Carbon and economic benefits of urban trees in two Sydney transport corridor case studies

Dr. Sumita Ghosh and Mr. Shih-Hsien Yung
School of Built Environment, Faculty of Design, Architecture and Building (DAB)
University of Technology Sydney (UTS), Sydney, Australia
Emails: Sumita.Ghosh@uts.edu.au; Shih-Hsien.Yung@uts.edu.au

Abstract

Trees in urban areas provide multiple local sustainability and climate change benefits. Roads as the movement arteries of cities are leading sources of greenhouse gas emissions from transport and impact different land uses along and around these networks. This paper estimates carbon sequestration and storage potential, air pollution reduction capability and associated economic benefits of urban trees using Geographic Information Systems (GIS) methods and i-Tree Eco v5.0. The research was conducted on selected sections of two transport corridor case studies along the Pacific Highway and Parramatta Road in Sydney, Australia. This research provided valuable information and evidence base on tree species, composition, characteristics and tree densities in these two Sydney case studies. Localities with larger trees were equipped with higher carbon sequestration potential and storage capacity. Variations in land use patterns can influence significantly urban forest compositions and subsequent carbon sequestration and storage potential and air pollution reduction capabilities of urban trees. This research established significant sustainability importance and ecosystem service benefits of urban trees. These outcomes could raise awareness for existing tree preservation and new tree planting and highlight the need for formulating meaningful planning policies for urban trees. The participation and building awareness of community and supports of government, private and other organisations would be essential in this process.

Keywords: *trees; carbon sequestration; carbon storage; urban forests; air pollution; urban planning*

1 Introduction

Trees as important elements of green infrastructure in urban environments can provide multiple environmental benefits and meaningful ecosystem services which are intrinsically linked to climate change mitigation possibilities. Trees can sequester atmospheric carbon dioxide by photosynthesis; store carbon as woody biomass; absorb nitrogen oxide (Hill, 2004); minimise space heating and cooling energy demand in buildings through shading (McPherson and Simpson, 2003); enhance air pollutant reduction and improve rainfall interception benefits (Peper, McPherson and Mori 2001); protect biodiversity (USDA Forest Service, 2003) and improve amenity and public health (Akbari, 2002; USDA Forest Service, 2003). Carbon uptake, storage and release potential depend on various tree variables (e.g. crown height, crown spread and diameter of the tree trunk at breast height), age, species, health, growing conditions, and tree maintenance factors specially pruning (Peper et al., 2001; Nowak and Crane, 2002). Davies, Edmondson and Heinemeyer (2011) quantified and mapped the ecosystem service provisions of above-ground carbon for Leicester, UK, at a city scale. The above-ground vegetation stored 3.16 kg C per m^2 of urban area, a total of 231,521 tonnes of carbon from a total urban area covering 46,9173 hectares with a total of 1489,244 trees and 97.3% of this carbon was stored in trees rather than herbaceous and other vegetation (Davies et al., 2011, p.1125). Based on field and national urban tree cover data, Nowak, Greenfield, Hoehn and Lapoint (2013) calculated carbon storage of 643 million tonnes and sequestration potential at 25.6 million tonnes from urban trees representing 38.6% of all urban tree cover in 28 cities and six states in the conterminous United States (adjacent states except Hawaii and Alaska) covering 9.3 million hectares of land area.

Roads as the movement networks of cities allow millions of vehicles to travel from different origins to various destinations and are significant sources of transport related greenhouse gas emissions. Planning for useful land use and transport integration in cities is essential for building compact and sustainable cities. Along the main roads various land uses such as commercial, retail, institutional, residential and others are located where people live and work. In these environments, resident and working communities are significantly exposed to comparatively higher levels of carbon emissions than those who live away from major transport arteries. Tree canopy cover along a main transport corridor is important because urban trees are capable of sequestering carbon emissions (Kiran and Shah 2011). Trees on either side of transport routes and their spatial distributions in different land uses along the network have the added potential to provide environmental benefits; to create continuous green infrastructure; absorb pollution from transport emissions; reduce urban heat island effects from paved surfaces by shading (Kiran and Shah, 2011; Peper et al., 2001; Hill, 2004) and saving further operational energy in buildings.

Sydney is the largest city and the main economic centre of Australia with a population over four million (New South Wales Government, 2014). Sydney lies in a humid subtropical climate zone according to the Köppen climate classification system (Encyclopedia Britannica, 2017) and receives on average six to eight hours daily sunshine throughout the year (Living in Australia, 2017). It faces significant challenges of population growth, rapid urbanisation and climate change impacts (Koleth 2011; Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2006). Research on the potential of urban trees is essential to understand their green infrastructure and ecosystem benefits which could be included in planning for Australian cities especially in Sydney. This paper focuses on measuring carbon and air pollution reduction benefits and characteristics of the trees along two major transport corridors in Sydney Australia.

2 Research aims and objectives

This research is a part of larger collaborative research project with a number of Australian universities and Nursery Gardens Industry Australia (NGIA). This project was funded by Australian Government through Horticulture Australia Limited (HAL) Category 1 funding grant. The main aims of this part of the research were to estimate land use/land cover distributions, carbon sequestration and storage potential, air pollution reduction capability and associated economic benefits of urban trees in selected sections of two main transport arteries, the Pacific Highway and the Parramatta Road in Sydney, Australia.

The main objectives of this research on estimating potential of urban trees in the selected two case studies follow.

- To measure existing spatial distributions of land use and land cover;
- To calculate carbon sequestration and storage potential;
- To determine air pollution reduction capacity;
- To estimate associated economic values provided by the urban trees;
- To provide recommendations for planning policies and to identify potential future research directions;

Other aspects of green infrastructure and ecosystem benefits from urban trees such as storm water management, rainfall interception by the trees, reduction of urban heat island effects and others are beyond the scope of this paper and therefore, are not included.

