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Pollution mitigation and carbon sequestration by an urban forest

C.L. Brack*

Department of Forestry, Australian National University, Canberra, ACT 0200, Australia

"Capsule": *The DISMUT model is a decision support system that has been used to assess Australian urban forest potential for carbon sequestration, pollution mitigation, and energy reduction.*

Abstract

At the beginning of the 1900s, the Canberra plain was largely treeless. Graziers had carried out extensive clearing of the original trees since the 1820s leaving only scattered remnants and some plantings near homesteads. With the selection of Canberra as the site for the new capital of Australia, extensive tree plantings began in 1911. These trees have delivered a number of benefits, including aesthetic values and the amelioration of climatic extremes. Recently, however, it was considered that the benefits might extend to pollution mitigation and the sequestration of carbon. This paper outlines a case study of the value of the Canberra urban forest with particular reference to pollution mitigation. This study uses a tree inventory, modelling and decision support system developed to collect and use data about trees for tree asset management. The decision support system (DISMUT) was developed to assist in the management of about 400,000 trees planted in Canberra. The size of trees during the 5-year Kyoto Commitment Period was estimated using DISMUT and multiplied by estimates of value per square meter of canopy derived from available literature. The planted trees are estimated to have a combined energy reduction, pollution mitigation and carbon sequestration value of US$20–67 million during the period 2008–2012. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Carbon sequestration; Urban forest; Tree asset management; Forest value

1. Introduction

More than 85% of the population of Australia currently live in an urban area, with the majority living in one of the capital cities (Australian Bureau of Statistics, 2000). Many of these city and urban areas are located in areas where trees and forests would naturally dominate (Fig. 1), but the trees were commonly cleared as the cities developed. However, trees have been formally and informally re-established in many of the cities for a wide range of reasons.

Canberra, the national capital of Australia, was established on the Canberra Plains in southern New South Wales during 1911. The plains would naturally have been covered in native eucalypt woodlands and forests, but graziers had carried out extensive clearing of the original trees since the 1820s, leaving only scattered remnants and some plantings near homesteads. Extensive tree planting was an early feature of Canberra's development and this has continued to the present. Plantings were made to provide landscape themes or desired vistas. For example, the view from the Parliament House down a major avenue to the War Memorial was to be surrounded by red-coloured trees and shrubs. Other plantings (e.g. Haig Park) were designed to ameliorate the dusty conditions of windswept Canberra. Residents of Canberra were also encouraged to plant trees; each new land purchaser was entitled to free supply of up to 20 trees and shrubs from the Government nurseries. The extensive nature of the plantings has resulted in Canberra becoming known as the Bush Capital of Australia.

In the mid-1990s, the managers responsible for the urban tree asset management in Canberra commissioned the development of a computer based system to assist in collecting, storing and using information about trees planted in the public areas of Canberra (Banks et al., 1999; Brack et al., 1999). This computer system—Decision Information System for Managing Urban Trees (DISMUT)—was primarily designed to assist in asset management. Inventory and growth models (e.g. Fig. 2) were developed to predict the likely areas, timing and cost of tree maintenance and management. For example, the location, timing and resources required to prune trees to ensure unrestricted access along streets and driveways could be predicted and planned. DISMUT can also be used to predict the value of an urban forest and the potential of trees to reduce greenhouse gas emissions. This paper presents a case study of the

* Fax: +61-2-6125-0746.
E-mail address: cris.brack@anu.edu.au (C.L. Brack).

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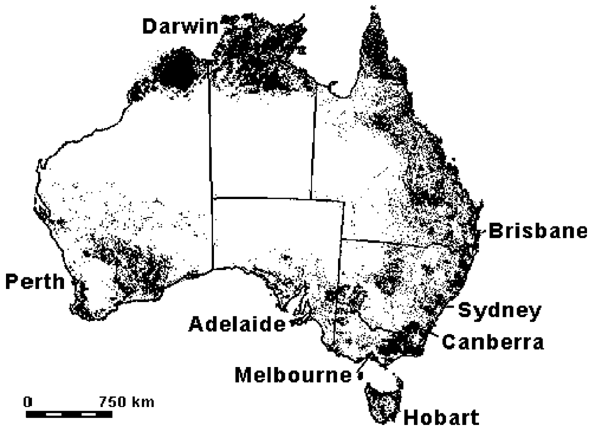

Fig. 1. Map of Australia with major cities and areas of forest and woodlands. Derived from National Forest Inventory (2000).

