Clean Air and Urban Landscapes Hub

National **Environmental Science** Programme

Benchmarking Urban Vegetation Cover: Melbourne, Perth, Sydney

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The University of Melbourne
RMIT University
The University of Western Australia
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All Australian cities are located on unceded Indigenous land. We acknowledge the traditional custodians of lands across Australia, their Elders, Ancestors, cultures and heritage. In particular we acknowledge and pay our respects to people of the Woiwarrung and Boowarung language groups of the eastern Kulin nation where RMIT University is located; and the Noongar people, where the University of Western Australia is located.

About the Clean Air and Urban Landscapes Hub

The Clean Air and Urban Landscapes Hub (CAUL) is a consortium of four universities: The University of Melbourne, RMIT University, the University of Western Australia and the University of Wollongong. The CAUL Hub is funded by the Australian Government's National Environmental Science Program. The task of the CAUL Hub is to undertake research to support environmental quality in our urban areas, especially in the areas of air quality, urban biodiversity, and with a focus on applying research to develop practical solutions.

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Contents

1. Introduction

A network of vigorous and extensive urban vegetation is critical to our health and wellbeing, and for protecting urban biodiversity. But how do we ensure we have abundant urban vegetation as our cities develop, consolidate and grow?

Measuring and monitoring tree canopy and urban greening provides essential information to the government and community to support the management of our urban forests. This report presents an examination of the current and changing state of tree canopy cover in three Australian cities: Sydney, Melbourne and Perth. The project sits within a broader research context, “Making greening happen in consolidating cities”, funded through the Clean Air and Urban Landscapes (CAUL) research hub, National Environmental Science Program. The project is a collaboration between RMIT University, The University of Western Australia and CSIRO. This research has evolved in response to critical gaps in our understanding of the spatial variability in vegetation cover, structure, and change across our major metropolitan regions.

The aim of this research was to understand the spatial distribution of urban vegetation, focusing on tree canopy cover, and its relationship with land-use; and to produce rich and targeted information to support decision making in practice.

To address this aim, the following objectives guide the work presented here:

- Provide tree canopy cover benchmarking data at the Local Government level for Greater Melbourne, Sydney and Perth, including the relationship with land-use.
- Provide a detailed dashboard approach to analysing community level tree canopy cover performance including key metrics of canopy cover, canopy cover by land-use, and canopy cover change over time; and allowing for comparative assessment of performance.

To deliver on these objectives we draw on high resolution, metropolitan-wide, mapping of vegetation cover for comparison with land-use activities and key policy implementations. We use high-resolution remotely sensed information of urban vegetation coverage (including canopy cover and total vegetation) mapped to a modified Mesh Block level, with land-use information derived from the Australian Bureau of Statistics (ABS). This enables detailed investigation of vegetation cover (particularly tree canopy) and the potential mitigating role of land management activity including land-use planning interventions.

In this report, the spatial distribution of tree canopy cover in Sydney, Melbourne, and Perth is first reported followed by an assessment of canopy cover by major land-use classes across metropolitan sub-regions. This approach allows for an initial comparison and benchmarking of canopy coverage by Local Government Areas (LGAs) across each metropolitan region, as well as an in-depth examination of how tree canopy is distributed across various land-uses in each LGA.

We then propose a Dashboard approach, consisting of maps, charts and indicators, that allows for in-depth assessment of community level urban forest performance and comparison against other communities. The Dashboard was designed to improve decision making fundamental to the enhancement and preservation of urban forest. Examples of the Dashboard results are presented for a selection of suburbs from Perth and Melbourne.

This report presents findings that pose challenging questions for urban policy and management with respect to canopy cover preservation and enhancement. But, also provides an evidence base to evaluate the very actions that support abundant and accessible vegetation across our ever-changing cities.

2. The Urban Forest and Urban Development

A vibrant and extensive urban forest is essential to health and welling in cities (Kendal et al 2016); and to the preservation of ecosystems and biodiversity (Threlfall et al 2019). An extensive urban forest reduces urban heat and heat related health impacts, which can be severe in Australian cities (Duncan et al 2019); and can enhance physical health and mental wellbeing. Urban forests support biodiversity and important ecosystem functions including healthy soil, clean air and water, and habitat for biodiversity. However, vegetation, particularly trees and tree canopy, across Australian cities is under significant pressure and is in decline in many areas (Amati et al 2017).

The urban forest occurs across all land types. Much public and policy attention is focused on parks and streetscapes (Phelan et al 2019; Croeser et al 2020). These two land uses are critical for supporting an extensive urban forest, providing a large yield, that is typically under the direct management of local and state governments; providing the opportunity to target strategy, management and investment to protect and enhance trees on public lands.

However, in most urban environments approximately half of the urban forest (measured as tree canopy coverage) exists on private land; and of this, the vast majority is on residential land (Hurley et al 2019). While harder for governments to control, there is an important role for local government, supported by State policy frameworks, to influence the retention and even expansion of vegetation on private land (Phelan et al 2019; Clark et al 2020; Ordóñez et al 2020).

As cities grow, pressure for urban consolidation increases. The move towards a compact city often increases market demand for smaller well-located dwellings. Urban consolidation is an important policy goal for improving the sustainability and liveability of cities, slowing outward expansion and providing a more energy efficient urban form (Hurley et al 2017). Yet, as cities become denser and the traditional suburban 'house and garden' is redeveloped, trees are being replaced by buildings and hard surfaces (Hall, 2010). Higher density modes of consolidation also typically eliminate vegetation. However, their greater housing contribution means that the cumulative impact of this form of consolidation on trees and tree canopy is significantly less than that of low density redevelopment. Further, urban fringe development increasingly sees high lot coverage with little space for trees.

Development is not the only driver of tree removal: a significant proportion of urban tree loss is not associated with development, but rather the practices and preferences of private landholders. Landowners remove trees for a variety of reasons, including landscaping, unlocking views, conflict with buildings, safety fears, and to reduce maintenance such as leaf removal.

In combination, these pressures erode the contribution of private land to urban tree canopy cover, impacting the benefits that the urban forest provides. Loss of vegetation is often stemmed by gains in the public realm, occurring in parks, streetscapes and publicly managed land. However, balancing the conflicts with other infrastructure and community aspirations is an ongoing challenge, placing incredible pressure on the public realm to provide urban forest.

The importance of residential land to support urban tree canopy highlights the potential importance of urban planning policy and development assessment processes in helping balance land development pressures with tree protection and provision. However, there is limited evidence that planning policy mechanisms are creating positive outcomes for private land canopy contribution (Daniel, Morrison et al 2016). Further, more recent development and associated planning policy is producing built form outcomes with less vegetation cover than earlier developments – for example, Daniel, Morrison et al. (2016) found 30% less canopy cover in areas developed from 1990 in their case study of Brisbane. If the benefits of a thriving urban forest are to be realised in cities undergoing expansion and change, then urban planning policy needs to be more attuned to the impact of development on this infrastructure, and include mechanisms to protect and enhance vegetation.

To protect and enhance the urban vegetation, particularly trees, requires a multi-pronged approach. Different land use types bring with them different landowners, managers, governance structures, policy and politics. To develop effective strategy and action across all land types it is essential to be able to benchmark and monitor the urban forest by land use. This allows accurate assessment of the contribution of different land use types to the urban forest; and assessment of change dynamics. This, in turn, can lead to more accurate diagnosis of drivers of change, and help in the development of appropriate strategy, policy, management and investment, that protects and enhances this valuable resource.

3. Approach

Overview

As identified above, the aim of this research was to understand the spatial distribution of urban vegetation, focusing on tree canopy cover, and its relationship with land-use; and to produce rich and targeted information to support decision making in practice. We focus on the metropolitan regions of Sydney, Melbourne, and Perth, together covering a population of nearly 12 million people. The project draws from several new primary and secondary datasets combining high resolution urban vegetation coverage data (including canopy cover and total vegetation) for several time-points; with land-use data derived from ABS Mesh Block attributes and state government data depicting cadastral parcels and road casements. The result provides a detailed map (vector-based GIS information) across each cities' Metropolitan area that enables spatial analysis of the relationship between vegetation cover, vegetation change and land-use characteristics.

Vegetation Data

Vegetation structure data was produced using The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) Urban Monitor® approach (Caccetta et al, 2016). The approach monitors land surface and cover across urban and peri-urban environments using digital aerial photography and other spatial data. The approach provides a three-dimensional representation of the spatial distribution of vegetation at deci-centimeter (typically 10-20cm) resolution for large spatial areas such as the greater metropolitan regions of cities and their surrounds. Vegetation cover was grouped into five height classes: grass (0-0.5m); shrub (0.5 - 3m); small tree (3 - 10m); medium tree (10 - 15m); and large tree (15m+). The Urban Monitor® data used as the basis of this study was provided in ERS raster format with a 0.2m cell size.

The Urban Monitor® methodology for measuring vegetation uses proprietary techniques developed by the CSIRO Australia to identify the presence or absence of reticulated vegetation within any given cell along with the height of the vegetation relative to the ground (Caccetta et al, 2016). Whilst the approach provides an accurate indication of the presence and height of vegetation, it is not able to identify specific typologies of vegetation, subsequently, for the purposes of this analysis we have adopted a vegetation height-based classification to describe different vegetation arrangements. This approach uses the terms grass, shrubs and trees to describe vegetation with heights of less than 0.5m, 0.5 to 3m and over 3m respectively (Table 1).

When examining change over time using the Urban Monitor® vegetation cover information it is important to note the limitations in mapping grass cover. Grass and ground cover detection is impacted by vegetation vigour, with dry and dormant cover often difficult to discriminate. This means there can be significant fluctuations in cover based on recent rainfall activity at the time of image capture. This impacts comparison over time. For this reason, the detailed two-date change example provided in this report largely focuses on tree canopy cover (> 3.0m and shrub cover (0.5m < 3.0m)).

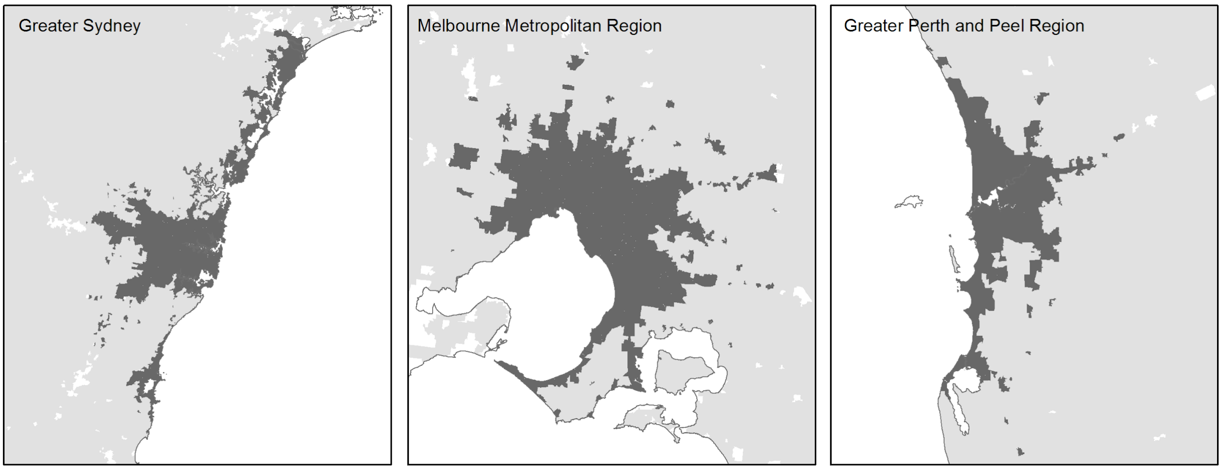
Table 1: Vegetation Typologies

Grass	Vegetation Height 0 < 0.5m
Shrubs	Vegetation Height 0.5m < 3.0m
Trees	Vegetation Height > 3.0m
Total Vegetation	Any vegetation > 0m high

Study area

The focus of this report was to provide summary statistics for vegetation change across the urbanised areas of three major metropolitan regions. For the purposes of this study, vegetation data were available for a geographical area covering the majority of Sydney, Melbourne and Perth. Coverage was limited to the extent of imagery capture by each State's annual high- resolution aerial image acquisition of urban areas, providing the primary data required for the Urban Monitor® approach (see figure 1).

Figure 1: Study Area Maps: Melbourne, Perth, Sydney



Urban Centres and Localities

Urban areas here were described as urban centres and localities (UCLs defined by the ABS in 2016). Urban Centres and Localities (UCLs) represent areas of concentrated urban development with populations of 200 people or more. These areas are primarily identified using objective dwelling and population density criteria using data from the 2016 Census (ABS Cat. 1270.0.55.004). Given the focus on urbanised areas, for some fringe LGAs, statistics generated relate to only a subset of the entire area. Allied with limitations of data coverage, this means that the reported statistics are limited to the portion of each region that is defined as urbanised and for which high levels of data coverage is available (see Figure 1). As such, we only present metrics for Modified Mesh Block vector features with over 90% data coverage.

Mesh Blocks

Within the study areas, the ABS Mesh Block, the smallest unit for which census information is publicly available (approximately 30-60 dwellings), provided our minimum mapping unit. Mesh Blocks can vary in size, but are generally relatively small, especially in urbanised areas. They form the building blocks of all other statistical geographies. From 2016 Mesh Blocks have been designed to align closely to local government boundaries. In addition, the ABS Mesh Block provides a consistent national measure of land-use whereby each area is categorised by the dominant land-use found within. Mesh Blocks are attributed with a principal land use to indicate the major use of lands within any given delineated area (Table 2) (For further information see ABS Cat: 1270.0.55.001).

Modified Mesh Block

A modified Mesh Block is a unit of measurement designed by the CAUL Hub that incorporates linear infrastructure into the ABS Mesh Block structure based on cadastral and road/rail casement boundaries. Modification of each ABS Mesh Block was performed by combining Mesh Block features with State level cadastral parcel and road casements information. GIS processing of these datasets has produced a new space-filling partition of land-use characteristics for each study area (referred to as the modified Mesh Block) allowing for the separation of council/state-controlled land from areas which may be privately held. The modified Mesh Block Structure works in a hierarchical manner with each feature retaining the original Mesh Block category and also being allocated a reclassified Mesh Block Code identifying whether the land in question is a lot or an infrastructure corridor (Table 3 and Figure 2). This allows for the addition of an extra land use class ('Infrastructure' to be designated in addition to the ABS categories; largely representing streets, but also rail) to help in the differentiation between private and council/state-controlled lands. The result is an innovative approach for examining urban vegetation by both land use and tenure providing an innovative decision support tool allowing for enhanced management of urban vegetation.

Public and Private Realm

As identified above, the modified Mesh Block reclassification is also allocated an attribute of either 'public realm' or 'private realm' (Table 3). The private realm is assumed to include all residential, commercial, industrial and primary production land, excluding the linear infrastructure networks within these categories. The public realm includes all the linear infrastructure networks from the ABS Mesh Block categories, plus the categories of parkland, education, hospital and/or medical, transport and water. It is acknowledged that this split will only approximate public land ownership/management as many of these service categories include privately owned and managed land. In this public/private designation, land classed as 'Other' by ABS remains as 'Other' (except for infrastructure networks within the class, which are added to 'public').

Table 2 - Mesh Block Based Land Use

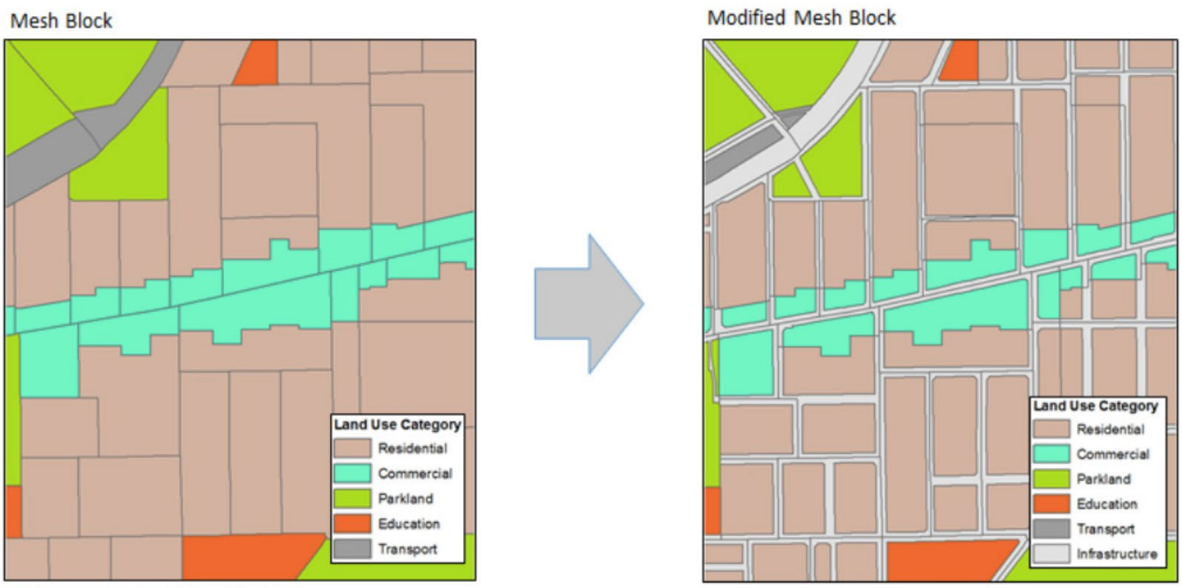
Mesh Block Category	**Description**
Residential	Generally, residential areas have been separated from other land uses. Residential Mesh Blocks can include houses, duplexes, apartments, serviced/long stay apartments, townhouses, gated communities, complexes, caravan parks, retirement villages, military bases where people live, and prisons.
Commercial	Mesh Blocks categorised as commercial will contain a number of businesses, and where possible, will have a zero population count. Some commercial Mesh Blocks may contain population, for example, where a residential flat is above a shop.
Industrial	Mesh Blocks categorised as industrial will contain a number of businesses, and where possible, will have a zero population count.
Parkland	Mesh Blocks with parkland, nature reserves and other minimal use protected or conserved areas have been categorised as Parkland. Parkland Mesh Blocks may also include any public open space and sporting arena or facility whether enclosed or open to the public, including racecourses, golf courses and stadiums.
Education	Education Mesh Blocks aim to capture education facilities and may contain population in non-private dwellings such as boarding schools or universities.
Hospital/Medical	Mesh Blocks with hospital or medical facilities have been classified as such. Hospital/Medical Mesh Blocks will also include aged care facilities, which are independent to larger retirement villages.
Transport	Mesh Blocks which only contain road or rail features have been categorised as transport.
Other	Mesh Blocks classified as other are representative of land uses which could not be easily placed in one of the other nine categories due to the nature of the land use, or due to evidence of high mixed use.
Primary Production	Primary production has replaced the previous category of agricultural. Mesh Blocks categorised as primary production must have more than 50 per cent of their area attributed to a primary production land use, and has been categorised as this using a range of available datasets. Mesh Blocks which were previously categorised as agricultural and did not meet this criteria were categorised as other.
Water	Water Mesh Blocks aim to identify water bodies where possible.