3 Research methodology

3.1 Selection of case studies

Two case studies were selected along the two main transport corridors of Sydney: the Pacific Highway and Parramatta Road connecting northern and inner west suburbs to the Central Business District (CBD) respectively. *A Plan for Growing Sydney* adopted in 2014 identifies the Pacific Highway and Parramatta Road and their surroundings as areas for urban renewal corridor development (New South Wales Government, 2014). Parramatta City is considered as Sydney’s second CBD and is connected to the main CBD via Parramatta Road (New South Wales Government, 2014). The selected segment of the Pacific Highway for this research is 19 kilometres in length, and lies across a number of Local Government Areas (LGAs) of North Sydney, Lane Cove, Willoughby, Ku-Ring Gai, and Hornsby as defined by the ABS 2006 Census. The length of Parramatta Road case study is 11 kilometres and traverses through Marrickville, Leichhardt, Ashfield, Burwood, Canada Bay, Strathfield, Auburn, Parramatta, and Holroyd LGAs of Sydney as defined by the ABS 2006 Census. These case studies were selected as these two roads are important transport corridors in Sydney; represent complex and varied land use patterns along the routes and have significant policy implications in planning for sustainable cities. The location and routes of the selected study sites along both transport corridors are shown in Fig. 1.

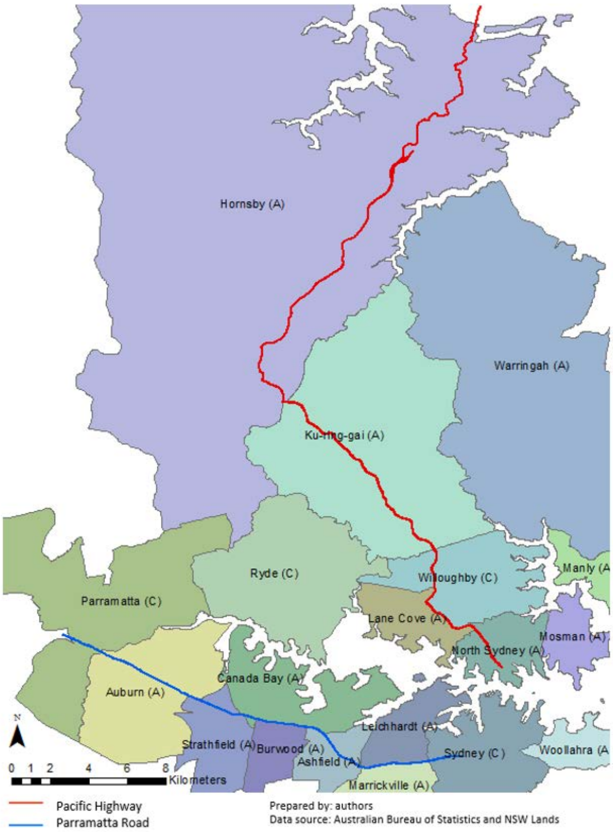

Figure 1: Routes and locations of Pacific Highway and Parramatta Road in Sydney

3.2 Method

A review of urban tree benefits achieved in four international and one national case studies were conducted that applied of 'i-Tree Eco software for assessing carbon benefits.

In the two case studies, using GIS methods, spatial distributions of different land use categories along a 200 meters wide area on either sides of Pacific Highway and Parramatta Road were determined. Spatial boundaries data were obtained from NSW Government Land and Property Information (LPI) and Australian Bureau of Statistics (ABS). Aerial imagery data was acquired from Sinclair Knight Merz (SKM). Customised GIS data and maps of land uses were prepared for these two case studies and cross checked with respective land use zoning allocations in various Local Environmental Plans and Planning Schemes of LGAs within the two case study boundaries. As residential land use has very different characteristics from the other major land uses in the case studies, residential land use was adopted as one of the landuse categories. Different land use categories were consolidated into three major land use categories, namely, 'Residential', 'Commercial, Retail, Business and Mixed Uses (CRBM)' and 'Institution, Recreation and Other Uses (IRO)'.

'i-Tree Eco' was developed by the United States Department of Agriculture (USDA) Forest Service to quantify the structure and functions of urban forests. 'i-Tree Eco v5.0' version is compatible in an Australian context as it integrates Australian tree species database, and climate, environmental, economic, pollution and weather data into the model (USDA Forest Service et al., 2013; USDA Forest Service et al., 2017c, 2017d). It can calculate subsequent parameters such as urban forest structure, composition such as species and age, air pollution removal, building energy savings, rainfall interception, carbon sequestration and storage, and resource values (USDA Forest Service et al., 2017a, 2017b and 2013). A plot based sample inventory method of assessment was adopted for this study following i-Tree Eco v5.0 protocol (USDA Forest Service.et al., 2017b; USDA Forest Service et al., 2013). The main steps for i-Tree Eco v5.0 analysis follow.

- *Areas of Interest (AOI)* included 200 meters wide area on either sides of Pacific Highway and Parramatta Road which was determined using GIS methods.

- *Ethics approval* was obtained from the Human Research Ethics Committee (HREC) at the University prior to conducting the field work. Before conducting the tree survey, consents to access private properties for tree data collection were obtained via telephone and email communications.

- The two study areas were stratified by the most suitable approach for this research, '*pre-stratification by land use*''. Using GIS analysis, three land use categories: CRBM, Residential, IRO ('Recreation' and 'Institutional' and 'Other Uses') were pre-stratified or consolidated.

