Horticulture Innovation Australia

# *Where should all the trees go? Investigating the impact of tree canopy cover on socio-economic status and wellbeing in LGA's*

Marco Amati, Bryan Boruff, Peter Caccetta, Drew Devereux, Joe Kaspar, Kath Phelan and Alex Saunders
RMIT University
With: CSIRO Data 61,
University of Western Australia

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Level 8
1 Chifley Square
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

# Content

# Summary


This project's objective was to inform the horticulture industry and the 202020 Vision's identification of priority areas for greening. Our central question was: how can local government greening efforts be most effective in addressing differences in metropolitan residents' social, economic and health outcomes and vulnerabilities, exposure to high temperatures and access to green areas? Where *should* all the trees go?

- The team answered this question through an update to the 2014 estimated canopy cover of Australia's 139 metropolitan local government areas (LGAs) using the i-Tree sampling method. The team examined the relationships between canopy cover and indices of socio-economic disadvantage (SEIFA), population under five years and over 65 years living alone, non-communicable disease health data from the Australian Health Survey (2011-12), and a calculation of heat island intensity derived from satellite imagery for summer 2015-2016. Using this data the team developed the VHHEDA (Vulnerability to Heat, poor Health, Economic Disadvantage and Access to green spaces) index.

The research provides an opportunity to update and track the estimates of canopy cover to monitor progress towards the goal of 20% canopy cover for Australia's urban environments by 2020. It also highlights the vulnerability of different communities to a lack of canopy cover, heat stress, poor health, and socio-economic circumstances. The data generated will inform the continuing development of the 202020 vision and will assist identifying locations for increased consumption of green life products by governments, businesses, schools and consumers. The work is targeted at horticulture industry levy payers and industry stakeholders involved in the 202020 vision.

Keywords

Tree canopy cover, Land-cover assessment, i-Tree, Urban Heat Island, Urban health

# Introduction

The development of a systematic method of assessing green land cover, aided by freely available satellite imagery, has led to growing government interest around the world in the extent and loss of urban canopy cover. The i-Tree suite of tools has contributed to this trend and is one of the most robust and cost-effective methods of measuring and monitoring urban greening.

In Australia since the early 2010s key developments have included the adaptation of the i-Tree suite of tools to Australian conditions and the first benchmark project to establish the quantity of green spaces in metropolitan LGAs (Jacobs et al. 2014). For these LGAs urban greenness has become an increasingly important consideration for strategic planning and enhanced liveability.

However, variation exists in local governments' engagement in translating information about urban green cover and coordinating action. Interest in measuring and monitoring green cover is likely to grow given common aims to achieve more equitable cities, adapt to climate change and improve liveablity.

The work described in this report and its appendices draws on and contributes to this growing interest. The central question that guided our work was:

- which LGA's residents have a high chance of poor health outcomes, economic hardship, exposure to high temperatures, and low levels of canopy cover?

The following sections describe how the team interpreted this question guided by their knowledge of data availability, the limitations of methodologies at our disposal and through their discussions with the 202020 Vision team.

# Methodology

Throughout, the project consisted of the development and analysis of a variety of geographic data layers, to answer the question "Where should all the trees go?" aiming to understand the rates of vegetation change in LGAs across Australia's major metropolitan regions, as well as the areas of abnormally high heat, socio-economic disadvantage and potential health concerns.

**Phase 1: Identifying change**

i-Tree was selected as the method to be used for identifying changes in canopy cover and other land uses. This method has the best combination of robustness and cost-effectiveness and its limitations are well understood (Parmehr, et al. 2016, Kaspar et al. 2017). The method relies on satellite or aerial imagery and an operator's identification of land cover associated with a set of random points generated within fixed boundaries. This enables the users to identify the percentage of land cover categories within an area. This method was also successfully used by Jacobs et al (2014) in the previous benchmarking process for Australia (NY13028).

