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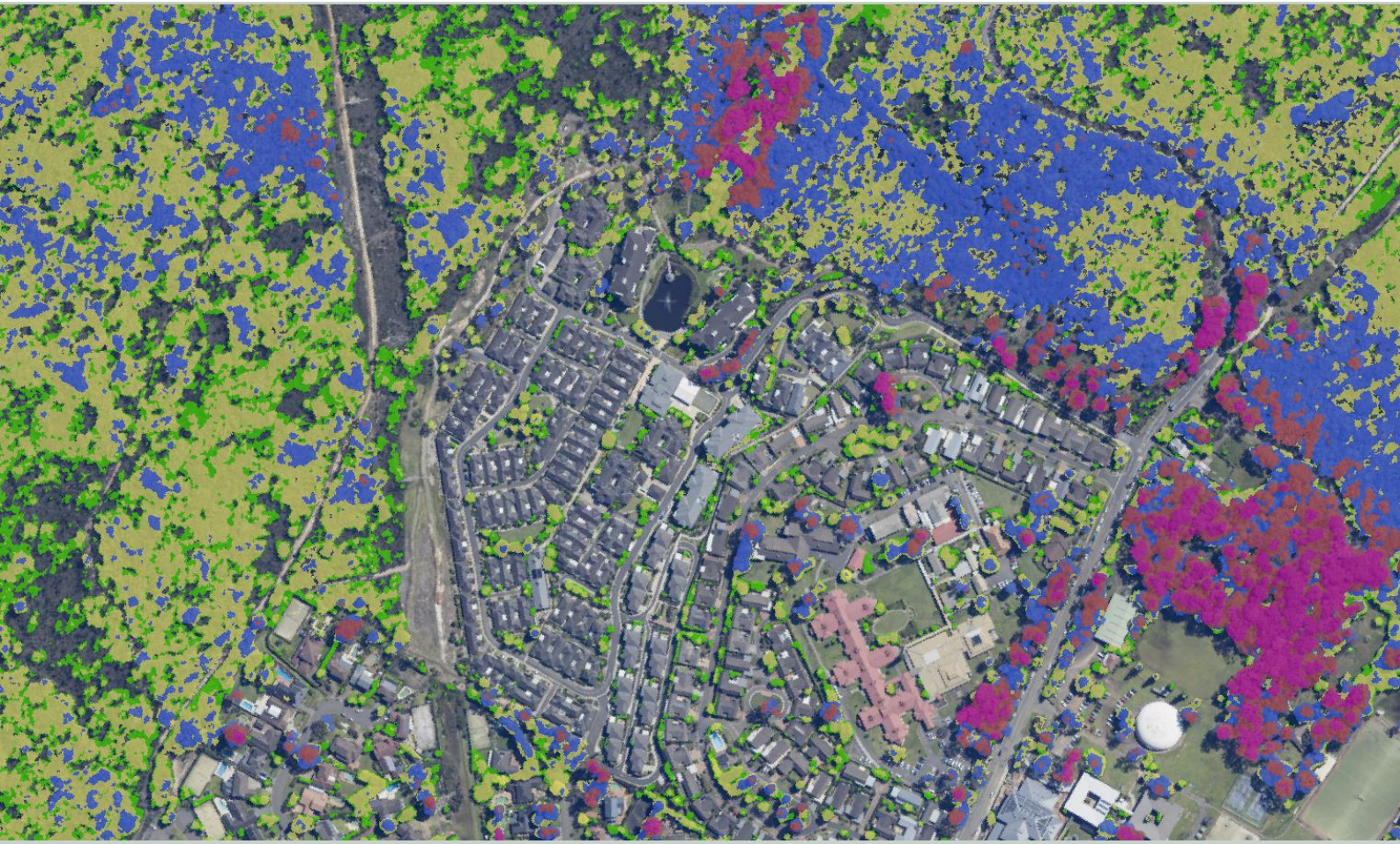

Ku-ring-gai Urban Forest Monitoring - an Aerial Measurement of Vegetation Cover

Ku-ring-gai Council

Report No. J20443

25th June 2020

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REVISION SCHEDULE

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Executive Summary

The Ku-ring-gai LGA covers approximately 85 km^2 and is favorably positioned in an area connecting a predominantly low-density urban environment, including medium densities generally nearer the pacific highway, with extensive bushland. The Ku-ring-gai Council area adjoins three national parks (Ku-ring-gai Chase, Garigal and Lane Cove), and possesses a significant native and introduced urban forest, all of which contributes to the distinctive natural beauty and sense of place of Ku-ring-gai. The Council contains nationally significant ecological communities, such as Blue Gum High Forest and Sydney Turpentine Ironbark Forest. As a result, Ku-ring-gai is frequently referred to as the 'Green Heart' of Sydney.

The Ku-ring-gai community place a high value on the natural environment, its biodiversity, the sense of place, the green and leafy nature of their streets and diverse heritage. Accordingly, environmental conservation is a key part of the Council vision statement (Community Strategic Plan, 2038).

The Council engaged ArborCarbon to acquire, process and deliver remotely sensed data to monitor their current canopy cover, as part of their Urban Forest management plan. ArborCarbon maintains a unique 11-band airborne multispectral camera system (ArborCam) optimised for the accurate detection of vegetation and subtle changes in vegetation condition. The ArborCam was used to acquire high resolution imagery to accurately quantify canopy cover, as well as thermal imagery to identify urban hot spots. Canopy cover statistics were extracted and categorized into different height strata, suburbs, and land zones across the entire Council.

High-resolution airborne multispectral imagery was acquired at 3657.6 m (12,000 ft) above ground level over the Council with cloudless conditions between 10:30 and 13:00 on March 19th 2020. Imagery was acquired for this project with the ArborCam system with a ground sample distance (GSD) ranging from 12 cm/pixel to 36 cm/pixel dependent on the spectral band. Thermal imagery was acquired at 4267.2 m (14,000 ft) above ground level, between 14:15 and 15:45 on March 20th 2020, with a GSD of 175 cm/pixel. The maximum temperature recorded on the 20th March at Sydney (Observatory Hill) (BoM reference: 66062) was 35°C (bom.gov.au).

The Council has an entire area of 8539 ha. Over two thirds of the Council (70.6%) was covered by vegetation. The remaining 29.4% was non-vegetated surfaces, such as buildings, roads, exposed soil and dead grass. Nearly 20% of the vegetation fell into the 0-3m category, which includes turf, grass, groundcovers and shrubs. 5.7% of the vegetation was in the 3-5m category. The remaining 45.7% was fairly evenly split between the 5-10, 10-15, 15-20 and >20m categories. Canopy (vegetation 3m and above) covered 51.4% of the Council, or 4389 ha.

Canopy cover (vegetation 3m and above) was calculated for each suburb within the Council. The suburb with the greatest proportional canopy cover was North Turramurra (64.8%), closely followed by South Turramurra (61.8%) and St Ives Chase (60.6%). North Turramurra and St Ives Chase are northern suburbs, and South Turramurra is in the south east of the Council, and large portions of each suburb are National Parks and Reserves (zone E1) and Environmental Conservation areas (zone E2). These areas, such as the Ku-ring-gai Chase National Park, are almost exclusively forest, therefore contributing significantly to canopy cover in these suburbs. Roseville had the lowest canopy cover of 35.7%, followed by Killara (36.7%) and East Lindfield (38.4%). The majority of these suburbs are made up of Low Density Residential areas (zone R2), and less

National Parks and Reserves, Environmental Conservation and Environmental Living (E4) areas than other suburbs in the Council, and therefore have comparatively less canopy.

Canopy cover (vegetation 3m and above) was calculated for each land zone within Ku-ring-gai council. The land zone with the greatest proportional canopy cover was E2 (Environmental Conservation, 83.4%) followed by special E1 (National Parks and Reserves, 76.2%) and E3 (Environmental Management, 67%). However, E3 is a small area of only 20 ha, so is not contributing significantly to the canopy cover of the entire Council, unlike E2 (1250.5 ha) and E1 (1747.4 ha), which together make up 35.1% of the total Council area.

All other land zone types had below average canopy cover. W1 (Waterways) had 42.3% canopy cover, however the area is small (5 ha). E4 (Environmental Living) and RE1 (Public Recreation) also had canopy coverage above 40%, and are relatively large areas (866.2 ha and 358.8 ha, respectively).

The seven land zones with the least amount of canopy (B4: Mixed Use, B2: Local Centre, B7: Business Park, B1: Neighbourhood Centre, B5: Business Development, R5: Large Lot Residential, and R1: General Residential), collectively make up 103.5 ha, or 1.2% of the total Council area. The land zone with the next lowest canopy cover is SP2 (Infrastructure), which has 30% canopy cover. This land zone makes up 3.5% of the total Council area (302.6 ha).

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1 Introduction

The Ku-ring-gai LGA covers approximately 85 km^2 and is favorably positioned in an area connecting a predominantly low-density urban environment, including medium densities generally nearer the Pacific Highway, with extensive bushland. The Ku-ring-gai Council area adjoins three national parks (Ku-ring-gai Chase, Garigal and Lane Cove), and possesses a significant native and introduced urban forest, all of which contributes to the distinctive natural beauty and sense of place of Ku-ring-gai. The Council contains nationally significant ecological communities, such as Blue Gum High Forest and Sydney Turpentine Ironbark Forest. As a result, Ku-ring-gai is frequently referred to as the 'Green Heart' of Sydney.

The Ku-ring-gai community place a high value on the natural environment, its biodiversity, the sense of place, the green and leafy nature of their streets and diverse heritage. Accordingly, environmental conservation is a key part of the Council vision statement (Community Strategic Plan, 2038).

The Ku-ring-gai Local Strategic Planning Statement outlines a range of key planning priorities to enhance the livability and sustainability of the Council, and to fulfil the vision to maintain the unique natural and heritage asset of the urban forest for future generations. These include;

- K30 '*Improving the quality and diversity of Ku-ring-gai's urban forest*' and
- K31 '*Increasing, managing and protecting Ku-ring-gai's urban tree canopy*'.

Ku-ring-gai's urban forest management policy establishes guiding principles for management of the urban forest. These include:

- That sustainable urban forest targets/indicators (including canopy coverage targets) be established and recognised as a provisional basis for monitoring the quality, and quantity and effectiveness of any special functions of Ku-ring-gai's urban forest.
- That monitoring and management of the urban forest be undertaken through a planned, systematic and integrated approach.

The Council engaged ArborCarbon to acquire, process and deliver remotely sensed data that will be used to monitor their current canopy cover, as part of their urban forest management plan. ArborCarbon maintains a unique 11-band airborne multispectral camera system (ArborCam) optimised for the accurate detection of vegetation and subtle changes in vegetation condition. The ArborCam was used to acquire high resolution imagery to accurately quantify canopy cover, as well as thermal imagery to identify urban hot spots. Canopy cover statistics were extracted and categorized into different height strata, suburbs, and land zones across the entire Council.

2 Methods

2.1 Airborne Imagery Acquisition

High-resolution airborne multispectral imagery was acquired at 3657.6 m (12,000 ft) above ground level over the Council with cloudless conditions between 10:30 and 13:00 on March 19th 2020. Imagery was acquired for this project with the ArborCam system with a ground sample distance (GSD) ranging from 12 cm/pixel to 36 cm/pixel dependent on the spectral band. Thermal imagery was acquired at 4267.2 m (14,000 ft) above ground level, between 14:15 and 15:45 on March 20th 2020, with a GSD of 175 cm/pixel. The maximum temperature recorded on the 20th March at Sydney (Observatory Hill) (BoM reference: 66062) was 35°C (bom.gov.au).

2.2 Data Processing and Analysis

The high-resolution airborne imagery datasets were geometrically corrected and orthorectified using 2016 high resolution imagery supplied by the Council. A Digital Surface Model was generated from the acquired imagery for the full extent of the Council, enabling the stratification of vegetation into six pre-determined height categories as follows: 0-3m, 3-5m, 5-10m, 10-15m, 15-20m and >20m. For the purposes of this report, all vegetation >3m above the ground was classified as canopy.

