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Identifying potential sources of variability between vegetation carbon storage estimates for urban areas

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ABSTRACT

Although urbanisation is a major cause of land-use change worldwide, towns and cities remain relatively understudied ecosystems. Research into urban ecosystem service provision is still an emerging field, yet evidence is accumulating rapidly to suggest that the biological carbon stores in cities are more substantial than previously assumed. However, as more vegetation carbon densities are derived, substantial variability between these estimates is becoming apparent. Here, we review procedural differences evident in the literature, which may be drivers of variation in carbon storage assessments. Additionally, we quantify the impact that some of these different approaches may have when extrapolating carbon figures derived from surveys up to a city-wide scale. To understand how/why carbon stocks vary within and between cities, researchers need to use more uniform methods to estimate stores and relate this quantitatively to standardised 'urbanisation' metrics, in order to facilitate comparisons.

1. Introduction

Globally, the urban human population has expanded rapidly in recent decades, with over half of people now living in towns and cities (United Nations, 2012). In turn, this has been accompanied by high rates of land conversion to urban areas (Seto et al., 2012). With urbanisation set to continue, the need to understand and quantify ecosystem service provision within cities is increasingly acknowledged as being highly apposite to the lives of inhabitants, and essential in helping to tackle the environmental and social challenges they experience (Gaston, 2010a).

One particular ecosystem service that has become a high-profile feature of climate change mitigation efforts is carbon storage within soils and vegetation (e.g., Schimel, 1995; Grimm et al., 2008). Indeed, to fulfil international reporting obligations (e.g., UN Convention on Climate Change and Kyoto protocol) and national reduction targets, many countries must produce inventories of greenhouse gas emissions by sources and removal by sinks, including accounting for biological carbon losses and sequestration arising from different land-uses and their conversion (Dyson et al., 2009). As the bulk of carbon emissions can be attributed to urban areas (International Energy Agency, 2008; Satterthwaite, 2008; Kennedy et al., 2010), the policies and actions of the local authorities that administer towns and cities are central to meeting the required cuts. However, in order to achieve measureable reductions in the long-term, reliable baseline assessments of carbon stocks need to be available. Only then can it be established whether interventions such as tree planting strategies and land development policies (e.g., Churkina et al., 2010; Escobedo et al., 2011; Pataki et al., 2011; Raciti et al., 2012a) can be advocated as effective tools that go some way to offsetting the emissions of urban inhabitants.

Although considerably smaller than carbon emissions per unit area, there a is growing consensus that urban biological carbon stocks warrant further investigation, as they are more substantial than previously assumed (e.g., Nowak and Crane, 2002; Pataki et al., 2006; Davies et al., 2011; Hutyra et al., 2011; Raciti et al., 2012b). However, as this relatively new field of research begins to expand and more urban carbon density measurements are derived, variability between estimates is becoming apparent. Whilst this is not unexpected, because carbon densities will be influenced by a range

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Table 1

The landcover map resolutions, landcover definitions and biomass estimation procedures used in the 13 independent studies that have generated vegetation carbon storage estimates for urban areas since 2000. The landcover terminology used in each individual article is retained and denoted by capitalisation and highlighting in italics; please refer to the relevant paper for detailed definitions.

Study	Resolution of underlying landcover map	Public and private land surveyed?	Definitions of forest/canopy landcover(s)	Inclusion of forest height/age into landcover definition	Minimum tree size recorded	Plot size	Allometric equations	Use of urban tree biomass correction factor[a]	Inclusion of root biomass into calculation	Inclusion of herbaceous vegetation carbon stocks
Jo (2002)	225 m^2 (100 m^2 for Junglang district)	Yes	Defined as: *Agricultural*; *Natural*; *Institutional Vegetation Dominated*, and; *Recreational Vegetation Dominated*	No	All woody plants measured (defined as shrubs for DBH < 2 cm)	225 m^2–600 m^2	From the literature. Equations developed for four tree and five shrub species	No	Yes	Estimate not stated separately
Nowak and Crane (2002)	1 km^2	Not stated	A single forest category	No	Methods follow Nowak and Crane (2000) who use a DBH > 2.54 cm	400 m^2	From the literature	Yes	Yes	Not estimated
Guan and Chen (2003a, b)	Not stated	Not stated	A single forest category	No	Not stated	100 m^2	From the literature		Not stated	Not estimated
Yang et al. (2005)	Landsat (30 m)	No - plots could not be surveyed on government land	A single tree/shrub category	No	Not stated	400 m^2	From the literature	Yes	Yes	Not estimated
Golubiewski (2006)	NA	No - private greenspaces only	NA	NA	All woody plants measured	387 m^2–22028 m^2	From the literature, including those for urban trees	Yes	No	0.282 kg C m^{-2}
Escobedo et al. (2010)	Not stated	Not stated	A single forest category	No	DBH > 2.5 cm	400 m^2 (100 m^2 for “even-aged, dense pine rockland, mangrove and *Melaleuca quinquinervia* plots in Miami-Dade)	From the literature	Yes	Yes	Not estimated
Zhao et al. (2010)	Not stated	Not stated	Forests defined based on age and species composition	Age	DBH > 4 cm	Not stated	Biomass equations stated in paper	No	No	Not estimated
Davies et al. (2011)	0.25 m^2	Yes	Three categories based on height: < 2 m *Shrub*; 2–5 m *Tall Shrub*, and; > 5 m *Trees*	Height	DBH > 1 cm	25 m^2	From the literature	No	No	0.14 kg C m^{-2}
Hutyra et al. (2011)	Landcover map (30 m); canopy cover map (0.46 m)	Yes	*Mixed* or *Conifer* forest categories	No	DBH > 5 cm	707 m^2 (15 m radius circle)	From the literature	Yes. For field plots containing < 7 trees	No	Not estimated
Ren et al. (2011)	1:10000 map	Not stated	Nine forest types based on species composition	Age	Not stated	Not stated	Biomass expansion factors convert landcover into biomass		No	Not estimated
Liu and Li (2012)	QuickBird (0.6 m)	Not stated	Five forest types based on forest function	No	Not stated	800 m^2–9300 m^2	From the literature	Yes. For large trees (DBH > 30 cm)	Yes	Not estimated
Raciti et al. (2012b)	30 m	Yes	A single forest category	No	DBH > 5 cm	707 m^2 (15 m radius circle)	From the literature	No	No	Not estimated
Strohbach and Haase (2012)	Land-cover map (minimum patch size 0.25 ha); canopy cover map (0.4 m)	Yes	Seven forest/woodland types, based on species composition/structure	No	DBH > 5 cm	707 m^2 (15 m radius circle)	From the literature	Yes. For trees growing in human dominated landcovers	No	Not estimated

[a] An arbitrary tree biomass correction factor has been used in some studies since Nowak 1994, to account for the fact that urban trees are often open-grown and/or maintained, which may result in a lower biomass than would be predicted by allometric equations derived from forest-grown trees of the same DBH.