BR01886 – LIDAR derived tree canopy coverage metrics across Adelaide, South Australia.

Report 2: Metropolitan Adelaide

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Contents

Abbreviations

AHD – Australian Height Datum

DCM – Digital Canopy Model

DTM – Digital Terrain Model

DPTI – Department of Planning, Transport and Infrastructure

DEW – Department of Environment and Water

ICSM – Intergovernmental Committee on Surveying and Mapping

LIDAR – Light Detection and Ranging

NDVI – Normalised Difference Vegetation Index

Glossary

Building Footprints – Vectorized horizontal extent of classified buildings within LIDAR point cloud.

Canopy Cover – A vector showing the precise horizontal extent of tree canopy. Allows for the percentage of tree canopy coverage to be calculated across a range of areas of interest (e.g. LGA or Unit Area).

Digital Canopy Model – A discontinuous raster that describes the horizontal extent and vertical height of tree canopy across an area of interest.

Digital Terrain Model – A continuous raster which shows the bare-earth elevation above sea level with buildings and trees removed.

Metropolitan Adelaide – within this report 'Metropolitan Adelaide' refers to the area that consists of the sixteen LGAs that are wholly within the 2018 and 2019 LIDAR data captures. These include City of Adelaide, City of Burnside, Campbelltown City Council, City of Charles Sturt, City of Holdfast Bay, City of Marion, City of Mitcham, City of Norwood Payneham & St Peters, City of Onkaparinga, City of Port Adelaide Enfield, City of Prospect, City of Salisbury, City of Tea Tree Gully, City of Unley, Town of Walkerville and City of West Torrens. 'Metropolitan Adelaide' excludes the partial coverages of the Town of Gawler and the City of Playford.

Relative Normalised Difference Vegetation Index – A continuous raster that qualitatively describes the 'greenness' of the landscape which has values ranging from -1 to +1. Higher positive values indicate greener vegetation.

Percentage Canopy Cover – the proportion of any given area that is covered by tree canopy greater than 3 m in height, expressed as a percentage of that area

Tree – for this study a tree is defined as any vegetation above three metres in height.

1. Project Summary

1.1 Fundamental Principles of LIDAR

Light Detection and Ranging (LIDAR) accurately images the landscape in three dimensions by measuring the time taken for a laser pulse to travel from the sensor mounted in the aircraft to the ground surface and for the pulse to be reflected back to the sensor. By combining the measured travel time and accurate measurements of the sensor position and orientation in space, the three-dimensional location of the point of reflectance can be ascertained (Dong and Chen, 2017a; Wehr and Lohr, 1999). Since LIDAR technology directly measures the landscape in three dimensions, the raw imagery produced is free of geometric distortions, e.g. relief displacements, that need to be removed from conventional two-dimensional imagery (Dong and Chen, 2017a).

The use of LIDAR (both terrestrial and airborne) to quantify vegetation characteristics has long been a powerful remote sensing tool in mapping forest ecosystems and quantitatively modelling plant attributes for use in ecology and forestry studies (Kane et al., 2010; Lefsky et al., 2002; Lim et al., 2003; Lovell et al., 2003). When a laser pulse emitted from a LIDAR sensor is incident on a tree, a portion of the energy is scattered or reflected back towards the sensor by the tree canopy, and the remaining energy is transmitted through gaps in the foliage and interacts with lower branches, leaves or stems or the ground surface (Dong and Chen, 2017b; Lefsky et al., 2002). Returns from the energy interacting with the lower portions of the tree and the underlying ground allows researchers to quantify vertically distributed forest and individual tree attributes and extend more traditional two-dimensional ecosystem models (generated from aerial photography and multispectral imagery) into the third dimension (Leckie et al., 2003; Wulder et al., 2007). LIDAR is often preferred to other active remote sensing technologies as it provides greater sensitivity to vertical changes in vegetation structure. It is possible to analyse LIDAR derived vegetation data as either a point-cloud or raster surface and it allows first order biomass indices to be derived (Chen, 2013; Dong and Chen, 2017b; Man et al., 2014). The ability to accurately quantify a wide range of fundamental vegetation parameters and the ease with which it can be combined with other quantitative datasets, such as aerial imagery (Bandyopadhyay et al., 2017; Singh et al., 2012), makes LIDAR an extremely powerful tool for generating highly accurate assessments of tree canopy cover and other vegetation parameters within urban areas (Parmehr et al., 2016; Shrestha and Wynne, 2012; Zhang et al., 2015) making them a critical tool in the future for LGAs to achieve regional environmental goals.