Source: ABS Cat: 1270.0.55.001

Table 3: Modified Mesh Block Based Land Use

Mesh Block Category	**Modified Mesh Block Reclassification**	**Description**	**Realm**
Residential	Residential	Land made up of residential lots	Private
Residential	Infrastructure	Linear infrastructure in residential streets	Public
Commercial	Commercial	Land made up of commercial lots	Private
Commercial	Infrastructure	Linear infrastructure in commercial areas	Public
Industrial	Industrial	Land made up of industrial lots	Private
Industrial	Infrastructure	Linear infrastructure in industrial areas	Public
Parkland	Parkland	Parkland	Public
Parkland	Infrastructure	Linear infrastructure in Parkland areas	Public
Education	Education	Education land	Public
Education	Infrastructure	Linear infrastructure in education areas	Public
Hospital/Medical	Hospital/Medical	Hospital/medical land	Public
Hospital/Medical	Infrastructure	Linear infrastructure in hospital/medical areas	Public
Transport	Transport	Transport land (major transport infrastructure)	Public
Transport	Infrastructure	Linear infrastructure in transport areas	Public
Other	Other	Other lots	Other
Other	Infrastructure	Linear infrastructure in other areas	Public
Primary Production	Primary Production	Land made up of primary production lots	Private
Primary Production	Infrastructure	Linear infrastructure in primary production areas	Public
Water	Water	Water bodies (minimal)	Public
Water	Infrastructure	Linear infrastructure around water bodies	Public

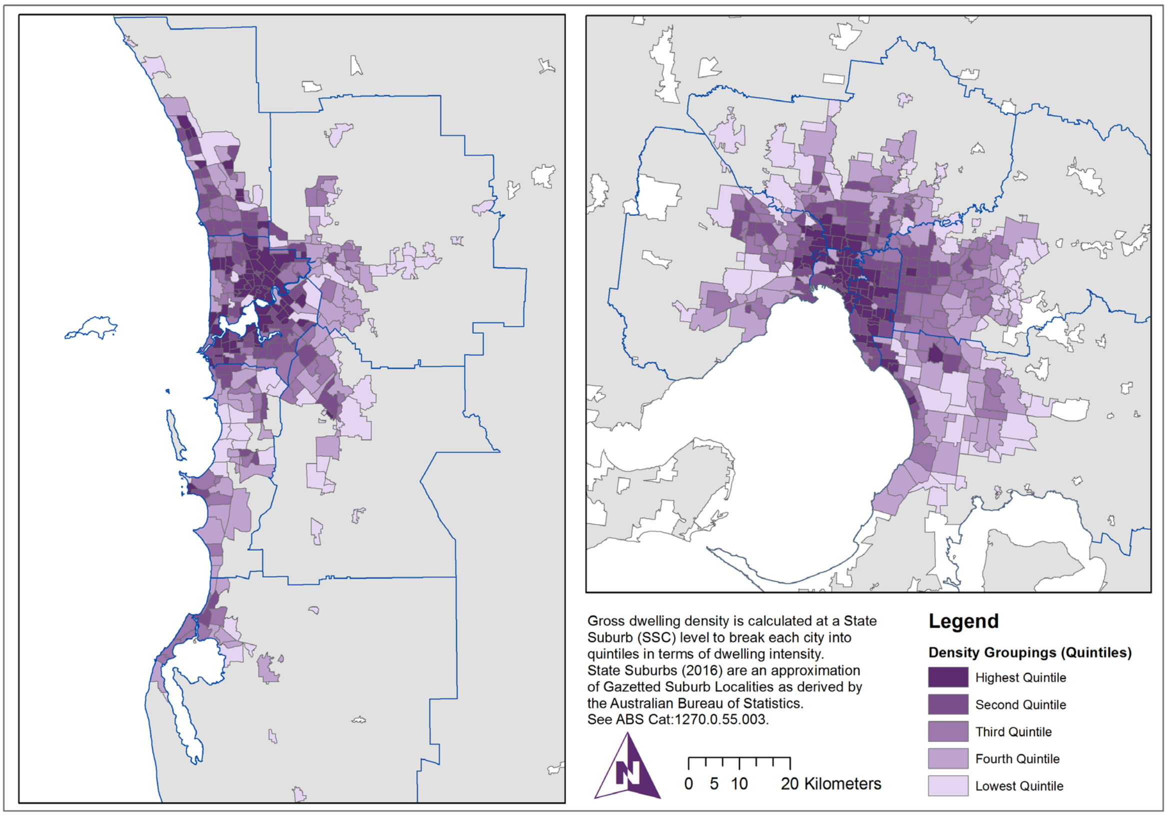
Figure 2: Mesh Block to Modified Mesh Block



Density Category

Based on previous work by Saunders et al. (2020), statistical modelling developed to predict tree canopy change across Perth, identified that the three primary drivers of tree canopy cover in residential neighbourhoods were: the mean year structures in the neighbourhood were built; the minimum year structures were built (or the 'age' of the suburb); and population density. Identification of mean and minimum build years requires specialised information not readily available for all cities across Australia. However, using information provided by the ABS, population density can be mapped across the nation for all census units including the Mesh Block. To this end, we categorise Suburbs (as defined by the ABS) based on population density quintiles to provide for a comparison of communities with similar composition (Figure 3). As a proof of concept, we then present a series of metrics for several Suburbs across Perth and Melbourne falling within a cross section of quintiles as a means for benchmarking and comparing community indicators of urban vegetation.

Figure 3: Dwelling Density Quintiles



4. Benchmarking Urban Canopy Cover and Relationship to Land-use

4.1 Introduction and City Comparison

This section provides an overview of urban tree canopy cover at a local government level across the metropolitan regions of Melbourne, Perth and Sydney. It focuses on urban canopy cover and its relationship to land use and is limited to Urban Centres and Localities for which Urban Monitor data are available. Tree canopy cover measures are based on data from 2016 for Sydney and Perth and 2018 for Melbourne.

Figures 4, 5, 6 and 7 present a high-level overview of the data, comparing headline results across the three cities. Following this, Sections 4.2, 4.3 and 4.4 report on greater capital city results for Melbourne, Perth and Sydney respectively.

Figure 4 presents headline tree canopy cover for each of the 98 LGAs we cover from the greater Melbourne, Perth and Sydney regions. While it is not particularly useful to compare in detail across cities, due to significantly different climatic and biophysical factors, the chart highlights the significant range of canopy cover across urban LGAs; and the significantly higher canopy cover that exists in Sydney. 16 of the top 20 LGAs for canopy cover are located in Sydney whilst none of the Sydney LGAs are in the bottom 20. Melbourne has the bottom 6 LGAs; although Perth has several with low cover including 7 in the bottom 20.

Figure 4: Tree Canopy Cover (%), all LGAs in Study

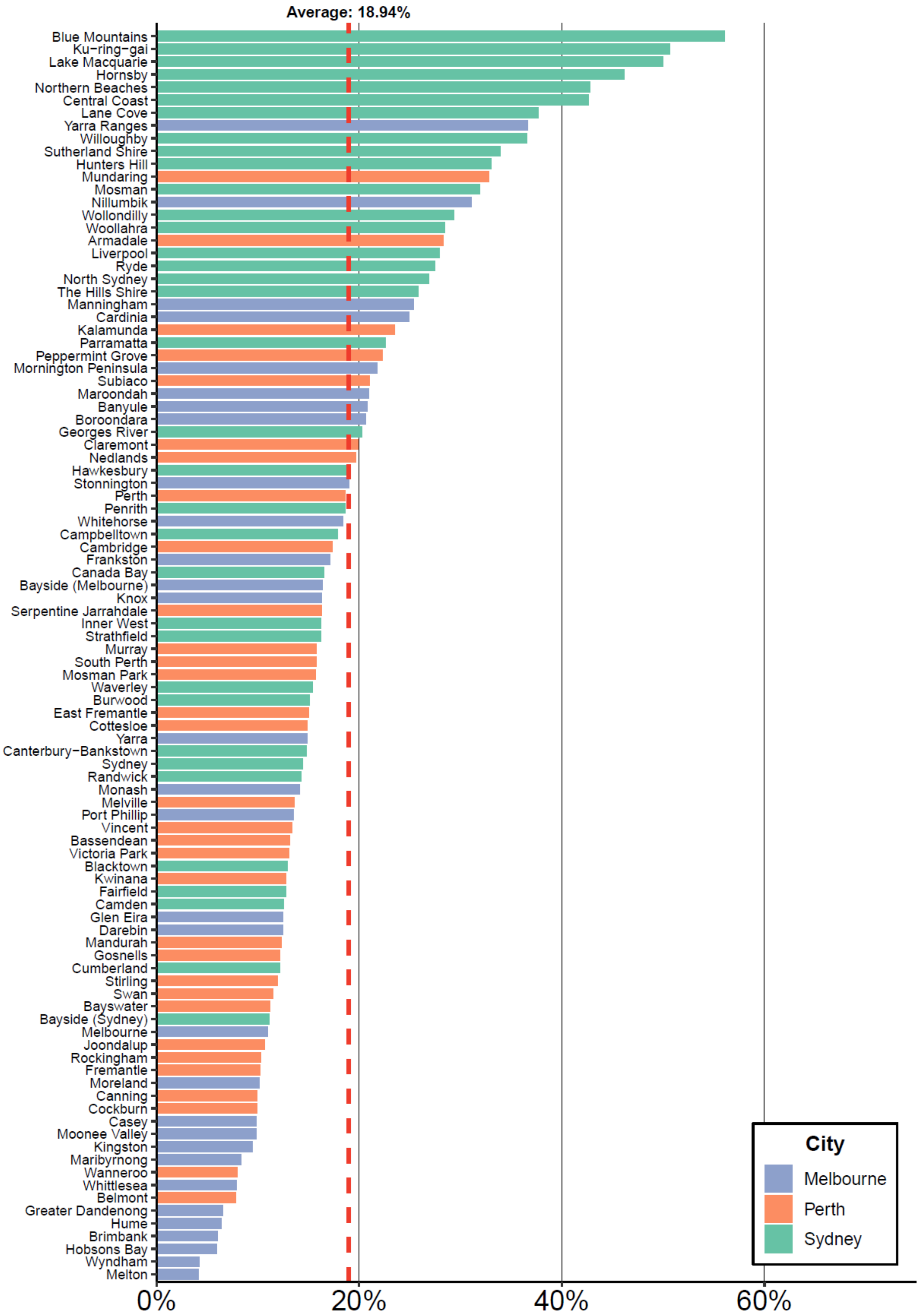


Figure 5 provides a comparison of the land-use distribution by city. At this aggregated level all cities have a similar distribution of land, reflecting the basic spatial requirements for the major land use functions in large capital cities. In all three locations the dominant land use categories are residential, parkland and streets (infrastructure) - these three land uses account for roughly 75% of all land area within each city.

Sydney and Melbourne show significantly higher proportions of land classified as “other” and primary production when compared with Perth. Educational and commercial land uses all make up similar quantities of each city’s land area. Melbourne has almost as much land classified as industrial or commercial as it does parkland (10% and 13% respectively). This will significantly impact on carrying capacity for tree canopy. In contrast, Sydney has over twice as much parkland as it does industrial and commercial land (20% in comparison to 9%).

Figure 5: City Comparison, by Land Use

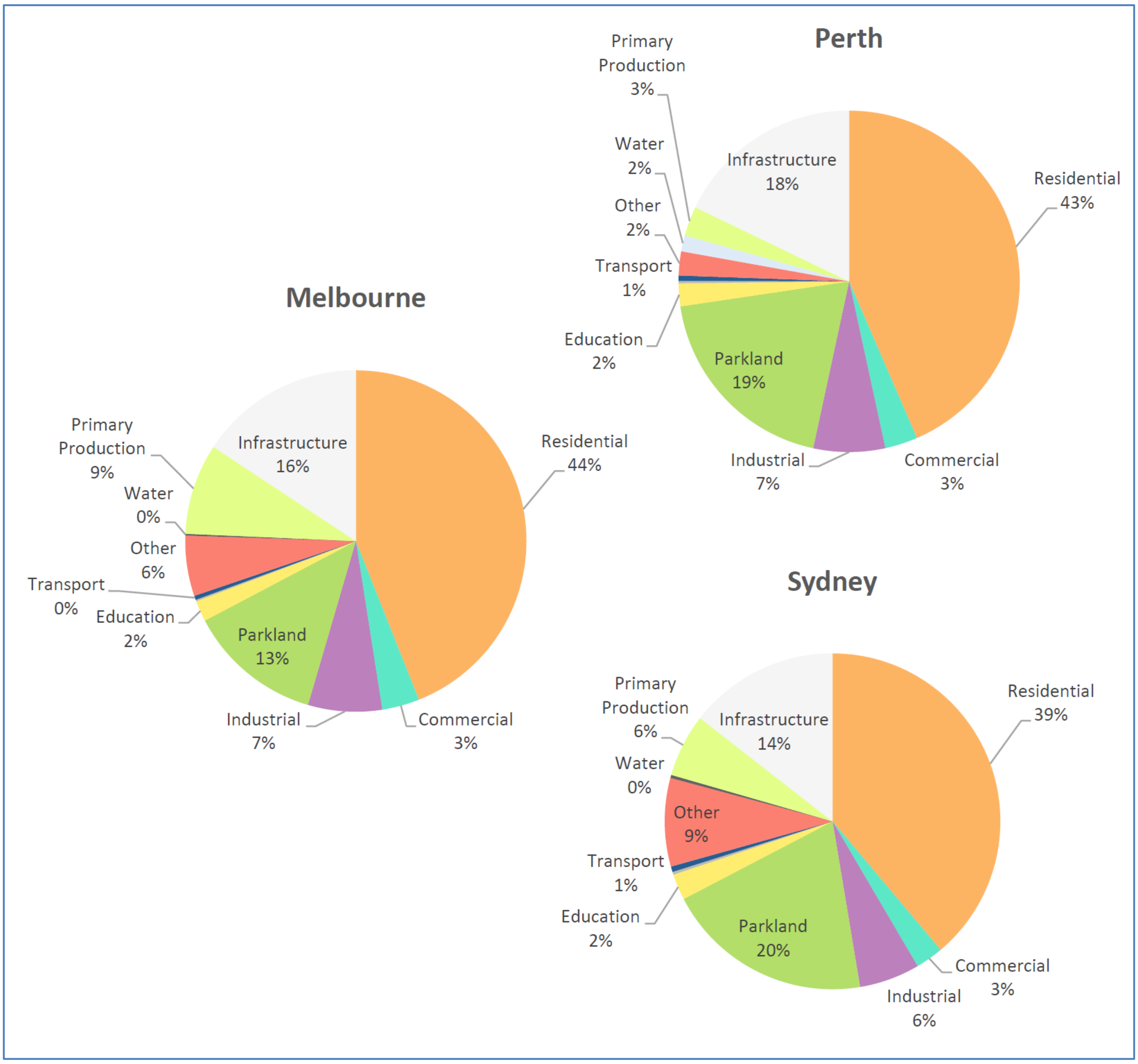
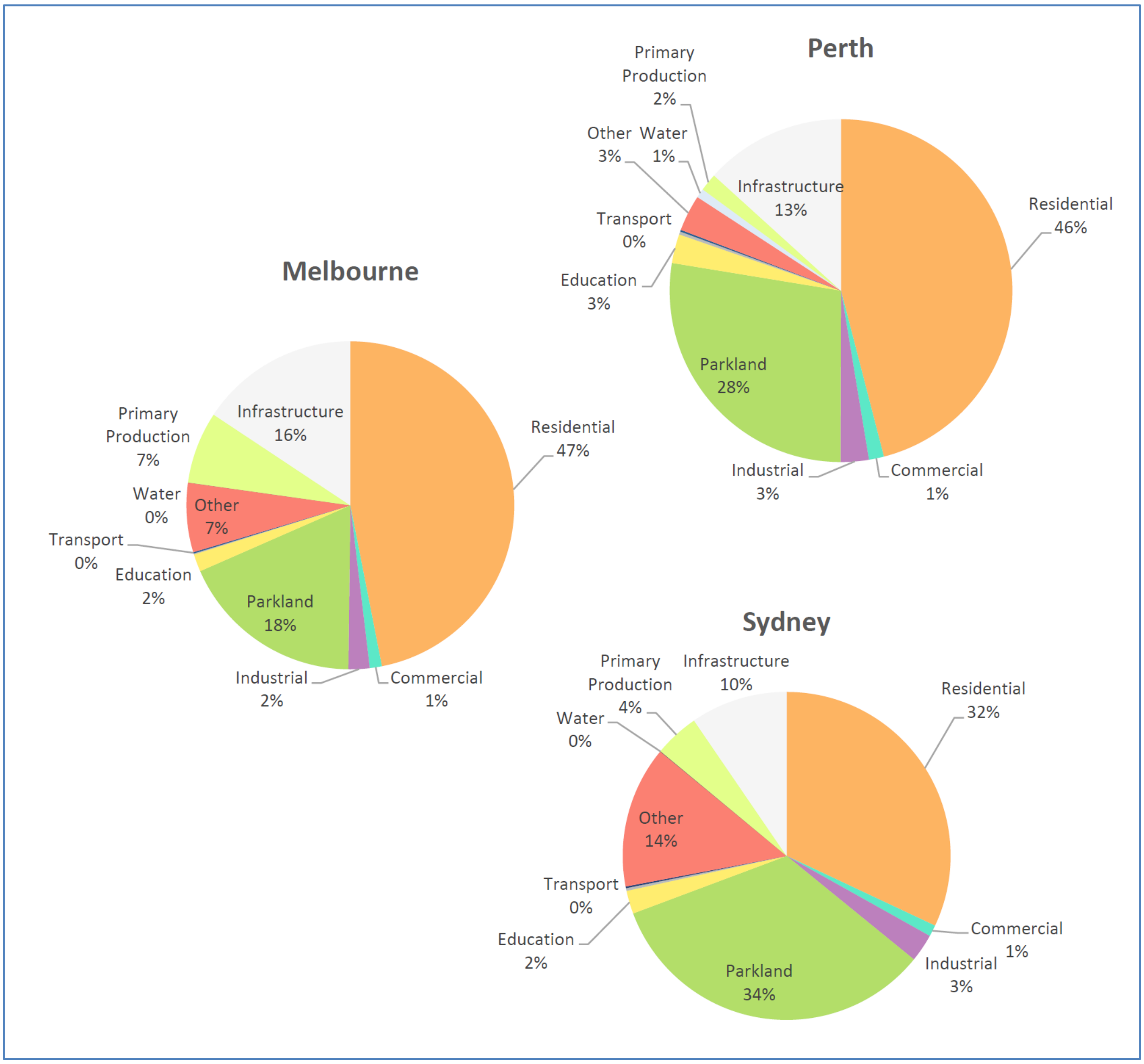


