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Random point sampling to detect gain and loss in tree canopy cover in response to urban densification

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ABSTRACT

Urban tree canopy cover (UTC) is a simple, and common, measure of urban forest resource. Urban infill development is likely to lead to losses in UTC under private tenure, at a time when local governments are setting ambitious targets to increase UTC overall. Simple, statistically rigorous methods are required to benchmark and track change in UTC, whilst identifying which land-use types or tenures experience change.

We estimated UTC in six Melbourne suburbs in 2010 and 2015 by randomly sampling 2000 points across public land, public streetscapes and private land. We were able to detect a net change in UTC of <2% over five years to a 95% level of confidence. A significant net decrease in UTC (−2.4%) was only detected in one of the six suburbs. Two suburbs had a net increase in UTC by +2.7% over five years. On private land, there was often areas of UTC loss, but this was generally offset by canopy gain in other areas of the private realm as well as in streetscapes and public land. Losses in UTC on private land were mainly due to tree removal, with or without subsequent construction works.

This study describes a simple, but statistically rigorous, method to quantify UTC change and the drivers of change in different land-use types and tenure. Despite studying two suburbs will high rates of infill development, only one suburb showed evidence of net UTC decrease. The 'dynamic equilibrium' in UTC, whereby canopy losses area approximately offset by concurrent canopy gain, means that ambitious targets being set by local governments to increase UTC may be difficult to achieve without changes in tree protection and infill development policy and planning.

1. Introduction

Urban tree canopy (UTC) cover is a simple, and common, measure of urban forest status that is easily understood by land managers and the public, and is a useful indicator of the ecosystem services provided by urban trees (Walton et al., 2008; Ward and Johnson, 2007; Richardson and Moskal, 2014; Kenney et al., 2011; Nowak and Greenfield, 2012). UTC is an estimate of the horizontal surface area that tree canopy occupies within a discrete spatial area, often expressed as a percentage of the total spatial area. Increasing tree canopy cover in urban areas is now an important policy priority for many local, state and federal governments aiming to cool cities, increase the wellbeing of residents and provide habitat for biodiversity (Brunner and Cozens, 2013; Nowak et al., 2010; McPherson et al., 2011; Roy et al., 2012). While the measurement of UTC is reasonably well understood, there has been relatively little investigation of measuring change in canopy cover.

There is great concern that UTC is decreasing in many urban landscapes because of the development on private land through infill development and subdivision (Byrne et al., 2010). At the same time, many local governments are setting ambitious targets and strategies to increase UTC to provide climate change adaptation benefits (McPherson et al., 2008; Hall et al., 2012). An increase in UTC is expected to provide ecosystem service benefits such as cooling, flood mitigation, and air particulate pollution reduction (Livesley et al., 2016) but also increase biodiversity (Fontana et al., 2011; Lerman et al., 2014) and provide human mental health and wellbeing benefits (Shanahan et al., 2017). When implementing urban forest strategies to increase UTC, urban forest managers typically assess current UTC so that progress can be monitored over time (Jacobs et al., 2014). There are multiple methods to estimate UTC, but these broadly fall into two groups:

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1. A census based approach – where all UTC is discretely identified, typically through remote sensing methods, such as multispectral satellite imagery (e.g. IKONOS) and airborne LiDAR data (Hostetler et al., 2013; Walton et al., 2008; Parmehr et al., 2016); or
2. A sampling based approach – where sample points or sample areas are analysed and results extrapolated to the total spatial area (DiSalvo et al., 2012; Parmehr et al., 2016; Nowak and Greenfield, 2012; Merry et al., 2014).

Many census-based, remote sensing, methods are expensive and require specialised skills for data processing and interpretation. In comparison, estimating UTC by random point sampling of an aerial image is simple, fast, cheap and able to be undertaken by most urban forest or planning professionals (Hostetler et al., 2013). Studies that have compared sampling versus census methods show there are no statistically significant differences in the measurement of tree canopy at a suburb scale, when the sample design and intensity is sufficient (King and Locke, 2013; Richardson and Moskal, 2014; Parmehr et al., 2016). Sampling based methods invariably rely on sampling design and statistical inference to estimate UTC and an associated measure of uncertainty e.g. a standard error. This uncertainty must be acknowledged when comparing measures of canopy cover, for example between different land uses or over time. A significance test should be undertaken to demonstrate that the measured difference was probably a real difference and not an artefact of sampling. Not doing so can potentially lead to false reporting of change i.e. claiming change when change may be simply due to sampling error (Merry et al., 2014). To reliably estimate UTC change between two random point samples there needs to be careful consideration of:

1. time for any change to be evident, dependent on rates of tree growth, planting and loss;
2. high resolution, georeferenced images collected at equivalent and suitable times of the year, e.g. when trees are in full leaf;
3. appropriate statistical methods to test significance between samples over time; and
4. sufficient sample points to be able to detect a small levels of change over time.