Q-GIS was used to generate 1000 random points within the boundaries of each 2015 Local Government Area (LGA) boundary polygon. The project used the 2015 boundaries in the first instance to ensure that the figures for 2016 were comparable with the previous (NY13028) estimates. Recent NSW LGA amalgamations have resulted in new local government boundaries. These new boundaries were used to calculate estimates of land cover for newly formed and anticipated LGAs for future benchmarking.

The project used the latest Nearmap images that covered the 139 LGAs. Nearmap is a fee-for-service provider of aerially captured photographs at a generally higher resolution over urban areas than Google Earth Images. Nearmap provides a more regularly updated service and higher quality imagery than Google Earth. This type of project should be conducted during leaf-on conditions to allow for full canopy identification. For the majority of LGAs this was possible (Table 1).

Table 1: Nearmap images and year used

| Nearmap image date | Number of LGAs | LGA names |
|---|---|---|
| Mar-Oct 2015 | 6 | Adelaide Hills Council; City of Clarence, City of Glenorchy; City of Hobart; Kingborough Council; City of Launceston |
| May-Oct 2016 | 9 | Toowoomba Regional Council; Gold Coast City; Townsville City Council; City of Darwin, City of Palmerston; Cairns Regional Council; Town of Gawler; City of Playford; City of Salisbury |
| Oct-Dec 2016 | 124 | All remaining metropolitan LGAs |

Team members were first trained to use i-Tree followed by a period of practice with an experienced user of i-Tree to ensure reliability in data collection across the entire team. For each of the 1000 points, a team member identified the land cover associated with each point based on visual interpretation of the Nearmap imagery. For consistency, land cover categories used for the 2013 project were again used for the 2016 update. These include: Tree, Shrub, Bare ground/grass, and Hard surface.

Following the i-Tree software technical notes, a sample size of 1,000 points was determined adequate to reach a confidence level of 95%. However, because each LGA has differing land cover category compositions, the standard error and confidence interval will vary by land cover category for each LGA. As this study was also a comparison of two i-Tree samples (i.e. estimating change between the 2013 and 2016 i-Tree samples), an additional statistical test (Two-Independent-Samples T Test) was calculated for the percentage difference in land cover categories between reports.

For a small number of points (<2%) Nearmap imagery was not available for the locations sampled. In these cases Google Earth imagery was used as a surrogate. An error checking protocol was applied to ensure that operator definitions were consistent and errors were minimised (see Appendices for a full description of the method).

**Phase 2: Estimating the Urban Heat Island effect**

Land surface temperature (LST) estimates were produced from freely available Landsat 8 satellite data. Landsat 8 passes over each location approximately every 16 days; in Australia these overpasses occur at around midnight UTC (8am AWST, 9:30am ACST, 10am AEST). Thus for each location there were multiple opportunities for Landsat 8 to collect viable data within the target window (October 2015 – April 2016). The amount of viable data actually collected varied with location based on the effects of cloud cover. Hobart, for example, was totally obscured by cloud during every overpass, so that no viable data was available.

The processing method used a *Single-Channel* of Landsat 8's thermal information in generalized form following methods proposed by Jiménez-Muñoz & Sobrino (2003), and adapted to Landsat 8 data by Yu *et al* (2014). In addition to thermal infrared data, this method required an atmospheric parameterization and an estimate of land surface emissivity (LSE).

The Bureau of Meteorology's daily 9am observations of temperature and relative humidity were used to calculate total atmospheric water vapor, as an input to the method's atmospheric parameterization.

Estimation of LSE required Landsat 8 surface reflectance data (specifically bands 4 and 5) and data was sourced from the Australian Reflectance Grid 25 (ARG25) (Geoscience Australia, 2015). This data was used to calculate a Normalized Differential Vegetation Index (NDVI) and to estimate fractional vegetation. This was then converted to an estimate of LSE, following Sobrino & Raissouni's (2000) method, with the emissivity of pure vegetation fixed at 0.9863 and non-vegetation at 0.93.