Figure 6 provides a comparison of the land-use contribution to tree canopy cover by city, indicating the existing land uses that most significantly contribute to existing canopy cover. All cities show the bulk of their tree canopy located in residential areas and parkland. Compared to Melbourne and Perth, Sydney has a comparatively smaller proportion of tree canopy within residential land, and a larger proportion within parkland. Sydney also has a significant amount of tree cover located in land designated as 'other'. Land uses classified as "other" were significantly less important in Melbourne and Perth.

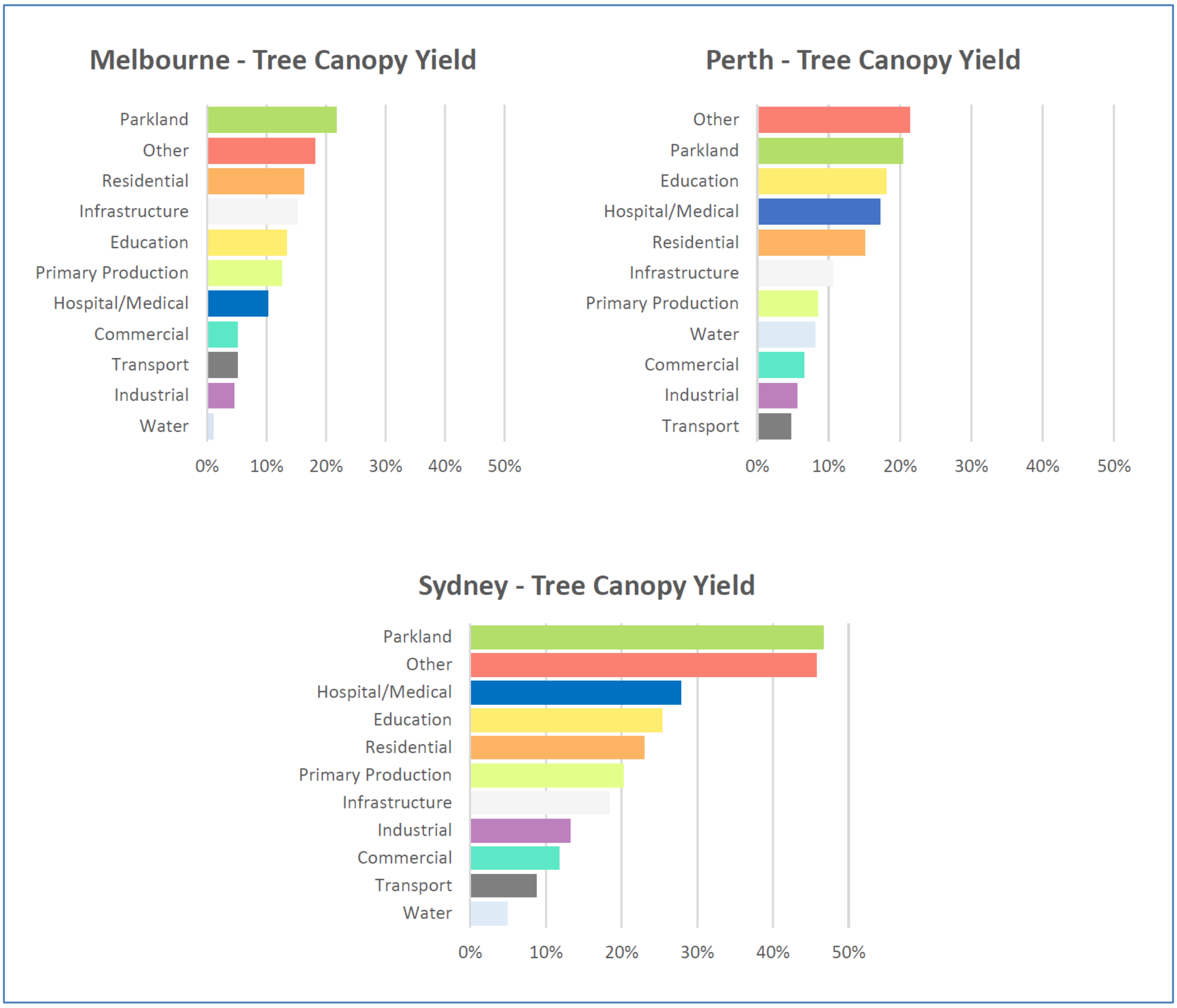
Across all three cities, infrastructure land uses (primarily streets) shows considerable contributions to tree canopy – being the 3rd largest contributor in Melbourne and Perth, and the 4th largest in Sydney. Commercial, industrial, education, and primary production land uses make comparatively minor contributions in each city (although primary production land in Melbourne is significant, supporting 7% of canopy cover). Melbourne and Perth demonstrate a very similar pattern in terms of the distribution of vegetation across different land uses. Collectively, residential land, parkland and Infrastructure, contribute 80.9%, 86.8% and 75.0% of tree canopy in Melbourne, Perth and Sydney respectively.

Figure 6: City Comparison, Land-Use Contribution to Tree Canopy Cover



While figure 6 identifies the most significant land uses associated with the provision of tree canopy, it is worth highlighting the canopy yield of different land use types. Yield indicates the average cover of a given land use type - see figure 7. For example, while hospital/medical land-cover is very low in each city, the yield of canopy cover is relatively high, particularly in Sydney and Perth. Figure 7 also highlights the significant yields underpinning Sydney's high canopy cover which comes from its parks and 'other' land classes (typically large institutional land uses such as water catchment and treatment land). Tree canopy yield from residential land is similar for both Melbourne and Perth (16.3% and 15.1% respectively) but is considerably higher in Sydney (22.9%). Likewise, industrial land shows similar levels of canopy cover in Melbourne/Perth (4.5% and 5.6%, respectively) but more than double the level of cover in Sydney (13.2%).

Figure 7: City Comparison, Tree Canopy Yield by Land Use



4.2 Melbourne

The city of Greater Melbourne is situated around Port Phillip Bay, and extends from the relatively dry and open basalt plains in the west, to wooded hills through the north-east and east, and on to the coastal plains of the south east. The region has an average tree cover in urban areas of 15.3%. However, this varies widely from a low of 4.1% average urban canopy cover in Melton to the west of the city with 36.6% canopy cover in the Yarra Ranges.

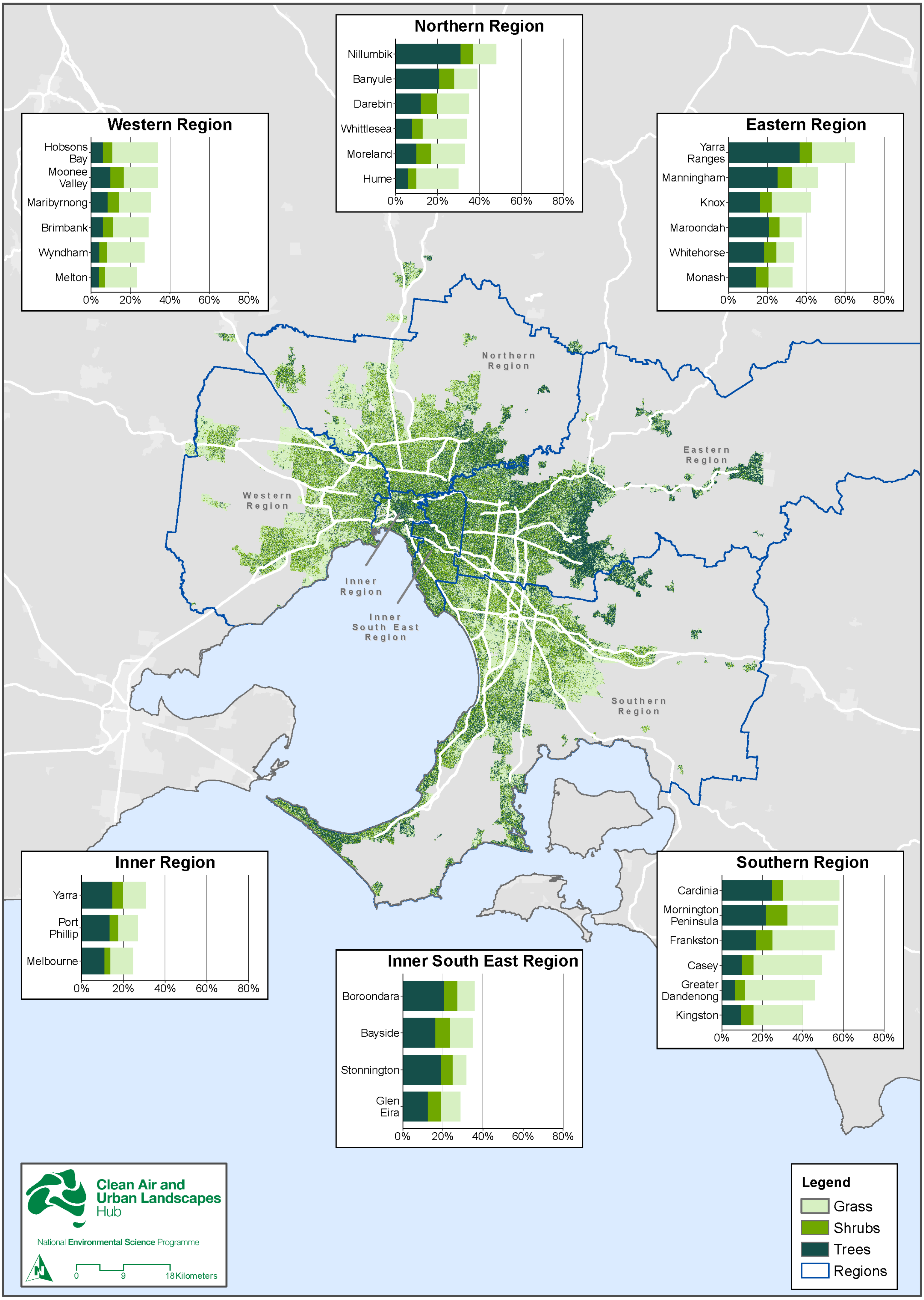
Figure 8 presents the distribution of vegetation across the urbanised area of Melbourne, showing trees, shrubs and grass. The charts within the figure highlight the vegetation cover by LGA for these three classes. The map highlights the concentration of areas of high tree canopy cover in the eastern and north-eastern suburbs, with Nillumbik (31.1%) and Manningham (25.4%) (along with Yarra Ranges 36.6%) having the highest canopy cover. By contrast the middle and outer western and north-western areas have significantly lower canopy cover - Brimbank, 6.0%; Melton, 4.1%; Wyndham, 4.2%; Hobsons Bay, 6.0%; and Hume, 6.4% (the five LGAs with the lowest canopy cover across Melbourne, Sydney and Perth).

Figure 9 focuses on the relationship between land-use and tree canopy cover. The map presents the distribution of land use types, highlighting the dominance of residential land, the networks of parks and open space; the street network and the concentrations of specialist land uses such as industrial land.

The charts within figure 9 present tree canopy cover by LGA, broken down by the underlying land use. For all LGAs the charts highlight the importance of three land classes for providing the clear majority of canopy cover: residential land; parkland; and (street) infrastructure. In some LGAs, typically on the urban fringe, land classed as primary production or ‘other’ by the ABS features within the urban area and supports noticeable tree cover. Land designated as ‘other’ is typically regional parks or large areas of institutionally managed land (such as land associated with water supply and treatment). In most LGAs residential land is clearly providing the largest contribution of any land class to canopy cover. However, this is not the case in the inner city as the higher density LGAs of Melbourne, Yarra, and Port Phillip, with parks and the street (infrastructure) network provide a similar or greater share of cover.

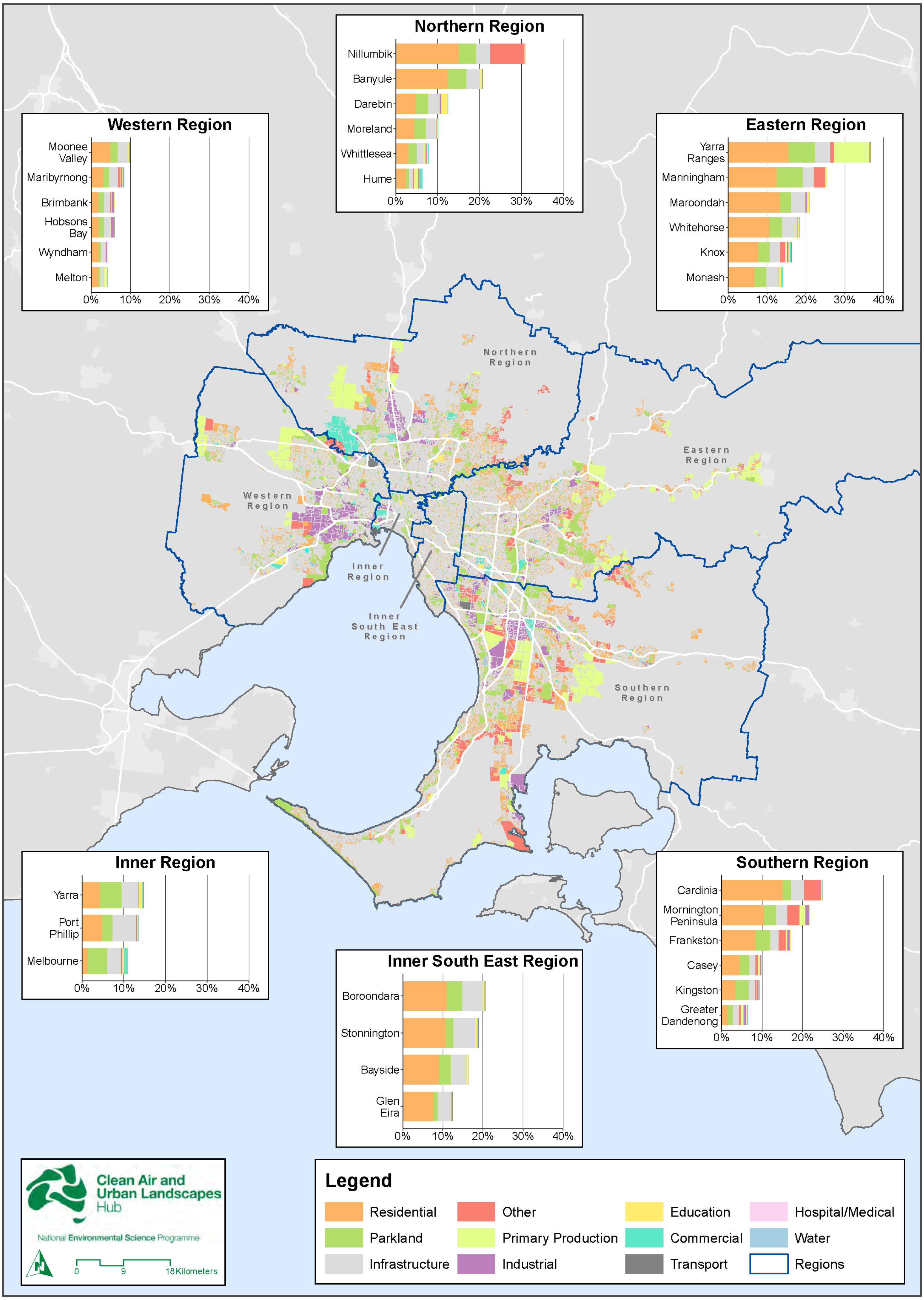
Figure 10 provides an alternative way to view the data presented in figure 9, grouping land use classes into two main categories of public and private realm (‘other’ land is retained as a third category). Presenting the data as public/private split highlights the importance of both the public and private realm in supporting urban canopy cover. In all LGAs, both make significant contributions, underscoring the need for strategy, policy and action for urban forest protection and enhancement to tackle both domains.