- *Sample plots* were generated by a random sampling method for CRBM, Residential, IRO, three land use categories for tree data collection. A total of 61 plots (sampled plots in CRBM - 20, IRO - 20 and Residential - 21) for the Pacific Highway and a total of 30 plots (sampled in CRBM - 15, IRO - 10 and Residential - 5) These plots were proportionately distributed in the three land use strata, CRBM, IRO and residential were surveyed (Table 2). Parramatta Road study area was shorter in length than the Pacific Highway case study, a proportionate adjustment in the sampled plots was conducted in consultation i-Tree team, USDA Forest Service.

- *Field work for data collection* was conducted following i-Tree Eco protocols and guidelines (USDA Forest Service et al., 2013). Tree specimen samples were collected (e.g. leaves, branches, barks, fruits and flowers) from each individual tree on the sample plots. The tree species were identified by the Royal Botanic Garden Sydney.

This paper focuses on estimating carbon, associated economic and air pollution reduction benefits by the urban trees in these two case studies. Other tree attributes were calculated by the model are beyond the scope of this paper, therefore, are not included in this paper.

4 Results

4.1 A review

A total of five i-Tree case studies from USA, Canada, UK and Australia and ranging from local to regional scales, were reviewed. The Auburn University case study in Alabama, USA, had conducted using the 100% or complete tree inventory analysis method at a local scale (Martin et al., 2011; Martin et al., 2012, p. 268). Rest of the case studies applied a post-stratified (classified by land use categories) plot-based sample inventory analysis. The City of Toronto (Canada) case study, was at a city scale (City of Toronto, 2010, p. 20) while Torbay (UK) case study, was at a county scale (Rogers, Jarratt, and Hansford, 2011). In Greater Kansas City case study (USA) a total 340 plots were surveyed at a regional scale and has the largest estimated study area of 1,145,600 ha (Nowak et al., 2012, p.4). The Perth, Western Australia case study had applied a randomised grid-sampling plot-based inventory (Saunders, Dade, and Van Niel, 2011). Table 1 presents the details of four international case studies in Auburn University, Alabama, USA, City of Toronto, Canada, Greater Kansas City, USA and Torbay, UK and one Australian case study from Perth.

Importance of trees in urban environments has been reflected through increasing importance on formulation of tree planning or urban forest policies and strategies. In District of Columbia, 'Urban Tree Canopy Plan', in the USA has a very effective incentive programs such as UFA's 'Canopy Keeper Program'. Assessments on carbon storage and sequestration and air pollution reduction potential of street tree canopy covers provide convincing pathways for successful implementation of the tree policies in this city (Government of the District of Columbia 2013). City of Phoenix's 'Tree and Shade Master Plan' is set out for a desert city and advocates for power of trees to transform the urban environments by reducing urban heat island effects by a network of shaded streets and also enhancing carbon benefits (City of Phoenix 2010). 'Streetscape Greenery Master Plan', Singapore is an excellent planning policy that takes a holistic approach to put together different green infrastructure and landscaping methods and provides high values for street trees in the policy (Newton 2014; National Park 2017; Jin 2017a and 2017b). Significance of meaningfully integrating roadways and immediate land uses at the vicinity of the roads within land use planning policies; formulating street typology based design applications for greenery and connecting this Plan to city level vision for Singapore, 'City in a garden' make this policy noteworthy.

Table 1: Five i-Tree Eco case studies

Case studies	Total number of sampled plots & one plot per hectares	Site area (ha) & Spatial scale	Tree density (/ha)	Percentage of tree canopy coverage of total site area (%) & Total Number of trees	Total gross carbon storage (metric tons)	Total gross carbon sequestration (metric tons)	Total air pollution removal per year (kilograms (kg)/year)
Auburn University Campus, USA (Martin et al. 2011, 2012)	All plots surveyed within site	237 Precinct	31	16.0% 7,345	1,576	69	2,969
Western Suburbs, Perth, Australia (Saunders et al., 2011)	76	2,310 Suburb	83	22.0% 191,700	35,640	960	294,000
Torbay, UK (Rogers et al.,2011)	241	6,391 Town	128	11.8% 818,000	98,100	3,320	50,000
City of Toronto, Canada (City of Toronto, 2010)	407	66,140 City	154	20.0% 10,200,000	1,100,000	46,700	1,430,000
Greater Kansas City, USA (Nowak et al., 2013b)	340	1,145,600 Regional	218	18.6% 249,450, 000	1,805,2976	90,7185	23532, 372

In Australia, City of Melbourne's 'Urban Forest Strategy: Making A Great City Greener 2012-2032' (2012), aims to increase the overall city tree canopy cover from 22% to 40% by 2040. City of Sydney LGA's Urban Forest Strategy (adopted in 2013) is to protect City's current urban forests and to increase by 50% the existing tree canopy cover of 15.5% by 2030 (City of Sydney 2013, p. vii). Currently 22.7% of the City's total land use is roads. Out of this 22.7%, only 4.9% of the roads has tree canopy cover (City of Sydney 2013).

4.2 GIS analysis of land use patterns

Using a GIS analysis land use distributions in the selected case studies were calculated. The study area on the Pacific Highway has a total area of 287 hectares and the same for Parramatta Road was 137.6 hectares. In the selected segments of the two case studies, population distribution estimated for the Pacific Highway was 6399 people and for Parramatta Road was 3821 people within the project sites. Fig 2 and Fig 3 and Table 2 present land use distributions in the two selected case studies. On the Pacific Highway, a significant share (58.6%) of the total area was under residential land use while only 15.8% was under residential use on the Parramatta Road. The total percentage of the CRBM land use category was the highest (51.7%) on the Parramatta Road while CRBM was lower (17.6%) on the Pacific Highway.