1.2 Project Scope

The scope of this project is to provide the sixteen contributing councils, the Department of Planning, Transport and Infrastructure (DPTI) and the Department of Environment and Water (DEW) with quantitative LIDAR derived datasets describing key tree canopy metrics across their respective government areas. Project deliverables are outlined in **Table 1**. Included in this report are the results of the Vegetation Metrics, excluding NDVI. All other deliverables were provided as spatial datasets to contributing LGAs and the state government.

Table 1 *– Summary of project deliverables.*

Summary of Project Deliverables

Vegetation Metrics

Deliverable	**Definition**
Digital Canopy Model	A discontinuous raster that describes the horizontal extent and vertical height of tree canopy across an area of interest. Spatial resolution of 1 m.
Canopy Stratification	Describes the horizontal extent of the tree canopy within defined height intervals showing the vertical structure and distribution of the canopy.
Canopy Cover	A vector showing the precise horizontal extent of tree canopy. Allows for the percentage of tree canopy coverage to be calculated across a range of areas of interest (e.g. LGA or Unit Area).
Canopy Coverage Classification	Classification of the canopy cover by what type of land use or land ownership it covers.
Relative Normalised Difference Vegetation Index	A continuous raster that has values ranging from -1 to +1 which qualitatively describes the 'greenness' of the landscape. Higher positive values indicate greener vegetation. Spatial resolution of 1 m.

Engineering

Deliverable	Definition
Digital Terrain Model	A continuous raster which shows the bare-earth elevation above sea level with buildings and trees removed. Spatial resolution of 1 m.
Contours	Describes points of equal elevation derived from the DTM. Provided at 1 m intervals.
Building Footprints	Vectorized horizontal extent of classified buildings within LIDAR point cloud.

