Review of tools for quantifying the contribution of green infrastructure to carbon performance

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1. Abstract

The exchange of carbon between the atmosphere and biosphere is an important factor in global climate regulation. Consequently, it is important to examine how carbon flows and cycles between different pools and how carbon stocks change in response to afforestation, reforestation, deforestation, and other land-cover and land-use activities.

Eco-cities and green-cities are emerging concepts for the retrofitting of our urban areas and important component in the creation of more sustainable development towards climate change adaptation and mitigation. Green infrastructure as a key part of eco-cities and green-cities contributes as a major carbon pool for. The term 'green infrastructure' refers to an interconnected network of landscape assets that are intertwined with engineered (grey) infrastructure and buildings.

The ability to assess the performance of green infrastructure, based on measurable criteria at a variety of temporal and spatial scales, is critical for defining the difference between effective and non-effective scenarios for sustainable urban development.

This paper aims to identify the most relevant and applicable evaluation tools, applications and methods for quantifying the carbon performance of green infrastructure in Australia.

The existing quantitative tools used to measure green infrastructure sustainability performance are varied in terms of the scale, components and input. This study has identified and tabulated the most relevant tools for quantifying the features and carbon services of green infrastructure. The aim is to help policymakers, environmental groups and researchers to choose the most appropriate tool(s) for the intended context and it will lead them to a more useful and accurate carbon foot printing assessment outcome.

Key words: Green infrastructure, greenhouse gas emissions, carbon performance, assessment, valuation toolkits, sustainability, infrastructure

2. Introduction

Climate change, linked to greenhouse gas emissions, is a critical long-term environmental concern for the global community (IPCC, 2001; Leary et al. 2008). The need to adapt to climate change is now widely recognized as one of the most important objectives of sustainable urban development (McMichael, 2013). While debate continues about the expected costs of, and best means to address the risk of global environmental, social and financial impacts of climate change, a growing scientific consensus believes that prompt action is required to reduce these risks (Leary et al. 2008; Wise et al., 2013; Robinson, 2014).

As elsewhere, within Australia climate change has the potential to create significant social and environmental problems. Australia is known to have the highest per capita GHG emissions in the world because of high energy consumption and reliance on fossil fuels, as well as deforestation and land clearing for conversion to crops (DCC, 2008; Garnaut, 2011; Robinson, 2014).

The current policy of the Australian Government aims to reduce emissions by 5% compared with 2000 levels by 2020 (and up to 15% where comparable actions are demonstrated elsewhere). It has also committed to a long-term target trajectory range for emissions reductions of between 40% and 60% below 2000 levels by 2030 (Climate Change Authority, 2014).

A number of national and local action programs have been developed and adopted to meet Australia's current emissions reduction obligation. According to Nowak (2001), trees and other types of vegetation, which act as a carbon sink, are proven to be the most effective solution for decreasing the levels of atmospheric CO_2. The Kyoto Protocol also recognizes trees as a valid means to offset greenhouse gas emissions and meet internationally agreed emissions targets (Grace & Basso, 2012). CO_2 fixation occurs during photosynthesis and the carbon is stored as plant biomass. Carbon fixation and subsequent release through vegetation decay is a natural cycle; however, actions such as deforestation and reforestation, whether natural or anthropogenic, change the net carbon storage volume over time (Nowak D., 2001). So in the quest to optimize opportunities for low carbon living, an inclusive tool is required to evaluate and monitor carbon emission and assimilation over time.

While carbon storage and sequestration in urban ecosystems is becoming a commonly used approach to mitigate climate change, quantifying the benefits of this is not fully developed or understood (Grace & Basso, 2012). Despite the numerous tools available for the assessment of carbon offsets, there is still a lack of publically available information that points to an effective integrated tool to quantify the carbon benefits delivered by green infrastructure.

This paper identifies and examines the capacity of Australian and international assessment tools for quantifying the level of carbon absorbed or emitted by green infrastructure.