Table 2: Land use distributions in two Sydney case studies

	Pacific Highway			**Parramatta Road**		
Stratum/Landuse	**Area (ha)**	**Percentage (% of total land use)**	**Sample plot numbers**	**Area (ha)**	**Percentage (% of total land use)**	**Sample plot numbers**
CRBM	50.6	17.6%	20	71.1	51.7%	15
IRO	68.3	23.8%	20	44.8	32.5%	10
Residential	168.1	58.6%	21	21.7	15.8%	5
Total	**287.0**	**100.0%**	**61**	**137.6**	**100.0%**	**20**

This suggests that a higher percentage of residential land use could be identified along the selected zone of the Pacific Highway but Parramatta Road had comparatively higher percentages of Commercial, Retail, Business and Mixed uses (CBRM) along the corridor. Institution, Recreation and Other uses (IRO) are 23.8% in the former and 32.5% in the latter.

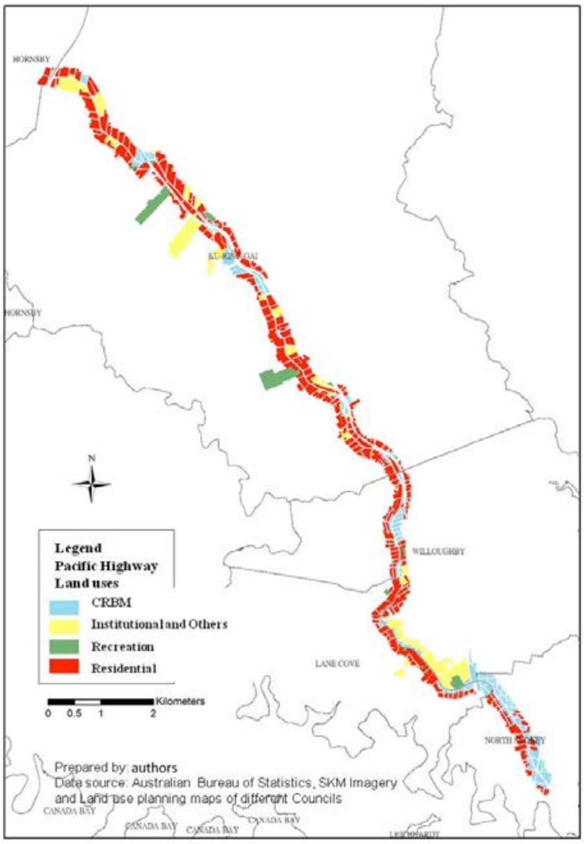

Figure 2: Landuse distribution on the Pacific Highway

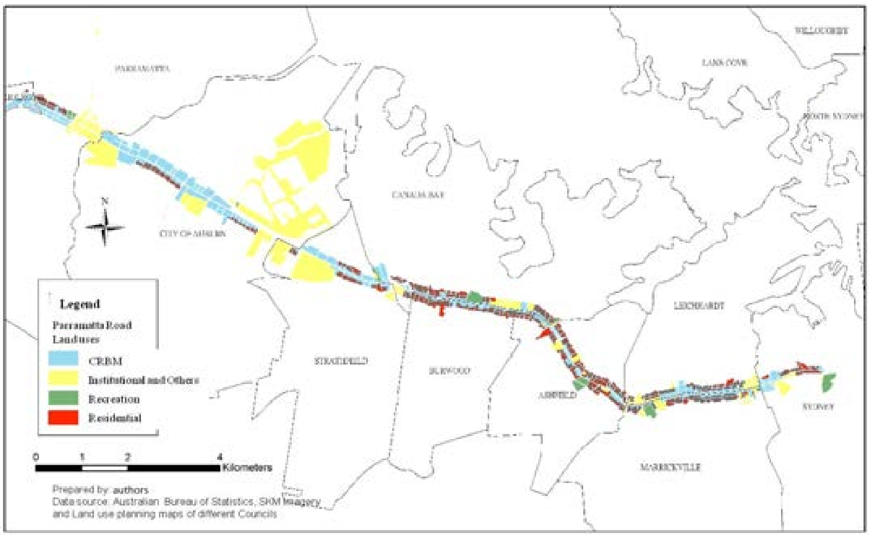

Figure 3: Landuse distribution on Parramatta Road

4.3 i-Tree Eco v5.0 analysis

A total of 332 trees across 91 plots along the two corridors was surveyed. Along the Pacific Highway, a total of 250 trees and 82 trees on Parramatta Road, were recorded. On the Pacific Highway and Parramatta Road a total of 81 and 28 different tree species respectively were documented. The model estimated that the sampled plots, on the Pacific Highway, the tree canopy cover is 40.3% and a total of 30,500 trees within the project site and Parramatta Road had a tree canopy cover of 14.2% and a total of 9,580 trees within the site. Parramatta Road has a significantly lower number of total trees compared to that on the Pacific Highway.

Tree canopy cover, tree species composition and tree densities

The overall tree density on the Pacific Highway (106 trees per hectare) which was considerably higher than the Parramatta Road (70 trees per hectare). In both case studies, IRO (Institution, Recreation and Other uses) land use had the highest values of tree densities (Pacific Highway - 112 trees per hectare and Parramatta Road - 93 trees per hectare). The recreational and institutional land uses such as churches, schools and parks, contained higher numbers of trees. The tree density of residential land use on the Parramatta Road was the lowest (45 trees per hectare) compared to other two land use categories. Land use is an important determinant of tree density in an urban area. A comparison of tree densities in two case studies is presented in Table 3.