Landsat 8 thermal infrared data (band 10) was downloaded from the United States Geological Survey (USGS), and reprojected to the same projection/datum/grid as the ARG25. Measurements of top of atmosphere radiance and at sensor temperature were calculated using provided constants, and the final calculation of LST was performed.

The individual LST images for each scene were then joined together into a single LST image covering the extent of the project's targeted area. Where multiple LST images overlap, averaging these images produced a central value more representative of seasonal temperature rather than the temperature of any particular day.

Urban Heat Islands are best understood as the difference in temperature between an urban and a corresponding non-urban area. To calculate the urban heat island effect, a modelled estimate of the LST in the absence of urbanization must be subtracted from the actual LST. For this project, a temperature gradient was fitted to forested areas within the image, while excluding forest boundaries, areas with high slope and areas with elevation that considerably differed to the urban area under consideration. This gradient is a first order correction that captures broad temperature trends independent of urbanization, such as those attributable to changes in latitude, elevation or distance from the coast. After subtracting this from the LST, the residuals are finer scale, localised temperature variations, some of which are attributable to urbanization. Further details of this processing is available in Devereux and Caccetta (2017) and the Appendix.

In order to generate a comparable measure for each individual LGA, further analyses of the LST were conducted to identify the proportion of each LGA that was subject to heat differentials considered to be significantly higher than those typically experienced within each individual city. For the purposes of this project a figure of greater than one standard deviation above the mean LST per city was considered to represent this threshold. Using this benchmark, all contiguous areas of greater than or equal to 5000m$^2$ with a temperature greater than one standard deviation above the mean LST were identified and flagged as hotspots. The proportion of each LGA subject to hotspots was then calculated.

**Phase 3: Identifying risk to the LGA populations from health and economic factors**

Datasets were sourced from the Social Health Atlas tables available from PHIDU (Torrens University). The team produced and analysed correlations between existing tree canopy and total vegetation cover for each LGA with a variety of socio-economic and health measures.

Differences in timing and periods of socio-economic and health data and greening data were a key limitation. I-Tree based land-cover information was from 2015 and 2016 while socio-economic and health data were based on the 2011 ABS Census. In addition, i-Tree data was only produced at the LGA level while socio-economic and health information are available at the sub-LGA level. These spatial area differences affected the strength and significance of the statistical relationships.

The team developed an index of vulnerability as an appropriate proxy to inform decision makers' conclusions about the resident vulnerabilities. Due to the coarse data resolution and limited number of samples, the team used a quadrant approach, assigning points to assess socio-economic and health risk for LGA populations (see Appendix). The Vulnerability to Heat, poor Health, Economic Disadvantage and Access to green space (VHHEDA) index is a combination of:

- Canopy percentage versus Hotspot percentage;
- Self-assessed Health age standardized rates (ASR) 100 versus diabetes ASR 100;
- SEIFA Index of Relative Socio-Economic Disadvantage versus SEIFA Index of Economic Resources;
- Average rate of change of canopy percentage cover versus rate of change of total green cover percentage
- Percentage of population under 5 years versus percentage of population over 65 years living alone.

The risk factors for the LGAs were aggregated and then divided to produce a five point scale.

## Outputs

- Frequent communication with and presentation to the 202020 Vision team
- A 2016 update to the of urban vegetation distribution using the i-Tree method in combination with high quality imagery.
- National level metrics identifying the change in tree canopy cover and total vegetation for each LGA between 2008-2013 and 2016 including standard error and significance statistics.
- New benchmarks of tree canopy, shrub, grass/bare ground and hard surface for recently created and proposed NSW LGAs and the de-amalgamated LGA of Sunshine Coast.
- State level metrics identify the change in tree canopy cover and total vegetation for LGAs between 2008-2013 and 2016 including standard error and significance statistics.
- A new method for identifying hotspots in Australian cities and contributions towards setting a national benchmark of heat in Australian cities.
- Metro area maps of urban hot spot; i.e. maps at the same scale identifying the spatial distribution of heat anomalies.
- Map(s) for each LGA (including both old and new NSW and Queensland boundaries) identifying temperature hot spots overlayed with distribution of the SEIFA Index of Relative Socio-Economic Disadvantage.
- An individual scorecard for each LGA describing relative position in relation to total vegetation and canopy cover change including maps of urban heat anomalies that allow for targeted interventions.
- The generation of a new ranking of metropolitan LGAs that takes into account the VHHEDA index or vulnerability of residents to heat, poor health, economic disadvantage and lack of access to green space.
- A publicity launch, media strategy including op-ed pieces to highlight the results of the project