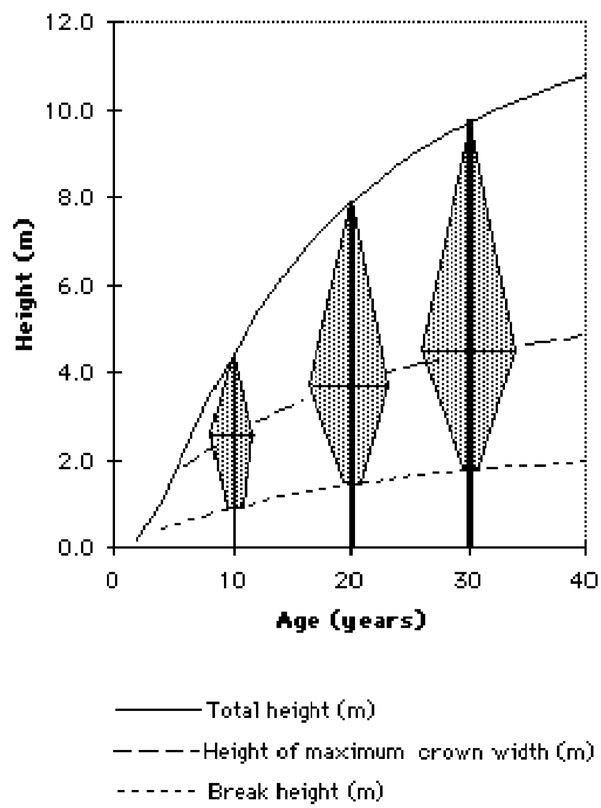

Fig. 2. Example growth model from DISMUT. This model predicts the height and crown dimensions by age for a member of the *Betula* genus in Canberra.

publicly managed urban forests in Canberra and an estimate of the contribution these forests can make towards reducing energy consumption, greenhouse gas emissions and other pollutants.

2. Modelling urban tree value

Numerous benefits of forests and trees in an urban environment have been variously reported (Table 1).

Table 1
Benefits of an urban forest

Benefits relating to pollution mitigation
Amelioration of urban climate extremes
Mitigation of urban heat islands
Store and sequester carbon
Reduce noise pollution
Improve air quality
Improve water quality
Lower temperatures of parked cars
Reduce volatilisation of bitumen
Reduce consumption of electricity for heating and cooling
Reduce need to invest in new power utilities
Other benefits
Aesthetic contribution, scenic beauty, visual amenity
Architectural enhancement of buildings
Improve property values
Increase privacy, barrier against unpleasant/stressful scenes
Control urban glare and reflection
Improve general livability and quality of urban life
Increase tourism
Provide opportunities for outdoor recreation and enjoyment
Contribute to human health and relaxation, reduce stress and anxiety levels
Attract birds and other wildlife
Act as a source of specialty timbers
Act as a source of general timbers

Some of these benefits are relevant to the amelioration of pollution by reducing energy requirements or capturing gaseous and particulate matter (Table 1).

While some of the benefits of an urban forest are a result of the colour of the foliage, species and other qualitative factors, most of the benefits are related to tree size. Larger trees tend to extract and store more carbon dioxide from the atmosphere and have a greater leaf area to trap air borne pollutants, cast shade, and intercept or slow rainfall run-off. In an extensive review, Wee (1999) found correlations between projected crown area and dollar benefits in a number of US studies (Table 2).