2.1 Green urbanism: transforming cities toward sustainability

This research is grounded in the perspective that nature plays a significant role in the creation of sustainable cities; ecologically, socially and economically (Spirn, 1984; Irvine et al. 2010). This concept offers many important benefits for physical health, psychological wellbeing (Ulrich, 2002) and the maintenance of ecosystem services and biodiversity. It enhances the aesthetic aspects of cities, improves air and water quality, reduces flooding and enhances property values (Spirn 1984 and 1988; Nowak 2001, Alm, 2007; Benedict and MacMahon 2006; Ahern 2007; Benepe, 2013).

2.2 Sustainable Infrastructure (Grey and Green)

2.2.1 Definitions

Infrastructure can be defined as the structural elements of the economy and of society which allow for the production and distribution of goods and services without themselves being part of the production process (Infrastructure Sustainability Council of Australia, 2012). While there are many classifications for infrastructure, one approach is to differentiate between ‘grey’ and ‘green’.

The Oxford English dictionary defines grey or conventional infrastructure as ‘facilities that support social and economic production such as roads, sewerage, and water treatment system and electricity supply networks.’

According to the US Environmental Protection Agency (2012), conventional infrastructure costs are rapidly increasing. Moreover, large infrastructure projects can have large carbon footprints and can impose harmful social and economic equity consequences. Traditional centralized systems typically serving single purposes may not be integrated well with their environments or with each other.

To counter some of these negative consequences, green infrastructure has been identified as an alternative cost-effective solution for enhancing sustainable development. It can provide a wide range of engineering, environmental and human services, known as ‘ecosystem services’.

While there is no single definition, some authors have defined green infrastructure as ‘all the natural, semi-natural and artificial networks of multifunctional ecological systems within, around, and between urban areas, at all spatial scales’ (Tzoulas et al., 2007, 6; Eisenman, 2013). The Australian Institute of Landscape Architects (AILA), (2012, p1) defines green infrastructure as ‘a network of natural landscape assets which underpin the economic, socio-cultural and environmental functionality of our cities and towns - i.e. the green spaces and water systems which intersperse, connect and provide vital life support for humans and other species within our urban environments.’

Green infrastructure potentially has lower capital, maintenance and operational costs than grey infrastructure. It can have fewer negative impacts on the environment and a lower carbon footprint (Talberg et al., 2013). In comparison to grey infrastructure, which typically tends to perform only solo functions, a further advantage of green infrastructure networks is that they often serve multiple environmental and cultural functions (e.g. a pocket park and street trees may provide storm water reduction and recreation opportunities).

2.3 Green infrastructure typology

Martin and Pitman (2012) classify green infrastructure into places such as public parks, national parks and nature reserves, gardens (public and private), squares and plazas, greenways, including river and creek corridors, cycle ways, and routes along major transport (road, rail, and tram) corridors, and green roofs and walls. On the other hand, the Natural England Commissioned Reports (2013) classified green infrastructure assets according to common categories of vegetation: (1) Street trees, (2) Hedges, (3) Grassland, (4) Woodland, (5) Ponds, (6) Grass verges, (7) Garden and parks including cemeteries, (8) Green walls ,(9) Green roofs, (10) Rivers and canals, and (11) Urban storm water drainage systems.

In this study green infrastructure is classified into two main groups: (1) Natural and semi natural features such as: greenways, street trees, verges and hedges, forests, farmland, cropland, wetland etc. and (2) engineered features such as bio retention and infiltration swales and green walls and roofs.

