# Boroondara Canopy Cover Assessment 2006 to 2016

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19 December 2017

# Content

# Summary

Tree canopy cover is a simple and common measure of urban forest status. The objective of this project is to inform the City of Boroondara of trends and changes in canopy cover in the Local Government Area (LGA) over a ten year period (2006-2016). Canopy cover and cover class were estimated for the twelve suburbs in Boroondara for 2006, 2011 and 2016 by random sampling of 2000 points for each suburb. Canopy cover was further separated by tenure: public land, public streetscapes and private land. The cause of any change in canopy cover was also investigated.

Over the ten year period, the Boroondara LGA experienced no statistically significant change in canopy cover. However, there was fluctuation in canopy cover over time and by different land tenures in the suburbs. Most suburbs had net stable canopy cover over the 10 year period, with tree canopy cover increasing significantly ($p<0.05$) for four suburbs (Kew, Kew East, Hawthorn, Glen Iris). Many suburbs such as Camberwell, Ashburton and Balwyn experienced high canopy loss between 2006 and 2011 only to have the canopy cover grow or stabilize between 2011 and 2016 - a result probably due in part to trees recovering from the millennium drought which did not end until 2010.

In every suburb of Boroondara the estimated canopy cover on public land and in public streetscapes was greater than that on private land. Similarly, public land and public streetscapes were the only land tenures to have net canopy cover growth between 2006-2016 and all significant declines in canopy cover were experienced in private tenures.

Despite the initial negative trend in private area loss during 2006-2011, which was most likely a result in part due to the millennium drought, this study has shown that Boroondara had a stable canopy cover over the past 10 years and that there was a consistent trend for growth in public areas and streetscapes in most suburbs. The fact that almost all significant growth in canopy cover came from public areas and streetscapes indicates that the City of Boroondara has successfully compensated for potential canopy cover loss from private development and environmental stress by effectively managing the relatively smaller component of canopy cover on streetscapes and public land.

## Introduction

Tree canopy cover is a simple measurement of the extent of the urban forest, and therefore an indicator of the magnitude of the ecosystem services provided by the forest (Nowak & Greenfield 2012). Increasing canopy cover in urban areas is thus an important policy priority for local governments across the developed world. Benchmarking projects on canopy cover by Jacobs et al. (2014), Amati et al. (2017) and Kaspar et al. (2017) provide important examples of measuring canopy cover and tracking change in canopy cover through different land tenures using the i-tree method. The work described in this report and its appendices draws on and contributes to those reports furthering the understanding of change canopy cover in the Boroondara LGA.

The aim of this project is to assess changes in canopy tree cover across Boroondara between 2006 and 2016 by land tenure and suburb. The project will enable the City of Boroondara to gain an understanding of the quantum of change to canopy tree cover over a 10 year period. The results of the project will assist the City of Boroondara in future planning for any further changes to Tree Protection Local Law, planning schemes and vegetation management on public land.