With regards to image capture, it is important the user has control over the images used and the selection of dates for image capture between which change is detected. The popular web-based tool 'i-Tree Canopy' does not enable this level of control at the moment.

UTC is not distributed in a uniform manner across the urban landscape, and varies by land use and tenure (Dobbs et al., 2013; DiSalvo et al., 2012; Loram et al., 2007; Mincey et al., 2013). Drivers of tree canopy amount, gain and loss differ across these land uses and tenures, and are strongly influenced by local factors such as local government planning and policy decisions (Conway and Urbani, 2007; Kendal et al., 2012) as well as private land owner behaviour and attitudes towards trees (Conway, 2016; Landry, 2013). The concern that urban densification of privately owned urban land will lead to green space and UTC loss, reiterates the need to separately detect and monitor UTC in private and public land use types. In areas with stable land use, tree canopy may increase over time from the growth of existing trees and the planting of new trees, whilst UTC can decrease from removal for construction and development (both to increase house size and where a single house is replaced by multiple dwellings), removal by private individuals, pests and diseases, natural mortality, local government removal and replacement, and extreme weather or storm events (DiSalvo et al., 2012; Luley et al., 2002). Importantly, all of these processes driving UTC increase or decrease can be operating concurrently within a neighbourhood, suburb or city. Local governments are able to directly influence UTC within streetscapes and other public land, but can only indirectly influence UTC management on private land through education, encouragement, incentives and planning legislation.

The aim of this project is to create a simple, cost effective and statistically valid method to estimate changes in canopy cover over time and to investigate how this varies with land use and tenure. The intent is not to look at significant differences in UTC amongst lands use types, but rather to investigate whether by separating, or stratifying, the urban landscape into dominant land use types, changes in UTC can be better detected and any evidence for the impact of urban densification investigated. There are three specific objectives:

1. to develop and demonstrate a random point sampling method to detect at least a 5% change in UTC (preferably less) over a five-year period with a 95% degree of confidence;
2. to identify UTC change in different land-uses and tenures; and
3. to identify whether tree removal for construction is the dominant driver for UTC loss in private land areas.

The findings are discussed in light of a growing trend worldwide for increased targets for urban infill development at the same time, and in the same suburbs as aspirational targets for increased UTC.

2. Materials and methods

2.1. Study areas

Melbourne, in the south east of Australia (*Lat*: 37.81°S *Long*: 144.97°E) has a temperate climate, with a mean annual temperature of 16 °C (Mean Max: 20.5 °C; Mean Min: 11.4 °C) and mean annual rainfall of 603 mm (1980–2010). Melbourne is a useful place to study the drivers of tree change as there is high-quality data available across time on land use and land tenure, and a highly regulated urban planning process. Historically, there has been great variation in tree cover (Kirkpatrick et al., 2011). There is rapid change within the existing urban fabric, both through active municipal tree planting programs at the same time as perceived loss of tree canopy in some neighbourhoods as a result of increases in housing size and density promoted by policies to increase population densities (Hall, 2010).

Within greater Melbourne, six suburbs were selected to assess UTC change within two Local Government Areas (LGAs) (Moreland and Boroondara) with very different demographic and UTC profiles (Fig. 1, Table 1). Representatives from both Moreland and Boroondara LGA helped identify suburbs that had experienced different levels of planning permits for sub-division and residential redevelopment, indicating varying levels of urban densification. This collection of six suburbs is therefore likely to exhibit different tree canopy trajectories between 2010 and 2015; some would likely lose UTC whilst others remain constant or even gain UTC.

2.2. Data collection

Study areas were defined using Statistical Area 2 (SA2) polygons sourced from the Australian Bureau of Statistics (ABS, 2016). SA2s approximately cover individual suburbs, and generally have a population of 3000–25,000 people (average 10,000), with an area dependent on population density and other factors (ABS, 2011).

A spatial polygon layer was created to distinguish three land-use ownership types (Private, Public land or Public street) by combining