The co-aligned thermal imagery was radiometrically corrected and converted to surface temperature in degrees Celsius by applying a standard emissivity correction of 0.95 across the scene.

Bands across the VIS-NIR were used to detect all living vegetation in sun and shadow. Vegetation that was not photosynthesizing at the time of acquisition, such as dead wood in tree crowns and dead grass, was not classified as vegetation.

Height-stratified vegetation cover statistics were calculated in client-provided suburb boundaries (Figure 1), and land zone boundaries (Figure 2) across the entire LGA.

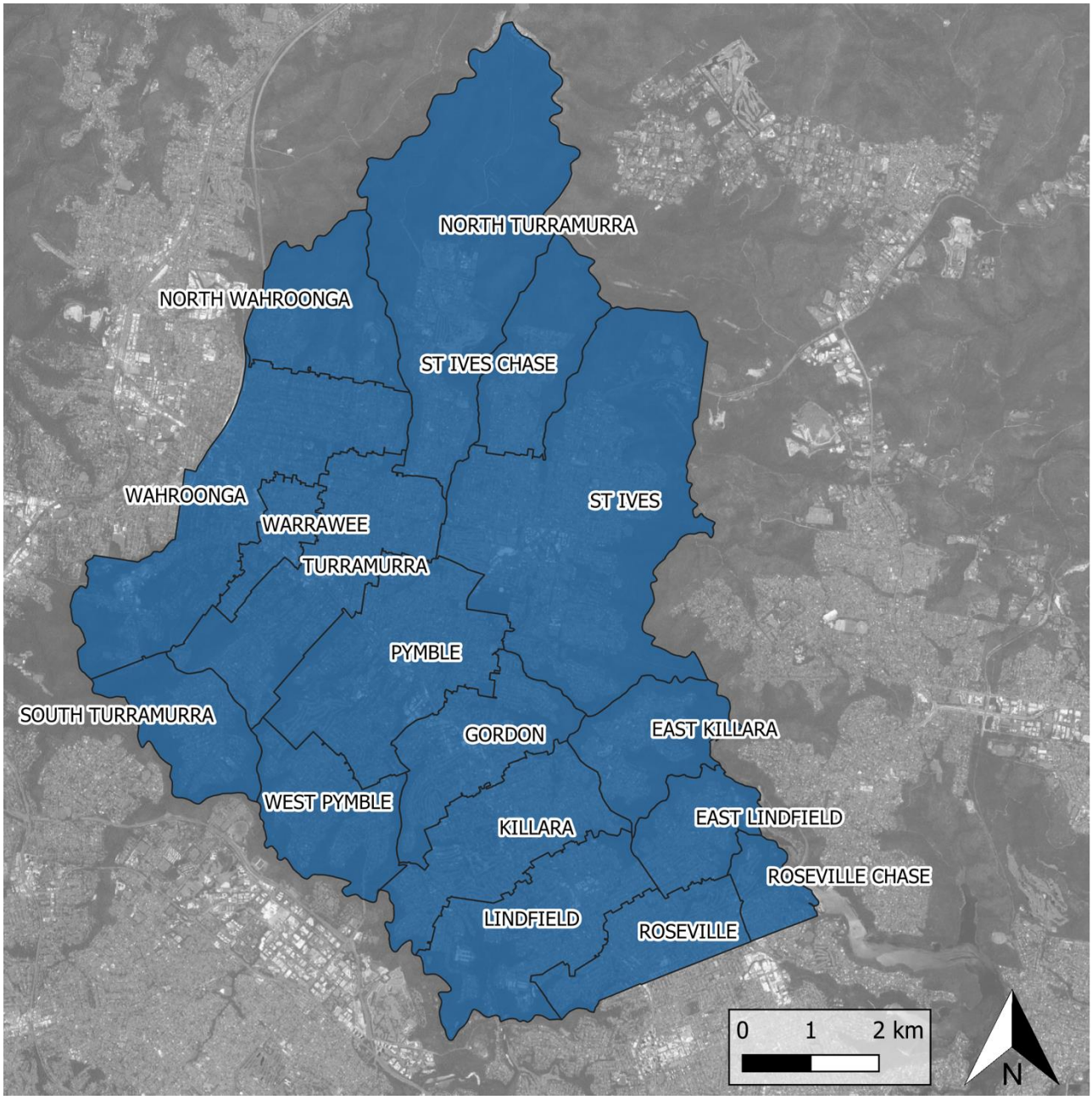

Figure 1: Ku-ring-gai Council suburb boundaries used to calculate vegetation cover statistics.

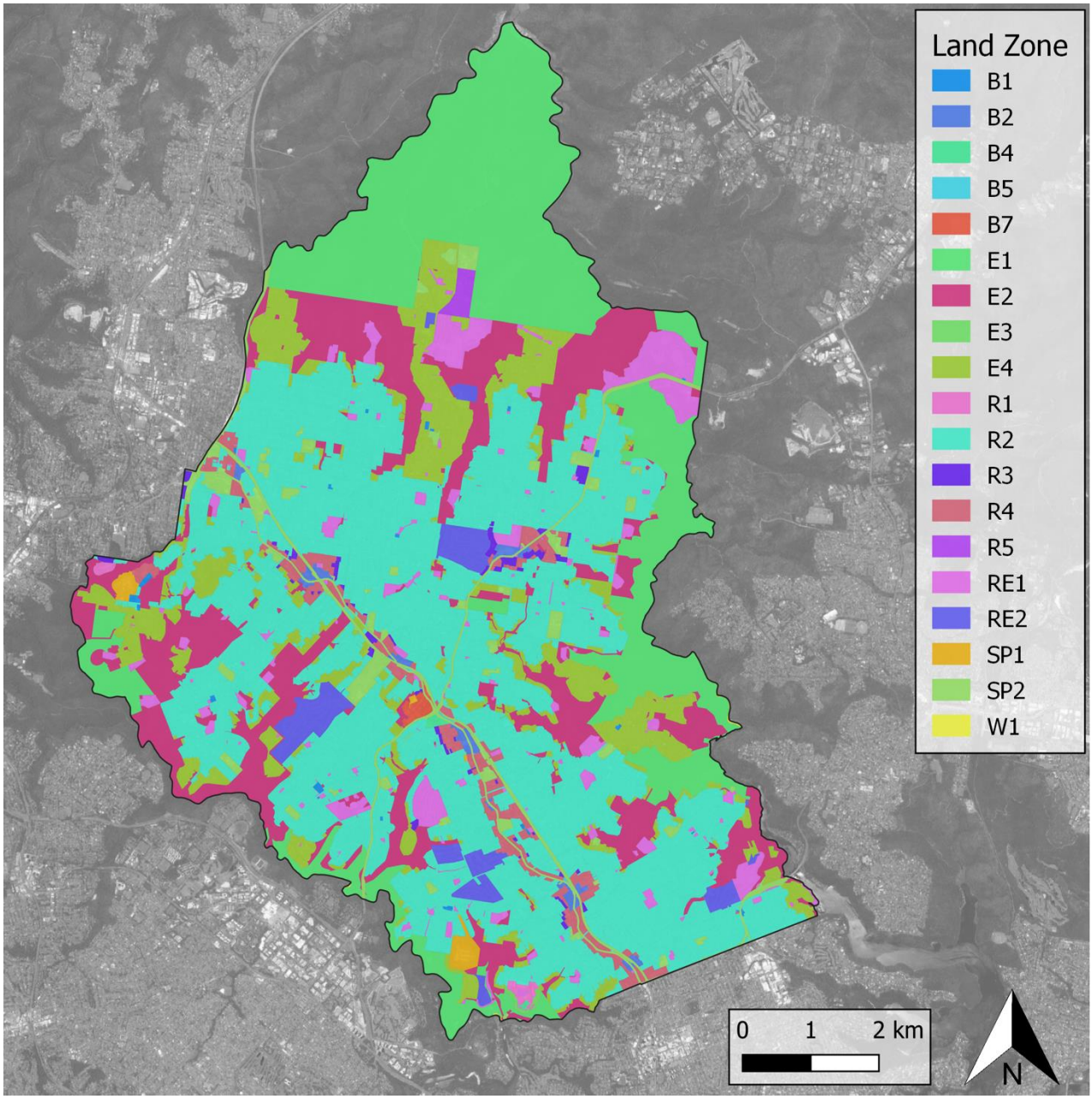

Figure 2: Ku-ring-gai Council land zone boundaries used to calculate vegetation cover statistics.

3 Results and Discussion

3.1 High-resolution Imagery

The acquired data was processed to produce high-resolution red, green and blue (RGB) imagery (Figure 3), False Colour Composite (FCC) imagery (Figure 4), a height-stratified vegetation cover dataset (Figure 5), and land surface temperature (°C) (Figure 6) across the 8539 ha of Ku-ring-gai Council.

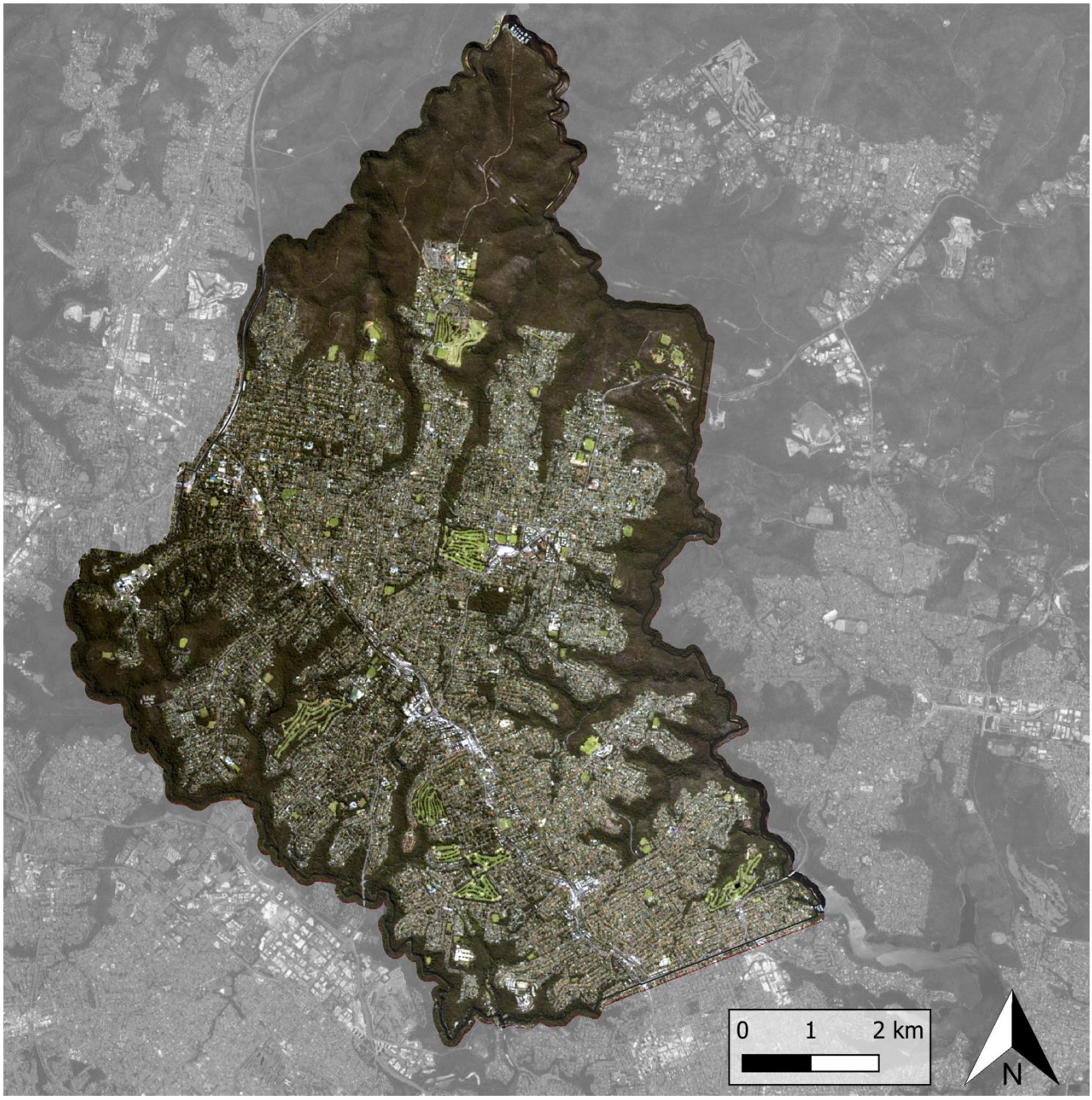

Figure 3: High-resolution RGB imagery of Ku-ring-gai Council.