Figure 8: Melbourne Metropolitan Region - Vegetation Cover (%)



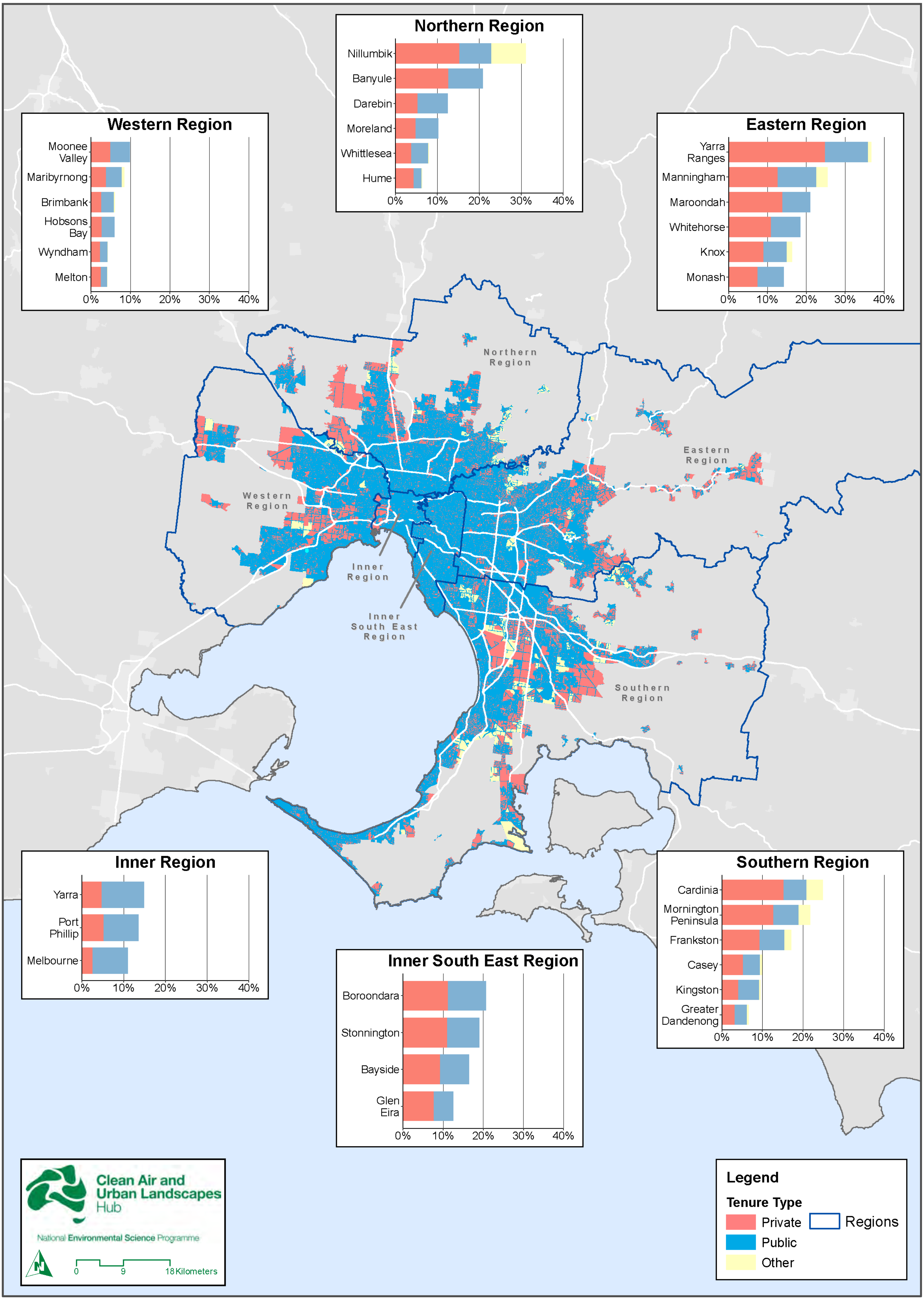
Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 9: Melbourne - Tree Canopy Cover by Land Use



Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 10 - Melbourne: Tree Canopy Cover (%) by Tenure Type



Study area limited to urban area (ABS urban centres and localities) and by data availability

4.3 Perth

The Perth Metropolitan Region (PMR) has grown from three historic settlements poised along the banks of the SWAN river; Guilford, Perth and Fremantle. Now constrained by the Darling Scarp to the east and Indian Ocean to the west, the PMR extends over 150 kilometres from the town of Two Rocks to the north to Mandura in the south. Marked by hot dry summers and cool wet winters, the sandy soils of the Swan coastal plain support flora ranging from coastal heath to banksia scrub, to eucalypt forests. Local Government Areas (LGAs) across the region have an average tree canopy cover in urban areas of 14.3%. However, this varies widely from a low of 7.8% tree canopy cover in Belmont just east of the CBD to highs of 32.8% canopy cover along the escarpment.

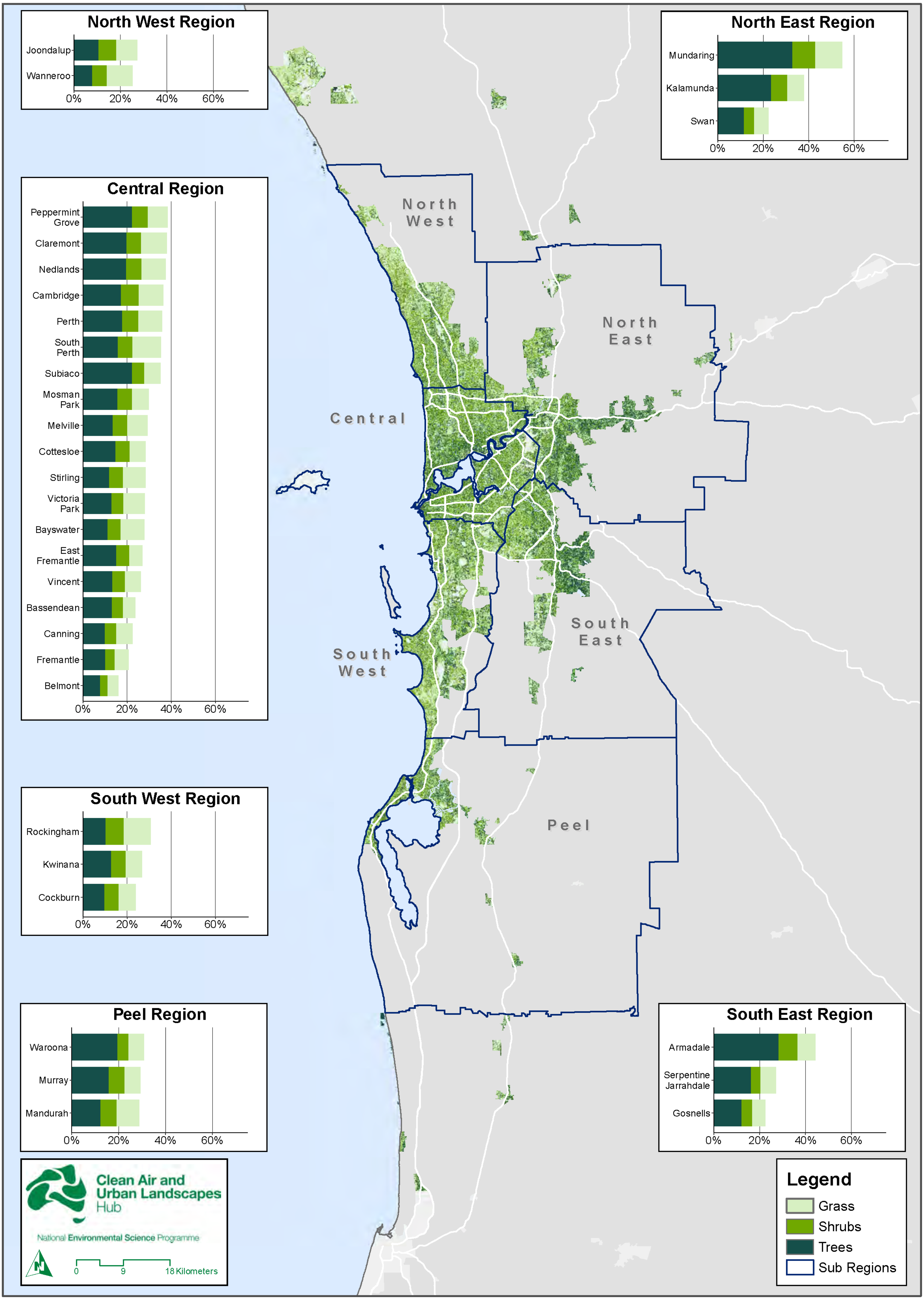
Figure 11 presents the distribution of vegetation across the urbanised areas of Perth, showing trees, shrubs and grass. The charts within the figure highlight the vegetation cover by LGA for these three classes of vegetation. The map highlights the concentration of areas of high tree canopy cover in the west-central and eastern suburbs, with Armadale (28.2%) and Mundaring (38.2%) (along the Darling Scarp) having the highest canopy cover. By contrast north and south-central suburbs have significantly lower canopy cover - Belmont, 7.8%; Wanneroo, 8.0%; and Canning 9.9% are of note.

Figure 12 focuses on the relationship between land use and tree canopy cover. The map presents the distribution of land use types, highlighting the dominance of residential land, the networks of parks and open space; the street network and the concentrations of specialist land uses such as industrial land.

The charts within figure 12 present tree canopy cover by LGA, broken down by the underlying land use. For all LGAs the charts highlight the importance of three land classes for providing the clear majority of canopy cover: residential land; parkland; and (street) infrastructure. In some LGAs, typically on the urban fringe, land classed as primary production or ‘other’ by the ABS features within the urban area and supports noticeable tree cover. Land designated as ‘other’ is typically regional parks or large areas of institutionally managed land (such as land associated with water supply and treatment). In most LGAs residential land is clearly providing the largest contribution of any land-class to canopy cover closely followed by parkland and infrastructure within the Perth context. In several areas to the south (Kwinana and Rockingham) and north-central, industrial land uses capture a greater extent of canopy cover than may be expected. Not surprisingly, the majority of tree canopy cover found within the Perth LGA can be attributed to parklands (particularly King’s Park). Interestingly, a large proportion of tree canopy cover in Belmont (east-central) is found on commercial lands but may be associated with a number of privately held sporting complexes found within the LGA.

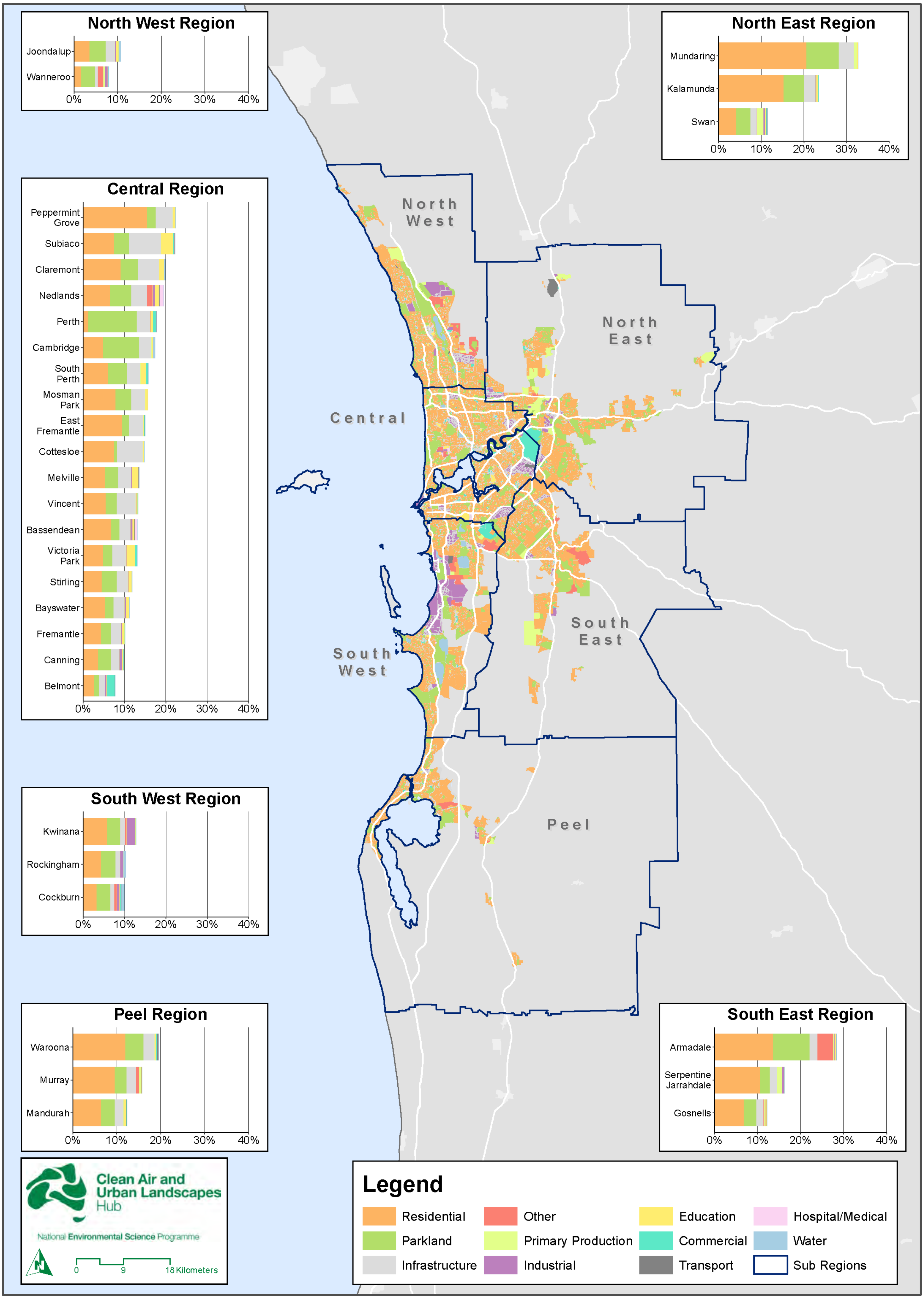
Figure 13 provides an alternative approach to view the data presented in figure 12, grouping land use classes into two main categories of public and private realm (‘other’ land is retained as a third category). Presenting the data as public/private split highlights the importance of both the public and private realm in supporting urban canopy cover. In all LGAs both make significant contributions, underscoring the need for strategy, policy and action for urban forest protection and enhancement to tackle both domains. Not surprisingly, LGA’s in Perth with higher proportions of tree canopy on public lands are those with large tracks set aside for parkland or neighbourhoods with wide road reserves.

