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Greening rail infrastructure for carbon benefits

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Abstract

Metropolitan Sydney has a network of rail corridors almost 400 kilometers in length, which vary in width from narrow cuttings to wide easements. With an appropriate selection of vegetation species, these corridors can be used to offset carbon emissions from railway operations. Simultaneously, the plantings will improve air quality, reduce pollution and storm water flows, ameliorate urban heating deliver biodiversity gains and improve urban design and property values. A pilot study was carried out on a representative section of one of the major rail lines in Sydney in 2016. A detailed inventory of vegetation on the selected site was obtained through a field survey and a variety of tools were used including i-Tree Eco to benchmark current carbon sequestration and storage (CS&S) levels. Study outcomes include the existing carbon capacity of the rail corridor's above-ground (and substrate) biomass and air pollution reduction. It also presents estimates of CS&S potential by identifying future planting areas within the pilot study corridor. These results are valuable for infrastructure policy formulation directed towards carbon emissions as well as securing the co-benefits noted above.

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Keywords: Green infrastructure; grey infrastructure; carbon sequestration; carbon storage; air pollution; railway corridor; urban forests;vegetation

1. Introduction and context

Trees and shrubs as important elements of green infrastructure can provide multiple environmental and ecological benefits. Their unique capacity to sequester carbon from the atmosphere by photosynthesis; store carbon as biomass; intercept rainfall and reduce stormwater runoff; reduce urban heating and air pollution, and enhance

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biodiversity and aesthetic values, have contributed to improved sustainability and better quality environments in cities and towns of the world [1, 2, 3]. Vegetating urban areas and infrastructure facilities such as motorways, landfill sites and railway corridors, while less prevalent in Australia, has been carried in other parts of the world because it has immense potential to harness the significant abilities of vegetation to provide positive outcomes for human habitats. Internationally government agencies, communities and other organisations are now recognising the importance of greening grey infrastructure and a few projects revegetating railway corridors and other infrastructure sites are beginning to appear.

While botanists and ecologists have conducted many studies on rail infrastructure, especially in the US and Europe, those studies have mainly had a specialist focus on plant species, their threatened or endangered status and the dispersal characteristics of railway lines. However, a project on two and half kilometres of railway corridor in London, with woodland planting in the corridor and adjacent lands has been formulated and is significantly strengthened by the involvement of the local community in the project. The key objective of this project is aesthetic, to enhance views, but aims are also to improve the travelling experience for rail users and protect wildlife habitats [4].

More locally, the Adelaide – Seaford rail line is a rare Australian example of corridor greening although much of the work has involved replacing trees and shrubs which must be removed as part of the electrification of the rail line. The project also aims to create a biodiversity corridor where flora and fauna can thrive. The project was completed in late 2015 ([5]). In addition, a rail transit greening project also runs from the City of Perth to Fremantle in Western Australia, "gracing travellers with a gorgeous green space composed of thousands of native trees and shrubs" (http://202020vision.com.au/partner/?id=1331). The City of Subiaco, in partnership with six other local councils and state agencies is establishing the green corridor utilising the vacant land surrounding the rail route.

Transport for NSW (TfNSW), a New South Wales (NSW) Government transport agency in Australia, is responsible for the delivery of transport services and owner of a number of transport corridors including Sydney's metropolitan heavy rail network of almost 400 kilometres, which vary in width from narrow strips of land to wider tracts of easement. In many ways, the vegetated and open space areas within these rail corridors are fine examples of green infrastructure. The corridor margins are often densely planted with shrubs, bushes and medium height trees. In addition, the corridors contain generous expanses of grassed areas, a feature being their general permeability to rainwater, even of the ballasted area supporting the operating rail tracks. Many sections of the corridors are underused and have significant potential for planting local indigenous species of shrubs and low growing trees.

2. Aim and objectives of the research

A pilot study was completed in 2016 on Sydney's Bankstown Line, on the north side of the rail corridor, one kilometre in length between Belmore and Lakemba Stations (Figure 1). The key objective of this practical research project was to estimate the study area's CS&S. The paper presents the results of this study and suggests that rail corridors could be transformed into functional green infrastructure sites with significant potential to provide multiple environmental and ecological benefits. Other objectives of the pilot study are:

To conduct a vegetation inventory for all vegetation above 1.0 m height and assess current floral biodiversity;

- To estimate the potential for further planting of local indigenous bushes and low growing trees and the prospective additional carbon storage that would represent;
- To estimate the air pollution removal capacity of bushes and trees in the study area; and
- To demonstrate a process for quantifying ecosystem services provided by vegetation for use in economic valuation in environmental policy.