Table 3: Tree densities in three land use categories in two Sydney case studies

Stratum/Landuse	Pacific Highway	Parramatta Road
CRBM	88.9	62.7
IRO	112.5	92.5
Residential	108.9	45
Total	**106.2**	**69.6**

Three most common tree species identified were 'Queen palm' (10.55 %), 'Sydney blue gum' (9.23%), and 'Camellia' (9.77 %) on the Pacific Highway and 'Gray ironbark' (14.0 %), 'Weeping bottlebrush' (9.8 %), and 'Australian Tallowwood' (9.7%) on the Parramatta Road. Top ten common tree species distributions for Pacific Highway and Parramatta Road are presented in Fig 4.

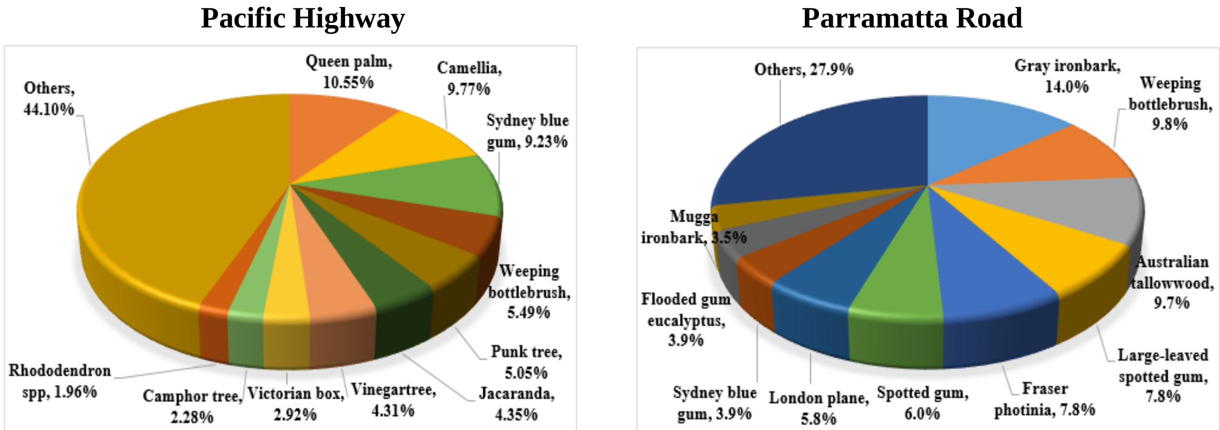

Fig 4: Most common ten tree species distributions in the two case studies

Land cover

The dominant land cover types on the Pacific Highway were grass (23.6%), buildings (22.8%) and tar (20.1%). Impervious cover considering building, tar and cement together was 54.9 % in Pacific Highway.

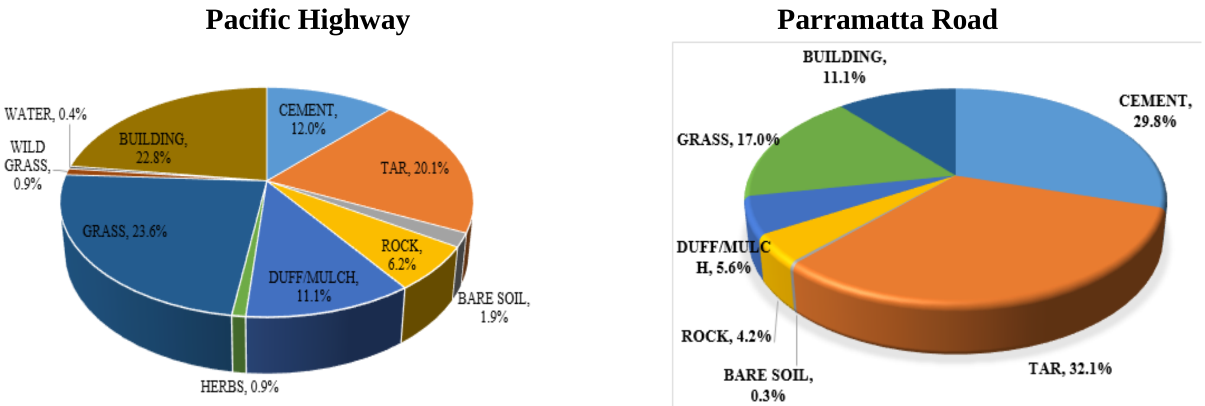

Fig. 5: Land cover distributions in the two case studies

On the Parramatta Road, tar (32.1%) and cement (29.8%) were the dominant land cover types while buildings covered 11.1% of the land area. All together (building, tar and cement) impervious surfaces accounted for over 73% of the total land cover in the Parramatta Road. This is higher compared to the same on the Pacific Highway. Higher proportion of impervious land cover on Parramatta Road influenced by land use distributions has impacted on the growing potential of urban trees. This explains why the tree density was lower and contained a smaller total number of trees on Parramatta Road. Fig. 5 present land cover distributions in the Pacific Highway and Parramatta Road case studies.

Carbon sequestration and storage benefits and air pollution removal potential

Total gross carbon storage and sequestration potential was 71,700 metric tons and 1220 metric tons respectively on the Pacific Highway. The same was 22,600 metric tons and 573 metric tons respectively on the Parramatta Road. The rate of gross carbon storage in metric tons per hectare was 52% higher on the Pacific Highway compared to that on the Parramatta Road. Although some trees may have greater potential to contribute to carbon storage and sequestration on a per tree basis, but collective performance of some tree species which exist in higher numbers in the project sites can provide larger benefits.

The net annual oxygen production by a tree guides its carbon sequestration capacity and carbon storage or tree biomass accumulation potential. Total annual oxygen production was 2120 metric tons on the Pacific Highway and 1060 metric tons on Parramatta Road. Air pollution removal potential includes removal of ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulphur dioxide (SO2) (USDA Forest Service et al., 2013, p.1). Total annual air pollution removal potential was 11000 kilograms per year on the Pacific Highway and 2000 kilograms per year on the Parramatta Road. Rate of air pollution removal was 38.3 kg of carbon per hectare per year on the Pacific Highway and 14.5 kg of carbon per hectare per year on the Parramatta Road.