Figure 11: Perth - Vegetation Cover (%)



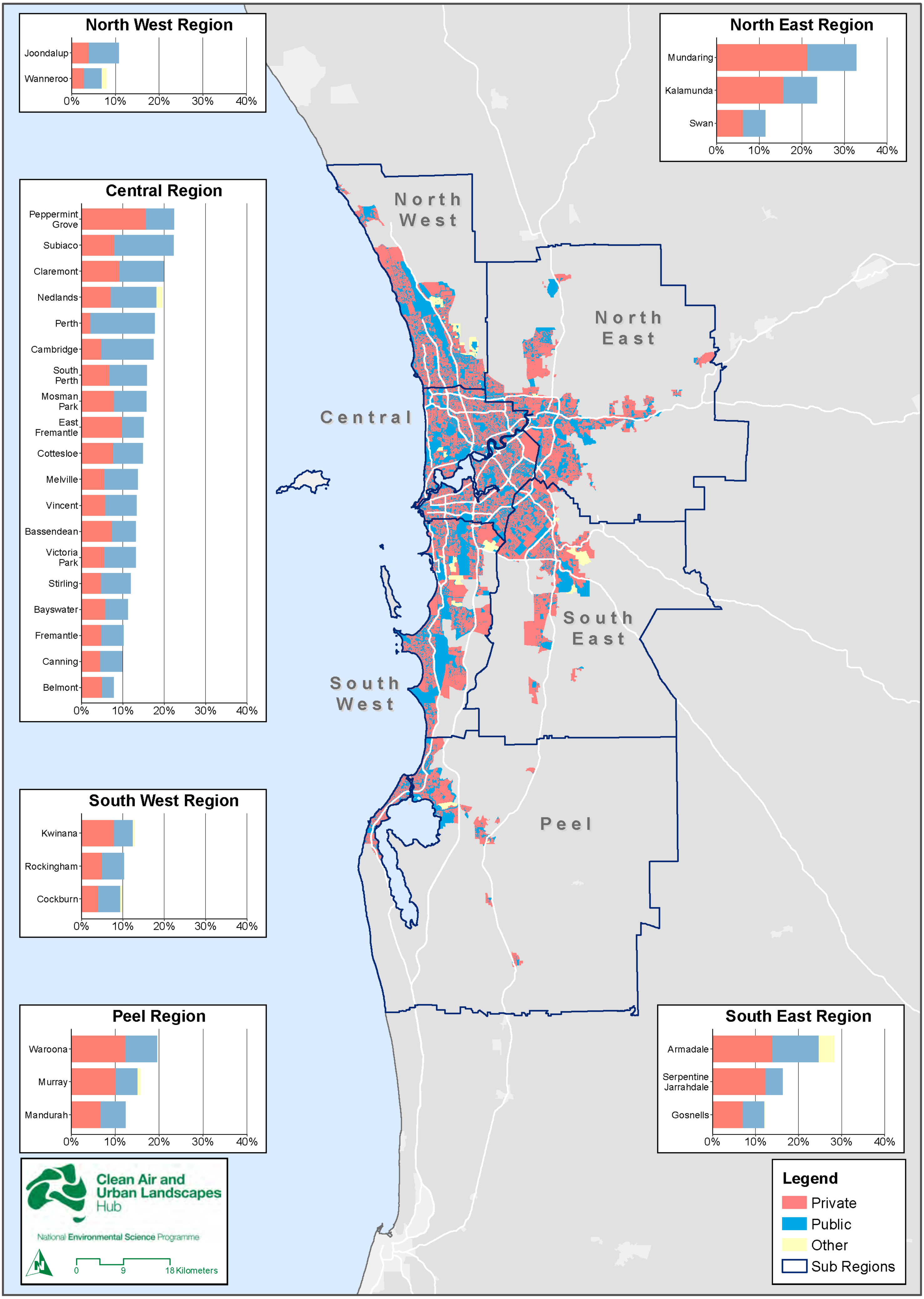
Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 12: Perth - Tree Canopy Cover (%) by Land Use



Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 13: Perth - Tree Canopy Cover (%) by Tenure Type



Study area limited to urban area (ABS urban centres and localities) and by data availability

4.4 Sydney

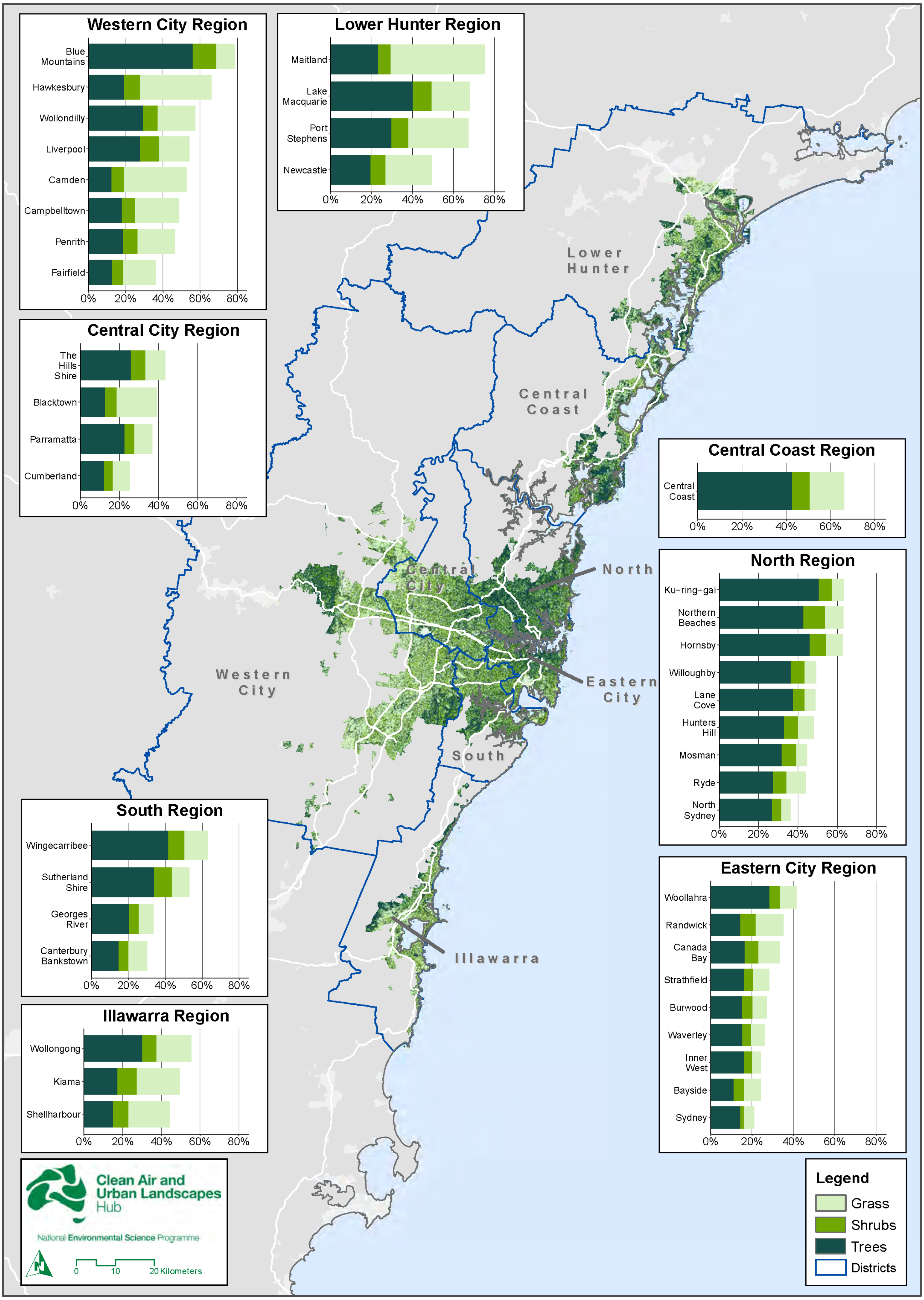
The Greater Sydney Region has expanded radially from Sydney Harbour and Botany Bay, constrained to the north and south by designated park land and to the west by the Blue Mountains. Classified as a humid subtropical climate, mild to cool winters transition to warm to hot summers with limited differences seasonal extremes particularly along the coast. Marked by a variety of woodlands, wetlands, heathlands, and forests, Sydney supports some of the highest proportions of tree canopy cover when compared to other Australian capital cities. Local Government Areas (LGAs) across the region have an average tree cover in urban areas of 27.9%, with a low of 11.1% in Bayside and a high of 56.1% along the Blue Mountains.

Figure 14 presents the distribution of vegetation across the urbanised areas of Sydney, showing trees, shrubs and grass. The charts within the figure highlight the vegetation cover by LGA for these three classes of vegetation. The map highlights the concentration of areas of high tree canopy cover along the urban fringes to the north, south and west, with Blue Mountain (56.1%) to the west, and Ku-ring-gai (50.1%) and Hornsby (46.2%) to the north exhibiting the highest canopy cover. By contrast the central and eastern portions of the city have significantly lower canopy coverage - Blacktown, 12.9%; Cumberland, 12.1%; and Bayside 11.1% are of note.

Figure 15 focuses on the relationship between land-use and tree canopy cover. The map presents the distribution of land use types, highlighting the dominance of residential land, the networks of parks and open space; the street network and the concentrations of specialist land uses such as industrial land. The charts within figure 15 present tree canopy cover by LGA, broken down by the underlying land use. For all LGAs the charts highlight the importance of three land classes for providing the clear majority of canopy cover: residential land; parkland; and (street) infrastructure. In some LGAs, typically on the urban fringe, land classed as primary production or 'other' by the ABS features within the urban area and supports noticeable tree cover. Land designated as 'other' is typically regional parks or large areas of institutionally managed land (such as land associated with water supply and treatment). In most LGAs, residential land is clearly providing the largest contribution of any land-class to canopy cover closely followed by parkland within the Sydney context. However, in the Lower Hunter, industrial land uses capture a greater extent of canopy cover than may be expected. Further, in the Central City Region much of the existing tree canopy cover is found on residential land with a few pronounced pockets of commercial land. Much of the tree canopy cover in the Northern Region and Central Coast is found on parkland or residential lands however, across the Greater Sydney Region, infrastructure does not account for as much tree canopy cover as may be expected.

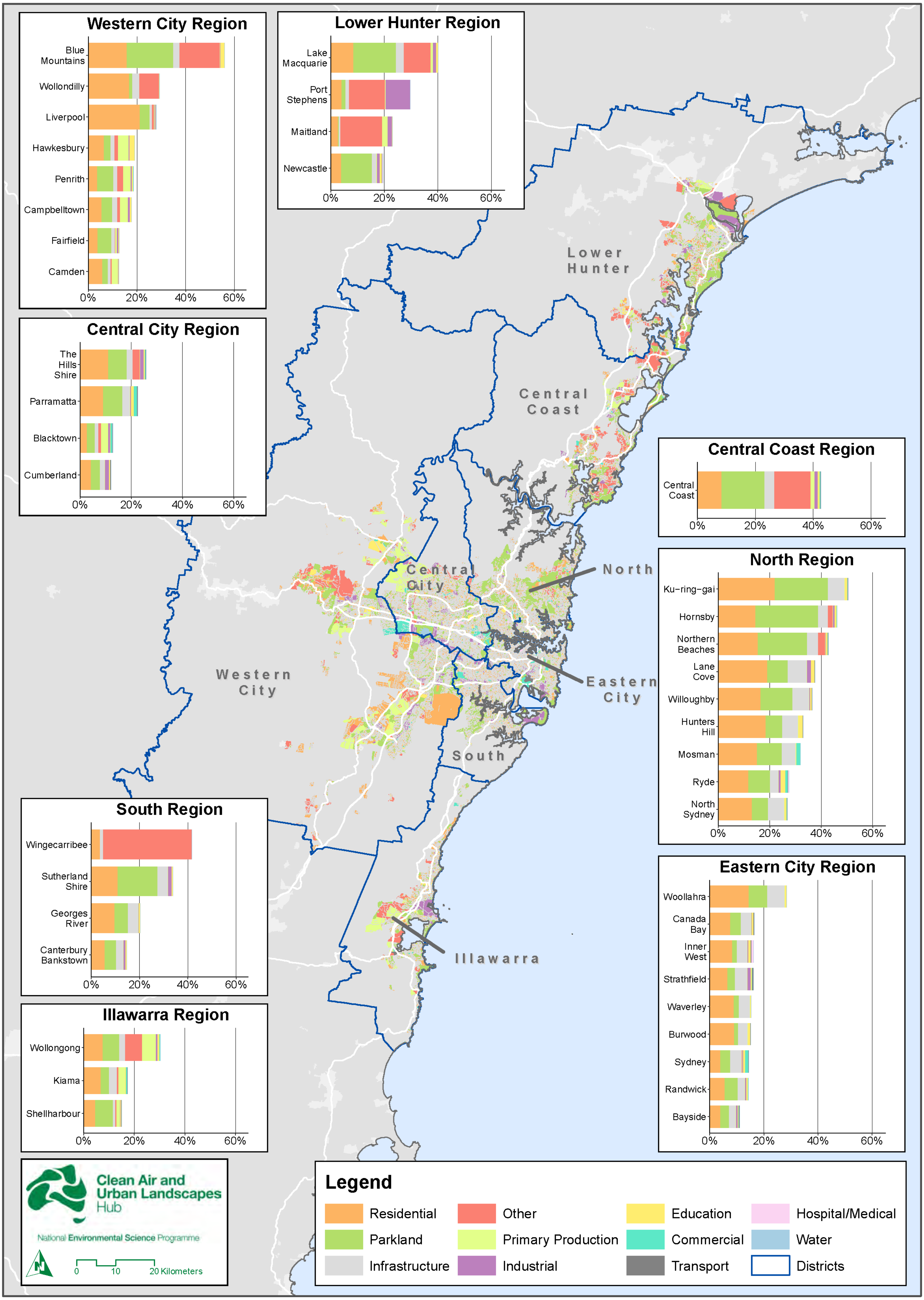
Figure 16 provides an alternative approach to view the data presented in figure 15, grouping land-use classes into two main categories of public and private realm ('other' land is retained as a third category). Presenting the data as public/private split highlights the importance of both the public and private realm in supporting urban canopy cover. In all LGAs both make significant contributions, underscoring the need for strategy, policy and action for urban forest protection and enhancement to tackle both domains. Not surprisingly, LGA's in the North Region and Eastern Central Region exhibit a near even split when examining the extent of canopy cover on public and private lands with marked variability in all other regions.

Figure 14: Sydney - Total Vegetation Cover (%)



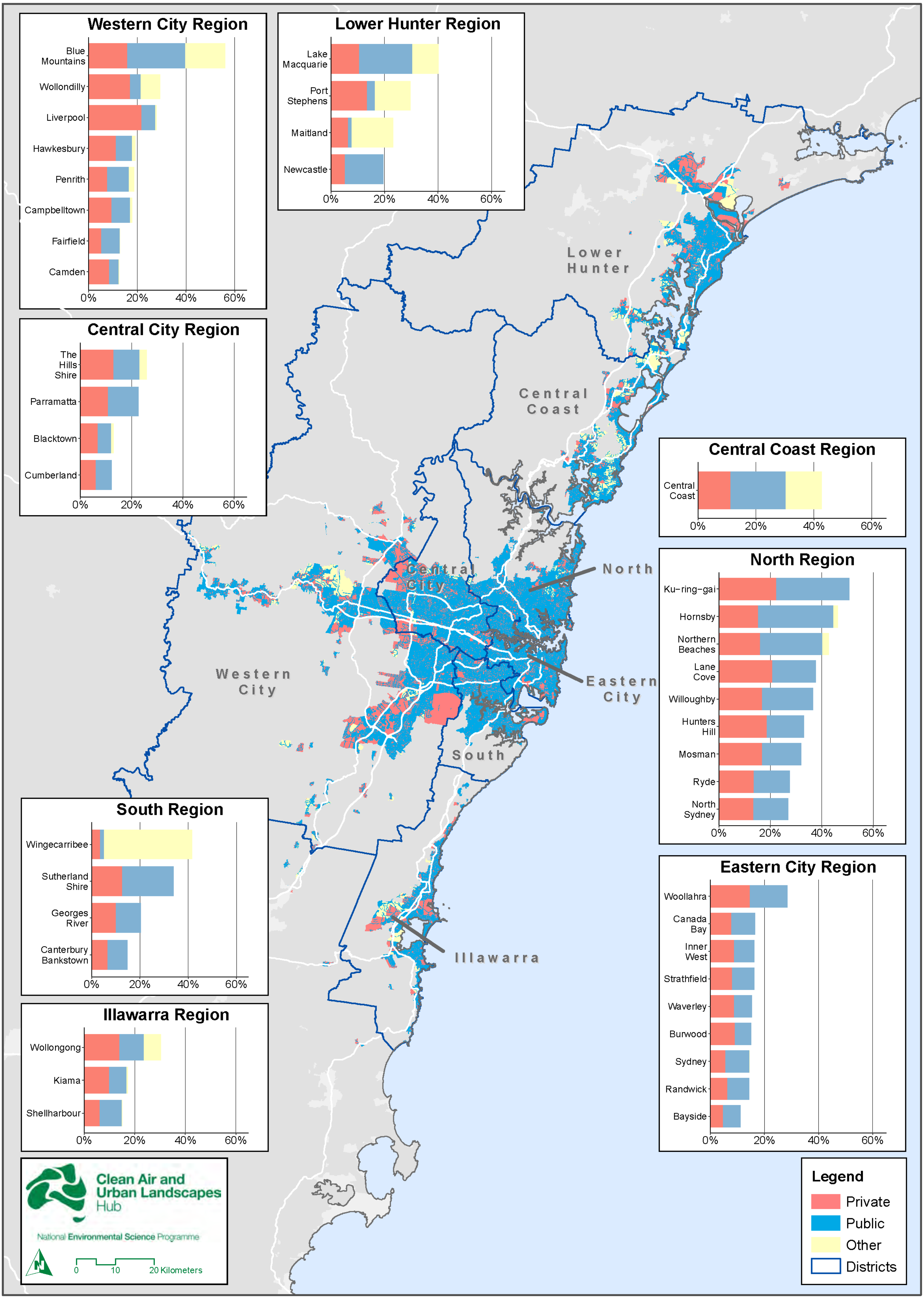
Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 15: Sydney - Tree Canopy Cover by Tenure Type (%)



Study area limited to urban area (ABS urban centres and localities) and by data availability

Figure 16: Sydney - Tree Canopy Cover by Tenure Type (%)



Study area limited to urban area (ABS urban centres and localities) and by data availability

5. Community Urban Forest Cover Dashboard

5.1 The Dashboard

To inform effective strategy and action for urban forest management, accurate and targeted information on existing canopy cover, change dynamics, and relationship to land use is critical. In this section we present a dashboard approach to community urban forest indicators, targeted at informing the development of urban forest strategy, policy and action across the major land-uses found in our cities. Our intention is to turn this dashboard template into an interactive dashboard, allowing users to more fully examine their own communities and compare their suburb with others across Australia.