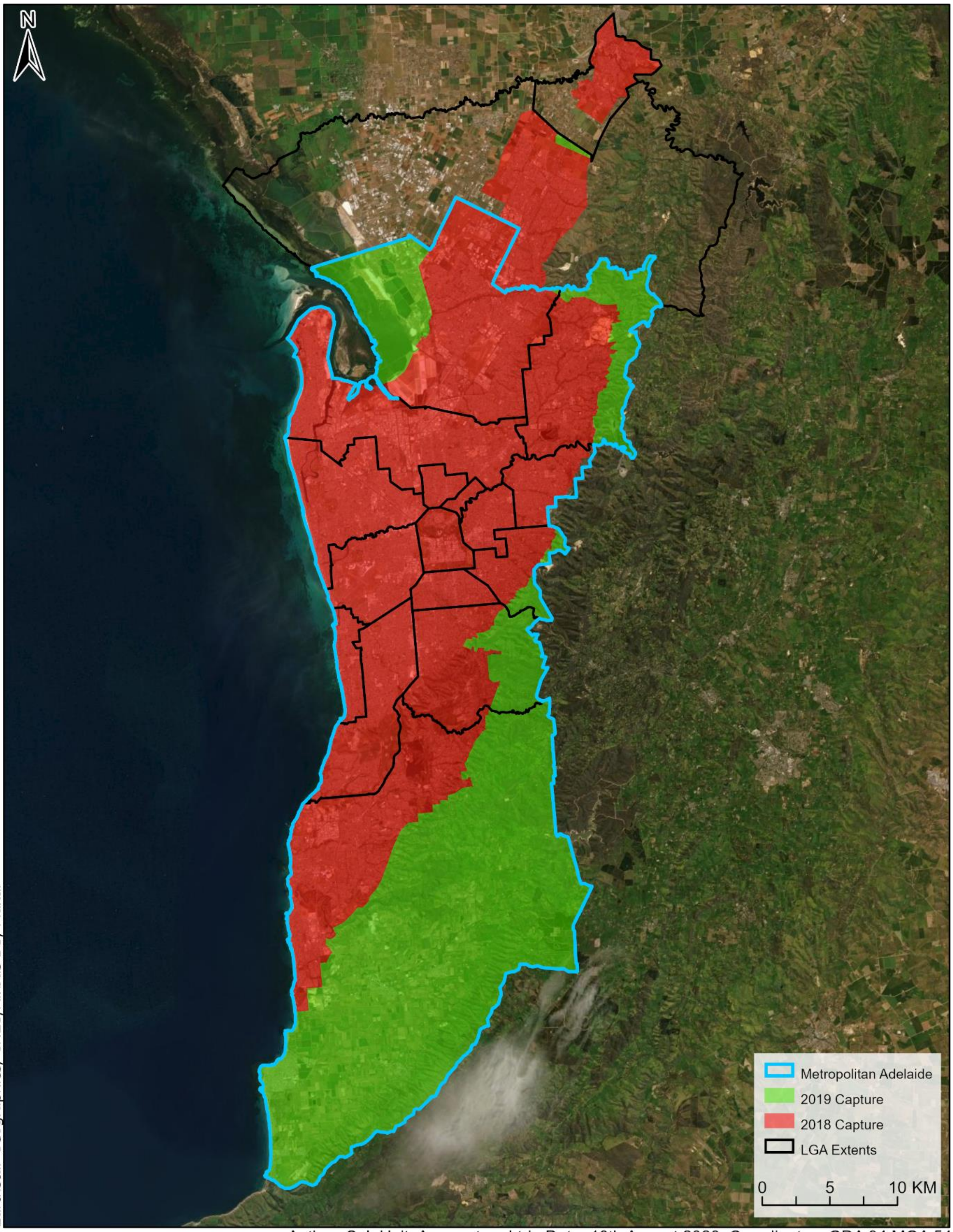
2. Datasets

The LIDAR data presented in this report was captured on two separate dates; firstly in April 2018, then in October 2019 to expand the surveyed area to include coverages of sixteen metropolitan councils (**Fig. 1**). Both airborne LiDAR datasets were collected using a Riegl VQ-780i sensor and are discrete, multi-return datasets with minimum spatial resolutions of 8 points/sq.m. The datasets are provided in .LAS format and have undergone proprietary pre-processing and classification to Level 2. After classification the two datasets were combined to produce a single dataset covering the entire study area with a total of 1,706 1km by 1km tiles. Additional datasets including LGA boundaries, Land Use boundaries, Land Ownership boundaries and Suburb boundaries were provided by DPTI.

3. Study Area – Metropolitan Adelaide

Within this report 'Metropolitan Adelaide' refers to the area that consists of the sixteen LGAs that are wholly within the 2018 and 2019 LIDAR data captures. These include City of Adelaide, City of Burnside, Campbelltown City Council, City of Charles Sturt, City of Holdfast Bay, City of Marion, City of Mitcham, City of Norwood Payneham & St Peters, City of

Onkaparinga, City of Port Adelaide Enfield, City of Prospect, City of Salisbury, City of Tea Tree Gully, City of Unley, Town of Walkerville and City of West Torrens. 'Metropolitan Adelaide' excludes the partial coverages of the Town of Gawler and the City of Playford.