## Outcomes

The project resulted in the following outcomes

1. Evidence to identify priority areas for green interventions across key local government areas

The project includes a series of detailed maps and graphs that can be used to encourage and interest local governments nationwide to devote more resources towards greening.

2. Prioritisation for further 202020 Vision activities and messaging

The project will guide future messaging for the 202020 Vision by highlighting some of the potential effects and benefits that greening can have on redressing imbalances and inequities in urban areas from the perspective of heat, health and economic disadvantage.

3. Tracking progress towards the achievement of the 202020 Vision

The project updates the report by Jacobs et al. (2014) and highlights areas which require attention to prevent greening loss.

4. Modelling a strategic metro-wide planning process that State governments could use as part of their own metropolitan planning process

The project allows the development of a series of scorecards that will be introduced to individual LGAs to highlight areas for improvement.

5. Understanding the relationships between Socio-economic indicators and the presence or absence of urban vegetation

The project developed the VHHEDA index which is the first of its kind to identify which areas of socio-economic and health disadvantage also coincide with a lack of green cover and a high incidence of heat.

6. Interpreting of the relationships between the prevalence of urban hotspots and the % canopy cover.

The project is unprecedented in Australia in demonstrating that a relationship, albeit limited by the scale of the data, exists between UHI and % tree canopy cover, guiding and underscoring the need for further research in this area.

## Evaluation and discussion

This project provides and valuable results with implications for the horticulture industry and government planning for greening. Cities in Australia are known internationally for their livability. The results in this report show that the livability in terms of access to greenspace and concentration of heat are spread unevenly, in addition to an uneven spread of economic and health circumstances.

Many Australian metropolitan local government areas contain national parks which will display natural fluctuations in vegetation cover. Trees and shrubs are subject to dieback and leave opportunities for new vegetation growth (either shrub or tree depending on the circumstance). Bushfire and drought can also reduce tree canopy cover but allow shrubs or juvenile trees to take their place. Conclusions drawn from the data need to take into account exchanges between land-cover classes and should note that a range of factors influence changes in cover.

*Understanding land cover changes for LGAs in Australian metropolitan areas*

This project's results display two consistent trends for tree canopy cover and total vegetation change: significant canopy cover loss during the five years (2009 to 2016), which are offset by gains in shrub cover (or saplings) during the same period. This represents a natural interchange between the canopy class and shrubs.

Local government areas which have lost green cover have no clear spatial pattern. The largest decreases are not concentrated in either peri-urban or inner-city areas but occur differentially across all States and in a variety of different LGA locations. This green cover loss results from a variety of processes that include bushfire mitigation policies, such as the 10/50 rule in NSW; subdivision of large suburban blocks and the disappearance of the backyard; consumer trends in housing towards smaller gardens; and greenfield development on the edge of urban areas.

*Interpreting the results: comparing internationally*

The closest study to this kind internationally was performed by Nowak and Greenfield (2012) for twenty cities in the United States using an i-Tree methodology, with points in the same location across images in two different years. Cities in the US displayed a wide variety of canopy cover (53.9% to 9.6%) but in Australia that variability is even more pronounced with canopy cover ranging from 79% (Cairns, QLD) to 3.2% (Wyndham, VIC).