Our approach is to develop a dashboard containing rich and easily digestible information for evaluating urban forest performance of an area. While the benchmarking data presented in section 4 provides a useful assessment of urban forest cover across a metropolitan region, and headline statistics for LGAs, does not provide the detail necessary to inform targeted interventions for better urban forest management. The dashboard we present here is targeted at the suburb scale (as defined by the ABS); although it can equally be applied at the LGA level, depending on the detail required by the decision maker. The suburb scale provides sufficient spatial granularity to reflect the diversity of urban landscapes, be that built form and use, biophysical factors, or demographic characteristics. The suburb scale also better reflects the scale of community understanding and identity.

The dashboard features the following information (see figure 17):

1. *Study area.* Name of the selected study area.

2. *Headline tree canopy cover and cover change*. These two statistics provide a high-level indication of cover and change dynamics.

3a. *Land-use mix - map.* The land-use map gives a visual representation of land-use mix and distribution in the selected study area.

3b. *Land-use mix - charts*. Two pie charts allow for the characterisation of land-use in a study area. The first shows the proportion of land-use by class, making clear which land-uses are the most prevalent in the selected study area. The second pie chart shows the distribution of canopy cover across land-use classes. In combination these two charts clearly indicate the most prevalent land uses, and the land-uses that contribute the most canopy cover. It is worth noting that in a significant majority of urban areas residential land, parks, and streets dominate these charts.

4a. *Vegetation cover - map.* The land-use map gives a visual representation of distribution of vegetation cover by three land classes (trees, shrubs, grass) in the selected study area.

4b. *Tree canopy cover - charts*. The four canopy cover scatter plots allow for comparison of canopy cover on key land-use classes for the selected area with two sets of comparator data: the rest of the city; and suburbs of similar dwelling density. On each chart the red dot is the selected suburb; the purple dots are the suburbs of similar density, and the grey dots are the remaining suburbs. These scatter plots provide a rich visual depiction of a suburbs performance with the four charts showing in turn:

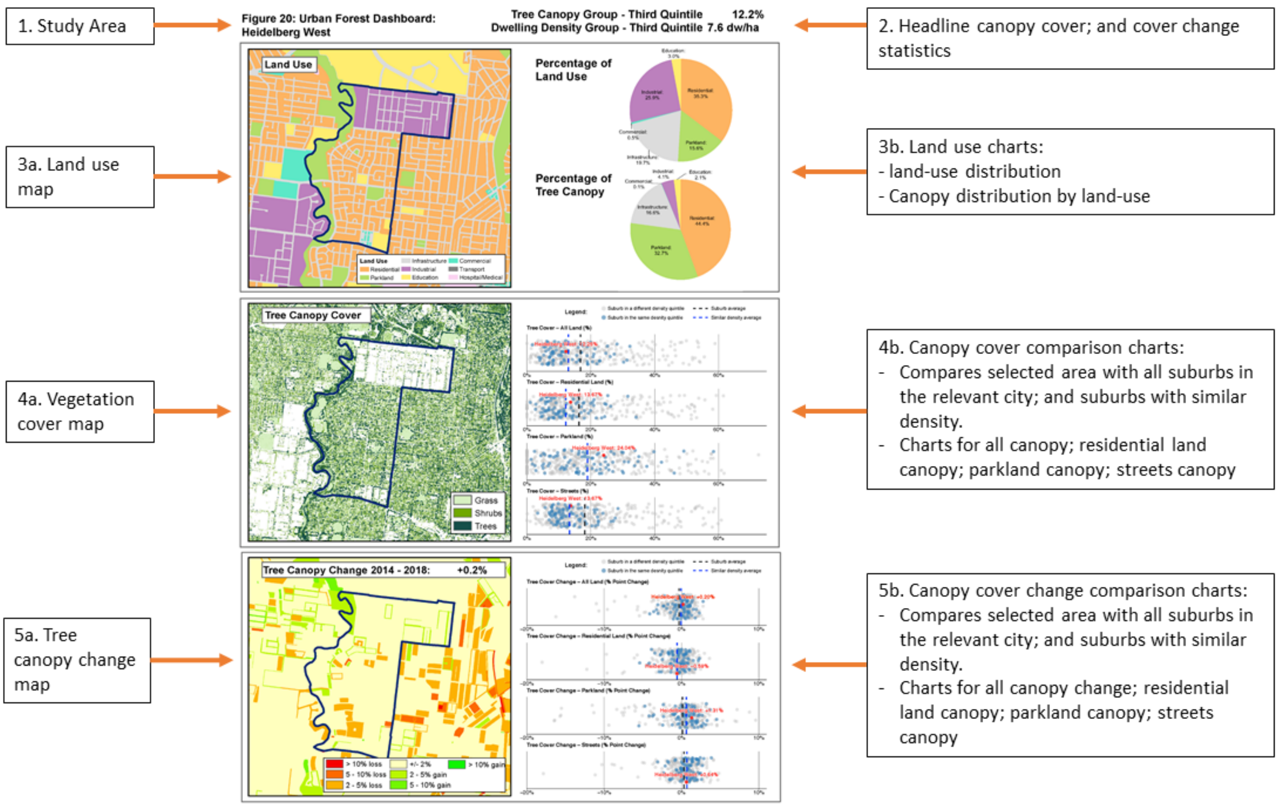
- Overall canopy cover performance against city distribution and average; and comparator distribution and average,
- Residential land canopy cover performance against city distribution and average; and comparator distribution and average,
- Parkland canopy cover performance against city distribution and average; and comparator distribution and average, and
- Streetscape canopy cover performance against city distribution and average; and comparator distribution and average.

We highlight residential, parks and streets as the three land uses that typically contribute the most tree cover to the urban forest. These three land-cover types are also the subject of extensive strategy, policy and action in the case of parks and streets; and in the case of residential land, traditionally with significant tree cover, poses a wicked problem for policy/practice to retain/enhance urban forests; increasing recognition of importance and appetite for change (Phelan et al 2017; Ordenez et al 2020). A fourth category that can feature here is land designated as ‘other’ by the ABS. This tends to designate large institutional land holdings or regional parks within the urban realm and given their variability and tendency towards singular institutional land managers, are not specifically profiled in the dashboard.

5a. Tree canopy cover change - map. The tree canopy cover change map provides a visual depiction of canopy cover change over time (in Perth 2009-2016), with areas of significant loss or gain easily discernible.

5b. *Tree canopy cover change - charts*. The four canopy cover change scatter plots, follow the same format as the canopy cover scatter plots above, but focus on change over time.

Figure 17: Dashboard Features



5.2 Suburb Examples

Butler, Perth, WA (see figure 18).

Butler is a new suburb on the northern fringe of Perth.

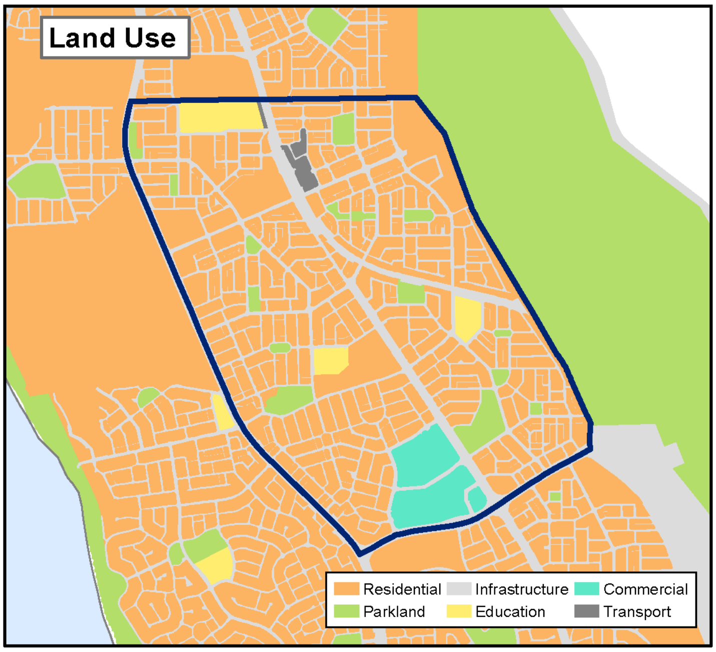
Key messages from the dashboard:

- Butler has a very low canopy cover figure (1.8%, 5th quintile), with some canopy cover gain between 2009 and 2016 (+1.0 percentage points), albeit from a very low base.
- The land-use map shows Butler is a largely residential area, with some local parks and a commercial district. The pie charts confirm residential and streets (infrastructure) as the major land uses. These two land uses, along with the local parks, provide nearly all of what little tree cover exists in the area.
- The tree canopy comparison charts show Butler as one of the lowest canopy cover suburbs in Perth, and one of the lowest when compared to suburbs of similar dwelling density. Parkland in Butler compares more favourably to other suburbs for canopy cover, although it is still well below average when compared to both the city suburb average and the average of suburbs with similar density.
- The tree cover change map indicates a few areas of significant loss, likely associated with development activity given this urban fringe location; as well as dispersed areas of gain, likely associated with tree growth in streets, parks and on residential lots given the establishing nature of this suburb. The comparison charts show that canopy change over time is closer to the Perth average and the average for similar density suburbs.

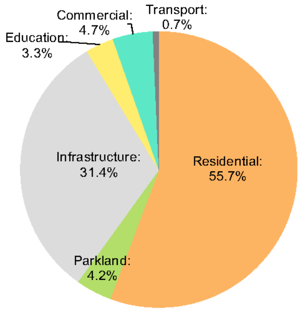
Overall, the dashboard reveals Butler as a suburb with very low tree cover, and some increase in tree cover over time, but below comparator averages. Butler is an establishing suburb, which is typically associated with low canopy cover and increases over time. However, if Butler is to achieve a significant level of canopy cover sufficient to support associated heath, amenity and biodiversity benefits, considerable effort will be required across all major land uses to generate new canopy, support the growth of establishing trees, and protect the limited canopy that currently exists.

Figure 18: Urban Forest Dashboard: Butler (WA)

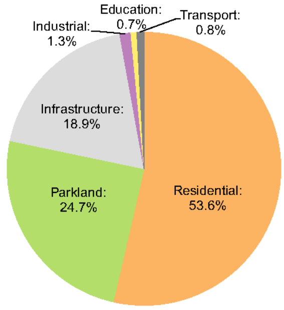
Tree Canopy Group - Lowest Quintile 1.8%
Dwelling Density Group - Highest Quintile 9.4 dw/ha

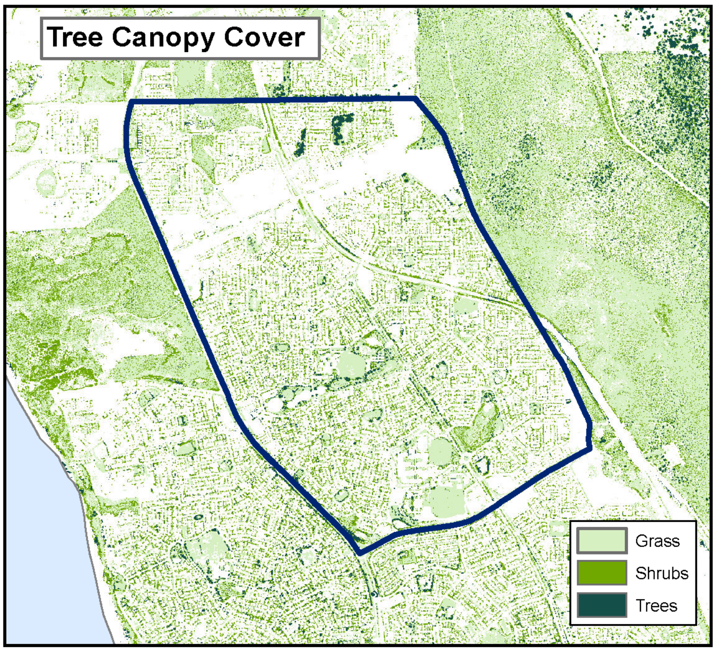


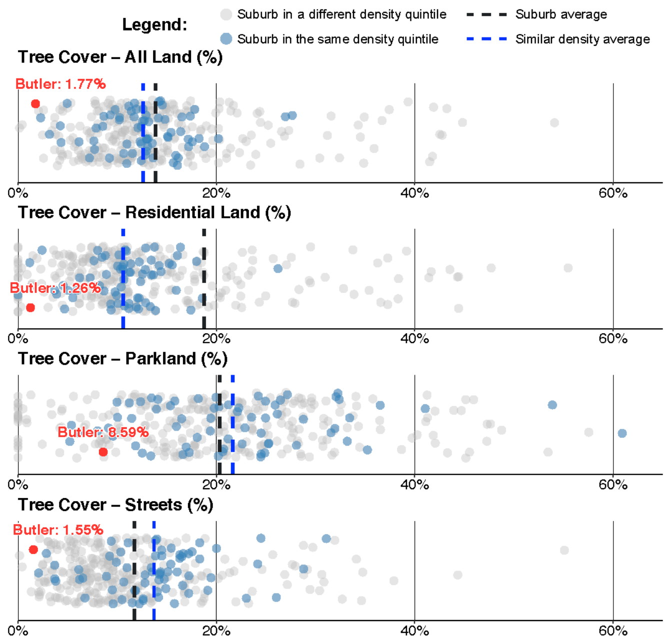
Percentage of Land Use

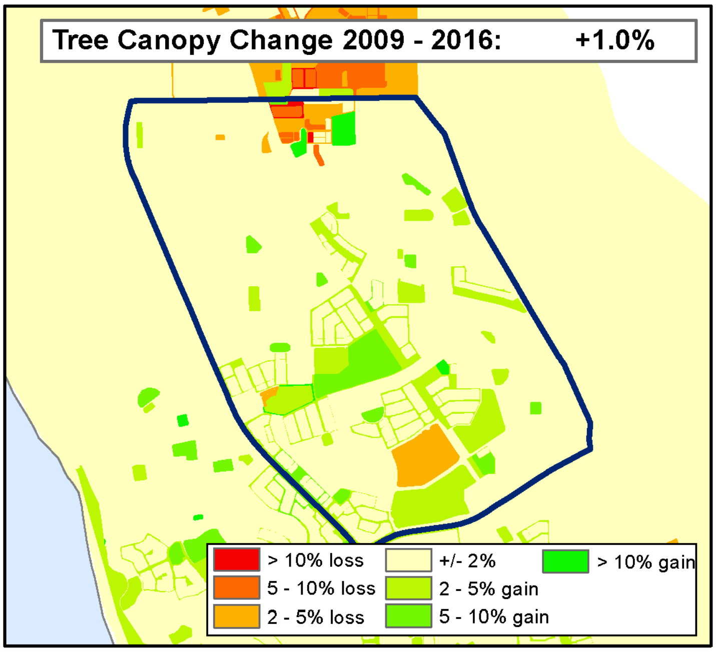


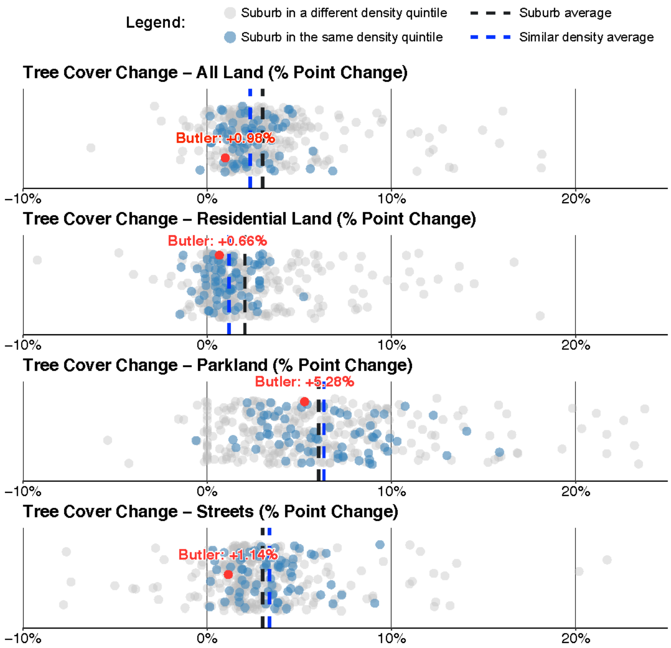
Percentage of Tree Canopy











Beckenham, Perth, WA (see figure 19).