Earthstar Geographics, CNES/Airbus DS, Maxar

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Figure 1 *– Map showing the extent of Metropolitan Adelaide. Also shown are the two LIDAR captures that were combined to produce the dataset utilised in this study. The extent of the April 2018 capture is shown in red, the extent of the additional areas captured in October 2019 is shown in green. Also shown are the extents of the Adelaide LGAs included within the study area (black).*

4. METHODOLOGY

The methods used to produce canopy metrics within this study were based upon those presented in Holt (2019) and Dong and Chen (2017b). For this study a minimum height above ground threshold of three metres is used to define a tree. This was chosen in consultation with LGA representatives as above this height trees begin to provide positive benefits to the community. As well as this it serves to minimise the effects of misclassification errors within the point cloud that are more common below 3 m. A 1 m by 1 m raster DCM was generated from the classified, normalised LIDAR point cloud. Binning was used to assign each cell a value which corresponds to the maximum height above ground of high vegetation returns (greater than or equal to 3 m) within each cell. No void filling interpolation was used in order to generate a discontinuous DCM. The DCM was then vectorized in order to calculate the horizontal extent of tree canopy above 3 m. Simple vector intersects were then used generate the statistics associated with canopy coverages and canopy classifications.

5. SUMMARY OF DELIVERABLES -VEGETATION METRICS

Outlined below is a summary for each vegetation analysis deliverable that is presented within this report for Metropolitan Adelaide.

Digital Canopy Model – Digital Canopy Models (DCMs), also known as Canopy Height Models (DCM) consist of a discontinuous raster that describes the height above ground of the top of tree canopies across an area of interest. In the case of this study, all DCMs have a cell size of one meter by one meter and describe trees that are above three meters in height. Therefore, areas of no data correspond to areas that either have no trees or have trees that are below the threshold of three meters. Not only is the amount of canopy cover important, studies suggest that solar radiation reduction (i.e. shading) is significantly related to canopy height (as well as canopy coverage) and that larger trees can provide more benefits than smaller trees (Wang et al., 2016).

Tree Canopy Coverage – A vector dataset showing the horizontal extent of tree canopy cover above 3 m across Metropolitan Adelaide. The Tree Canopy Coverage maps provided in this report contain two pieces of valuable information. Firstly, a map that shows the horizontal coverage of tree canopy that is above three meters across the area of interest. This data is derived from the DCM and depicts the exact area that is covered by tree canopy. Included on the Tree Canopy Coverage maps is a chart showing the exact proportion of the area of interest that is covered by tree canopy above three meters in height. This percentage value can be used as a precise benchmark to compare the increase or decrease in tree canopy cover within the area of interest over time. Quantifying the tree canopy cover within urban areas is an important, fundamental variable that needs to be understood in order to assess the urban environmental benefits and increased thermal comfort provided by urban forests (Elmes et al., 2017; Geneletti et al., 2020; Graham et al., 2016; Howe et al., 2017; Jamei and Rajagopalan, 2017).

Canopy Cover by Unit Area – Tree Canopy Coverage by Unit Area maps are generated by dividing the area of interest into uniform 100m by 100m cells and then calculating the percentage of tree canopy cover within each individual cell. All cells are then colour coded by canopy coverage percentage. Maps such as these provide a snapshot of the distribution of tree canopy cover above three meters in height that are free of biases that can be caused by depicting tree canopy coverage per LGA or suburb area. All Tree Canopy Coverage by Unit Area maps in this report are colour coded using a standardised colour scheme to a standard dataset that can be used to make accurate comparisons across areas of interest, both within LGAs and across multiple LGAs.

6. Results

6.1 Digital Canopy Model and Canopy Coverage

The DCM map for Metropolitan Adelaide is shown in **Figure 2** (see attached) and the Tree Canopy Coverage Map is shown in **Figure 3** (see attached)**.** The DCM shows the distribution and height of tree canopy above 3 m across Metropolitan Adelaide. Qualitative inspection of the dataset shows that the highest tree canopies are approximately 47-48 m high in both Belair National Park and Bone Gully Forest near Kuitpo in Onkaparinga. **Figure 3** (see attached) shows that 23.37% of the Metropolitan Adelaide area is covered by tree canopy.