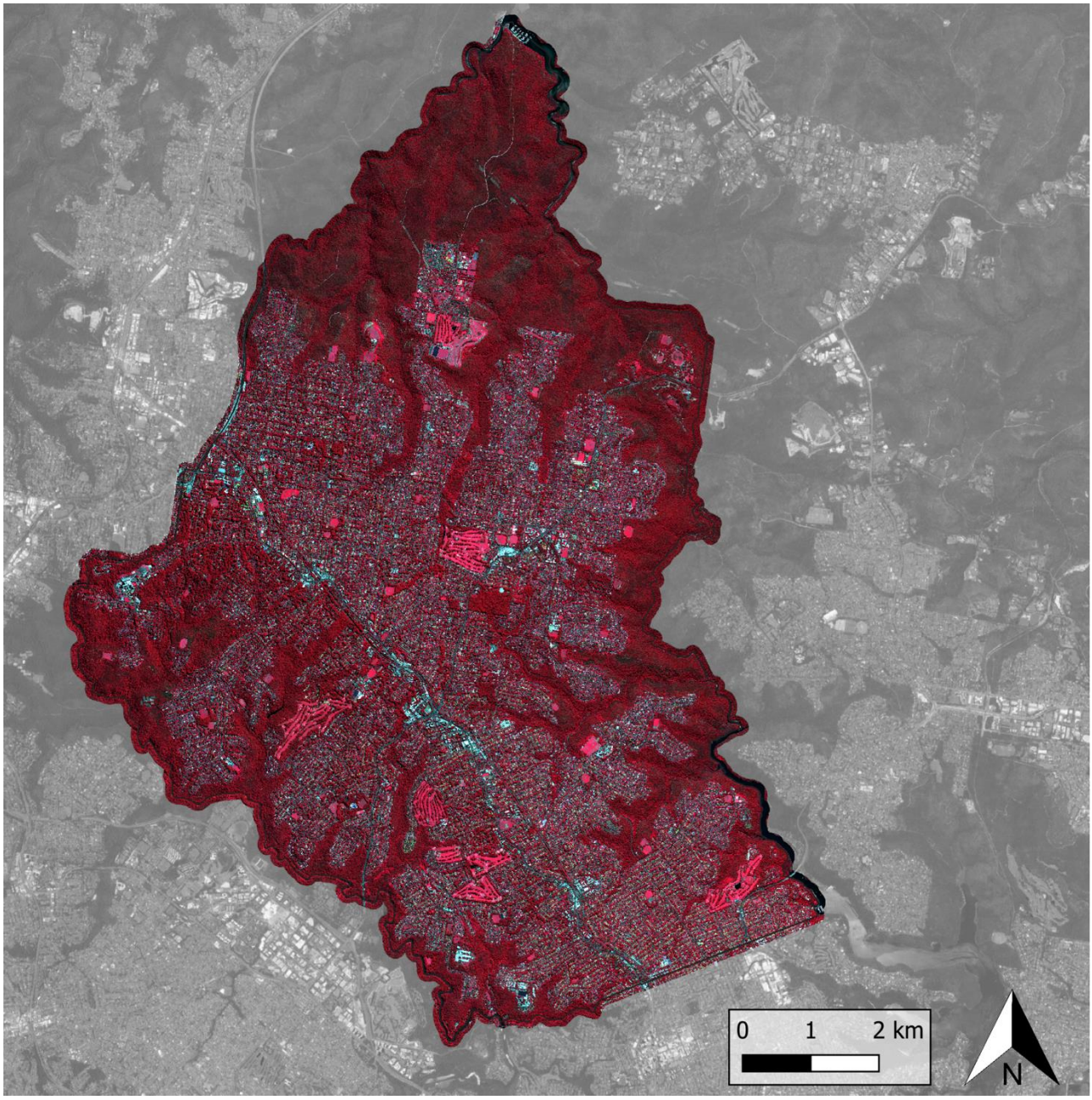

Figure 4: False colour composite over Ku-ring-gai Council showing vegetation (red pixels).

The FCC dataset (Figure 4) was derived from a 3-band subset of the multispectral imagery (NIR, red and green). FCC imagery is commonly used in remote sensing to illustrate vegetation cover, which is displayed as red pixels.

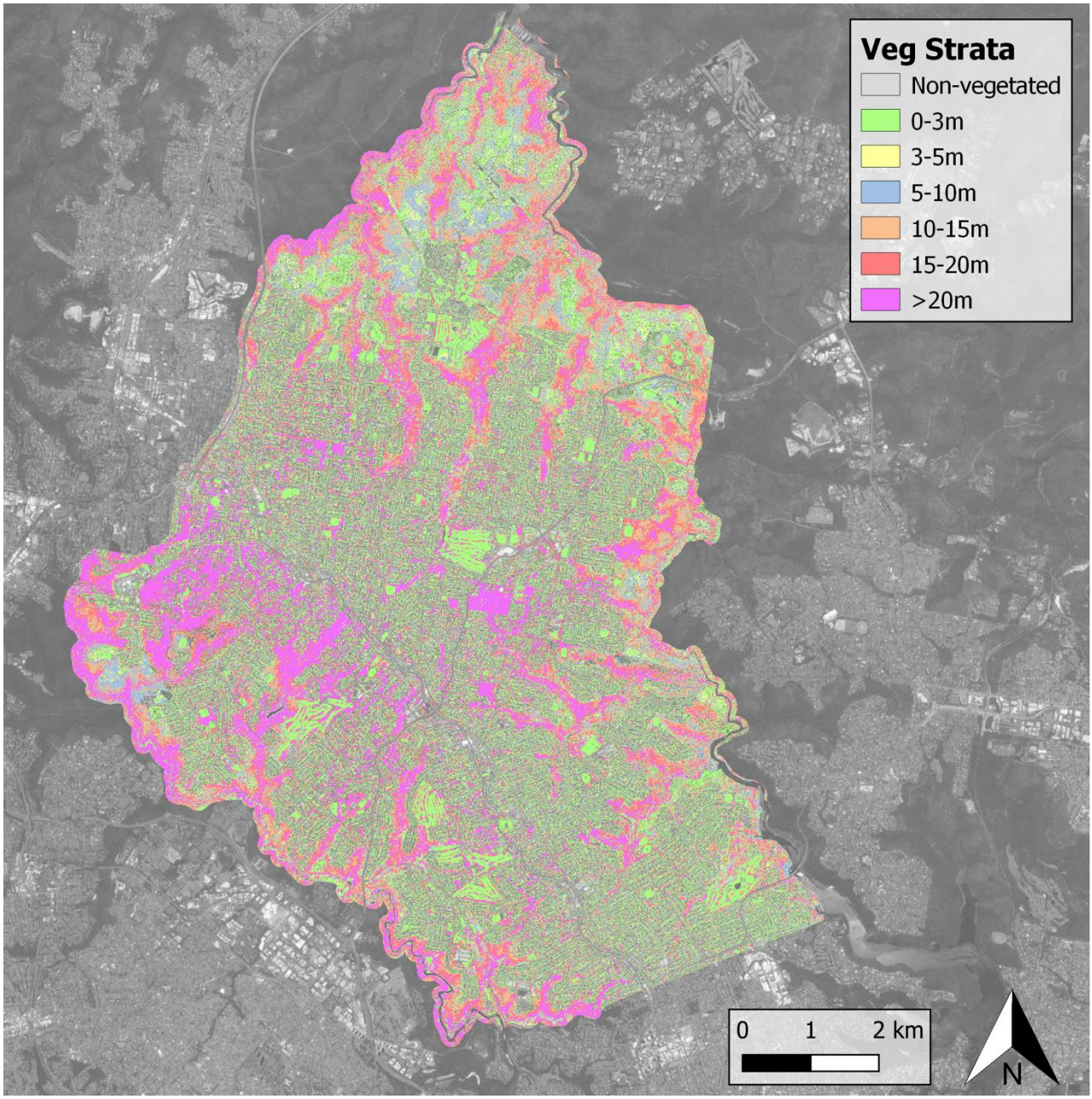

Figure 5: Height-stratified vegetation dataset derived with each strata displayed in a different colour: 0-3m light green, 3-5m yellow, 5-10m blue, 10-15m orange, 15-20m red, and >20m magenta.

The height-stratified vegetation cover dataset (Figure 5) is comprised of specific height strata colourised as follows: 0-3m light green, 3-5m yellow, 5-10m blue, 10-15m orange, 15-20m red, and >20m magenta. This colour scheme is used in all illustrations of the height-stratified vegetation cover dataset in this report.

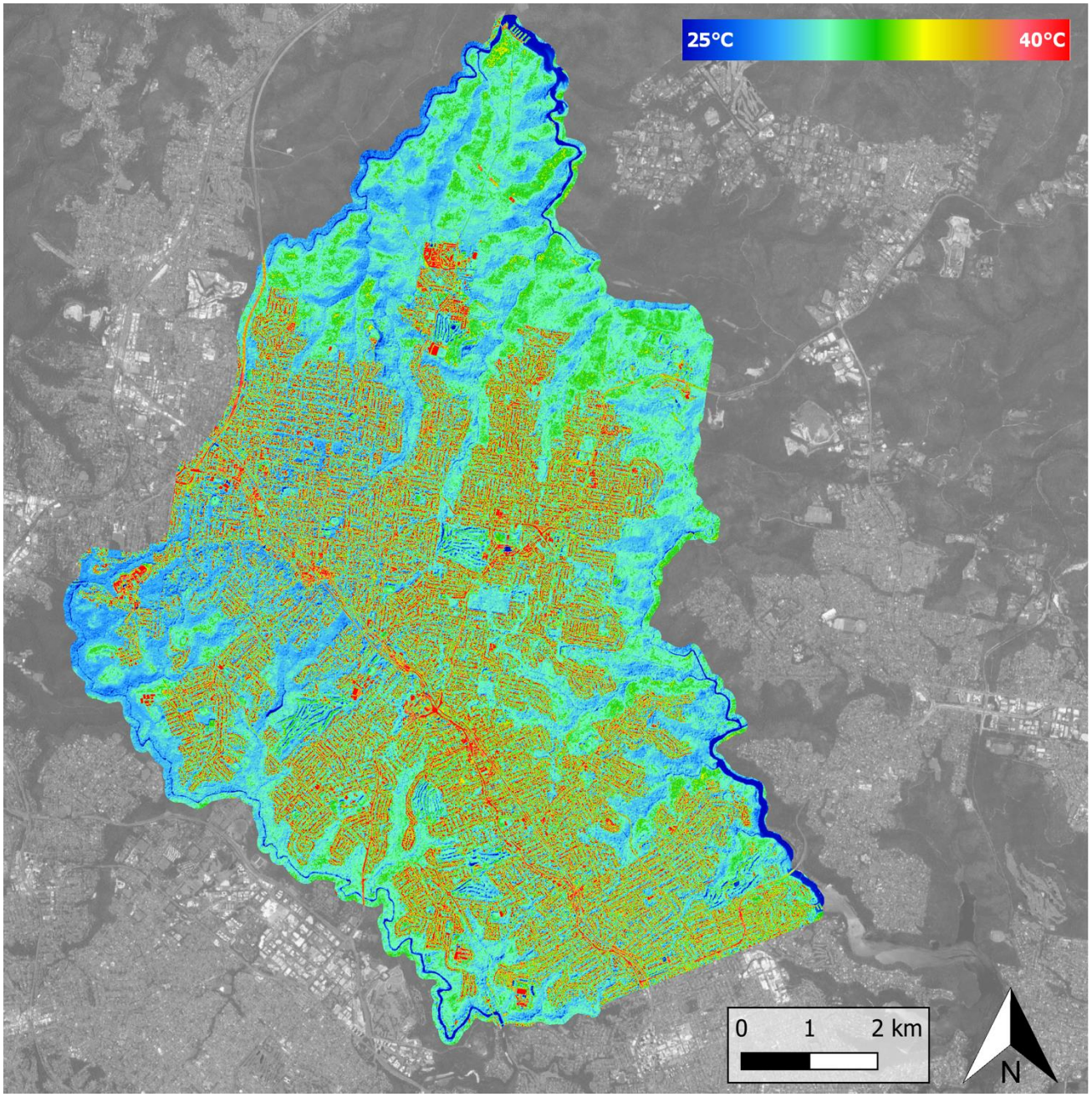

Figure 6: Radiometrically corrected thermal ortho land surface temperature of Ku-ring-gai Council ranging from 25°C (blue) to 40°C (red).