2.4 Ecosystem services and green infrastructure

Green infrastructure provides a variety of ecosystem services that deliver clean air, fresh water and generate food, soil, regulate climate and sequester carbon. The Millennium Ecosystem Assessment, responsible for the most comprehensive assessments of the state of the global environment to date, classified ecosystem services as follows (MEA, 2003): (1) Provisioning services, which provide food, fibre, fuel, materials and drinking water; (2) Cultural services, which provide aesthetic and psychological benefits, recreational activities and related health benefits and a sense of place; (3) Regulating services, which moderate environmental conditions for such aspects as stormwater regulation, pollution clean-up, carbon storage and sequestration and local climate modification; and (4) Supporting services, which underlie all ecosystem services including soil formation.

Green infrastructure affords a comprehensive approach to planning and design to optimize ecosystem services and ecological benefits; the remainder of this paper focuses on carbon storage and sequestration.

3. Carbon cycle processes and GHG fluxes through green infrastructure assets

Carbon storage and sequestration through biomass and soil is recognized as a key benefit of green infrastructure. Currently, several tools are applied to evaluate the carbon cycle across a diversity of ecosystems. However, most carbon cycle assessment models and toolkits are based on the land use and land cover classification system (LULC) as modified by geographic, climatic and land management criteria (Sohl et al. 2012; Bagstad et al. 2013).

The basic equation to represent the carbon cycle (Federici, 2011) is:

$$\Delta CLUi = \Delta CAB + \Delta CBB + \Delta CDW + \Delta CLI + \Delta CSO + \Delta CHWP$$

Where ΔCLUi= Carbon stock changes

ΔCAB= above ground biomass ΔCBB= below ground biomass ΔCDW= deadwood

ΔCLI= litter ΔCSO= Soils ΔCHWP= harvested wood products

The carbon cycle is defined as a flow of carbon between the atmosphere and a series of carbon pools. Federici (2011) grouped these carbon pools into three main categories (Table 1).

Carbon Pools		**Description**
Biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage.
	Below- ground biomass	All biomass of live roots. Roots less than 2mm diameter are not included because they often cannot be distinguished empirically from soil organic matter.
Dead organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil larger than 10 cm diameter.
	Litter	Includes all non-living biomass greater than 2mm and less than 10cm lying dead in various states of decomposition above or within the mineral or organic soil.
Soils	Soil organic matter	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series.

Table 1 carbon pool types (Federici 2011)

Although carbon cycling and GHG fluxes vary, the basic processes such as the accumulation and loss of carbon are similar in all cases. The primary CO_2 fluxes between the atmosphere and carbon pools occur through plant photosynthesis (carbon sequestration and storage) and processes which release carbon through respiration, decomposition and the combustion of organic matter.

The amount of carbon stored in plant biomass and soil is affected by two key factors – land use and land cover (McPherson et al., 1997; Nowak et al., 2001) Changes in land use and land cover (LULC) have potential impacts on the capacity of carbon pools, especially soils. This means that any given land may have the capacity to increase its carbon stocks through changes in LULC. This can be achieved, for example, by converting marginal cropland or shrubland into forest or wetland. Hence, in order to quantify carbon storage, sequestration and emissions a complete analysis of the changes in both land use and land cover is required.

This implies an integrated multi-disciplinary approach because GHG emissions, carbon storage and sequestration within infrastructure projects, are the result of complex interactions between land use, land cover, management activities, ecosystem composition and structure, natural and anthropogenic disturbances and biogeochemical processes. Hence the assessment method should:

1. Consider all major carbon pools, stocks, flux types and controlling processes. It should fully encompass the uncertainties in the assessment results. It should address the key factors that affect carbon cycling and GHG emissions, such as land-use and land-cover changes, ecosystem disturbances (for example, fire), lateral fluxes, and management activities. (Loveland and DeFries, 2004; Running, 2008).
2. Cover both the present and future GHG fluxes and carbon sequestration capacities during the full life cycle. An evaluation of the future potential of ecosystem carbon and GHG conditions should be based on alternative and proposed land cover and management scenarios. These scenarios should be calibrated by local and regional policies and strategies.
3. Cover temporal scales and geographical distributions for ecological carbon sequestration by pool and flux type. Some of the assessment methods can be used globally but some are limited in geographic scale and are only applicable to specific climates.
4. Align with existing national policies and programs that evaluate carbon storage and GHG fluxes.