Lack of tree growing spaces due to high impervious land cover on the Parramatta Road had impacted the carbon storage and sequestration potential and air pollution reduction capacity. The total tree numbers, tree canopy cover and distribution patterns of the trees on the plots affect the collective potential and carbon performance of urban trees. If trees could be planted on each plot, collectively they could activate further significant environmental benefits. Table 4 presents carbon storage and sequestration oxygen production and air pollution removal values in two case studies.

Table 4: Annual carbon storage and sequestration, and air pollution removal potential

Potential of urban trees	Pacific Highway	Parramatta Road
Total land area (hectares)	287	137.6
Total number of trees	30500	9580
Total tree canopy cover as a percentage of total land area (%)	40.3%	14.2%
Total gross carbon storage[1] (metric tons)	71700	22600
Rate of gross carbon storage (metric tons per hectare)	249.8	164.2
Total gross carbon sequestration[2] (metric tons per year)	1220	573
Rate of gross carbon sequestration (metric tons per hectare per year)	4.3	4.2
Total oxygen production (metric tons per year)	2120	1060
Rate of oxygen production (metric tons per hectare per year)	7.4	7.7
Total air pollution removal* (kg per year)	11000	2000
Rate of air pollution removal (kg per hectare per year)	38.3	14.5

Note: 1 metric ton is equal to 1000 kg according to i-Tree Eco v5.0 manual (USDA Forest Service et al., 2013)
[1] Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.
[2] Carbon sequestration: the removal of carbon dioxide from the air by plants.
*Air pollution removal collectively include ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2) removals) (USDA Forest Service et al., 2013, p.1)

Economic benefits

Urban trees are valuable assets and have significant economic value associated with the trees. Total economic value of carbon storage and total structural values of trees of urban trees were calculated to be equal to $AUD 1.64 million and $AUD 27,700 respectively in Australian dollars from the trees on the Pacific Highway. On the Parramatta Road, total economic value of carbon storage and total carbon sequestration of trees of urban trees were calculated to be equal to $AUD 516,000 and $AUD 13,100 in Australian dollars respectively. Total economic value of annual air pollution removal were AUD$5,220 and AUD$857 respectively on the Pacific Highway and on the Parramatta Road. Total economic values carbon and air pollution reduction benefits of the urban trees on the Parramatta Road were lower compared to Pacific Highway as the total number of trees was less in the Parramatta Road case study. The structural values of trees were $AUD 640 million and $AUD 206 million in Pacific Highway and Parramatta Road respectively. i-Tree Eco manual suggests that structural value is calculated based on the cost of replacing a tree with a similar tree, considering the characteristics of the tree which would be removed (USDA Forest Service, 2013). Table 5 describes the economic benefits in Australian dollars ($AUD) generated from carbon sequestration and storage, air pollution removal and structural values of urban trees in the Pacific Highway and Parramatta Road case studies.

Table 4: Economic benefits generated by urban trees

Economic values (in $AUD or Australian Dollars)	**Pacific Highway**	**Parramatta Road**
Total carbon storage value (million)	1.64	0.516
Total carbon sequestration value (thousand per year)	27,700	13,100
Total structural value of trees (million)	640	206
Total annual air pollution removal value (thousand)	5.220	0.857

5 Discussion, recommendations and conclusion

This research estimated carbon storage and sequestration benefits, and air pollution reduction potential of urban trees along two primary transport corridors in Sydney. Different land use distributions, variations in urban morphologies, land uses (e.g. residential, institutional etc.) and land cover types such as impervious cover (e.g. buildings, paved surfaces such cement and tar), and pervious cover (e.g. grass) in the two case studies guided significantly varied performances of trees as green infrastructure (Table 2, Fig 5). Percentages of tree canopy cover, tree compositions, species, age, tree densities and growing conditions guided by the land cover patterns play important roles. Potential tree growth rate is influenced by age, tree health, tree maintenance factors such as pruning (Nowak et.al, 2008) and various climate patterns. Larger trees can provide higher functional values such as greater carbon storage prospects. The selection of a higher number of sampled plots for comparatively for smaller areas of two Sydney case study sites provided higher accuracy and consistency in this research. This research can help to determine tree canopy cover goals and to understand the associated tangible monetary values of urban trees. These outcomes could assist in developing appropriate and informed green infrastructure and urban planning strategies, policies and guidelines for effective management, maintenance and protection of urban trees for generating meaningful local sustainability benefits.

Five i-tree case studies presented in this paper highlights the importance of understanding how the values of carbon benefits could be shaped by changing variables in different parts of the world. According to the Köppen climate classification system (Encyclopedia Britannica, 2017), Toronto and Kansas case studies at city and regional levels were in humid continental climate zones which are different from Sydney case studies. Perth has a Mediterranean climate while Torbay has an oceanic climate (Encyclopedia of Britannica, 2017). Different climates generate different growing conditions for trees. Although Sydney and Auburn University case studies are at local scales and were located in similar humid subtropical climate zones, significant land use differences exist between them. As a university campus, Auburn’s land use is institutional while the Sydney case studies contained a range of different land use categories. The percentage of residential land use was the highest of all land uses on the Pacific Highway and contained a very good tree canopy cover and therefore, were equipped with higher carbon sequestration and storage capacities.