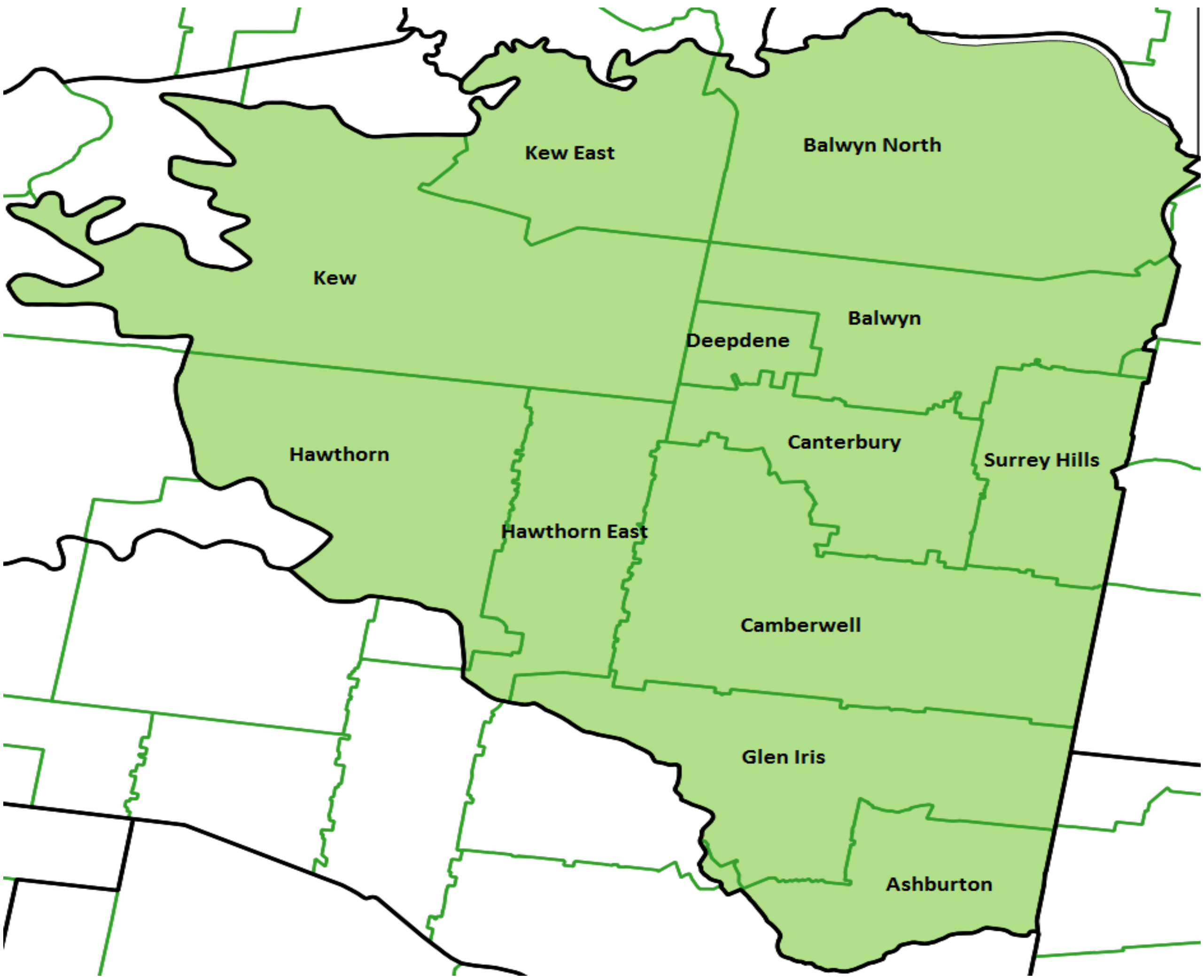
## Methodology

The research methodology for this report was conducted consistent with previous tree canopy cover benchmarking completed by Jacobs et al. (2014), Amati et al. (2017) and Kaspar et al. (2017). A dependent sample of 2000 random points was used to classify features for each of the 12 suburbs in the Boroondara LGA for 2006, 2011 and 2016. Points were assessed through QGIS software on remote imaging provided by the City of Boroondara. Each point was assessed as either one of four variables: Tree canopy cover (1), Shrub cover (2), Bare earth/ grass (3), or Hard surface (4) and were assessed as landing on either public streetscape, private land or public space. If change was recorded between 2006, 2011 and 2016 an additional assessment of the area was made to ascertain the cause of the loss. The data was then assessed statistically for significance and variation.

*Statistical boundaries*

Statistical boundaries for each suburb were 2016 State Suburb polygons (SSCs) sourced from the ABS (ABS 2016).

*Figure 1.1. Boroondara LGA and the suburbs assessed*



*Aerial Images*

Aerial images were provided by the City of Boroondara for each of the three time periods: July 21 2006, October 4 & 14 2011, March 21 & 22 2016.