4. International and Australian approaches

Estimating carbon sequestration and total carbon storage for biomass can be complicated, time consuming and data intensive. For example, for trees, this requires the calculation of the core tree volume, estimation of the dry biomass content and conversion of the biomass into a quantity of carbon. According to Gallagher (2010), the most efficient and thorough estimation of carbon storage in trees requires destructive sampling, excavation of the root systems and drying and weighing of the biomass (Sprecht et al. 2003). Another method of estimating tree biomass has been developed from allometric equations that use measurable factors such as height and diameter at breast height (DBH). Considerable research has been undertaken to develop these allometric equations for individual species internationally and in Australia (Keith et al 2000; Grierson et al. 1992; Sprecht et al 2003; Waterworth et al 2007; Miehle et al 2009).

In 2006, the IPCC published guidelines for agriculture, forestry and other land uses (AFOLU) that defined methods for assessing and reporting on GHG emissions (IPCC, 2006). The report recommended six standard AFOLU categories for consistent and comparable reporting: forest land, cropland, grassland, wetlands, settlements and other lands. It also discussed two methods for GHG emission accounting, the gain-loss method and the stock-difference method (IPCC, 2006).

A large number of research papers and guidance documents have been released based on the models and biomass equations from two research groups within the USDA Forest Service. (McHale et al 2009). The first group from the Urban Forest, Human Health and Environmental Quality unit developed the UFORE model (renamed i–Tree Eco), with key authors Nowak and Crane, which provides total carbon stored and net carbon sequestered annually by trees. In addition, i-Tree Eco currently calculates parameters such as hourly pollution removal by urban forest, effect of trees on building energy use and rainfall interception and value. The second group of researchers, from the Centre for Urban Forest Research, developed a model called STRATUM (renamed i–Tree Streets). This tool is a user-friendly online model which allows communities to quantify the environmental benefits of their urban forest, in comparison with its management costs. This model can quantify benefits such as energy conservation, air quality improvement, CO_2 reduction, stormwater control and property value increase. Key authors from this group are McPherson and Simpson. Subsequently these tools were combined into a single software package called 'i-Tree'. Biomass predictions for urban street trees in these models have been mainly based on forest trees (McHale et al 2009; Gallagher 2010).

In Australia, Brack (2000), Keith et al (2000) and Waterworth et al. (2007) have focused on developing carbon accounting tools for forests and ecosystem biomass calculations to establish baseline data and projected biomass growth and storage capacity. These tools include the Carbon Sequestration Predictor for Land Use Change in Inland Areas of New South Wales (CSP) released in 2008 by the NSW Department of Primary Industries, (Fortunaso et al, 2008), the Full Carbon Accounting Model for Forests (FullCAM) in the National Carbon Accounting system (NCAS) and the National Carbon Accounting Toolbox (NCAT), both developed by the Australian Government. The NCAS methodology is based on the combined use of Landsat remote-sensing imagery, current and future potential climate-model estimates, soil inventory, and land-management databases. The NCAS inventory estimates carbon and GHG fluxes with a spatially and temporally explicit method for major ecosystems such as forests, grasslands, and croplands. It achieves this by considering the major controlling processes which include climate change, soil productivity, land-cover change, soil decomposition and land-management activities. Estimates for biomass in the FullCAM and CSP models are 'stand based', which means that they are not suitable for application to individual trees. Therefore, like i-Tree, the FullCAM model is not applicable for estimating carbon storage by individual urban street trees.