A number of challenges were noted in the two Sydney case studies. Obtaining written consents prior to access to private properties for tree data collection were significantly time consuming and challenging. In some cases, owners refused to grant permissions despite the huge amount of time spent on making contacts by phone, email and visits to the properties. In addition, some plots required multiple permissions and a small number of trees already had permissions approved by the council for removal at the time of the survey. The nature of carbon storage and sequestration in urban trees could be ‘temporal’ as both are affected by tree removals, tree pruning methods and maintenance factors which need to be recognised (Nowak et al, 2008; Peper et al., 2001). Identifying tree species usually requires fruit or flowers available in the spring, autumn and summer. Seasonal variations on trees could alter the quality of specimens gathered and affect the time required for collection. Therefore, seasonal factors should be taken into consideration when scheduling on the fieldwork for tree data collection. Socio-economic conditions, lifestyle choices and awareness of the resident community, business and land owners had influenced tree species choices and the protection and maintenance of trees over a longer term. A higher percentage of land use on the Pacific Highway is residential and therefore, the types of trees in residential gardens are dependent on the householders' choices (Head and Muir, 2007).

Tree canopy cover goals with specific timeframes for cities and neighbourhoods at different spatial scales should be formulated. These initiatives are already happening in many cities of the world. Green infrastructure planning and land use planning policies for roads and other land uses along transport routes should be connected and developed in an integrated manner. Appropriate urban tree planning policy could contribute immensely to achieving increased environmental values and ecosystem service benefits. Tree planting guidelines should be based on potential of individual tree species to provide carbon storage and sequestration and collective performance potential when larger number trees could be planted. Trees are valuable assets as have significant associated economic values. Asset management plans for effective tree management, protection and maintenance, and removal should be formulated. Tree removal applications should consider overall tree and land use planning and urban design policy goals and structural values of the trees to be removed. These should be linked to the council's asset database and tree canopy goal of the overall LGA and should be integrated within the local planning process. These regulations could be incorporated within the statutory Local Environmental Plan (LEP) and Development Control Plan (DCP) guidelines prepared by the local governments in Australia. New and innovative incentives to the property owners for new tree planting and maintenance of trees could assist in tree protection and improved values of urban trees. State governments and local councils should focus on developing possible implementation methods for the protection of existing urban trees and the creation of new urban forests through innovative programs. Web based mapping tools could be developed to incorporate the tree information database and to provide easy access to public to estimate local sustainability benefits provided by the trees on individual properties to neighbourhoods or precinct scales. More focus is needed in raising awareness of residents and land and business owners towards protecting existing and planting new urban trees. Training workshops could be organized to build knowledge within communities. Tree planting programs, community workshops and preparation of fact sheets are important ways to assist in community education programs. Community groups and urban green infrastructure teams could be formed to take leadership roles for these initiatives in neighbourhoods and urban areas.

Future research would play an important role in this process. Practice oriented research involving communities, professional and academic researchers would provide effective and realistic solutions. Further research to comprehend and evaluate the performance and feasibility analyses on urban trees in urban design, master planning and structure planning projects could effectively assist local governments, private and public institutions, land managers, and tree management authorities to develop for better management processes and informed decision making about the urban trees. Research on other environmental benefits of urban trees in transport corridors such as traffic calming and, reducing urban heat island effects through shading etc. in addition to carbon benefits should be analysed. It should also explore how variations in climate, extent of spatial scales, basic community profiles and other related factors and qualitative analysis of people's perceptions, aspirations and motivations would influence the potential of trees to perform as important green infrastructure creating liveable environments. Research on urban trees encompasses multiple disciplinary fields of forestry, urban planning, urban design, geography, architecture/landscape architecture, health, social sciences and others. A transdisciplinary and holistic approach is vital for the success of this research. Researchers in this field should take determined efforts to understand and value different disciplinary perspectives and work collaboratively. This paper brings together urban forestry and urban planning research outcomes for effective tree policy formulation for urban areas. This research provided an appraisal on potential of urban trees in mitigating local environmental impacts and their enormous importance as valuable assets in managing and creating meaningful responsive human environments now and into the future.

Acknowledgements

Authors would like to thank Horticulture Australia Limited (HAL) for funding support to conduct this research and Nursery Gardens Industry Australia (NGIA) and research team members for their all help. Authors would also like to thank all participants who gave consents to conduct tree data collection; all who helped to conduct the field survey and the Royal Botanic Garden Sydney for identifying tree species in this project.