*Land tenure*

Land tenure areas were classified based on policy relevant clusters of area use: private, public or street (Table 1.1 below). Areas were aggregated using zoning data and polygons from the *Vicdata* planning database (Vicdata 2016). Tenure types included the following:

- *Streetscapes* including streets, roads, alleyways and nature strips and is mostly an area under the jurisdiction of local government or road management authorities (e.g. VicRoads);
- *Public areas* including aggregates of areas under local, state or federal government, for example parks, libraries, cemeteries and education facilities; and
- *Private* land-use comprised commercial, industrial, residential and other land use types.

*Table 1.1 Land tenure categories from Vicdata planning database used in the study*

| Land-use class | Zoning code | Zoning class description |
|---|---|---|
| *Public* | PC, PP, PU | Public Park, Education, Health and Community, Transport, Cemetery Crematorium, Local Government, Conservation Zone, Other public use or service area |
| *Private* | AC, AE, B, BM, C, CA, CC, CD, CL, D, DC, DD, DP, DZ, EA, EM, ER, ES, FO, FZ, GA, GR, GW, HO, IA, IN, IP, LD, LS, MA, MU, NC, NR, PA, PD, PZ, R, RA, RC, RF, RG, RL, RO, RU, RX, SB, SL, SM, SR, SU, TZ, UF, UG, UR, VP, WM | Commercial, Industrial, Residential, Other land-use types |
| *Street* | RD | Streets, Roads, Nature Strips |

Points were classified as being on private, public or streetscapes prior to assessment of points through aerial imagery. Each of the points in the suburb were manually assessed as falling under one of four variables: Tree Canopy Cover (1), Shrub Cover (2), Bare Earth/ Grass (3) and Hard surface (4) which was the same classification used by Jacobs et al. (2014) for the 2014 Benchmarking Australia's Urban Tree Canopy report.

*Table 1.2 Classification of variables*

| Tree Canopy | Shrub Canopy | Grass/ Bare Earth | Hard Surface |
|---|---|---|---|
| Tree that is >2 meters | Plant that is <2 meters but not grass | o Agricultural pasture | o Buildings |
| o Any plant that looks like a tree from above | o Agricultural crops such as grape vines | o Residential lawns | o Roads |
| | o Bushland shrubs | o Cleared areas to the sides<br>of roads and railway tracts | o Footpaths<br>o Train lines |
| | | o Golf Courses | o Car parks |
| | | o School Ovals | o Water bodies |
| | | o Airports | o Sandy beaches |
| | | o Sports Fields | o Rocky coastlines |
| | | o Cemeteries | |
| | | o Horse racing tracks | |
| | | o Lawn Bowls | |
| | | o Grass Tennis Courts | |
| | | o Industrial estates | |
| | | o Sites cleared for development | |
| | | o Dirt roads and walking tracks | |

*Source: Jacobs et al. 2014*

*Identifying trees from shrubs*

The aim for the project was to classify trees with a canopy height greater than 3 metres. There is no definitive method to identify a tree from a shrub in an aerial image due to the 2D nature of the remote images provided (Rogers & Jaluzot 2015). However, similar to other research on canopy cover, shadows, growth over fences and buildings and other contextual information was used to help differentiate between trees and shrubs (Richardson & Moskal 2014). Research from Parmehr et al. (2016) indicate that the results are broadly similar when the i-tree method is compared with other canopy cover estimation methods such as Light Detection And Ranging (LiDAR) and multi-spectral imagery, indicating that non sampling error from the misclassification of shrubs and trees is minor. Therefore, it is not considered that difficulty in determining the difference between shrubs and trees is a significant source of non statistical error in this study.

Other potential sources for misclassification include excessive shadows resulting from the time of the day the remote image was taken, user error and vegetation height. Vegetation height, coupled with the angle that the image was taken can potentially lead to image parallax errors where tall objects appear to lean and 'move' the point between the two time images (Nowak & Greenfield 2012). More details on parallax and data quality are discussed in the **Appendix**.