6.2 Canopy Coverage per Unit Area

Quantifying the amount of canopy coverage per unit area (in this case per 100m by 100 m cell) can provide a more unbiased measure of a region's tree canopy cover (Holt, 2019). **Figure 4** (see attached) shows the Tree Canopy Coverage by Unit Area for Metropolitan Adelaide. In general, the areas with the highest proportion of tree canopy cover are predominantly located in the Eastern hills regions as well as the southern parts of the City of Onkaparinga. One exception to this is the Mangrove forest located in the western area of the City of Salisbury Council which is dominated by 80-100% canopy coverage. The majority of the flat, urban areas of Metropolitan Adelaide are dominated by tree canopy coverages between 0% to 30%.

7. Limitations

7.1 Temporal Resolution

As requested, the data presented in this report is derived from the combined LIDAR dataset that consists of both the April 2018 and the October 2019 captures. As such, it is recommended that any future quantitative analyses should be carried out on each individual dataset corresponding to each capture. This will ensure the robustness of future results. This is particularly important for the following council areas that are bisected by the boundary between the two survey captures: City of Salisbury, City of Tea Tree Gully, The City of Norwood Payneham and St. Peters, City of Burnside, City of Mitcham and City of Onkaparinga. Despite being based on two separate datasets, the results from this study represent a robust benchmark that future vegetation analyses can be measured against.

7.2 Spatial Resolution

As is the case in all spatial analysis, the accuracy of the results is intrinsically linked to the spatial resolution of the datasets the analysis is based upon. Based on the resolution of the LIDAR data (8 points.m^{-2}), the highest suitable spatial resolution for tree canopy coverage in this study is 1m by 1m (i.e. the smallest area of canopy cover measurable is $1m^2$). This can result in small overestimations where a single pixel is classified as tree canopy, but when overlaid on corresponding ortho-imagery is not wholly filled by tree canopy, thus attributing a slightly larger area to its canopy than in reality. This by no means invalidates the results of this study, as this is a well-understood limitation of these commonly used geospatial methods linked to the spatial resolution of the LIDAR dataset.

8. FUTURE WORK

Studies have shown that LIDAR derived tree canopy metrics can be utilised to monitor and quantify tree canopy change in time (both loss and gain) across urban landscapes (O'Neil-Dunne et al., 2019). Compared to some other statistical estimation methods (Ellingsworth et al., 2015), LIDAR explicitly measures the tree's location in space in three dimensions, from which the precise coverage of that tree can be calculated (within limitations as defined by the LIDAR resolution). As such LIDAR derived tree canopy metrics provide a robust benchmark for comparisons across time as it is not dependent on training data and user input which can vary across separate iterations. Repeated, targeted LIDAR captures and vegetation analyses using consistent methodologies allow for ongoing assessments of the effectiveness of tree canopy management policies and practices within government areas.

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Figure 2
Digital Canopy Model - Metropolitan Adelaide