References

Akbari, H., 2002. Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution*, 116, 119 – 126.
Australia Bureau of Statistics (ABS), 2011. QuickStats. Available from: http://www.abs.gov.au/websitedbs/censushome.nsf/home/quickstats?opendocument&navpos=220 [Accessed 21 April, 2017].
Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2006. *Climate Change in the Sydney Metropolitan Catchments*. Available from: http://www.smh.com.au/pdf/climate.pdf [Accessed 14 June, 2017].
City of Melbourne, 2012. *Urban Forest Strategy*: *Making A Great City Greener 2012-2032*, Available from: http://www.melbourne.vic.gov.au/Sustainability/UrbanForest/Documents/Urban_Forest_Strategy.pdf [Accessed 12 April, 2017]
City of Phoenix. 2010. *City of Phoenix: Tree and Shade Master Plan*, Available from: https://www.phoenix.gov/parkssite/Documents/T%20and%20A%202010.pdf [Accessed 15 May2017].
City of Sydney. 2013. Available from: http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0003/132249/Urban-Forest-Strategy-Adopted-Feb-2013.pdf [Accessed 12 May, 2017].
City of Toronto, 2010. *Every Tree Counts: A Portrait of Toronto's Urban Forest*. Available from: https://www.itreetools.org/resources/reports/Toronto_Every_Tree_Counts.pdf Accessed 21 July, 2017]
Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R., and Gaston, K.J., 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale, *Journal of Applied Ecology*, 48 (5), 1125–1134.
Encyclopedia Britannica, 2017. Koppen Climate Classification System. Available from https://www.britannica.com/science/Koppen-climate-classification [Accessed 3 July, 2017].
Government of the District of Columbia. 2013. *District of Columbia Urban Tree Canopy Plan*, Available from: https://ddoe.dc.gov/sites/default/files/dc/sites/ddoe/page_content/attachments/Draft_Urban_Tree_Canopy_Plan_Final.pdf [Accessed 15 October 2016].
Head, L., and Muir, P., 2007. *Backyard*. University of Wollongong Press, Wollongong, New South Wales, Australia.
Hill, M. K., 2004. *Understanding Environmental Pollution – A Premier*, Second Edition, Cambridge University Press, UK.
Jin, M. T. B., 2017a, *Urban Biodiversity and Greening Strategies in Singapore*, Available from: http://www.macestudio.com.sg/sites/macestudio.com.sg/files/Planting_Strategies_Paper.pdf [Accessed 15 June 2017].
Jin, M. T. B., 2017b, *A Perspective on Landscape Planting Strategies in Singapore*, Available from: http://www.macestudio.com.sg/sites/macestudio.com.sg/files/Planting_Strategies_Paper.pdf [Accessed 15 June 2017].
Kiran, S. G., and Shah, K., 2011. Carbon Sequestration by urban trees on roadsides of Vadodara city, *International Journal of Engineering Science & Technology*, 3 (4), 3066-3070.
Koleth, E., 2011. *Population Issues for Sydney and NSW: policy frameworks and responses*, Briefing Paper No 5/2011, New South Wales Parliament Library, Research Service, New South Wales Parliament, Australia.
Living in Australia, 2017. *Sydney's Climate*. Available from: http://www.livingin-australia.com/climate-weather-sydney/ [Accessed 15 July 2017].
Martin, N. A., Chappelka, A. H., Keever, G. J., Loewenstein, E. F., 2011. A 100% Tree Inventory Using i-Tree Eco Protocol: A Case Study at Auburn University, Alabama, U.S. *Journal of Arboriculture*, 37(5), 207-212.
Martin, N. A., Chappelka, A. H., Loewenstein, E. F., Keever, G. J., 2012. Comparison of carbon storage, carbon sequestration, and air pollution removal by protected and maintained urban forests in Alabama, USA. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8(3), 265-272.
Mcpherson, G.E., and Simpson, JR, 2003. Potential energy savings in buildings by an urban tree planting programme in California. *Urban Forestry and Urban Greening*, 2, 73- 86.
New South Wales Government, 2014. *A Plan for Growing Sydney*. Available from: http://www.planning.nsw.gov.au/~/media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx [Accessed 15 October 2016].

National Parks, 2017, *What is the Streetscape Greenery Masterplan?* Singapore Government. Available from: http://www.ifaq.gov.sg/NPARKS/ [Accessed 15 July 2017].
Newton, P. 2014. *Biophilic urbanism: a case study on Singapore, Australian Planner,* 51 (1), 47-65.
Nowak. D. and Crane. D., 2002. Carbon storage and sequestration by urban trees in USA. *Environmental Pollution*, 116, 381-389.
Nowak, D.J., Crane, D.E., Stevens, J.C., Hoehn, R.E., Walton, J.T., and Bond, J., 2008. A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services, *Arboriculture and Urban Forestry*, 34(6), 347-357.
Nowak, D. J., Bodine, A. R., Hoehn III, R. E., Crane, D. et al. 2012. *Assessing Urban Forest Effects and Values: the Greater Kansas City Region*. Resource Bulletin NRS-75, Northern Research Station**,** United States Department of Agriculture Forest Service (USDA Forest Service).
Nowak, D.J, Greenfield, E.J., Hoehn, R.E., Lapoint, E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, 178, 229-236.
Peper, P. J., McPherson G. E., and Mori M. S., 2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. *Journal of Arboriculture*, 27 (4), 306-317.
Rogers, K., Jarratt, T., Hansford, D., 2011. *Torbay's Urban Forest-Assessing Urban Forest Effects and Values. A report on the findings from the UK i-Tree Eco pilot project*. Available from: http://www.itreetools.org/resources/reports/Torbay_UF_Report.pdf [Accessed 7 January 2017].
Saunders, S., Dade, E. and Van Niel, K., 2011. An Urban Forest Effects (UFORE) model study of the integrated effects of vegetation on local air pollution in the Western Suburbs of Perth, WA, MODSIM 12–16th December, 2011, *19th International Congress on Modelling and Simulation*, Sustaining Our Future: Understanding and Living with Uncertainty, 1824-1830.
USDA - Forest Service, 2003. *Urban Tree Canopy - The Chesapeake Bay Watershed Forestry Program*. Northeastern Area State and Private Forestry, USA.
USDA Forest Service, Davey, Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture and Casey Trees (USDA et al.), 2017a. *What is i-Tree?* Available from: http://www.itreetools.org/index.php [Accessed 14 July 2017].
USDA et al., 2017b. *i-Tree Applications*, Available from: http://www.itreetools.org/applications.php [Accessed 14 July 2017].
USDA et al. , 2017c. i-Tree, Tools for Managing Community Forests: i-Tree Eco (UFORE) Species Code List (updated Apr 30 2012). Available from: http://www.itreetools.org/eco/resources/ufore_species_list_apr30_2012.pdf [Accessed 15 January, 2017]
USDA et al., 2017d. *Australian and Canadian i-Tree Eco Versions*. Available from: http://www.itreetools.org/eco/international.php[Accessed 15 January, 2017].