Also, a variety of decision-support tools and models has developed to support more systematic ecosystem services assessment including carbon sequestration and storage. Current tools range from simple spreadsheet models (e.g. Ecosystem Services Review-ESR), web-based (e.g. EcoServ, Co$ting and Nature Artificial Intelligence for Ecosystem Services- ARIES) to complex software packages such as Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), LUCI (formerly Polyscape), Multiscale Integrated Models of Ecosystem Services (MIMES) and Envision. Most of these models run with ArcGIS. InVEST and ARIES are perhaps the best known of the generalizable, public-domain tools (Vigerstol et al. 2011). 'Both use a variety of spatial data as model inputs and encode ecological production functions in deterministic models' (Bagstad et al. 2013). For provisioning and regulating services, both InVEST and ARIES produce maps to visualize results in biophysical units, to which per-unit monetary values can be applied; for cultural services and some additional models (e.g., InVEST biodiversity and habitat risk) outputs are in relative rankings. The ARIES uses agent-based models to quantify the flow of ecosystem services between ecosystem services and human beneficiaries. It is an open source and free tool. The ARIES carbon models estimate the difference between vegetation and soil carbon sequestration and stored carbon release (i.e., due to deforestation, land use change, or fire). The InVest model estimates the net amount of carbon stored in a land parcel over time; the total biomass removed from a harvested area of the parcel, and the market and social values of the carbon sequestered in remaining stock. Limitations of the model include an oversimplified carbon cycle, an assumed linear change in carbon sequestration over time, and potentially inaccurate discounting rates.

Number of models such as LUCI, EcoServ, Co$ting Nature and MIMES biophysically model ecosystem services but they have not been as widely applied and documented yet. Envision is a multi-agent and open-source modeling framework that can incorporate external ecosystem service models such as InVEST which can include ecosystem services such as water provisioning, carbon sequestration, nutrient regulation, food and fiber production, shoreline protection, and pollination.

There are number of the evaluation models that are well-known for simulating carbon fluxes in the soils (e.g. CENTURY, RothC, SOCRATES, EPIC and DNDC). However, we limited this review to tools with an explicit focus on all carbon pools, rather than just soils or biomass.

5. Summary of findings and conclusion

A three stage approach was used to identify the tools that should be assessed as part of this study. The first stage generated a list of tools currently available for use. The second stage screened the tools to select a shortlist for further assessment against suitable criteria. The third stage tabulated the interrelationship between green infrastructure components and the carbon life cycle covered by each tool.

The purpose of the screening stage was to identify the most suitable tools that addressed the criteria of credibility, accessibility, transparency, having been tested in practice, ease of use, and applicability to the Australian context. The table below demonstrates the degree of importance of each criterion, as determined through semi-structured interviews with a panel of experts.

Credibility	Accessibility	Transparency	Tested	Ease of use	Applicability
21.8%	6.6%	15.1%	13.2%	7.1%	36.2%

Table 2: Weightings assigned to each criterion

At the first stage 42 tools were identified and 10 were selected that met all criteria and scored more than 75%.

Table 3 shows how the selected tools have performed against the capacity to measure across the full carbon life cycle, and the various green infrastructure types.The table shows that there is a gap across existing tools, as certain aspects of carbon performance are not typically covered as well as certain green infrastructure types. i-Tree Eco, Envision, Aries and FullCam are the most comprehensive tools. The Green Infrastructure Valuation Toolkit (GIVT) provides a monetized estimate of the carbon performance, although additional effort is required to convert this output to Australian currency.

Green infrastructure Types / Complete life cycle of carbon	Forest	Agroforestry	Cropland	urban trees	Shrubs	Grassland	Bioretention and Infiltration for sustainable urban drainage	Reforestation
CO_2 carbon sequestration rates	FarmGas, FulCam	FulCam	FarmGas, FulCam	iTreeEco, CNT	iTreeEco, i	CNT	CNT	CFI, NCAT
CO_2 releases from decomposition	FulCam, Envision, InVest,		FulCam	iTreeEco	iTreeEco	FulCam		CFI
CO_2 releases from maintenance activities								
CO_2 avoided emissions because of reduced energy use				iTreeEco	iTreeEco			
CO_2 reductions or increases because of land use changes (comparison of alternate scenarios; past, present and future) Landscape scale	FulCam, InVest, Envision, Aries,	Envision, InVest, Aries	Envision, InVest, Aries	GIVT, Envision, InVest	GIVT, Envision, InVest, Aries	GIVT, Envision, UnVest, Aries		Envision, InVest, Aries