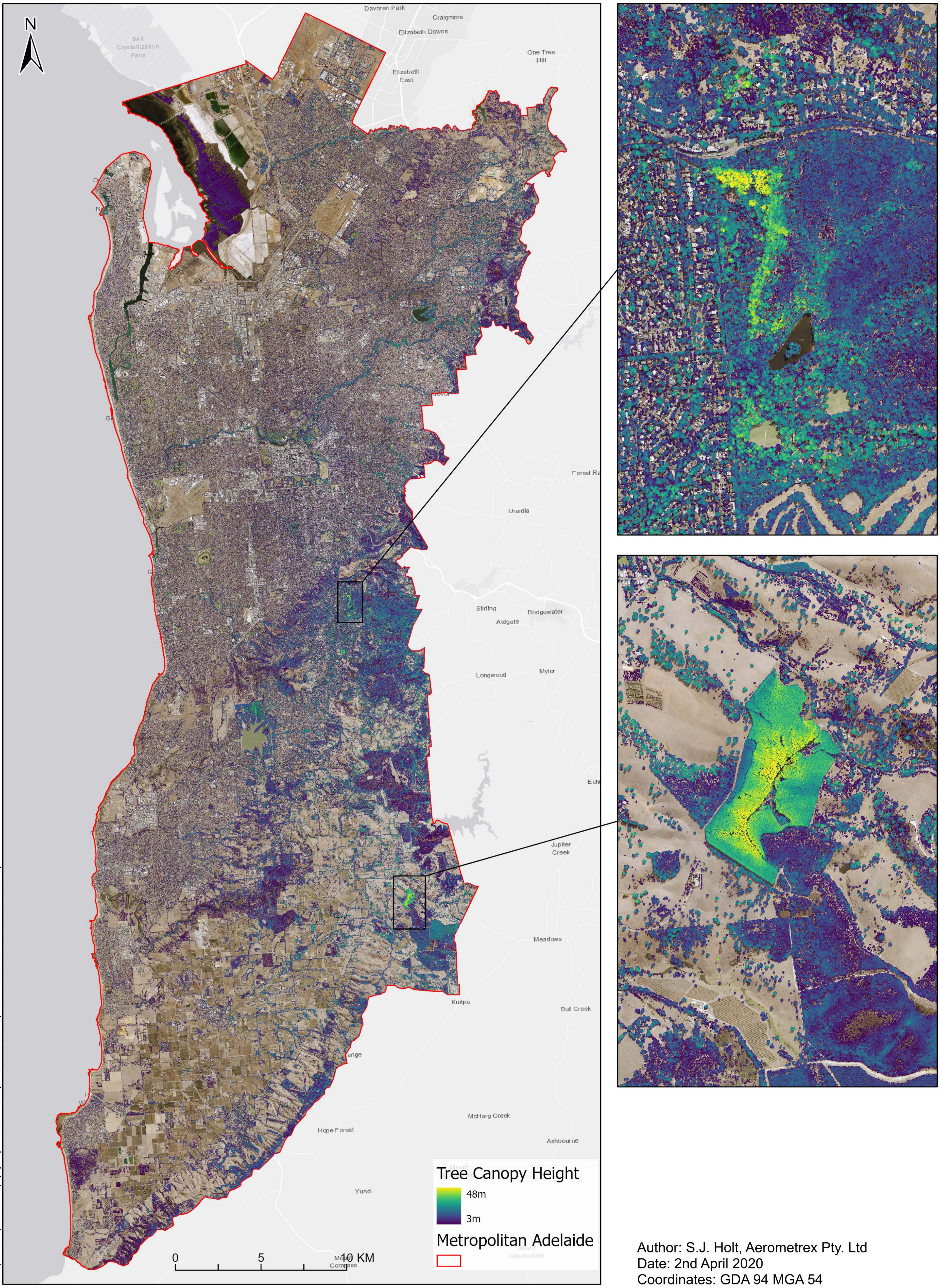

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