Beckenham in an established suburb in the south east of Perth.

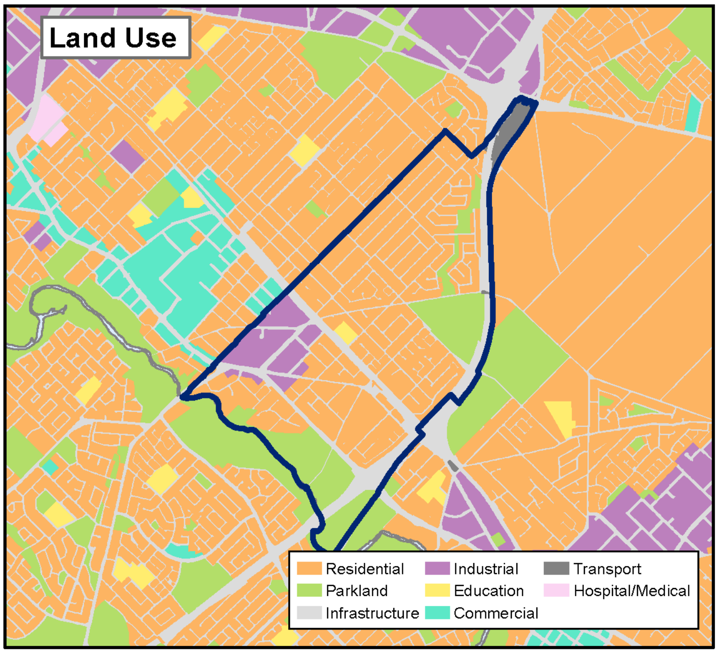
Key messages from the dashboard:

- Beckenham has a middle range canopy cover figure (11.3%, 3rd quintile), with minor canopy cover loss between 2009 and 2016 (-0.1 percentage points).
- The land-use map shows Beckenham is a largely residential area, with some local parks, significant regional parkland, and an industrial precinct. The pie charts confirm residential and streets (infrastructure) as the major land uses. Nearly all (98%) canopy in Beckenham is provided by residential land, parkland, and streets (infrastructure and transport). Despite industrial land making up 7% of the land-use, it only contributes 1.3% to the canopy.
- The vegetation cover map shows the concentration of trees in the regional parkland along the Canning River. The tree canopy comparison charts show Beckenham as being close to the average of suburbs with similar dwelling density, being slightly above average on residential land, and below average on streets and parkland.
- The tree cover change map indicates many areas of significant loss, largely associated with residential land. This is likely associated with redevelopment activity and land-management decisions of residents given the established nature of this suburb. There are gains associated with parkland. The comparison charts show that canopy change over time is below the Perth average and the average for similar density suburbs across residential land, parkland and streets. In particular, there is a significant loss in canopy cover on residential land (-1.37 percentage points).

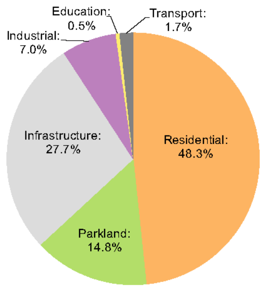
Overall, the dashboard reveals Beckenham as a suburb with average tree cover, which is stagnant over time. Within this, moderate gains in parkland cover (lower than comparator averages) is offsetting significant loss on residential land, providing evidence that the suburb is maintaining cover against development and changed land practices on residential land. For Beckingham to maintain or increase canopy and achieve a level of canopy cover sufficient to support associated heath, amenity and biodiversity benefits, effort will be required to reduce losses on residential land and improve the contribution of streets and parkland. There is also an opportunity to investigate a more significant contribution from the industrial estate.

Figure 19: Urban Forest Dashboard: Beckenham

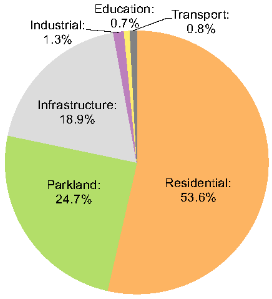
Tree Canopy Group - Third Quintile 11.3%
Dwelling Density Group - Third Quintile 5.3 dw/ha

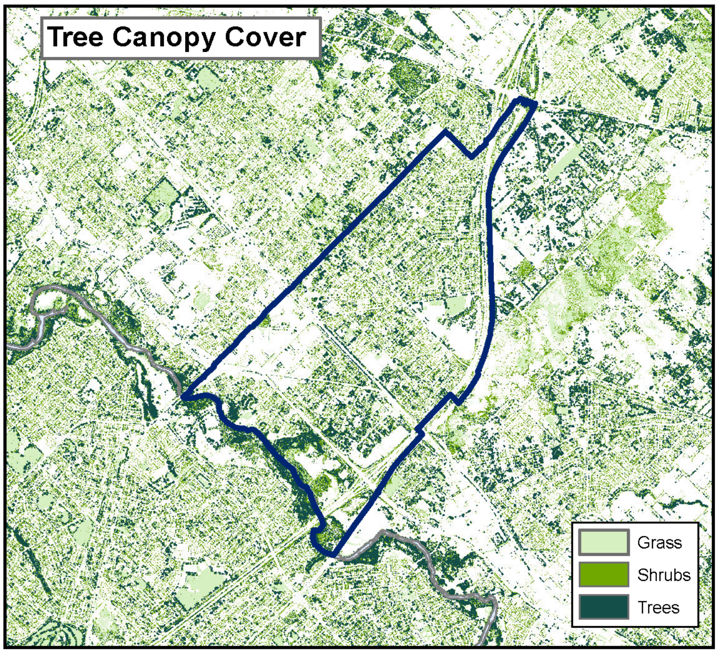


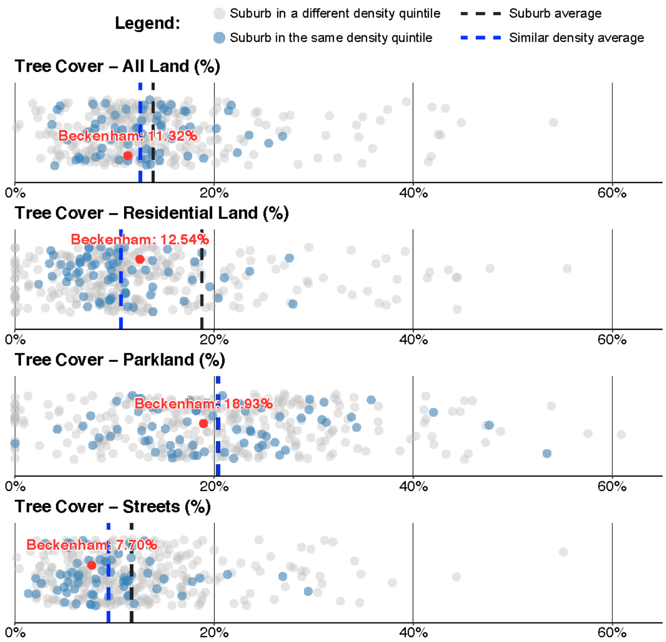
Percentage of Land Use

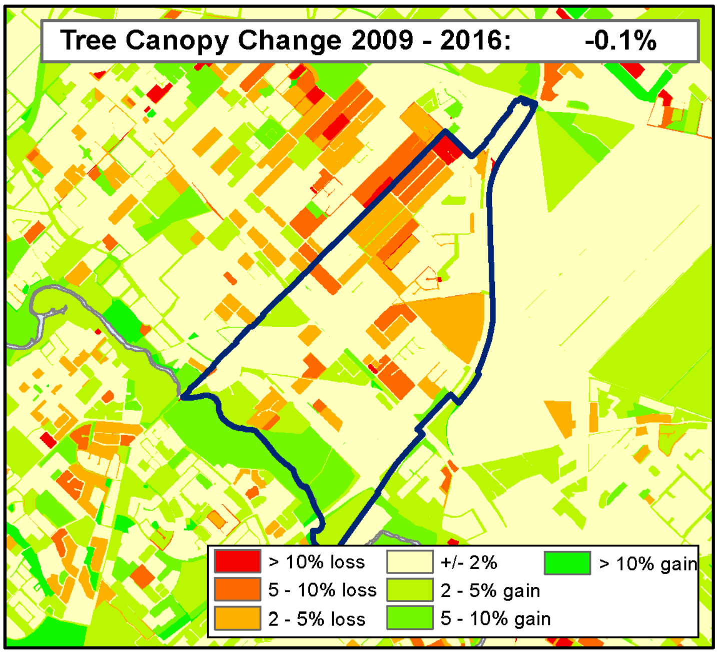


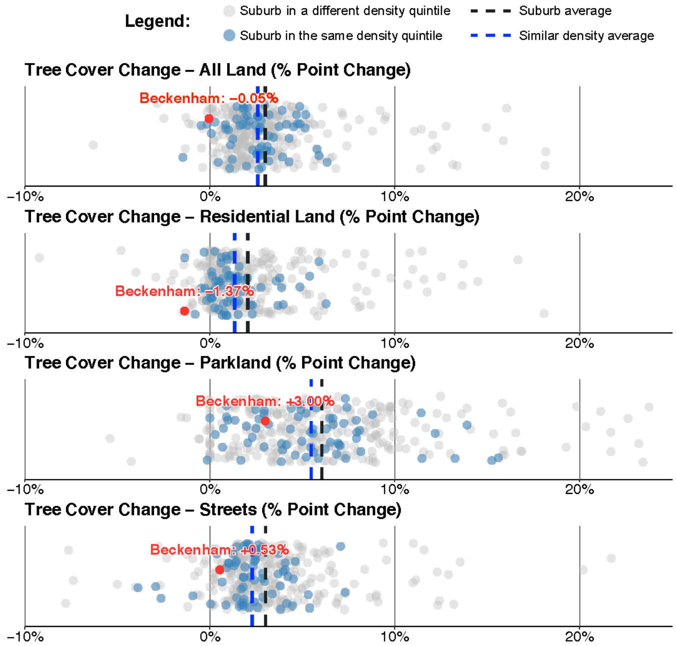
Percentage of Tree Canopy











Heidelberg West, Melbourne, VIC (see figure 20).

Heidelberg West is an established middle suburb in the north east of Melbourne.

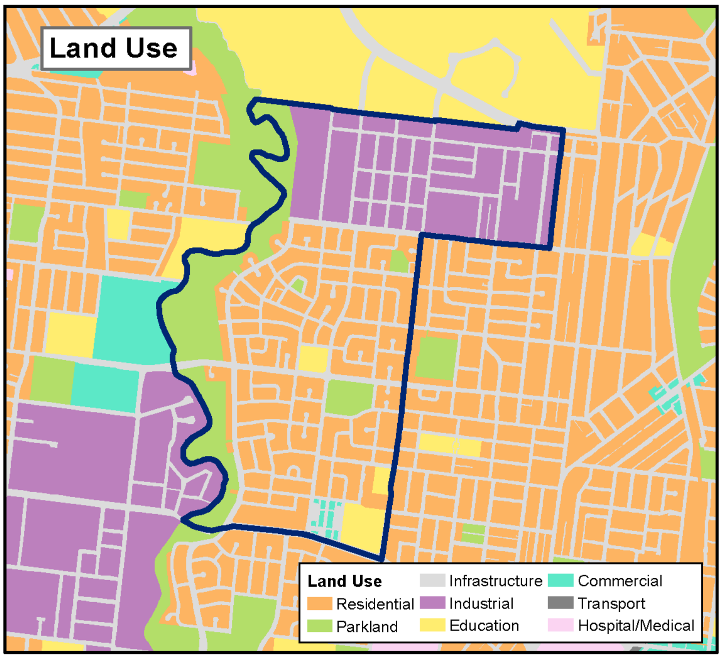
Key messages from the dashboard:

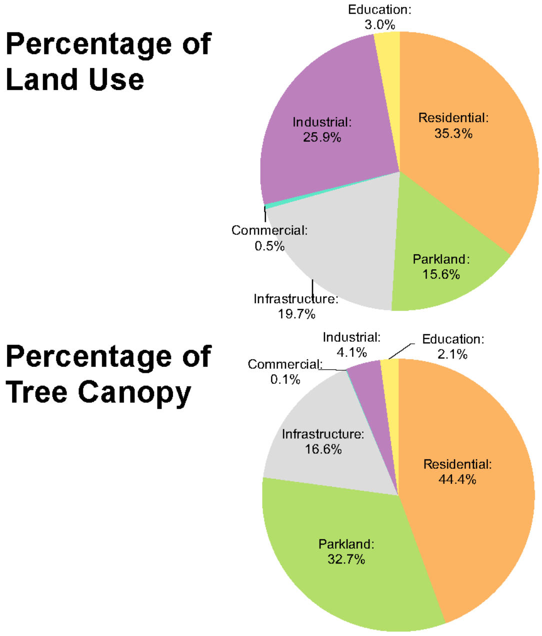
- Heidelberg West has a middle range canopy cover figure (12.2%, 3rd quintile), with minor canopy cover gain between 2014 and 2018 (+0.2 percentage points).
- The land-use map shows Heidelberg West has a large residential area; a large industrial precinct; some local parks and significant regional parkland; and small but significant areas of education and commercial land. The pie charts confirm the major role of industrial land in this suburb, along with residential land, parkland, and streets as the major land uses. Nearly all canopy in Heidelberg West is provided by residential land, parkland, and streets, despite the large industrial area.
- The vegetation cover map shows the concentration of trees in the regional parkland along the Darebin Creek, moderate distribution of canopy trees in the residential areas, and the distinct lack of trees in the industrial precinct except for on the street network. The tree canopy comparison charts show Heidelberg West as being close to the average of suburbs with similar dwelling density, being slightly above average on parkland.
- The tree cover change map indicates some areas of loss, largely associated with residential land. This is likely associated with redevelopment activity and land-management decisions of residents given the established nature of this suburb. There are some limited gains associated with the street network and parkland. The comparison charts show that canopy change over time close to the Melbourne average and close to the average for similar density suburbs across residential land, parkland and streets.

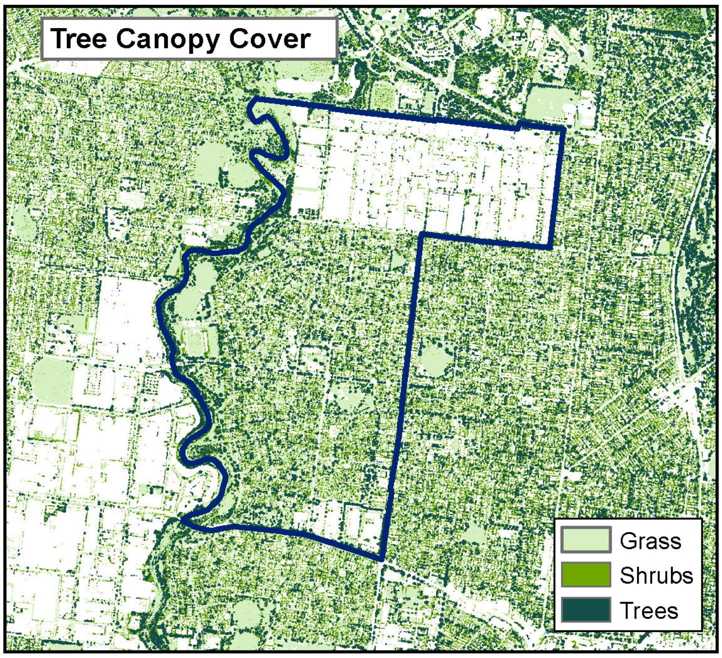
Overall the dashboard reveals Heidelberg West as a suburb with average tree cover, and limited growth in canopy cover over time. There are minor gains on parkland and the street network, mostly offset by minor losses on residential land. While Heidelberg West has a reasonable canopy cover, and is showing marginal increases over time, the loss on residential land points to continued pressure on the urban canopy. To maintain or increase canopy and achieve a significant level of canopy cover sufficient to support associated heath, amenity and biodiversity benefits, effort will be required to reduce losses on residential land and improve the contribution of streets and parkland. There is also an opportunity to investigate a more significant contribution from the large industrial area.