3. Research methodology

3.1. Selection of the site

The north side of the rail corridor, approximately one kilometer in length between Belmore and Lakemba railway stations on the T3 Bankstown Line was selected for the pilot study. There were two key selection criteria: that the corridor be sufficiently wide to contain both existing vegetation and unused land offering potential for future plantings and that the corridor is reasonably representative of the network in the metropolitan area. A number of other locations on the T3 line and the North Shore line were inspected and the selection checked with TfNSW. Fig. 1, presents an aerial photograph of the selected corridor. Fig. 2, is an example of plantable land in the corridor and Fig. 3, provides a glimpse of the range of vegetation in the corridor and its natural appearance.

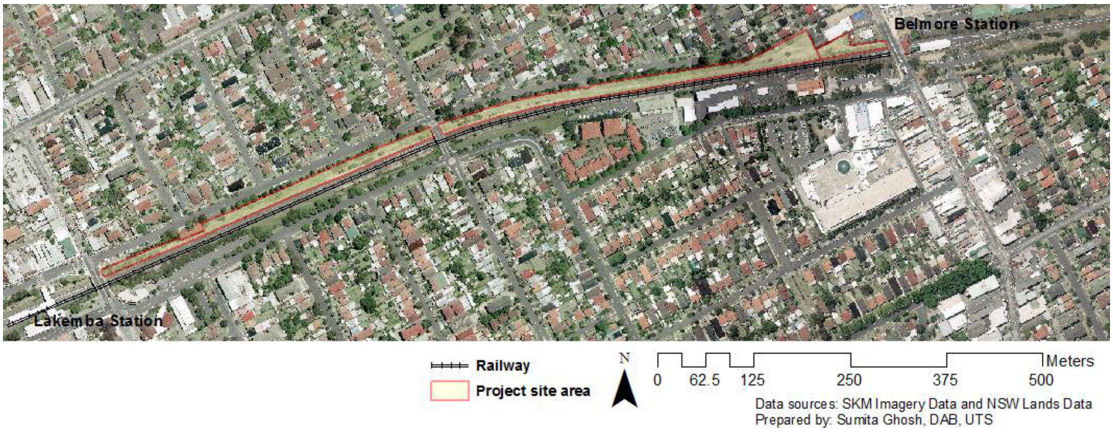

Fig. 1. Selected project site between Belmore and Lakemba Stations.

Fig. 2. Available plantable space in the corridor.

Fig. 3. Existing vegetation in the corridor.

The pilot study was carried out in the selected section of the corridor jointly by TfNSW, the University of New South Wales (UNSW) and University of Technology Sydney (UTS) using a combination of field observation within and outside the easement; TfNSW easement plans; Google Earth and Near Map; the use of an on-line carbon calculator and i-Tree software tools (https://www.itreetools.org/) for urban trees assessment. The study applied to lands owned by TfNSW which are outside the *danger zone* part of the corridor, that is, 3 meters from the nearest rail track.

3.2. Key elements of the methodology

i) A vegetation survey, benchmarking the extent and characteristics of existing vegetation over 1 metre in height, was done on site using a tape for diameter at breast height (DBH) and a laser measuring device for heights. Identifying indigenous versus exotic flora species was carried out simultaneously with the help of a botanist [6]. The number of plant species and number of plants representing a species, were summed on an Excel vegetation spreadsheet;

ii) Existing CS&S and the carbon potential of the pilot study area was estimated using four different methods. Each approach complements the other and provides a cumulative total:

a) Vegetation >1metre in height and 30mm or more DBH: An established urban tree assessment tool, i-Tree Eco v5.0, compatible in an Australian context, was applied in this pilot project. In-field data collection was conducted following i-Tree Eco v5.0 protocols and using equipment like a laser and GPS. Tree species information and part of the DBH and height data for trees were supplemented from the vegetation survey in Item (i). In addition, the air pollution reduction potential and health condition of trees in the corridor are calculated using i-Tree Eco.