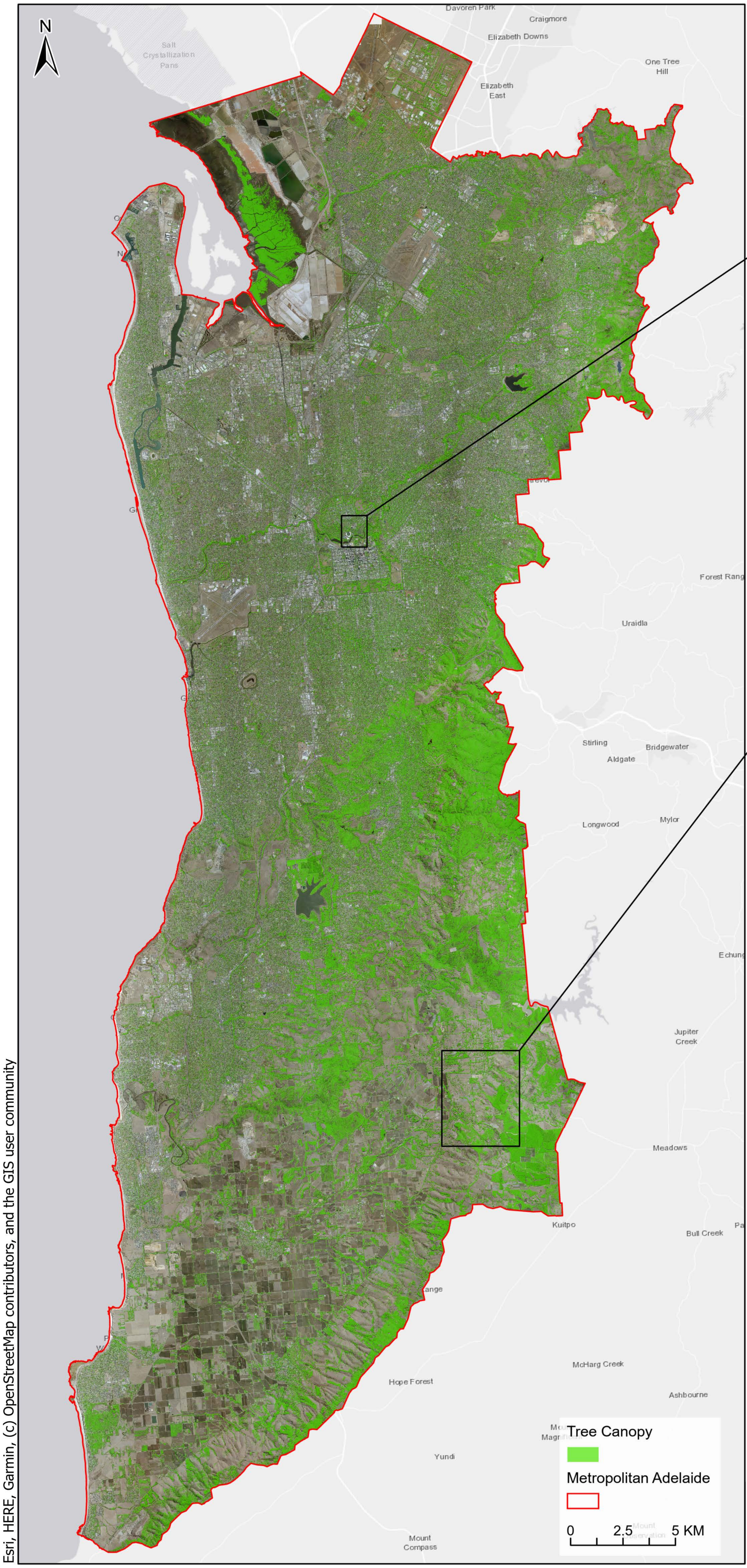
Figure 3
Tree Canopy Coverage - Metropolitan Adelaide