Table 3: Classification of carbon cycle assessment tools against green infrastructure types

This study determined that the i-Tree Eco tool is the most appropriate tool for assessing carbon performance of green infrastructure assets. It is free and easily accessible, it has been adjusted for the Australian context and it covers most green infrastructure types.

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References

Ahern, J., 2007: *Green Infrastructure for Cities: The Spatial Dimension.* University of Massachusetts.

Alm, E. L., 2007: Urban Green Structure: A Hidden Resource. *The Baltic University Urban Forum***,** 12-16.

Australian Institute of Landscape Architects, 2012: Adapting to Climate Change: Green Infrastructure.

Bagstad, K. J., D.J. Semmens, S. Waage, R. Winthrop, 2013: A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services, **5**, e27-e39.

Benedict, M., and E. T. McMahon, 2007: *Green Infrastructure: Smart Conservation for the 21st Century.* Sprawl Watch Clearing House.

Benedict, M. A., and E. T. McMahon, 2006: *Green Infrastructure: Linking Landscapes and Communities.* Island Press.

Benepe, A., 2013: Parks as green infrastructure, green infrastructure as parks: How need, design and technology are coming together to make better cities. http://www.thenatureofcities.com/2013/04/17/parks-as-green-infrastructure-green-infrastructure-as-parks-how-need-design-and-technology-are-coming-together-to-make-better-cities/.

Brack, C. L., 2000: Forecasting carbon sequestration from individual eucalyptus plantations. *National Carbon Accounting System Technical Report*, **27**.

Climate Change Authority, 2014: Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review - Final Report. Climate Change Authority, Ed., Australian Government.

DCC, 2008: Tracking to the Kyoto Target: Australia's greenhouse emissions trends 1990 to 2008–2012 and 2020. Department of Climate Change, Ed., Australian Government.

DCCEE, 2009: National Carbon Accounting Toolbox. Department of Climate Change and Energy Efficiency, Ed., Australian Government.

Federici, S., 2011: Regional workshop: "Capacity Development for Sustainable National Greenhouse Gas Inventories – AFOLU sector (CD-REDD II) Programme; General methods for estimating stock changes in carbon pools. *http://www.rainforestcoalition.org/TinyMceFiles/CD%20REDD%20II,%20May%202011/8%20General%20methods%20for%20estimating%20stock%20changes%20in%20carbon%20pools_Federici.pdf*.

Garnaut, R., 2011: *The Garnaut Climate Change Review 2011: Australia in the Global Response to Climate Change.* Cambridge University Press.

Grace, P., and B. Basso, 2012: Offsetting greenhouse gas emissions through biological carbon sequestration in North Eastern Australia. *Agricultural Systems*, **1,** 1-6.

Grierson, P., M. Adams, and O. Attiwill, 1992: Estimates of carbon storage in the above-ground biomass of Victoria's forests. *Australian Journal of Botany*, **40,** 631-640.

Infrastructure Sustainability Council of Australia, 2012.

IPCC, 2001: Climate change: The scientific basis. *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J. Houghton, Y. Ding, D. Griggs, M. Noguer, P. van Linden, and X. Dai, Eds., Cambridge University Press.

Irvine, K. N., R. A. Fuller, P. Devine-Wright, and J. Tratolos, 2010: Ecological and Psychological Value of Urban Green Space. *Dimensions of the Sustainable City 2*, M. Jenks, and C. Jones, Eds., Springer.