Comparisons across countries however, should be treated with caution particularly because of the variability of the size of Local Government Authorities in Australia compared to those in the US. For example, the US city with the highest level of hard or impervious cover is New York at 61.1%. The highest level of hard or impervious cover in Australian LGAs is the City of Sydney at 68.3%. However, New York City's surface area is 789 $km^2$ compared to the City of Sydney's 25 $km^2$. When comparing the 12,368 $km^2$ of Metropolitan Sydney with that of New York City the hard surface is comparatively less (43.1%).

In the US the effect of natural forces on tree cover is evident. New Orleans lost the largest amount of canopy cover (-9.6%) since the period examined included the damage inflicted by Hurricane Katrina. In Australia, natural forces also account for changes particularly as trees undergo dieback and then regrowth as shrubs or juvenile trees. The City of Glenorchy (Tasmania) had a drastic reduction in canopy cover in the period studied of 17.0% although this would have been offset by an increased in shrub cover of 12.4%. Similarly, Armadale (WA) enjoyed the greatest increase of canopy cover for the period studied among all the LGAs in Australia of 13.2% but this came at the expense of a reduction in shrub cover of -18.4%.

Finally, similar to the US, canopy cover is dropping in Australia. Shrubs and trees in the US dropped overall by 1.1% over a four year period in the mid-2000s. In Australia in approximately four years tree and shrub canopy cover dropped by 2.1%. The results show that no LGAs have had significant increases in total vegetation cover over the period studied. The majority have lost vegetation. The total surface area of all the LGAs is 61,001 square kilometres; green vegetated surface area declined by 2.6% between 2008 and 2016, equivalent to 1,586 square kilometres or an area larger than the City of Brisbane.

*The significance of heat in Australian cities*

Heat islands (HI) are usually understood as the difference in temperature between an urban and a corresponding rural area. A measurement of HI should identify the heat that is produced and exacerbated by an urban area when compared with a non-urbanised baseline. The HI effect is most pronounced at night as urban areas take longer to decrease in temperature compared to surrounding rural areas. Buildings and hard surfaces store more latent heat energy than green spaces in general. Buildings are sources of heat (e.g. air conditioning) and also slow wind speeds that otherwise help to reduce the temperature in urban areas. Tree canopies also provide shade which reduces the amount of solar radiation that hard surfaces receive and absorb.

Understanding of HI originated in temperate arable environments such as the UK and US (Gregory, 1954; Bornstein, 1958). This concept needs re-evaluation in an Australian context where cities are generally located in dry, semi-arid locations or tropical areas. In the middle of the summer, grazed arable land in dry areas is often hotter in the morning than urban areas because it is unshaded. Earth or sand takes less time to heat up than materials associated with urban areas such as concrete or asphalt.

Furthermore, in Australian cities the concept of large areas of native vegetation and national parks that shape and confine the spatial extent of cities are more present than in countries that have been urbanised for long periods such as in the UK and US. This means that taking areas of native vegetation as the baseline of the non-urbanised state is more defensible than using agricultural areas.

Large temperature fluctuations also occur within Australian cities where a hotspot can be defined as 10 degrees centigrade warmer than the norm. It is important to note that a 10 degree centigrade as calculated for this project may not represent the hot spot in the middle of the day or at night.

However, when considered in relative terms the data are useful for strategic greening. For example, a single hot spot can cover large areas of a city (see Appendix). They are also associated with areas of socio-economic disadvantage. Breaking up patches of high heat anomalies such as through planting corridors should be a key component in strategic planning of green infrastructure in large metropolitan areas. These large patches form a stable area of heat in a city and may resist mitigating effects of wind when compared to smaller patches. Some areas of extreme heat anomalies exist in areas of relative socio-economic disadvantage, for example, in Sydney's West.

In contrast, areas exhibiting lower relative surface temperatures in Melbourne and Sydney are related to the presence of national parks and socio-economic affluence as measured by the SEIFA Index of Economic Resources. Melbourne's eastern areas are generally cooler than those in the West. In Sydney the upper

North Shore is cooler compared to areas to the South and West. In Perth, the inner-city areas are cooler than the outer inland areas. Yet, in the areas of greater vulnerability with high levels of heat, river corridors and large areas of green space such as golf courses have a clear cooling effects on heat patterns. This highlights the importance of corridors of native bush and other plantings, particularly in areas of economic disadvantage.