Examples of close-up imagery derived from each of these datasets and the different layers of information they provide appear in Figure 7.

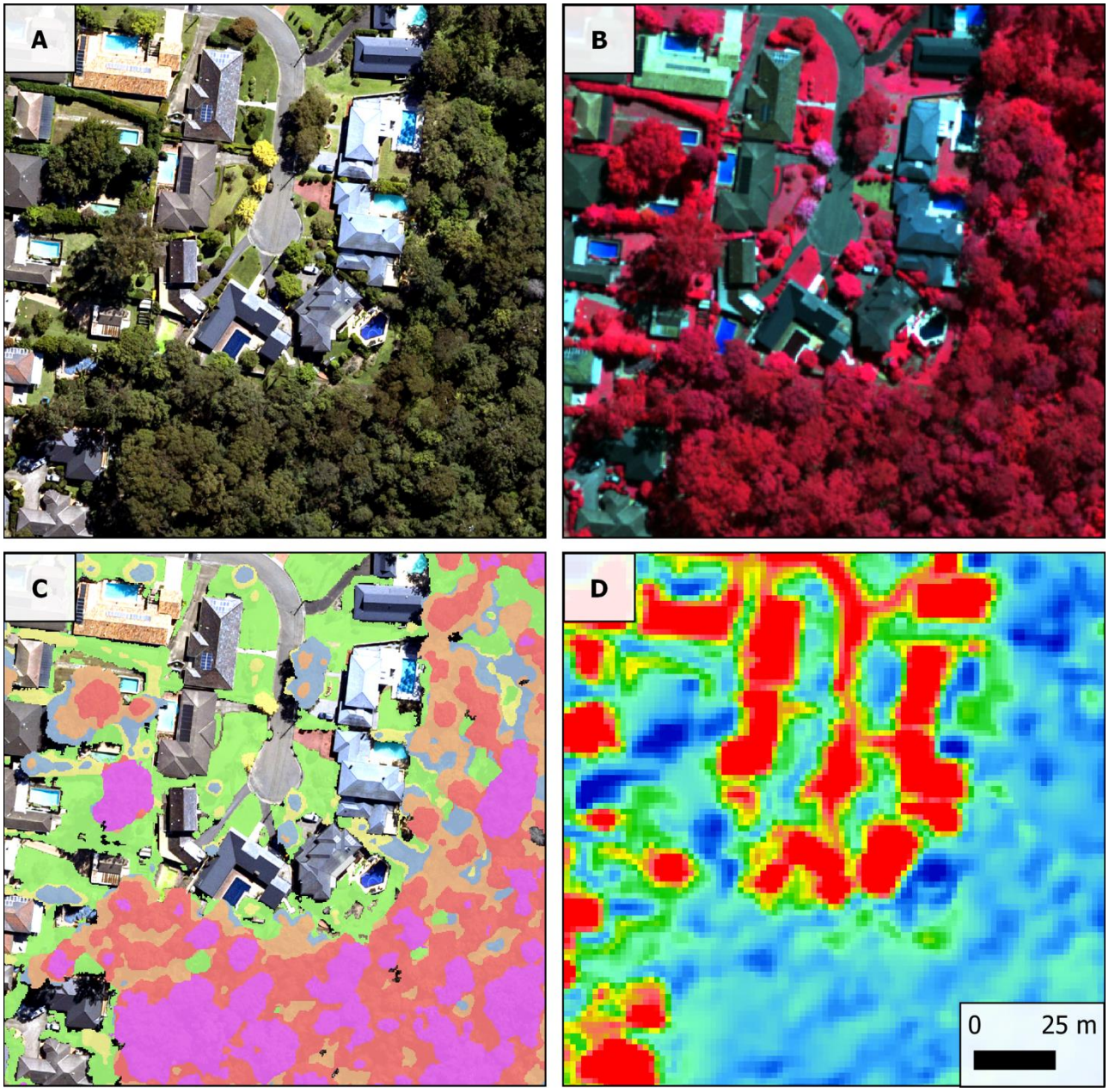

Figure 7: Close-up image of each of the datasets generated for Ku-ring-gai Council: A) High-resolution RGB imagery; B) False Colour Composite (FCC) showing vegetation as red pixels; C) Height-stratified vegetation cover, with each stratum displayed as a different colour; and D) land surface temperature with hottest materials shown as red pixels and coolest materials as blue pixels.

3.2 Analysis of Vegetation Cover

Height stratified vegetation cover was calculated for each suburb, land zone, and the Council as a whole.

3.2.1 Council Wide

The entire area of the Council is 8539 ha. Over two thirds of the Council (70.6%) was covered by vegetation. The remaining 29.4% was non-vegetated surfaces, such as buildings, roads, exposed soil and dead grass (Figure 8). Nearly 20% of the vegetation fell into the 0-3m height category, which includes turf, grass, groundcovers and shrubs. 5.7% of the vegetation was in the 3-5m height category. The remaining 45.7% was fairly evenly split between the 5-10, 10-15, 15-20 and >20m height categories. Canopy (vegetation 3m and above) covered 51.4% of the Council, or 4389 ha.

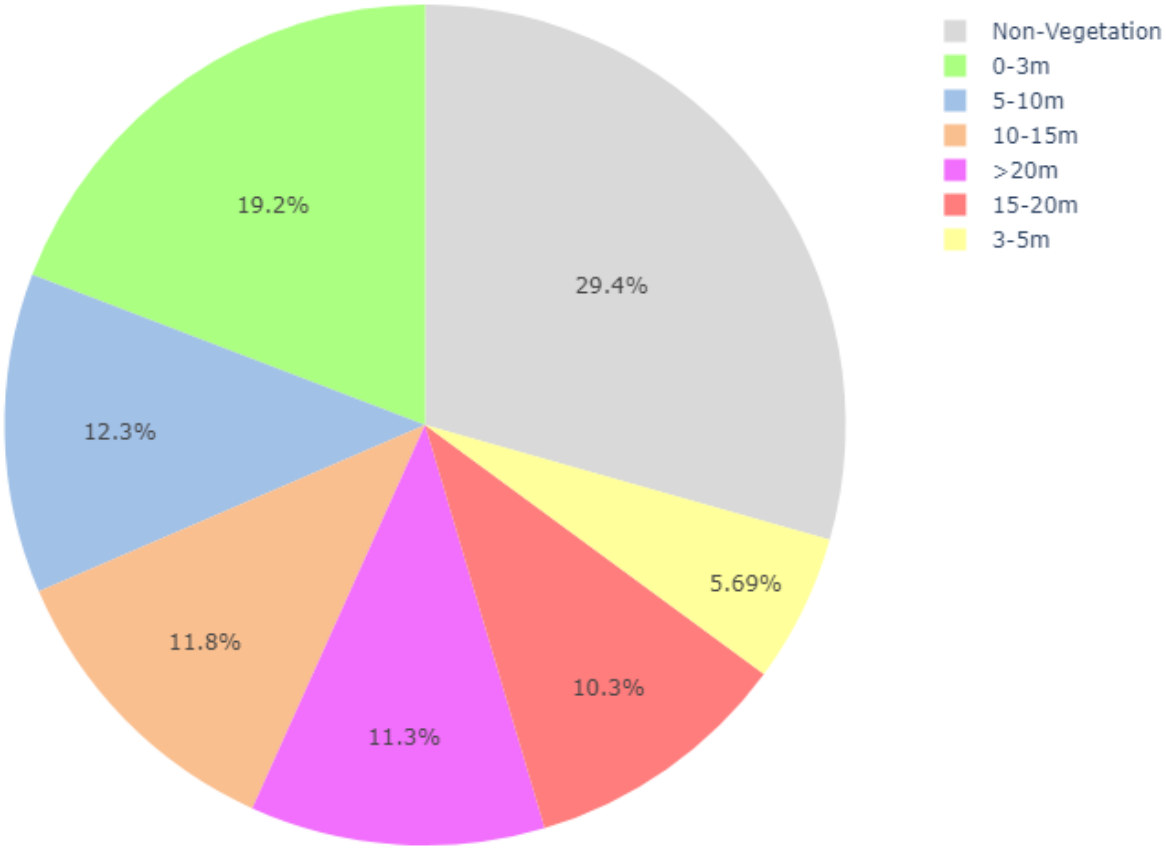

Figure 8: Land cover by strata (%) of the entire Ku-ring-gai Council area.

3.2.2 Suburbs

Canopy cover (vegetation 3m and above) was calculated for each suburb within the Council. The suburb with the greatest proportional canopy cover was North Turramurra (64.8%), closely followed by South Turramurra (61.8%) and St Ives Chase (60.6%) (Figure 9). North Turramurra and St Ives Chase are northern suburbs, and South Turramurra is in the south east of the Council, and large portions of each suburb are National Parks and Reserves (zone E1) and Environmental Conservation areas (zone E2). These areas, such as the Ku-ring-gai Chase National Park, are almost exclusively forest, therefore contributing significantly to canopy cover in these suburbs. Roseville had the lowest canopy cover of 35.7%, followed by Killara (36.7%) and East Lindfield (38.4%). The majority of these suburbs are made up of Low Density Residential areas (zone R2), and less National Parks and Reserves, Environmental Conservation and Environmental Living (E4) areas than other suburbs in the Council, and therefore have comparatively less canopy.

Percentage of canopy cover in each suburb is spatially presented in Figure 10 as a thematic map. Increasing green intensity in the map corresponds to increasing proportional canopy cover.

A breakdown of proportional land cover by vegetation strata for each suburb can be found in Appendix A. Vegetation and canopy cover of each suburb, with E1 and E2 removed, can be found in Appendix D.