b) Vegetation >1m but < 30mm DBH: This comprises 51% of vegetation on site. The CS&S characteristics were gained by inputting the vegetation data from the vegetation survey in Item (i) into an on-line carbon calculator [†] since i-Tree Eco does not handle dimensions less than this. It is available at: http://www.northsydney.nsw.gov.au/carbon/carbon.html. The CS&S of potentially plantable land was calculated by simple proportionality.

c) Below ground carbon except the trees included in i-Tree ECO calculation was calculated using data provided in [8][‡] as follows:
- Soil carbon – trees: 6.93kgC/m^2 and sequesters 25.3kg CO_2 per year;
- Soil carbon – Grass: 5.43kgC/m^2 and sequesters approx. 19.8 kg CO_2 per year.

d) The definition of soil carbon generally excludes the below ground root biomass of trees and bushes ([7], [9], so the soil carbon calculations include a separate sub-category for root-mass carbon[§]

iii) The existing vegetated area was calculated using Google Maps with the boundaries of TfNSW's easement corridor superimposed on the plans. The potentially plantable area was calculated using TfNSW's large scale easement maps accompanied by Google Earth. The net potential area accounted for constraints critical to TfNSW such as minimum offset distances prescribed in relation to proximity to the active rail lines, maintenance vehicle access tracks and overhead electrical infrastructure.

4. Results

A summary of the outcomes of the research is presented below. Carbon stores and sequestration data is derived from the two forms of carbon calculator. Carbon stores from trees, vegetation over 1 metre in height and up to 30mm in diameter, together with soil carbon, are summarized in Table 3.

4.1. Carbon sequestration and storage

4.1.1. Vegetation >1metre and 30mm DBH

Table 1 presents the carbon sequestration, storage and storm water runoff benefits provided by the on-site trees. Some 158 trees, representing 507 individual plants in i-Tree Eco, store 8,488 kg of carbon and have a carbon sequestration rate of 979 kg per year. They have a canopy cover of 2827m^2.

Each tree will provide different carbon sequestration and storage benefits depending on the tree health and growing conditions. Altogether 16 different species of trees have been identified in the corridor (Table 2) each with different CS&S benefits. *Casuarina glauca* is the dominant species on the project site. *Acacia parramattensis* has the highest carbon sequestration potential per tree, equal to 21 kg/year while *Cinnamomum camphora* has the highest annual carbon storage potential per tree equal to 340 kg.

† Above ground biomass is based on allometrics in [10].

‡ Some 25 soil samples were taken around campus and carbon levels calculated by combustion in laboratory conditions. Soil carbon is defined as roots less than 2mm in diameter.

§ The ratio of below to above ground biomass used the default value of 0.25 for all forest classes, as used in the National Greenhouse Gas Inventory Workbook 2 (1997), on the basis of several research reports.

Table 1. Carbon sequestration and storage benefits provided by trees.

Benefit category	Benefit
Total Trees	158
Canopy Cover (m2)	2,827
Leaf Area (m2)	9,380
Leaf Biomass (kg)	928
Carbon Storage (kg)	8,488
Gross Carbon Sequestration (kg/year)	979

Table 2. Carbon sequestration and storage by sample tree species in the corridor.

ID	Tree Species in pilot rail corridor	Annual carbon sequestration per tree species (kg/year)	Annual carbon storage potential per tree species (kg)
1	*Acacia fimbriata*	1.4	8
2.	*Acacia parramattensis*	21.5	166
3.	*Acacia saligna*	9.1	72
4.	*Acacia species (other)*	0.0	4
5.	*Casuarina glauca*	5.1	30
6.	*Ceratonia silique*	17.5	129
7.	*Cinnamomum camphora*	13.8	340
8.	*Corymbia citriodora*	16.3	104
9.	*Eucalyptus robusta*	0.5	32
10.	*Eucalyptus species (other)*	15.3	259
11.	*Ligustrum lucidum*	6.5	48
12.	*Ligustrum sinense*	1.0	3
13	*Magnoliopsida species*	0.0	205
14.	*Phoenix canariensis*	0.4	34
15.	*Pittosporum undulatum*	6.4	21
16.	*Syncarpia glomulifera*	17.5	119

4.1.2. Vegetation > 1m but < 30mm DBH

Using the on-line carbon calculator, 523 shrubs and trees under 30mm and over 1 metre in height store a mere 560 kg of carbon. Sequestration data is unavailable from this source. Many of the species in this category are woody and low growing perennials and there is considerable potential for carbon intensification by selecting low growing tree species.