Energy savings attributable to urban forests are largely due to a reduction in the use of air conditioners or heaters in homes and offices when temperatures fall outside human comfort zones (Akbari et al., 1989; Huang et al., 1987; McPherson, 1994a). The range of values reported in the literature reflects the different sources of energy (e.g. coal, hydrological, or gas), tree habits, and climatic conditions. About 50% of trees planted on public land in Canberra are evergreen (Fig. 3). Evergreen and deciduous trees would both contribute to reducing cooling costs during the hotter months through shading and evapotranspiration. Evergreen trees may reduce the need for heating by reducing the cooling effects of the winds although this effect may be balanced by their shading of the winter sun.

A reduction in energy consumption, as well as providing a cost saving, may also result in the avoidance of

Table 2
Derived US$ value/each square metre of projected tree crown area for selected urban tree benefits. (Source: Wee, 1999)

Based on	Study area	Energy $/m²/year	Pollution $/m²/year	Hydrology $/m²/year
McPherson (1992)	Tuscon	0.6058	0.1215	
McPherson (1994b)	Chicago	0.6896		
McPherson (1994a)	Chicago	1.3179	0.0895	0.1740
McPherson et al. (1998)	Sacramento		0.0738	
Scott et al. (1998)	Sacramento		0.1509	
McPherson et al. (1999a)	Modesto	0.1668	0.2404	0.1027
McPherson et al. (1999b)	San Joaquin	0.1110	0.3093	0.0516
Mean	–	0.5782	0.1642	0.1094

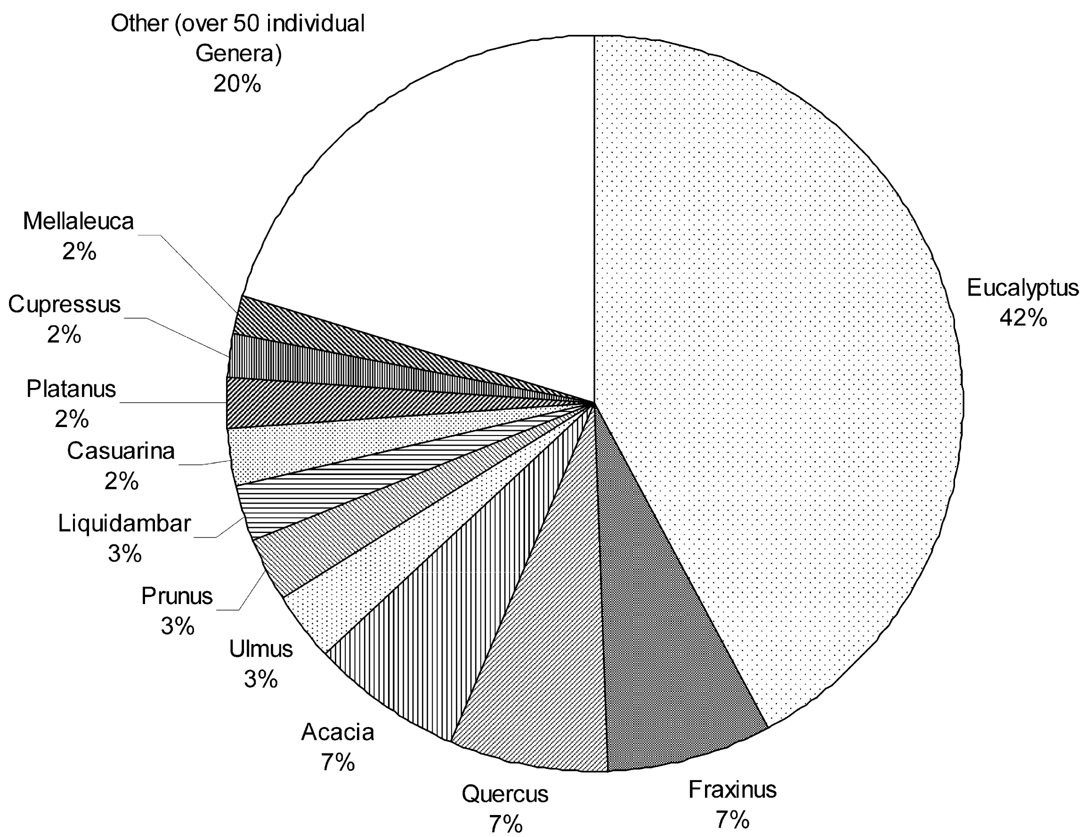

Fig. 3. Percentage of trees, by Genus, planted on public streetscapes in Canberra.