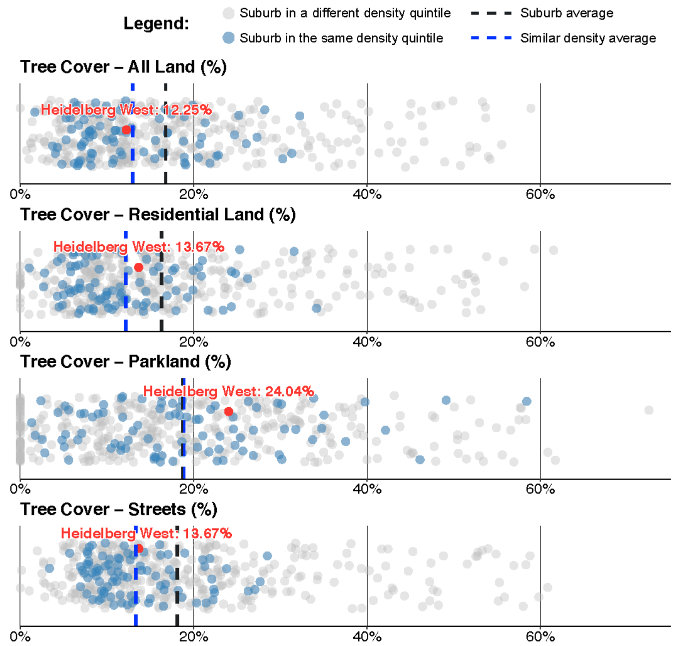
Figure 20: Urban Forest Dashboard: Heidelberg West

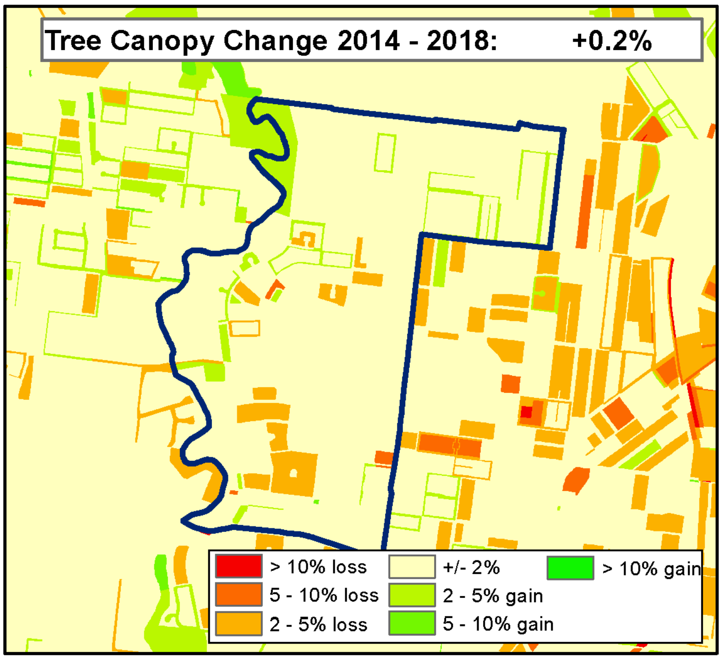
Tree Canopy Group - Third Quintile 12.2%
Dwelling Density Group - Third Quintile 7.6 dw/ha

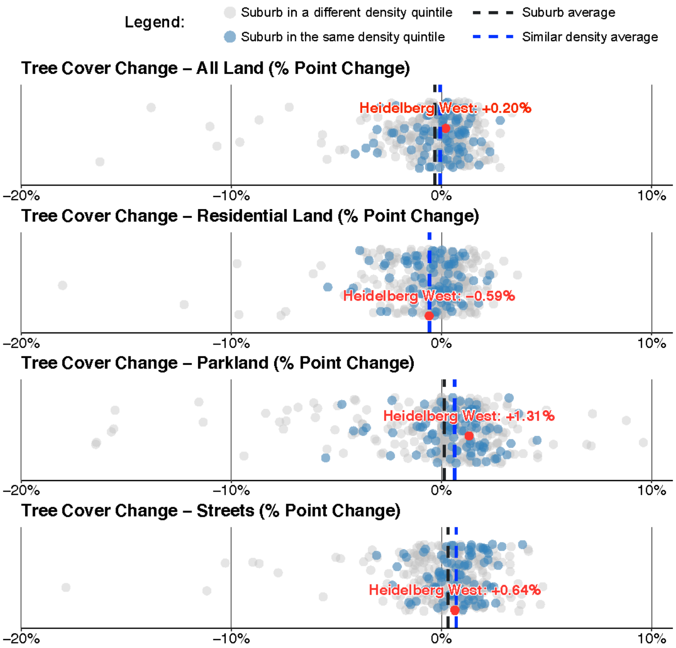












Brunswick, Melbourne, VIC (see figure 21).

Brunswick in an established suburb in the inner north of Melbourne.

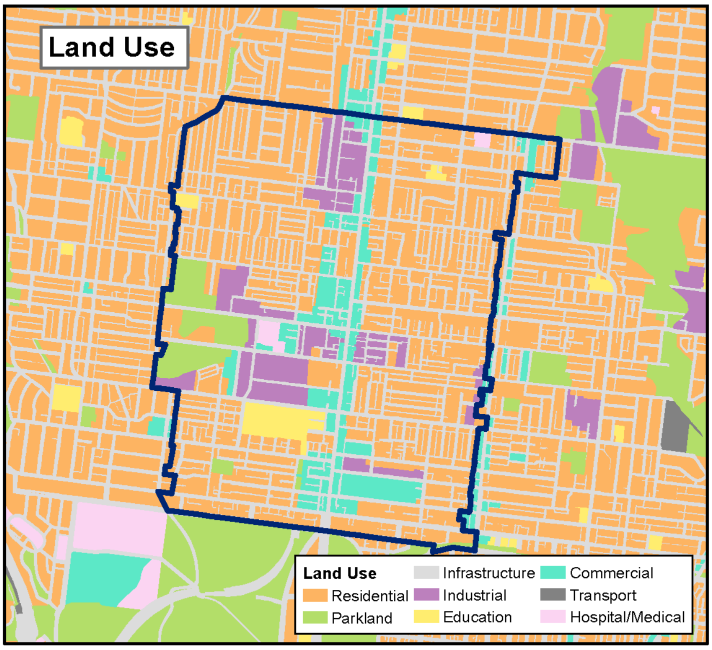
Key messages from the dashboard:

- Brunswick has a below average canopy cover figure (9.0%, 4th quintile), with some canopy cover gain between 2014 and 2018 (+1.0 percentage points).
- The land-use map shows Brunswick has a large residential area; a large commercial precinct; a large area of industrial land; and limited local parkland. The pie charts confirm the major role of commercial and industrial land in this suburb, along with residential land and streets as the major land uses; and the limited role of parkland. The biggest contributors to canopy in Brunswick are residential land (a high reliance at 58.5%) and streets (18.8%). Despite the small area of parkland, it still makes a considerable contribution to canopy in the suburb (15.2%). The large commercial and industrial areas contribute very little canopy to the area.
- The vegetation cover map shows the distinct lack of trees in the commercial and industrial precinct. The tree canopy comparison charts show Brunswick as being below the average of suburbs with similar dwelling density, being below the average on residential land and streets, and of a similar average for parkland.
- The tree cover change map indicates significant areas of gain, associated with parkland, streets and residential land, and some areas of loss associated with residential land. The comparison charts show that canopy change over time is above the Melbourne average and above the average for similar density suburbs across residential land, parkland and streets.

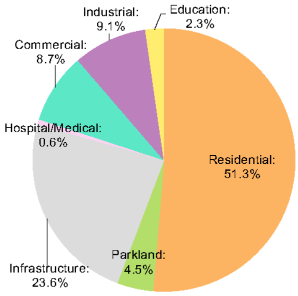
Overall, the dashboard reveals Brunswick as a suburb with below average tree cover, and some growth over time, despite the considerable redevelopment pressure in this inner suburb. While Brunswick has a low canopy cover, the signs here are that efforts to offset losses are having an impact. However, to maintain or increase canopy and achieve a level of canopy cover sufficient to support associated heath, amenity and biodiversity benefits, continued effort will be required to reduce losses on residential land and continue to increase the contribution of streets and parkland. There is also an opportunity to investigate a more significant contribution from the large commercial and industrial land areas.

Figure 21: Urban Forest Dashboard: Brunswick (Vic.)

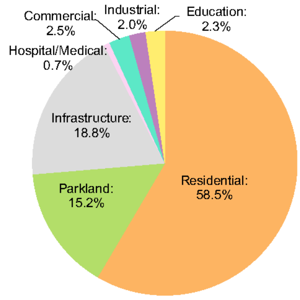
Tree Canopy Group - Fourth Quintile 9.0%
Dwelling Density Group - Highest Quintile 23.6 dw/ha

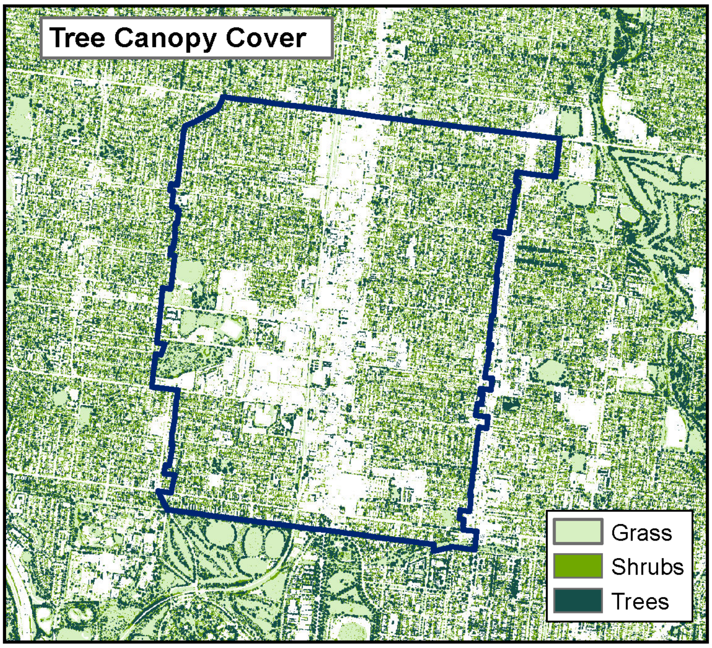


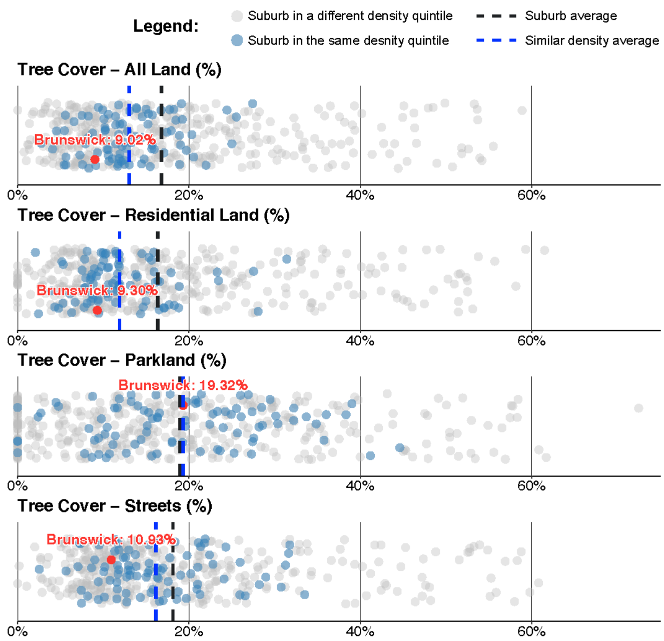
Percentage of Land Use

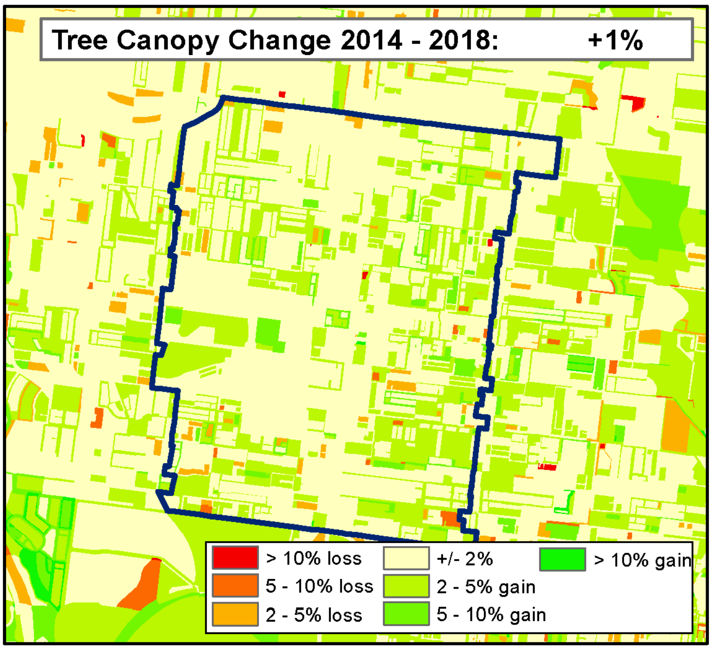


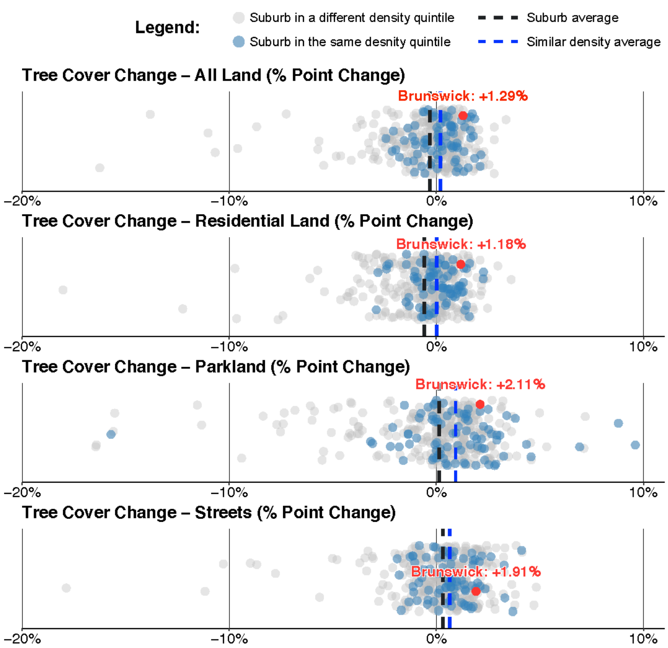
Percentage of Tree Canopy











6. Conclusions

The aim of this research was to understand the spatial distribution of urban vegetation, focusing on tree canopy cover, and its relationship with land-use; and to produce rich and targeted information to support decision making in practice. To do this we combined high resolution vegetation cover mapping with land-use data at the modified Mesh Block scale. The separation of the street network from the ABS Mesh Block allows detailed and accurate measurement of the major land-use types that contribute to vegetation cover in cities: residential land; parkland; and streets. This allows us to analyse existing tree canopy cover across the metropolitan regions of Melbourne, Perth and Sydney and its relationship to land use. In Perth and Melbourne, where we have multiple time points of data, it also allows us to interrogate change over time. This provides a critical evidence base to support decision-making, strategy and policy formation, and to underpin action for improved management of urban vegetation.

Comparing canopy cover across the three cities in this study highlights the significant variation of tree cover across space. The range in baseline vegetation reflects differences in climate, soil type and quality, ecology and geography; but also, differences related to suburb age and era, built form, socio-economic factors, and development pressures. Sydney has significantly more canopy cover than Perth and Melbourne; with Melbourne's western region having the lowest canopy cover levels across the three cities. In nearly all LGAs the three main land use classes contributing to vegetation cover are residential land, parkland and infrastructure land (primarily street networks). Of these, residential land nearly always provides the largest contribution. Exceptions to this tend to be high density inner-city areas, where parkland and sometimes street networks can exceed the contribution from residential land. These findings underscore the need for a multi-pronged approach to urban forest management. Efforts to better manage canopy on public land can and are having significant impact; but given the major contribution of private land, increased attention and action is needed in these areas to successfully protect and enhance the urban forest.

To support better urban forest management, we have developed a dashboard to assess community urban forest performance. The dashboard presents rich but digestible information for evaluating the urban forest performance of an area. The dashboard is targeted at the suburb scale, which provides sufficient spatial granularity to reflect the diversity of urban landscapes.

The four example suburbs presented demonstrate the utility of the dashboard. It allows nuanced diagnosis of the relationship between tree canopy cover and land use; the nature of change in canopy over time; areas of strong performance, and where the suburb is behind relative to comparator suburbs; and opportunities for improved urban forest outcomes.

The urban forest data we have assembled, as featured in the four suburb dashboard examples, reinforces the importance of a multi-pronged approach to urban forest management. They also reveal dynamics in tree cover over time in cities, with many areas recording loss in canopy cover that offsets any gain resulting from tree growth or new plantings. The most loss is evident in residential land, suggesting a combination of urban re-development, landowner land-management practices, and climatic effects are combining to reduce urban vegetation cover. In the pubic realm, particularly in parkland and streets, we see less areas of loss and noticeable gains in some areas, suggesting that public realm strategy and action is having a positive impact.

Such public realm efforts are critical, but the results also highlight the need to engage with the private realm, given the magnitude of its contribution to urban forest cover. The governance of private land presents many challenges, though leading jurisdictions are increasingly engaging with this challenge (Ordenez et al 2020).

Increased efforts to change management practices and outcomes on private land are needed. A national monitoring program, building on the work presented here, would provide much needed evidence to support such action, allowing the monitoring of performance and the evaluation of policy, policy reform, programs, and investment over time. Such evaluation work should include detailed assessment of the impact of spatial land-use policy mechanisms and associated implementation and resourcing for improved urban forest outcomes. It would also support land-use policy reform to better maximise the synergies and co-benefits of urban development and a healthy urban forest.

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