*Assessing the cause of canopy cover loss*

This research used a dependent sampling regime i.e. the same sample was used for each time period. This method enables an assessment of the cause of loss of canopy cover from time A to time B and thus could be done for assessments of change between 2006-2011 and 2011-2016. For example, if a point was classed as Tree (1) in 2006 but then classed as Not Tree (2-4) in 2011 then an additional visual assessment of both aerial images around the point was undertaken to identify the cause of the loss. A new variable was created to capture this with two values identifying the general cause of the canopy cover loss: construction or removal and one value to classify potential parallax and thus data quality for comparisons.

- *Construction* was identified as the cause if there was evident building activity in the surrounding area of canopy loss (for example renovation, a new building/pool);
- *Removal* was identified if there was not a direct identifiable cause of the canopy loss (for example tree pruning or tree removal); and
- *Parallax* was identified as the cause if the tree appeared to move between times and was used as a variable to indicate data quality for comparisons.

## Outcomes: General

*Boroondara by cover class*

Hard surfaces made up the largest component of land cover for Boroondara in 2016 at approximately 52% of the land area, followed by tree canopy cover (25%), Bare Earth/ Grass (19%) and shrubs (4%).

*Figure 2.1 Percentage of cover classes for Boroondara LGA*

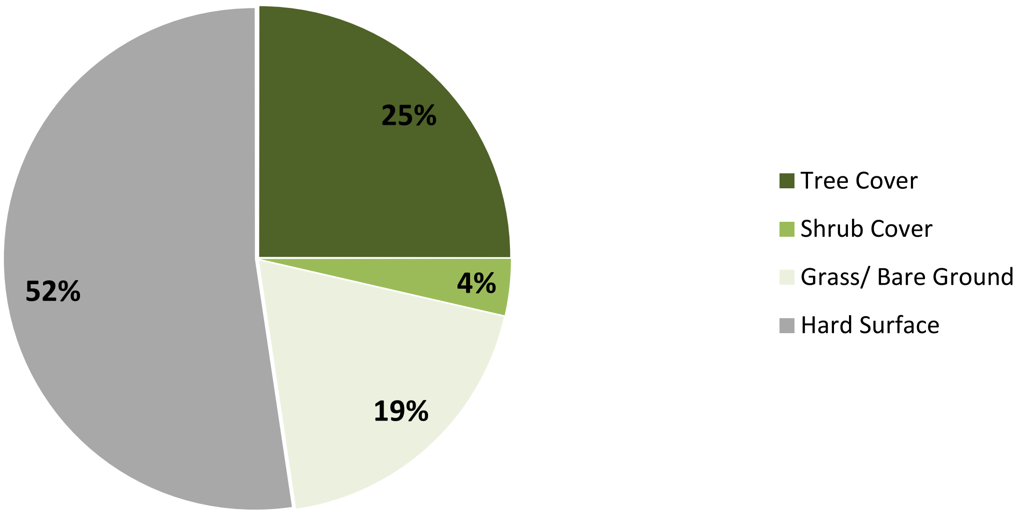
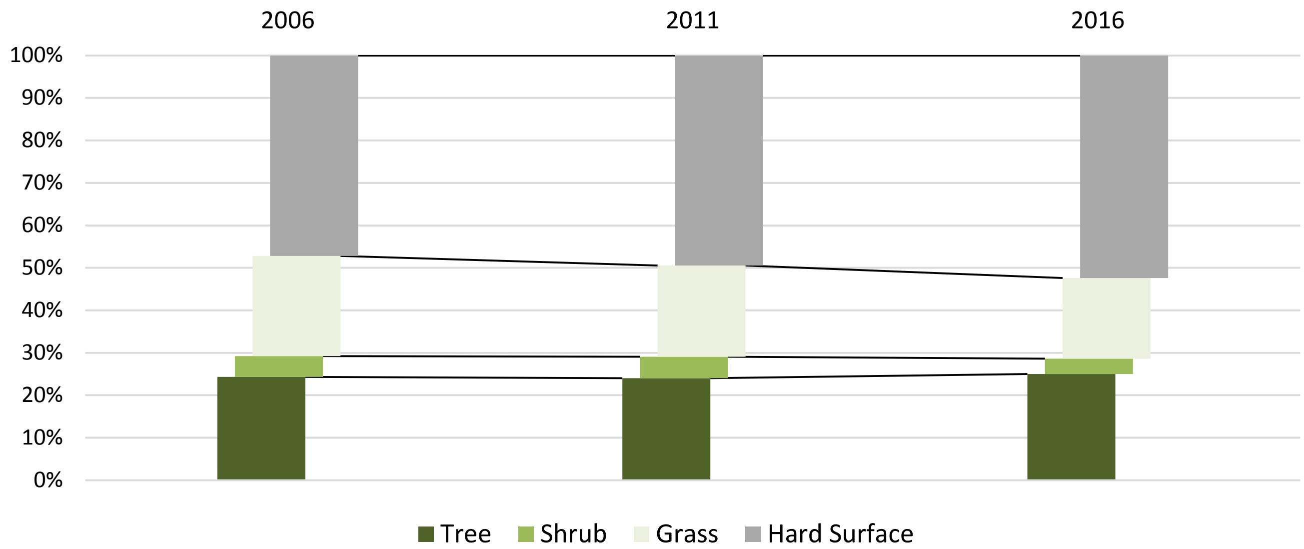
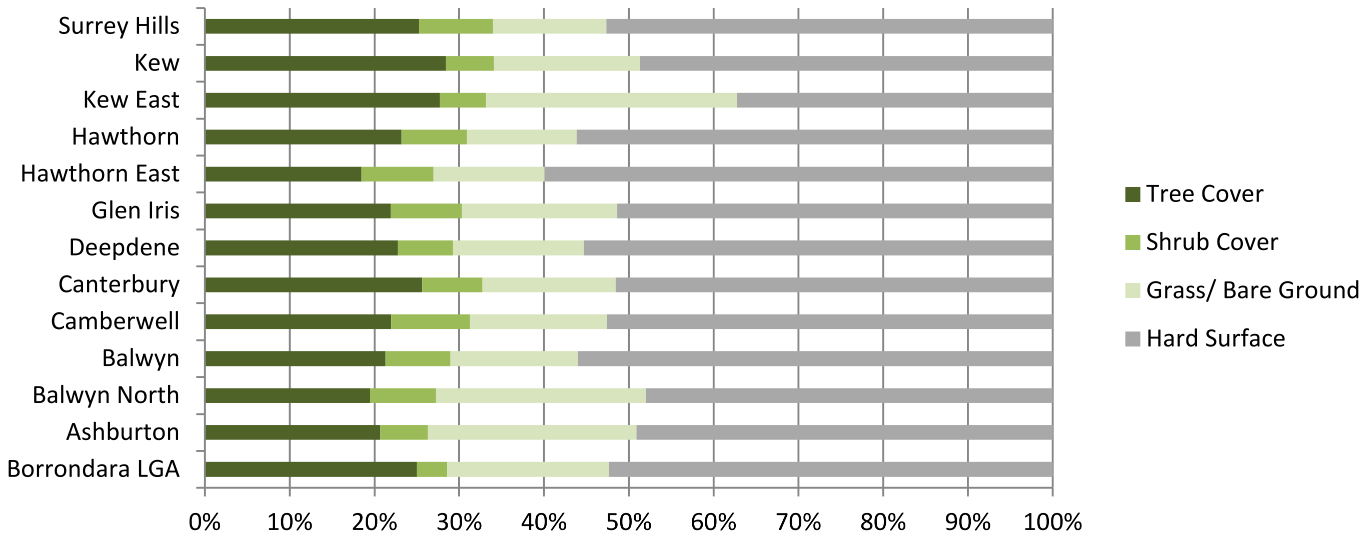