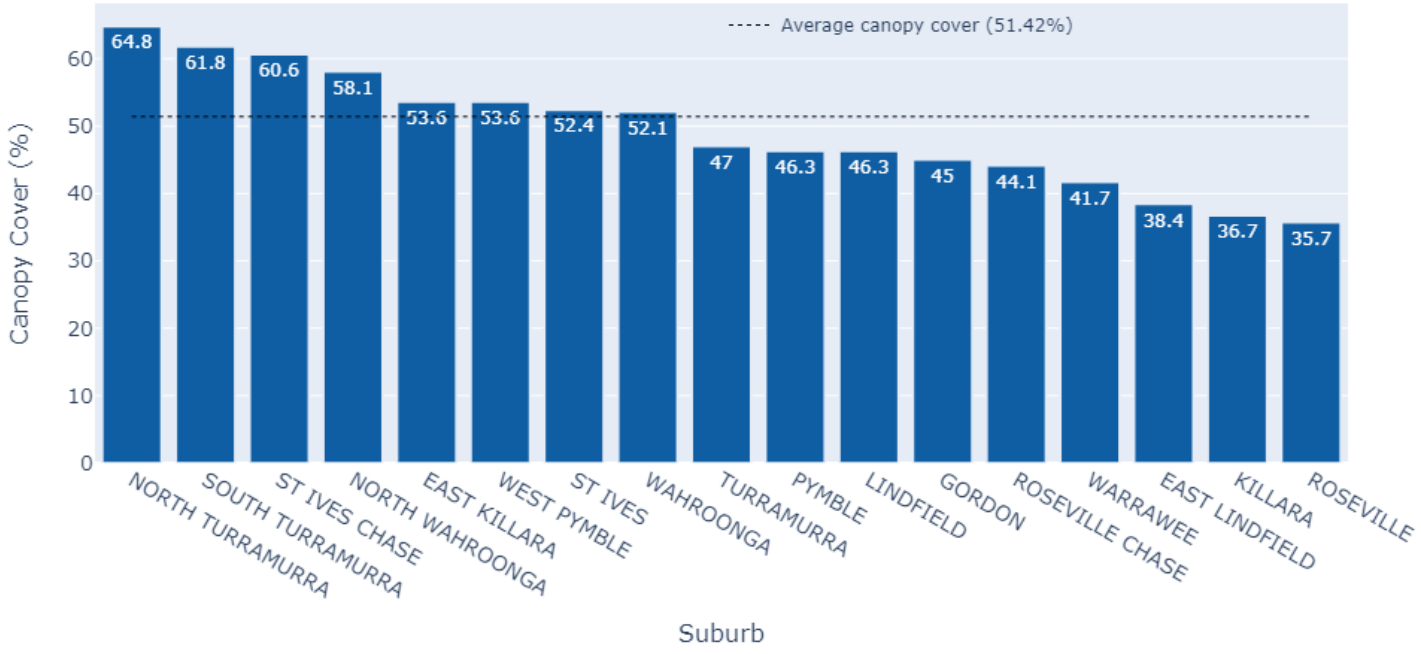

Figure 9: Canopy cover of each suburb in Ku-ring-gai Council by percentage of total suburb area.

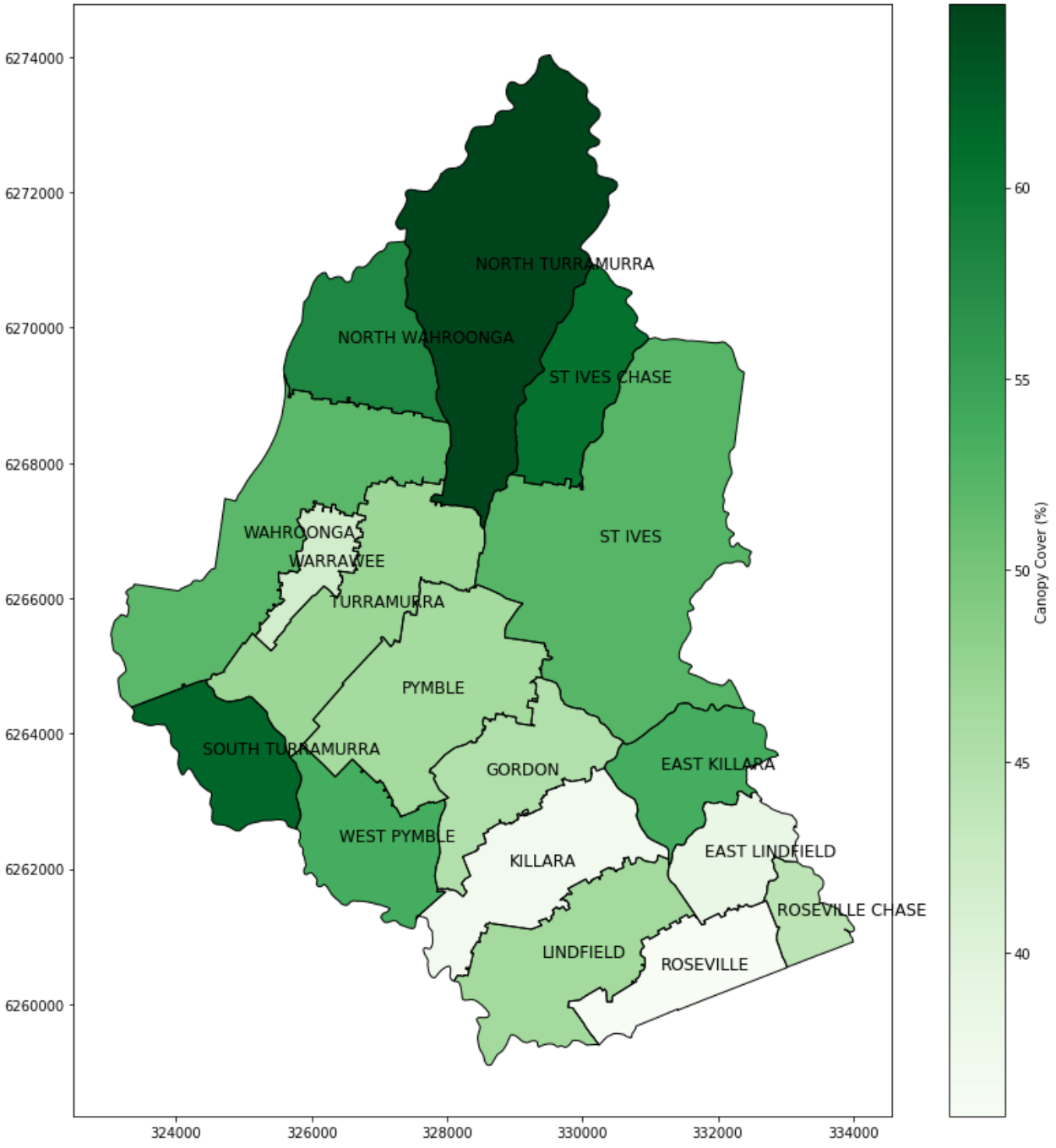

Figure 10: Thematic map showing canopy cover as a percentage of total suburb area. The darker green indicates higher relative canopy cover percentage.

3.2.3 Land Zones

Canopy cover (vegetation 3m and above) was calculated for each land zone within Ku-ring-gai Council. R2 and E4 were combined to make an additional category 'R2+E4' (low density residential areas), and R3 and R4 combined to make an additional category 'R3+R4' (medium/high density residential areas). The land zone with the greatest proportional canopy cover was E2 (Environmental Conservation, 83.4%) followed by special E1 (National Parks and Reserves, 76.2%) and E3 (Environmental Management, 67%) (Figure 11). However, E3 is a small area of only 20 ha, so is not contributing significantly to the canopy cover of the entire Council, unlike E2 (1250.5 ha) and E1 (1747.4 ha), which together make up 35.1% of the total Council area.

All other land zone types had below average canopy cover (Figure 11). W1 (Waterways) had 42.3% canopy cover, however the area is small (5 ha). E4 (Environmental Living) and RE1 (Public Recreation) also had canopy coverage above 40%, and are relatively large areas (866.2 ha and 358.8 ha, respectively).

The seven land zones with the least amount of canopy (B4: Mixed Use, B2: Local Centre, B7: Business Park, B1: Neighbourhood Centre, B5: Business Development, R5: Large Lot Residential, and R1: General Residential), collectively make up 103.5 ha, or 1.2% of the total Council area. The land zone with the next lowest canopy cover is SP2 (Infrastructure), which has 30% canopy cover. This land zone makes up 3.5% of the total Council area (302.6 ha).

Percentage of canopy cover of each land zone is spatially presented in Figure 12 as a thematic map. Increasing green intensity in the map corresponds to increasing proportional canopy cover.

A breakdown of proportional land cover by vegetation strata for each land zone area can be found in Appendix C.

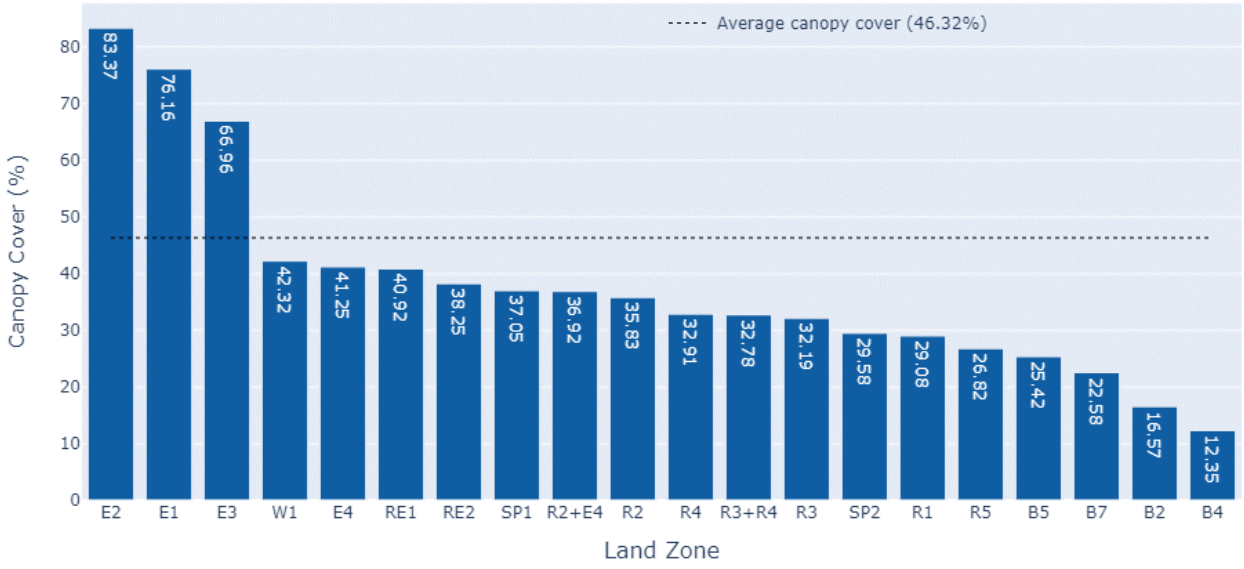

Figure 11: Canopy cover of each land zone in Ku-ring-gai Council by percentage of total land zone area.

