence different preferences into an expanding Canberra, would generate a demand for different tree species in the streetscape.

From the 1980's the number of species planted declined and the appetite for native species waned, as many proved unsatisfactory as urban trees and/or in the local environment. Only about 20 species of each category are currently planted and with the absence of experimental work new introductions are relying on the availability of new cultivars in the tree nursery trade, e.g. *Pryus calleryana* 'Redspire'. The Australian Urban Street Tree Evaluation Program – AUSTEP – provides an opportunity to collate information on the success of these cultivars (Peters & Pennicuil 2001).

Some of the species no longer established may have been found to be weed-like, causing problems by escaping into the surrounding areas. A recent publication (Conservation Council of the South-east Region 2001) for example indicates that many species that grow well in Canberra and have a showy flower or foliage display are now classified as weeds e.g. *Acacia baileyana, Celtis australis, Salix* spp. and *Pinus radiata*. Other species, like *E. bicostata* and *E. nicholli* may no longer be being planted because they were found to be relatively expensive to maintain or because they presented an unacceptable hazard with falling branches.

Tree species were selected and planned for in the original design for Canberra, but over time the species mix changed as public perception evolved, understanding of the environmental constraints and the safe-life of the species improved, and the city expanded significantly beyond the original expectations. We would expect that other cities, where trees were not explicitly included in their design may have similar or even much more diverse mixtures of species and condition. However, this diversity is unlikely to be the "uniform diversity" as recommended by Gardner (1989). Gardner contends that the key concept in avoiding the situation were trees become perceived as a "threat and liability" to the city is to have about the same number of trees in each acceptable species, size and age group. When focusing on urban woodlands, Konijnendijk (1999) indicates that many European cities diverge significantly from this uniform diversity with highly unbalanced age class structures and species compositions that range from almost monocultures to broad mixtures of species. Large but non-uniform diversity would make forest-level planning for the maintenance needs of the urban forest very difficult – simply reacting to demand as it happens will be very inefficient and is likely to prove impossible as the trees reach maturity and the end of their safe life.

The species mix into the future is likely to remain variable in Canberra. It is important that the diverse species mix and age distribution does not result in extremely variable maintenance commitments. Workload should be relatively regular so that there is no need for an expensive pool (public or private) of specialized equipment to support large workloads in one period with no follow up work in subsequent periods. In addition, where there is little diversity of species or ages in a suburb, then potentially all the trees in a street or suburb may reach the end of their safe life at approximately the same

time – resulting in a "lunar landscape, devoid of any majestic trees". Some tree removals may therefore need to be scheduled before the end of their maximum safe life to introduce a diversity of tree ages and species. Future streetscapes would ideally contain a range of species and age/size classes to maintain a continuity of trees and a range of maintenance activities each year. However, the scale of this diversity is critical – should each street contain a range of age classes or only one age class but with the suburb containing streets with a range? If the street only has one age class, then it is likely that every tree in that street will need treatment and eventually replacement at the same time. Removing or crown pruning all the trees in the street at once may be efficient, but is likely to be unacceptable to the residents who have become used to a streetscape dominated by mature trees. DISMUT models can be used to plan for street or suburb mixtures of species and size, and predict the flow of the resulting work commitments.

After trees are removed, new trees must be replanted. A number of factors must be considered in the selection of the species used in replanting programs. On a local level, species must be able to "earn their own keep", i.e. the value of the tree must exceed the cost of its periodic maintenance. Different species have different maintenance needs and costs and planners may be tempted to restrict species selection to small, cheaply maintained trees. This simple approach to cost minimization however may not deliver an optimal solution over the whole urban forest. Selection and breeding of endemic species to reduce their maintenance needs may allow the tree value to exceed costs.

Restricting species diversity introduces a risk that irregular environmental stresses and/or insect and disease outbreaks could devastate large areas of the urban forest. Public perception of an aesthetic tree species may also change which may lead to large areas of the city being labeled as unattractive or unfashionable. The maintenance of a diversity of species provides for a more robust urban forest and insurance against changes in the values of Canberra's inhabitants.

Conclusions

In Canberra, the trees make the city. Managers of the urban forest need to plan for its future well before the safe life of the existing trees are reached. The planning must incorporate the rationalization of workloads over time and within suburbs as well as the selection of species for replanting. Decisions about species selection will need to be based on species performance, cost of maintenance, longevity, public perceptions, etc. A decision support tool, like DISMUT, which can store details and make predictions about the health, size and species mix of the urban forest is essential for the urban forest manager. With good record keeping DISMUT can provide current and future managers instant access to the history of earlier suburban plantings. These records will ensure that the original urban forest concepts in individual suburbs and town centers can be maintained and the historical significance of individual trees or species is not lost.

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