Leary, N., C. Conde, J. Kulkarni, and A. Nyong, 2008: For whom the bell tolls:Vulnerabilities in a changing climate. *Climate Change and Vulnerability and Adaptation: Two Volume Set* Routledge, 1-30.

Loveland, T. R., and R. DeFries, (), , In , , , , eds., , pp. . 2004: Observing and Monitoring Land Use and Land Cover Change. *Ecosystems and Land Use Change, Geophysical Monograph Series*, R. DeFries, G. Asner, and R. Houghton, Eds., American Geophysical Union, 231-246.

Martin, E., and S. Pitman, 2012: Green Infrastructure: Life support for human habitats. A. B. Gardens, Ed., Department of Environment, Water and Natural Resources.

McMichael, A. J., 2013: Globalization, climate change and human ealth. *New England Journal of Medicine***,** 1335-1343.

McPherson, E. G., N. Nowak, G. Heisler, S. Grimmond, C. Souch, R. Grant, and R. Rowntree, 1997: Quantifying urban forest structure, function and value: The Chicago Urban Forest Climate Project. *Urban Ecosystems*, **1,** 49-61.

Millennium Ecosystem Assessment, 2003: *Ecosystems and human well-being: A framework for assessment.* Island Press.

Natural England, 2013: Green Infrastructure -Valuation Tools Assessment. *Natural England Commissioned Reports 126*, Natural England.

Nowak, D., 1994: Atmospheric carbon dioxide reduction by Chicago's urban forest. *Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project*, E. G. McPherson, D. J. Nowak, and R. A. Rowntree, Eds., US Department of Agriculture, 83–94.

Nowak, D. J., and D. E. Crane, 2002: Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, **116,** 381-389.

Robinson, P., 2014: IPCC expert wrap: the need for emissions-negative energy. *The Conversation*, http://theconversation.com/ipcc-expert-wrap-the-need-for-emissions-negative-energy-25577.

Running, S. W., 2008: Ecosystem disturbance, carbon and climate. *Science*, **321,** 652–653.

Sohl, T. L., B. M. Sleeter, Z. Zhu, K. L. Sayler, S. Bennett, M. Bouchard, and W. Acevedo, 2012: A land-use and land-cover modelling strategy to support a national assessment of carbon stocks and fluxes. *Applied Geography*, **34,** 111-124.

Specht, A., and P. West, 2003: Estimation of biomass and sequestered carbon on forest farm plantations in northern NSW, Australia. *Biomass and Bioenergy*, **25,** 363-379.

Spirn, A. W., 1984: *The Granite Garden.* Basic Books.

Talberg, A., S. Hui, and K. Loynes, 2013: Australian climate change policy: a chronology. Parliament of Australia, Ed., http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1314/ClimateChangeTimeline.

Tzoulas, K., K. Korpela, S. Venn, A. E. Kazmierzcak, V. Yli-Pelkonen, J. Niemela, and P. James, 2007: Enhancing ecosystem and human health through Green Infrastructure: A literature review. *Landscape and Urban Planning*, **81,** 167-178.

Ulrich, R. S., 2002: Communicating with the healthcare community about plant benefits. *Proceedings of the Sixth International People Plant Symposium*, Chicago Botanic Garden.

USEPA, 2012: Green Infrastructure Modeling Tools. United States Environmental Protection Agency, Ed., http://water.epa.gov/infrastructure/greeninfrastructure/gi_modelingtools.cfm

Vigerstol,K.L.,Aukema,J.E.,2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of Environmental Management* **92**,2403–2409.

Waterworth, R., G. Richards, C. Brack, and D. Evans, 2007: A generalised hybrid process-empirical model for predicting plantation forest growth. *Forest Ecology and Management*, **238,** 231-243.

Wise, R. M., I. Fazey, M. Stafford Smith, S. E. Park, H. C. Eakin, E. A. Van Garderen, and B. Campbell, 2013: Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, **28,** 325-336.