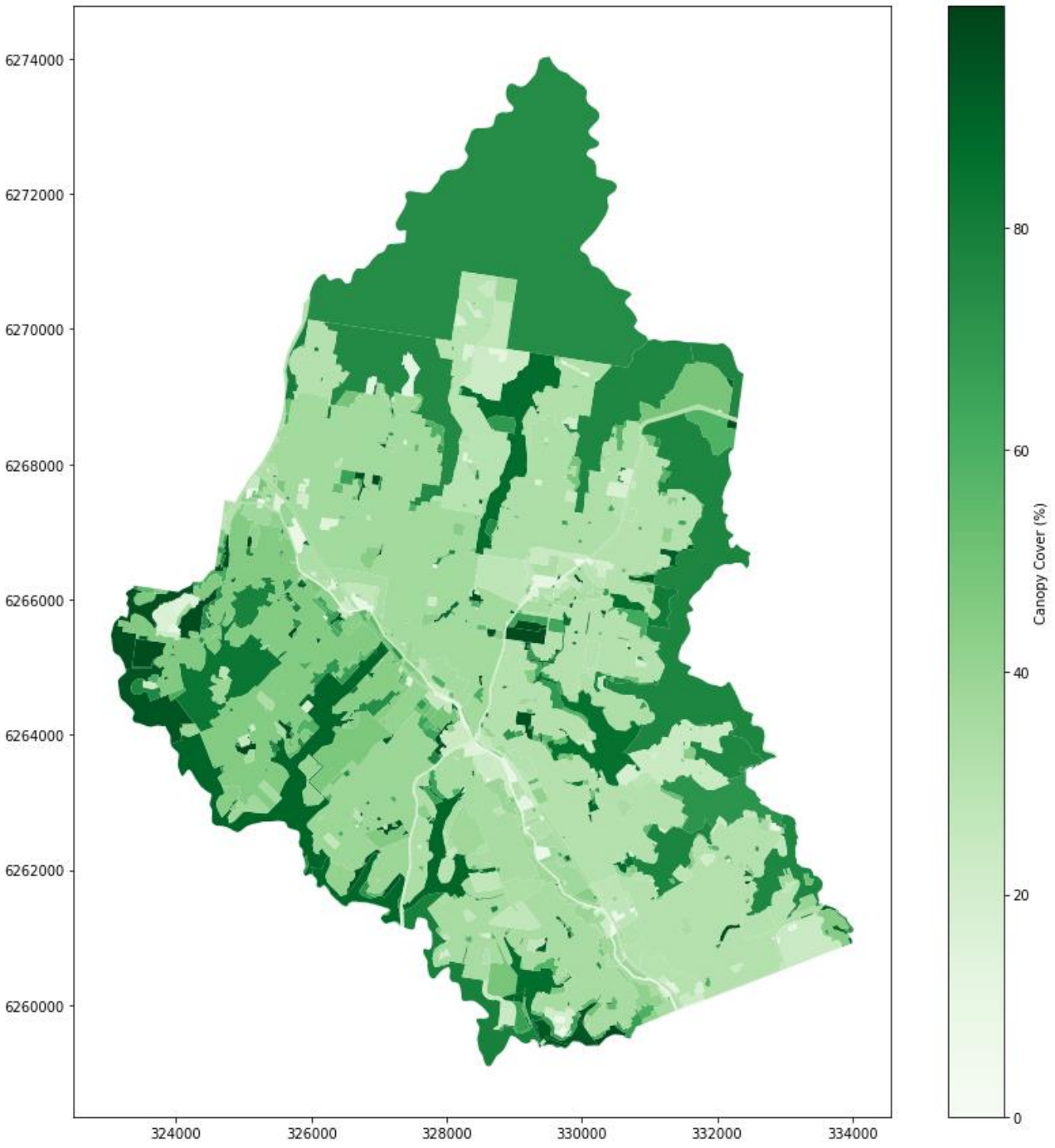

Figure 12: Thematic map showing canopy cover as a percentage of each land zone area. The darker green indicates higher relative canopy cover percentage.

Additionally, canopy cover was further broken down into proportional canopy cover of each land zone within each suburb, and is presented in Appendix C.

3.3 Land Surface Temperature

The maximum air temperature recorded in Sydney on the day of acquisition was 35°C, and land surface temperatures recorded in the thermal imagery ranged from 25 to 40°C. The cooling effect of vegetation is clearly visible in the thermal imagery. Areas of dense vegetation in the north and south-west, particularly in the suburbs Wahroonga, North Wahroonga, North Turramurra, St Ives and St Ives Chase, appear to have the lowest land surface temperatures. Golf courses, which have high canopy cover and areas of irrigated turf,

also have very low surface temperatures. Different materials absorb and retain heat at different rates, resulting in different surface temperatures. In general, impervious surfaces, such as buildings, roads, carparks, synthetic turf, dead grass and bare earth have higher land surface temperatures. The Council has a very high canopy cover, with little area of bare earth and dead grass. Most of the hot spots throughout the Council are buildings, roads and synthetic playing fields, which were scattered throughout the Council. Figure 13 illustrates some of these hotspots.

Figure 13 A and B demonstrate the surface temperature difference between a synthetic turf playing field (marked with an S) and a natural turf playing field (marked with an N) at North Turramurra Recreation Area. The synthetic turf has a similar temperature to the adjacent bitumen carpark and is much hotter than the natural irrigated turf playing field. Built up areas such as Lady Division Private Hospital (C and D) and the Bupa Aged Care St Ives retirement home (E and F) are significantly hotter than adjacent vegetation and are similar surface temperature to the surrounding roads.

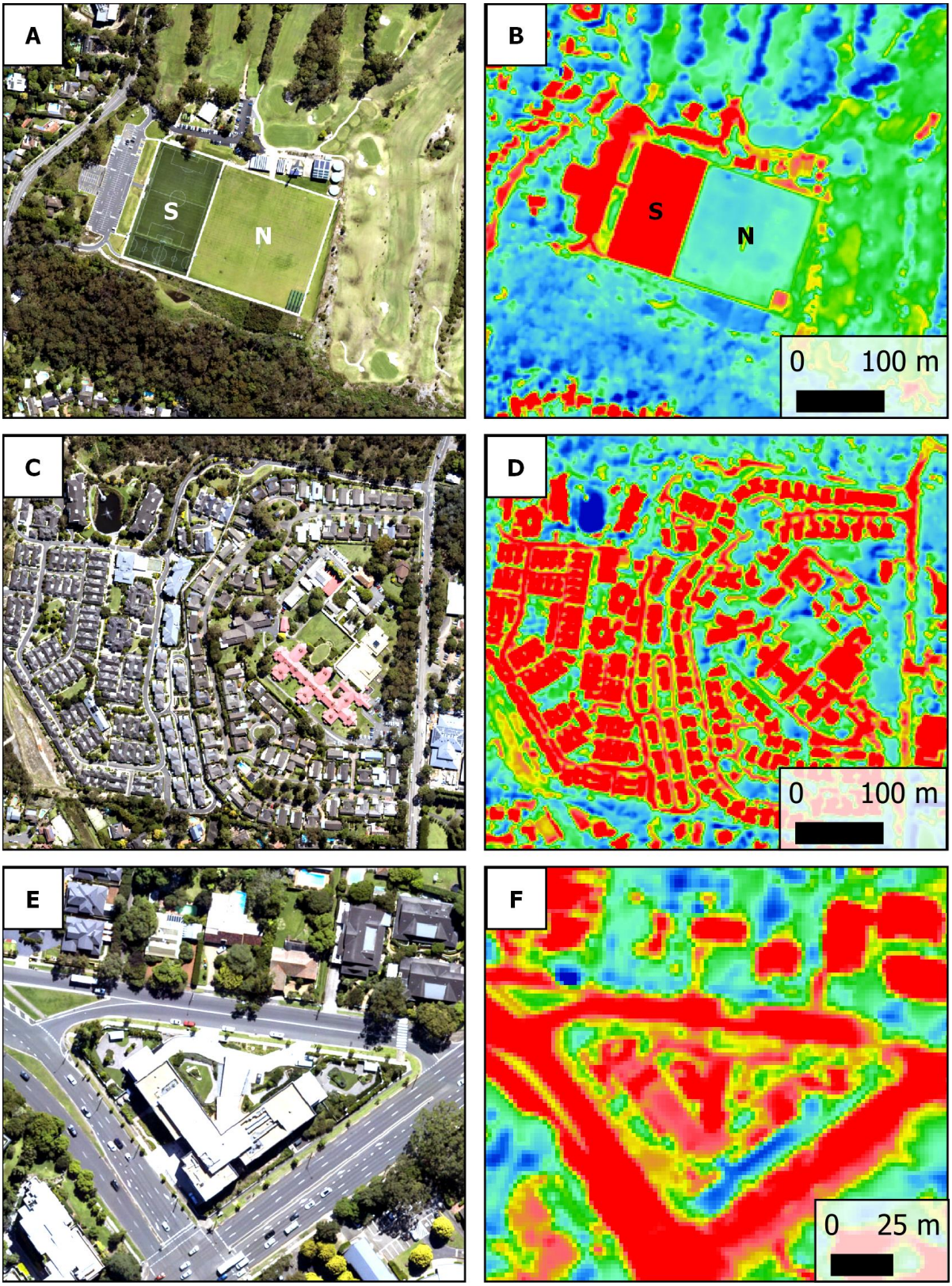

Figure 13: Thermal hot spots throughout the Council. High-resolution imagery of North Turramurra Recreation Area (A) and corresponding thermal imagery (B). Synthetic turf is indicated with an 'S', while natural turf is indicated with an 'N'. High-resolution imagery of Lady Division Private Hospital (C) and corresponding thermal imagery (D). High-resolution imagery of Bupa Aged Care St Ives (E) and corresponding thermal imagery (F). Surface temperatures are displayed on a colour scale from highest (red) through to lowest (blue).

3.3.1 Comparison to Previous Datasets

Vegetation and canopy mapping over Ku-ring-gai Council has been undertaken to certain extents, multiple times. These studies are not directly comparable with the current analysis, as different boundaries were used to extract statistics and methods of remote sensing have changed significantly over the time period. The greatly improved resolution of the ArborCam imagery and subsequent processing and analysis of the imagery to produce a highly accurate 3D dataset (to differentiate canopy from non-canopy) is not conducive to direct and accurate comparison between datasets. In 2002, Agrecon used satellite imagery collected from multiple years (1990 to 2002) to estimate canopy cover (Agrecon, 2002). The data had a spatial pixel resolution of 25m and found 2387 ha of canopy across the Council in 2002. In 2011, the Ku-ring-gai Council and Teresa James Flora Consultant used aerial imagery from 2005 to map key vegetation communities across the Council (Ku-ring-gai Council, 2011). The total area of the polygons in this study can be summed to total 3908 ha. The 2014 canopy cover study by Jacobs used 1.5m resolution imagery, and found canopy cover to be 52.1% of the total area (Ku-ring-gai Council, 2020). The current study found canopy covered 51.4% of the Council, or 4,389 ha. However, the Jacobs study used different boundaries to the current study, the main difference being their inclusion of the National Parks and Reserves within the Ku-ring-gai Council, and therefore is not directly comparable. Figure 14 illustrates the difference between the four datasets, highlighting the coarser resolution and tendency to miss areas of canopy in the older datasets, while potentially overestimating canopy around the edges of trees.