producing pollutants. Canberra sources much of its energy needs from the NSW electricity grid, and this grid is largely supplied from coal fired stations (Australian Bureau of Statistics, 2001). Thus, a reduction in demand would result in a reduction in the amount of coal burnt. A sufficient reduction in demand may also delay or avoid the need for the development of new power stations (Dwyer et al., 1992). The benefits in reduced direct and indirect pollution would be gained outside Canberra.

Urban trees directly reduce the amount of air borne pollution by capturing particulate pollutants on their leaf surface and either trapping them there or directing them into the ground during rain. Gaseous pollutants (e.g. ozone and nitrogen dioxide) may be directly absorbed into the leaf. Canberra supports only a minor manufacturing industry so most of the air borne pollutants are likely to be produced by motor vehicles and domestic fuel heaters.

Trees intercept rainfall and slow down water run-off, which allows particulate matter to precipitate out and thus not pollute waterways (Sanders, 1986; Xiao et al., 1998). Slowing run-off also means that less effort and expense is required to build sophisticated flood control and mitigation engineering works. Floodways—drainage depressions that carry rainfall run-off during moderate or heavy rain events—are common across Canberra. These floodways are located within urban parks and normally include extensive tree cover. The tree-induced benefits in hydrology control are therefore probably significant in Canberra.

DISMUT records the number, health and size of cohorts of trees planted in each of the streets and parks in Canberra prior to 1990. The tree cohort contains trees of the same species planted in the same year. The street trees include all those planted on publicly managed road verges—a variable width strip of land on either side of the road that can extend to within 2 m of a building. Statistical models are used in DISMUT to predict the average tree height, bole dimensions (length, diameter at base and top), and crown dimensions (crown depth, radius and height of the maximum width) for any given year. The statistical models were used to predict the crown cover and volume of the trees during 2008–2012. The predicted crown area in each year was then multiplied by the minimum values in Table 2 to estimate a conservative value of the urban trees in Canberra for energy, pollution and hydrology benefits. Trees planted in parks were not assumed to contribute significantly to energy and pollution savings. These trees were assumed to be too far from industry, roads or houses to effectively shade or capture air borne pollutants.

The mass of carbon sequestered in trees during the Kyoto commitment period (2008–2012) may also be of interest. The bole volumes predicted by DISMUT were converted to bole mass (multiplying by basic density) and then carbon (multiplying by average carbon content). Total carbon was estimated by multiplying the bole carbon by an above-ground expansion factor and then adding a below ground carbon mass estimated from a root:shoot ratio. The difference in the total carbon between 2008 and 2012 represents the amount of carbon sequestered during the Kyoto commitment period. For this study, an average basic density of 500 kg/m^3 was assumed. This density is a minimum value for all *Acacia* and *Eucalyptus* species reported by Ilic et al. (2000) and is a conservative estimate for the Canberra urban trees. The average carbon content was assumed to be 50% as suggested by Gifford et al. (2000a, 2000b). An expansion factor of 1.25 and a root:shoot ratio of 10% were introduced as conservative multipliers based on Snowdon et al. (2000). Although trees planted prior to 1990 are excluded from the Kyoto Protocol for the purposes of meeting carbon emission targets, the carbon sequestered by these trees may still be significant in reducing the overall greenhouse gas emission. A nominal value of US$10/tonne was used to allow a comparison between direct carbon sequestration and the value of the urban forests for energy reduction, other pollution mitigation and hydrology.