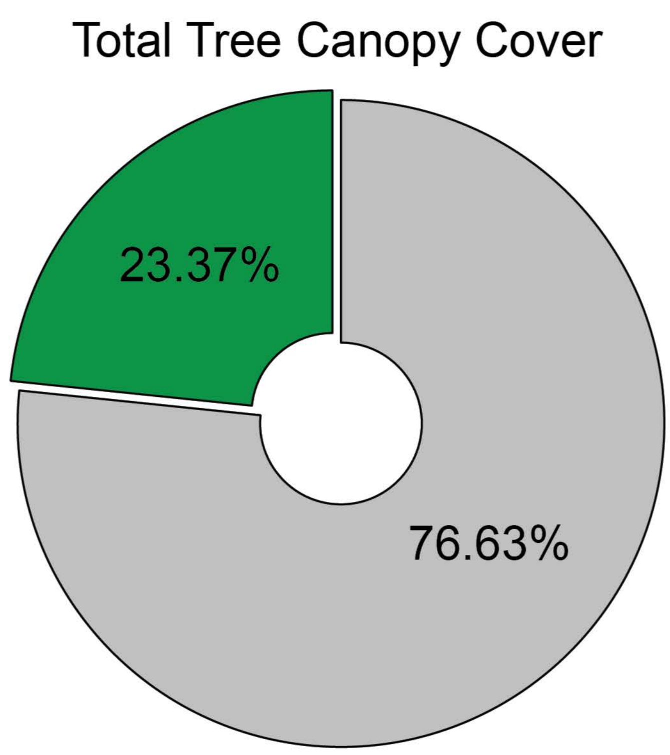


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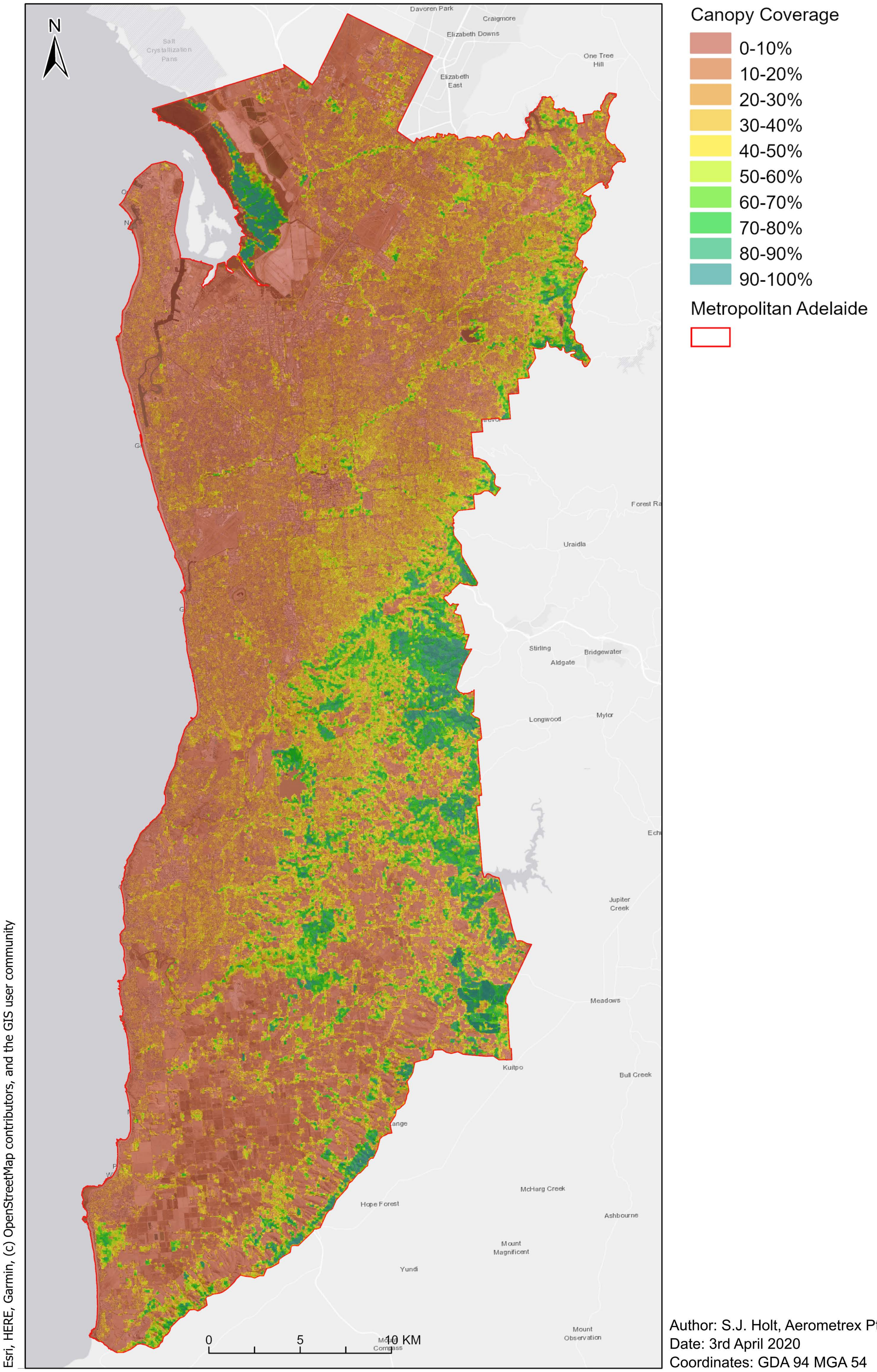
Figure 4
Canopy Coverage by Unit Area - Metropolitan Adelaide



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