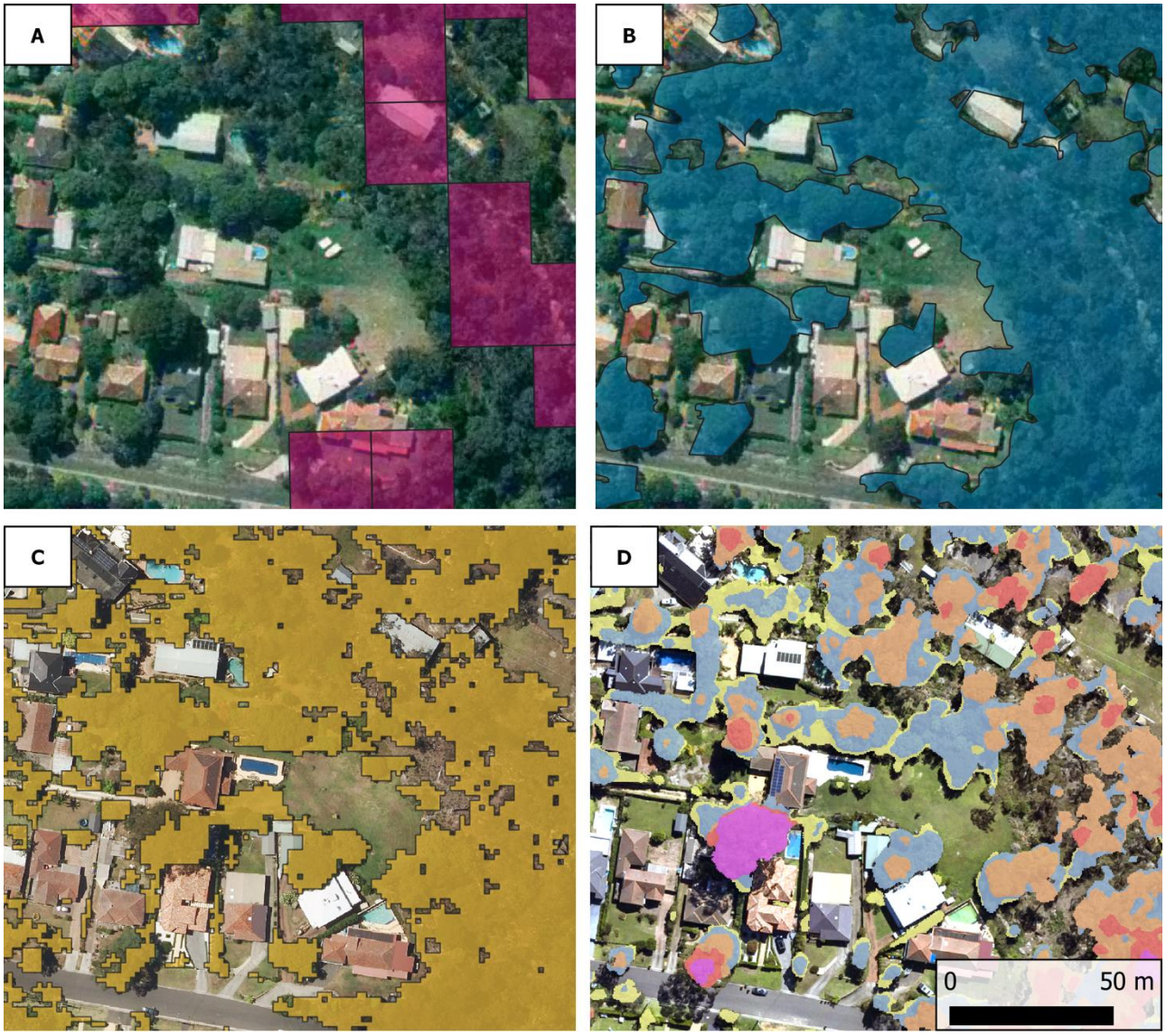

Figure 14: Comparison of the available recent vegetation cover datasets of Ku-ring-gai Council: (A) Agrecon 2002 dataset overlaid 2001 aerial imagery, canopy polygons shown in pink; (B) Extant vegetation cover by Ku-ring-gai Council and Teresa James Flora Consultant using 2005 data (blue polygons) overlaid on 2001 aerial imagery; (C) Jacobs 2014 canopy dataset (yellow polygons) overlaid on 2014 aerial imagery; and (D) the current ArborCarbon 2020 height stratified vegetation dataset, showing only canopy (3-5m yellow, 5-10m blue, 10-15m orange, >15m magenta) overlaid on the 2020 high resolution RGB imagery.

3.3.2 Natural Disasters

70.6 % of Ku-ring-gai Council is covered by vegetation, the majority of which is canopy (3m or higher). Much of the vegetation is within national parks around the perimeters of the Council, however, the natural forest extends into urban and residential areas of the Council, resulting in an urban area that is marbled with well-established extant vegetation and urban forest. This results in a Council that is vulnerable to natural disasters. The climate of NSW is influenced by many large-scale natural climate drivers, which can result in natural disasters like heatwaves, droughts, storms, floods and fires. The Ku-ring-gai Council has experienced several catastrophic natural disasters in recent years, such as the storm of November 2019, causing significant damage to the urban forest and infrastructure of the Council. Bushfires also pose a huge risk to the Council, and can cause significant damage to the vegetation in national parks and urban forest intertwined throughout the Council. The Council has a number of Community Protection Plans and bushfire preparation plans/maps to help residents understand bushfire risk and prepare for it in their community.

4 Conclusion

4.1.1 Urban Forest Monitoring

Local governments throughout Australia are increasingly appreciating the value provided by their urban forests and the risks to urban forest systems of pressures from increasing population density, and challenges of managing a resource which is fragmented across many land parcels, the majority of which are typically under private ownership.

The purpose of monitoring urban forest cover is to guide effective management and fulfil the aim or vision of the Council and community. These aims often take the form of targets for a desired level of canopy cover, or to maintain current canopy under pressure from urban development. Typically, the major question to be answered that requires monitoring canopy cover is: Has urban forest cover changed over the measurement period? Identifying change is critical for effective management to take place. It is therefore essential that the monitoring technology adopted has the accuracy and precision required to detect changes from the baseline, relative to the management action threshold.

It is important to note that airborne remote sensing methods can vary considerably in their accuracy for measuring urban tree canopy cover.

A common issue in environmental monitoring is the variability inherent in natural systems. For example, measurement of canopy cover can be impacted by foliage quality and density, which can fluctuate on an annual cycle or in response to drought. These may manifest as small changes in the metric of canopy cover, even though the number and size or trees has not changed. Variability can also be introduced by the technology itself, depending on the precision of the measuring equipment and conditions of measurement. Our analysis of various datasets utilised by Ku-ring-gai Council for measuring canopy cover suggests variations of several percent between them dependent on the system and methods used for acquisition and processing. For these reasons it is recommended that consistency is maintained in the monitoring technology and conditions of data acquisition.

In order to determine if small changes in canopy cover measured over time represent an accurate trend in urban forest area or condition, it is necessary to have an estimate of precision for the monitoring system. This is best achieved through regular monitoring of the canopy area and analysis of data over time. More frequent monitoring increases the ability of the monitoring system to detect subtle changes in true canopy area, therefore giving confidence to urban forest managers to take appropriate action in a timely manner in order to meet the expectation of the Council and community.

Local governments are increasingly looking at better methods to measure their baseline canopy cover, setting of targets, and temporal and spatial modelling of patterns within their boundaries (i.e. land use categories, suburbs etc.). Remote sensing technologies have been identified as a powerful tool that can be used for the collection of data that guides their Greening and Urban Forest Plans (ArborCarbon, 2015). Councils have recognised that the same remote sensing technologies can be used not only to measure canopy, but also measure precise changes in tree condition for early detection of impacts from abiotic and biotic factors (ArborCarbon, 2015, 2018), or to help build the resilience of their communities to climate change (ArborCarbon, 2016). As the technology improves additional applications are being discovered, such as modelling the extent and impact of shade from trees (ArborCarbon, 2017), species classification, tree counting, and the relationship between trees and the built environment.

Using accurate and repeatable measures of vegetation cover, condition and surface temperature will help to increase, protect and restore canopy cover across Ku-ring-gai Council and facilitate it to reach the United Nation's Sustainable Development Goals. These goals are the blueprint to achieving a better and more sustainable future for all, particularly goals 1: No Poverty, 3: Good Health and Well-Being, 7: Affordable and Clean Living, 11: Sustainable Cities and Communities, 13: Climate Action, 15: Life on Land, and 17: Partnerships.

The main findings of this report are:

- The total vegetation cover in Ku-ring-gai Council was 70.6% of the total Council area of 8539 ha.
- Canopy (vegetation 3m and above) covered 51.4% of the Council. This is less than the most recent canopy cover estimate in 2014 of 52.1%. This is unlikely to represent a true decline in cover given the different measurement techniques used.
- North Turramurra had the greatest canopy cover as a proportion of suburb area (61.8%), while Roseville had the least (35.7%).
- The majority of the Council's canopy area falls within the E2 land zone (Environmental Conservation) (83.4%), while the least was in B4 (Mixed Use) (12.4%), however, the areas with low canopy in general were small proportions of the whole Council area.
- High canopy cover kept land surface temperatures low, however, impervious surface hotspots were prevalent throughout the Council.

Based on the findings of this analysis, we recommend the following:

1. Airborne multispectral vegetation surveys over Ku-ring-gai Council should be conducted on an annual or periodic basis to track changes in vegetation cover and condition over time and the data used to monitor and set achievable targets for future canopy cover and condition.
2. Further analysis should be conducted on urban areas only, by removing National Parks and Reserves and large areas of environmental conservation. Urban areas are managed differently and are under different set of pressures than canopy within National Parks and reserves, therefore, these areas should be monitored separately. This would give a more targeted assessment of urban forest cover and potentially highlight differences between suburbs and changes over time caused by urban development.
3. Consider the significant impact to the urban heat environment caused by synthetic turf.
4. Undertake further analysis to quantify the urban heat island effect, in order to identify where to focus tree planting efforts.
5. Undertake vegetation condition analysis, by using vegetation condition indices to set a baseline condition index that can be compared to in future acquisitions.
6. Further analysis should consider the differences in canopy cover between developed and undeveloped residential and business land, as well as style of development. This could be used to forecast potential future canopy loss as the Council grows.