4.1.3. Soil carbon

The area currently vegetated with bushes and trees holds some 27,000kg as soil carbon (see Table 4), on the basis of 6.93kg of below ground carbon per m^2 [10]. The area currently covered in grass or groundcover is substantial ($12,000m^{2)}$ and contains over 66,000 kgs carbon [9]. The latter represents a large area of land which has potential for above-ground CS&S by planting bushes and trees which will also increase soil carbon content beyond that sequestered by grasses and groundcover (see Section 4.3).

4.1.4. Carbon in root mass

Root mass is accounted for in i-Tree Eco's above-ground carbon count but still exists in the balance of the plants (523) not accommodated by the software. It is a very minor amount, however – 141kg.

4.1.5. Summary

The four components of carbon calculated by i-Tree, the on-line calculator and soil carbon averages are summarized in Table 3 below. The below-ground carbon stores in the root mass of the trees is also added.

Table 3. Summary of current carbon storage characteristics.

Vegetation element	Existing carbon stores (kg – numbers rounded)		Total
	Combined area of shrubs and trees	Grassed areas	
i-Tree: above ground trees: Vegetation >1m and 30mm or more DBH)[1]	8,500	--	8,500
On-line carbon calculator: shrubs/ bushes >1m high and <30 mm DBH	--	570	570
Soil carbon [2]	27,000	66,000	93,000
Below ground carbon in root mass of the trees < 20mm[3]	140	--	140
Total			102,100

Note 1: Some of the tracts of shrubs and trees contain groundcover; Note 2: The figures in Columns 2 and 3 use the conversion factors in Thomason (2011) of 6.93 kgC/ m^2 and 5.43 kgC/m^2 respectively to calculate soil carbon quantities. Note 3: derived from the National Greenhouse Gas Inventory Workbook 2 (1997). All numbers are rounded.

4.2. Air Pollution

Using the same i-Tree Eco software, the air pollution removal potential of vegetation >1m and >30mm DBH on the project site was estimated to be about 17,000 grams annually (see Table 4). This is an *indicative* figure only which is derived from algorithms in the software which may not reflect on-site air quality characteristics exactly.

Table 4. Air purification capacity.

Pollutant	Purification capacity per year (gms – numbers rounded)
CO	562
O_3	9178
NO_2	1,184
PM10	5,589
SO_2	434
PM2.5	110

Note: CO (Carbon Monoxide); O3 (Ozone); NO2 (Nitrogen dioxide); SO2 (Sulphur dioxide); PM10 (2.5 microns <Particulate matter <10 microns in diameter) and PM2.5 (Particulate matter ≤ 2.5 microns in diameter).

4.3. Land and carbon potential

The land area of the pilot corridor is fixed but the extensive area which is grassed (some 9,500m^2) is largely available for planting bushes and low-growing trees. This is a net plantable area, accounting for offset distances from the rail tracks, vehicle access needs, and the presence of overhead electrical infrastructure, over double the existing planted area).

The total existing carbon pool is 102,620 kg., shown as Item 1 in Table 5. Multiplying the existing carbon store of bushes and trees, (9,000 kgC) by a factor of 2.43, the ratio between existing treed land (3,900m^2) and that available for planting (9,500m^2); adding an increased soil carbon quotient of 1.5kg/m^2 for converting from grass to trees (14,290 kgC); and making a small allocation for root biomass under the new plantings of trees/bushes, brings the potential carbon store to an additional 38,670 kg. It is a grand total of approximately 140 tonnes carbon. This is a deliberately conservative estimate which does not account for intensification of existing shrub vegetation, targeted selection of species for carbon storage and sequestration or replacement of existing grasses with more carbon favourable perennials like Rhodes grass (*Chloris gayana)*.

Table 5. Summary of carbon potential, north side Belmore – Lakemba corridor.