3. Results

Table 3 summarises the number of trees planted in the public spaces of Canberra and their predicted sizes in 2008 and 2012. Table 4 summarises the value of these trees using the minimum estimates provided from Table 2 and a nominal $US 10/tonne of Carbon sequestered.

The values in Table 3 discount trees planted on privately managed land (e.g. house lots and leasehold land)

Table 3
Number and size of trees predicted by DISMUT for Canberra in 2008 and 2012

Data	Streets	Parks	Total
Total number of trees (10^3)	224.4	200.8	425.2
Predicted total crown area ($m^2 \times 10^6$) in 2008	13.2	10.7	23.9
Predicted total crown area ($m^2 \times 10^6$) in 2012	15.1	12.6	27.7
Predicted increment in bole volume ($m^3 \times 10^3$) between 2008–2012	37.9	49.9	87.8
Predicted carbon sequestration ($t \times 10^3$) between 2008–2012	13.0	17.2	30.2

Table 4
Predicted value ($US) of benefits related to greenhouse gas and pollution mitigation from Canberra urban forests

	Street verge	Park	Total
Energy saving/year[a]	1,570,000	–	1,570,000
Pollution amelioration/year[a]	1,050,000	–	1,050,000
Hydrology amelioration/year[a]	730,000	600,000	1,330,000
Carbon sequestration over 2008–2012[b]	130,000	170,000	300,000
Total forest value over 5 years from 2008–2012	16,880,000	770,000	20,050,000

[a] Based on the mean crown area between 2008 and 2012, multiplied by the minimum $\$/m^2$ from Table 2.
[b] Based on the total increment in Carbon (t) predicted between 2008 and 2012 and multiplied by a nominal $10/t.

and naturally regenerated lands (e.g. public nature reserves). Thus there is a significant underestimate of the quantity of trees in Canberra in Table 3.

Table 4 discounts all the values not specifically quantifiable and related to energy and pollution mitigation. As the primary value of the urban forest lies in its landscape and aesthetic contribution to the city, the total value estimated in Table 4 is probably only a minor proportion of the forest's overall benefit. If the much less conservative means rather than the minimum values from Table 2 are used in the calculations for Table 4, the value of these urban forests increases to $67,000,000 (street verges—$60,480,000 and parks $6,570,000).

The values summarised in Table 4 are gross value estimates that do not incorporate the cost of tree maintenance. Models in DISMUT predict that approximately one-quarter of the publicly managed trees in Canberra would require inspection or routine maintenance during 2008–2012. The maintenance would include pruning for aesthetics and access. In addition, the DISMUT models predict that about 17,000 trees (about 4% of the total) would need to be treated for damage, stress and health problems—dead branches would be pruned and dangerous trees removed and replaced. However, since these treatments are largely carried out to support the aesthetic and landscape values of the forest, it is probably inappropriate to charge these costs against the pollution mitigation benefits. The carbon lost to the atmosphere from the removed trees is assumed to be relatively insignificant as only a small percentage of trees would be removed and replaced by fast growing young trees.

The dollar value of carbon sequestered in the urban forest is low relative to the estimated value of avoiding energy consumption and ameliorating air borne and water pollution. This relative difference may be due to the nominal value placed on the carbon and the conservative density and multiplier values. However, these values would need to increase ten- to twenty-fold to match the totals of the other benefits. Most trees in Canberra would have achieved maturity by 2008 and therefore would have large crown areas but only be making small increments to their net mass (Fig. 2). The large crown area would maximise the shade and leaf area and so maximise the energy reduction and pollution mitigation. Carbon sequestration depends, not on the cumulative size, but rather on the small increment.

4. Conclusions

Canberra has a population of about 300 000 residents and about 400 000 trees planted in publicly managed areas. These trees have a significant value for the aesthetic and landscape qualities. They also have a significant value in their potential to reduce energy consumption and ameliorate pollution in the city. This example study estimated the value of this amelioration may be between US$20–$67 million (or $66–$223/resident) between 2008 and 2012. Management of this important resource and the establishment or re-establishment of trees as suburbs grow and change must take these values into account.

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