5 References

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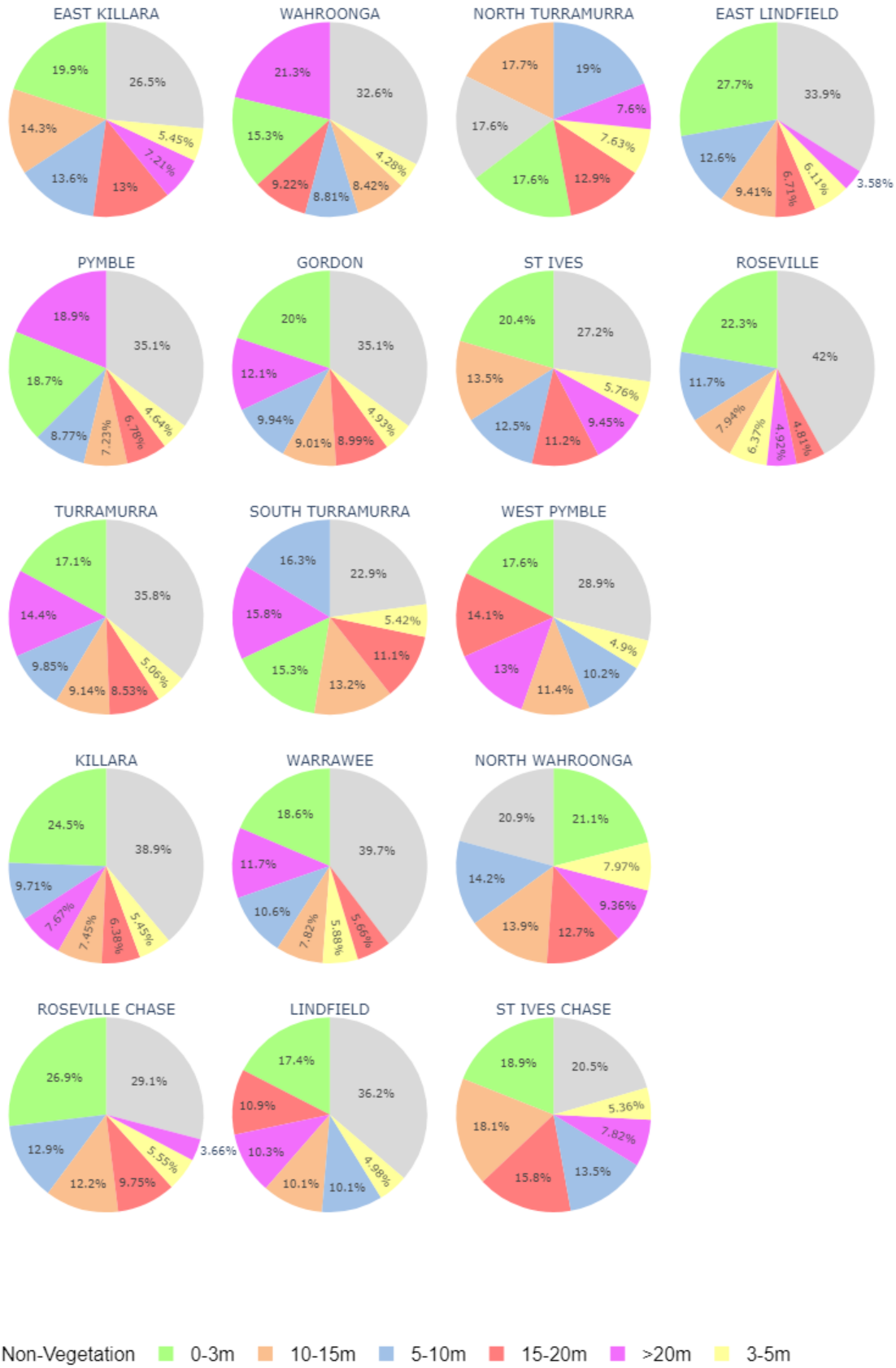
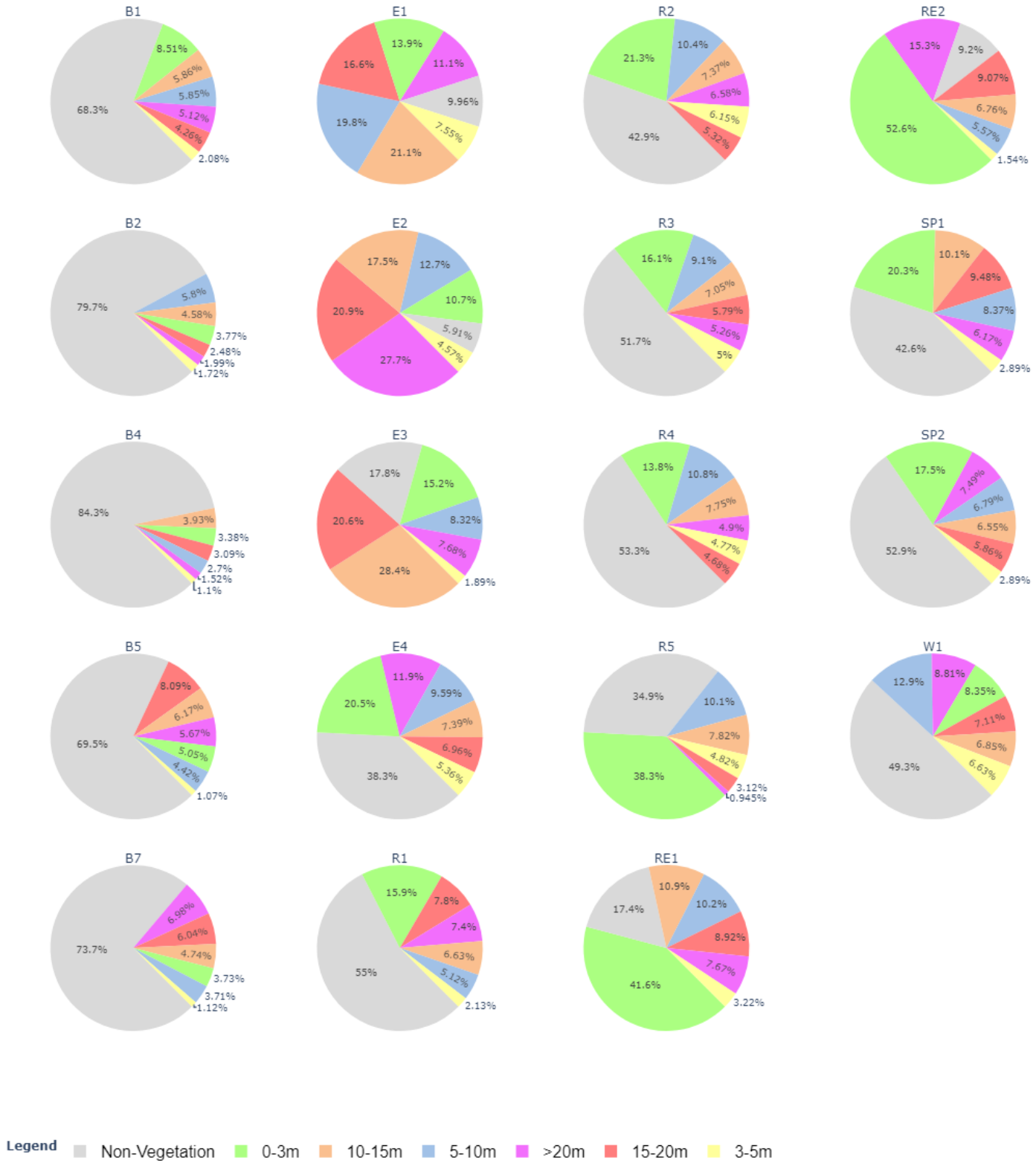
Appendix A – Vegetation Cover by Suburb



Appendix B – Vegetation Cover by Land Zone



Appendix C – Canopy cover of Land Zones within Suburbs

Table 1: Proportional canopy cover of each land zone within each suburb of the Ku-ring-gai Council.

	Canopy cover (%)																		
Suburb	B1	B2	B4	B5	B7	E1	E2	E3	E4	R1	R2	R3	R4	R5	RE1	RE2	SP1	SP2	W1
EAST KILLARA	19.7					74.1	8.6		25.7		25.4				26.5			29.7	22.7
EAST LINDFIELD	2.0					47.7	69.3		32.0		27.6				36.0	39.5		23.4	
GORDON		17.5	15.5	42.8			86.4		49.1		37.5	27.8	28.2		38.4		38.9	18.9	
KILLARA	58.5	18.7				84.0	8.7		41.6		32.6	44.5	36.6		51.9	29.4		25.2	
LINDFIELD	17.1	15.9	3.4	21.8		8.3	86.7	67.0	37.8	2.5	34.9	4.4	33.3		41.1	66.5	48.4	24.2	59.7
NORTH TURRAMURRA	1.6					74.2	87.8		29.5		37.5			26.8	24.5	56.5		31.3	
NORTH WAHROONGA						67.2	7.4		32.4		4.0				13.9			43.4	
PYMBLE		24.6		0.6	22.6		93.9		65.2		4.2	35.8	33.3		6.3	46.6	42.5	34.4	
ROSEVILLE	1.4	15.0		1.9			93.4	78.9	59.3		32.2		32.6		45.7	31.4		18.9	95.4
ROSEVILLE CHASE	9.8						81.9		42.9		24.4				34.7	26.5		43.2	
SOUTH TURRAMURRA	22.2					95.0	86.0		44.4		34.2				4.5			35.2	
ST IVES	21.8	13.0				79.8	79.7		44.6		32.2	28.4	28.6		49.3	28.0		3.4	11.9
ST IVES CHASE	23.7					78.8	84.4		33.3		28.3				23.2				
TURRAMURRA	15.2	17.4					85.4		57.8		4.7	36.2	37.4		43.4			32.3	
WAHROONGA	24.4	14.2				94.5	92.8		58.1	46.2	42.3	43.4	31.6		45.7		16.6	28.7	
WARRAWEE							93.6		77.5		41.4	19.1	34.6		74.2			29.6	
WEST PYMBLE	25.8					86.4	89.8		42.4		35.1				49.3	57.5		27.2	59.9

Table 2: Area (ha) of canopy cover in each land zone within each suburb of the Ku-ring-gai Council.

	Canopy cover (ha)																		
Suburb	B1	B2	B4	B5	B7	E1	E2	E3	E4	R1	R2	R3	R4	R5	RE1	RE2	SP1	SP2	W1	TOTAL
EAST KILLARA	0.1					79.0	53.1		21.5		10.9				2.7			1.1	0.4	168.8
EAST LINDFIELD	0.0					13.4	31.3		4.2		35.9				3.2	0.1		0.8		89.0
GORDON		1.2	0.6	0.2			56.5		17.4		71.7	1.3	6.7		11.2	0.0	0.2	3.1		170.1
KILLARA	0.4	0.2				16.0	12.4		4.2		103.3	0.3	11.0		5.4	12.7		4.3		170.2
LINDFIELD	0.1	1.1	0.0	0.1		52.0	48.2	3.8	11.0	1.9	87.5	1.5	9.4		5.3	4.1	9.9	3.6	0.6	240.4
NORTH TURRAMURRA	0.1					592.0	81.4		50.0		1.1			5.7	12.3	6.1		5.9		754.7
NORTH WAHROONGA						91.7	99.9		22.4		6.7				1.7			3.0		225.4
PYMBLE		0.7	0.0	0.0	2.9	0.0	54.9		26.0		160.6	1.4	4.8		7.2	23.7	0.5	19.4		302.2
ROSEVILLE	0.0	0.5		0.0		0.0	12.2	0.0	8.9	0.0	69.3		5.6		3.2	4.8		2.4	0.1	107.0
ROSEVILLE CHASE	0.0						24.2		10.3		10.2				6.7	0.4		3.1		54.9
SOUTH TURRAMURRA	0.2					30.9	102.4		10.4		39.4				4.5			1.5		189.4
ST IVES	0.2	0.8				277.8	163.6		38.2		170.4	5.5	6.1		58.2	11.4		16.0	0.1	748.4
ST IVES CHASE	0.1					102.6	65.2		24.9		16.8				1.4					210.9
TURRAMURRA	0.1	1.2					70.5		24.2		163.3	1.4	9.9		8.2	0.0		3.9		282.8
WAHROONGA	1.0	0.4				33.1	102.9		66.6	2.2	181.4	2.0	8.2		6.9		2.0	14.4		420.9
WARRAWEE							1.1		3.9		45.4	0.4	1.4		0.6			3.6		56.4
WEST PYMBLE	0.5					42.2	62.2		13.3		63.2				8.0	4.1		3.3	0.9	197.7
TOTAL	2.8	6.1	0.6	0.3	2.9	1330.8	1042.2	3.8	357.3	4.1	1237.3	14.0	63.2	5.7	146.8	67.5	12.6	89.5	2.1	4389.4

Appendix D – Vegetation cover of Suburbs (E1 and E2 removed)

Table 3: Area of vegetation cover and proportion of canopy cover for each suburb in the Ku-ring-gai Council, with E1 and E2 removed.

Area (ha)										
Suburb Name	**Suburb Area**	**Non-Vegetation**	**0-3m**	**3-5m**	**5-10m**	**10-15m**	**15-20m**	**>20m**	**Canopy (>3m)**	**Canopy Cover (%)**
EAST KILLARA	142.6	69.1	36.8	8.1	13.5	7.8	4.5	2.8	36.7	25.7
EAST LINDFIELD	158.7	71.3	43.2	9.7	15.5	10.1	6.0	2.9	44.3	27.9
GORDON	312.7	129.8	69.2	16.5	30.9	24.6	20.3	21.3	113.6	36.3
KILLARA	429.9	177.3	110.8	24.1	41.2	28.4	21.2	27.0	141.9	33.0
LINDFIELD	398.3	178.6	79.6	22.3	41.6	32.9	24.8	18.6	140.1	35.2
NORTH TURRAMURRA	274.8	104.7	88.8	13.9	24.0	18.9	14.4	9.9	81.2	29.6
NORTH WAHROONGA	109.8	47.4	28.6	6.3	11.1	7.7	5.6	3.2	33.8	30.8
PYMBLE	594.6	227.4	119.9	29.4	54.6	43.2	37.5	82.6	247.3	41.6
ROSEVILLE	286.3	125.5	66.0	18.5	33.0	21.6	11.9	9.7	94.8	33.1
ROSEVILLE CHASE	94.8	34.5	29.6	5.5	10.7	7.4	5.0	2.2	30.7	32.4
SOUTH TURRAMURRA	154.8	62.4	36.4	8.9	17.2	12.4	9.6	7.9	56.0	36.2
ST IVES	875.6	350.1	218.7	43.0	85.7	73.0	55.2	50.1	306.9	35.0
ST IVES CHASE	140.6	60.6	36.8	8.2	15.0	9.9	6.6	3.5	43.2	30.7
TURRAMURRA	518.8	207.9	98.5	29.4	53.9	40.7	32.8	55.5	212.3	40.9
WAHROONGA	662.8	259.8	118.0	31.7	58.2	49.2	48.2	97.8	285.0	43.0
WARRAWEE	134.0	53.6	25.1	7.9	14.3	10.5	7.6	15.0	55.3	41.3
WEST PYMBLE	250.9	102.0	55.5	13.5	24.3	20.3	18.9	16.4	93.3	37.2
TOTAL	3973.5	1638.8	964.2	214.4	394.0	297.9	222.7	241.6	1370.5	34.5