Item No	Category	Existing and Potential Carbon Store (kgs)
1	Existing carbon content of bushes and trees, all soil carbon including root biomass	102,620
2	Above ground carbon potential of 9,528m^2 grassed area as bushes and trees[1]	22,000
3	Additional soil carbon of formerly grassed area as bushes/trees[2]	14,290
4	Additional root biomass carbon of newly treed area[3]	2,380
	Net realizable potential (Items 2-4)	38,670

4.4. Baseline floristic diversity

Of the 1,030 plants over 1 metre in height in the survey area, 51.6% are introduced species and 48.3% are indigenous to Australia. Of the 495 *native* plants in the corridor, some 408 or 82% are locally indigenous. There are a total of 12 different species of native plant which are local to the area and an additional four species which are native to Australia as a whole. The range of exotic plant species is also limited with only 9 separate species in the corridor (see Table 6).

Table 6. Plant species and their abundance in the pilot rail corridor.

Local Indigenous Species	No. of Plants	Other Australian Native Species	No. of Plants	Exotic Species	No. of Plants
Acacia parramattensis	4	Acacia saligna	52	Ligustrum sinese	4
Acacia fimbriata	9	Grevillea robusta	1	Cinn. camphora	34
Bursaria spinosa	3	Eucalyptus spp.	7	Phoenix canariensis	4
Pittosporum undulatum	6	Corymbia Citriodora	29	Ligustrum lucidum	245
Casuarina glauca	359	Eucalyptus spp	7	Cotoneaster glaucophyllus	42
Melia azedarach	2			Olea europaea	70
Acacia falcata	20			Pyracantha crenulata	42
Eucalyptus robusta	1			Ceratonia siliqua	4
Eucalyptus spp. Sect. Adnatia (Box Group)	1			Rondeletia amoena	35
Acacia parvipinnula	3			Eriobotrya japonica	1
Syncarpia glomulifera	1				
Polyscias sambucifolia	1				
Total: 12 species		Total: 4 species		Total: 9 species	

Plant species are quite unevenly distributed botanically as well as geographically. By far the most numerically rich local native plant is *Casuarina glauca*, accounting for about 27% of total plants within the corridor. Similarly, abundant, privet (*Ligustrum lucidum*) accounts for 24% of the total. Wattles like *Acacia falcata* and *A. saligna* are also reasonably abundant as are Camphor Laurel (*Cinnamomun camphora*) and *Pyracantha crenulata* amongst the introduced species.

5. Discussion

5.1. Carbon offsetting

The current carbon storage capacity of the north side of the easement in this particular 1 km section of rail corridor is estimated to be 100 tonnes. There is an additional capacity of almost 40 tonnes if the substantial area of vacant, grassed land were converted to bushes and trees (of a size appropriate for the rail corridor. Intensifying existing small bushes and converting groundcover plants and weeds to more substantial carbon-sequestering vegetation would add to this total so it may be considered a very conservative estimate.

Carbon storage and offsetting is one positive externality which should be considered noting that there are a number of additional economic benefits which would flow from intensifying the vegetation in the corridor, discussed very briefly below.

5.2. Economic Valuation in Environmental Policy

TfNSW together with its key agencies and partners in the private sector are often faced with decisions that involve the balancing of the three pillars of sustainability: environmental, social, and economic values. Fortunately, a number of valuation techniques have been developed in order to evaluate non-market ecosystem services. One of the methodologies used to manage this ‘balancing act’ when making infrastructure project decisions is to carry out a cost-benefit analysis (CBA) over the whole of life of the asset [10]. However, this still requires the challenging step of quantifying the resource benefits provided by green infrastructure. This essential first step in economic valuation has been partly achieved in the pilot study. Using i-TreeEco, it has identified three particular ecosystem services associated with the vegetation in the rail corridor: numerical values for carbon storage and sequestration and air pollution and storm water reduction. With these numerical values it now becomes possible to conduct a full CBA to estimate the monetary value of these elements of green infrastructure.

6. Conclusions

The key conclusion from this small, 1km long pilot study on one side of a rail easement is that there is abundant opportunity for TfNSW to build on its assets – railway easements. With careful plant selection to ensure that size (height and spread) and maintenance requirements do not impact on the safe operations of rail services, greening the rail corridor offers an opportunity for TfNSW to offset its CO_2 emissions, potentially gain carbon income and ultimately improve its sustainability performance in other respects, too.

While there are capital and maintenance costs in undertaking a vegetation enhancement program there are also wider economic benefits and potential financial revenue that can be gained through the ecosystem services from vegetation. Some of these services are of strategic value to rail operations such as the corridor cooling effect of vegetation as well as the reduction of storm water flows. A comprehensive cost-benefit study would throw considerable light on the value of those benefits in relation to costs.

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