**Limitations**

The following are limitations of this study

- Sometimes, low inter-rater reliability and errors of omission and commission.

- Image parallax or inconsistency of the classification of points between reports.

- If the proportion of tree canopy cover between reports is different for each LGA, this does not necessarily mean that there has been a change, the difference may be due to statistical error and variations in spatial sampling.

- The difference between the estimate derived in the report from the sample and the 'true value' if a full census of the LGA canopy cover were actually to be conducted.

- Land cover changes calculated as a % using i-Tree will hide a multitude of effects that range from changes in forestry management, to inner-city gentrification

- In addition, some analysis was undertaken for sub-LGA level land cover for the ACT, but the boundaries were incompatible with current ABS definitions (see Appendix)

- Changes underway in NSW to amalgamate LGAs and the de-amalgamation of Sunshine Coast into Sunshine Coast and Noosa Shire, meaning that newly amalgamated LGAs do not have an earlier baseline to compare against.

- Differences in the study time period affect the use of ABS statistics. At time of writing, the ABS had not yet released 2016 Census data.

- The VHHEDA index allows a ranking of different local governments across Australia using the data generated by the project. The index provides a relative estimate of risk instead of an absolute measurement. In other words because the index is generated in relation to all other LGA metrics in any given year, it is only appropriate for use as part of a benchmarking process when showing changes in LGAs' ranking.

# Recommendations

*Adopting the correct benchmarks for urban greening*

This project confirms the already dominant place of i-Tree as a methodology for monitoring urban green spaces. It also increases understanding of the methodology's benefits and drawbacks. While i-Tree is robust, relatively cost-effective and can be improved by more accurate and timely imagery, the costs rapidly escalate at the sub-LGA level. This makes it unfeasible for national benchmarking at this scale. Since there is a natural interchange between shrub and tree canopy cover reporting on the growth in either, without considering the other should be treated with particular caution. For example, if tree canopy is used as a benchmarking for greening or urban environmental performance this should not be without considering the shrub layer.

The project shows that an adherence to i-Tree fixes the work to the LGA level only. This reduces the headline indicators of heat to percentage hot spot. If canopy cover could be calculated at a block by block or at the street level this would bring it into line with the various data sources used in the project. The project shows how it is possible to establish a benchmark of urban heat island for Australian cities.

*Correct or renew efforts at urban greening*

Over the three to eight year time period since the previous study, rates of greening in Australian cities were anticipated to be stable. However, this study presents the surprising result that greening has decreased by 2.6 percent. This figure can be reported on with a higher degree of confidence than the LGA percentages since it is based on the total number of points nationally (139,000 compared to 1000).

Further work is required to understand why this change is occurring. This line of enquiry will follow through communication with LGAs and the work of 202020 Vision Team in the first instance and later through further research. While it is known that the Australian backyard is disappearing (e.g. Hall, 2010; Daniel et al. 2016) much more research is required to understand the factors influencing this unanticipated trend.

*Identify areas where heat is produced in urban areas and what can be done about this?*

The study's identification of hotspots at a sub-LGA level demonstrates that cost-effective data can be sourced from Landsat 8 satellites. This data could collected at regular intervals as an alternative to expensive individual LGA airborne infra-red data capture. The data also provides the opportunity for a research project to analyse heat sources and types of greening which could be used to alleviate it. Industrial facilities and infrastructure such as airports, present few possibilities for greening, but large areas of railway land, roofs that could be greened and major highways could be important locations for reducing urban heat. In other words the next question to ask from this project is: *how much potential greening area is there to effectively mitigate Australia's metropolitan hot spots?*

# Scientific refereed publications

None

## Intellectual property/commercialisation

No commercial IP generated

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# Appendices

Where should all the trees go - appendices