*Figure 2.2 Change in cover classes for Boroondara LGA, 2006, 2011 and 2016*




Between 2006 and 2016 there was significant change in Boroondara cover classes, particularly between hard surfaces and bare earth/ grass. Tree canopy cover overall remained relatively stable from 24.3% in 2006 to 25.0% in 2016. Hard surfaces however, increased  5.2%, from 47.2% in 2006 to 52.4% in 2016 and was largely at the expense of bare earth/ grass which declined  4.6%, from 23.7% of the land area in 2006 to 19.1% in 2016.

*Figure 2.3 Percent land area by cover class and suburb, Boroondara LGA, 2016*




Boroondara LGA had variable canopy cover by suburb in 2016 with Kew and Kew East recording the highest canopy cover proportion (28.4% and 27.7% percent respectively). Hawthorn East and Balwyn North recorded the lowest canopy cover percentage at 18.5% and 18.6% respectively. Hawthorn East had the highest proportion of the suburb as hard surface (60%), followed by Hawthorn, Camberwell and Balwyn (52% each).

*Figure 2.4 Canopy cover by suburb, 2006, 2011 and 2016*

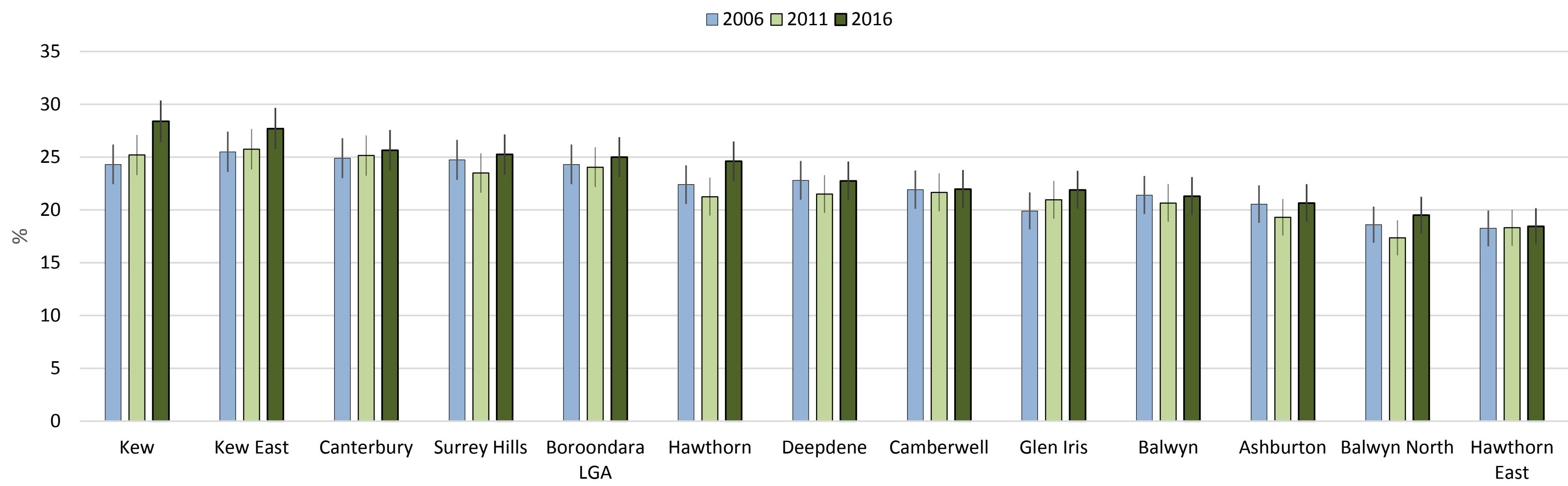



*Figure 2.5 Change in canopy cover between 2006-2011 and 2011-2016 by suburb*

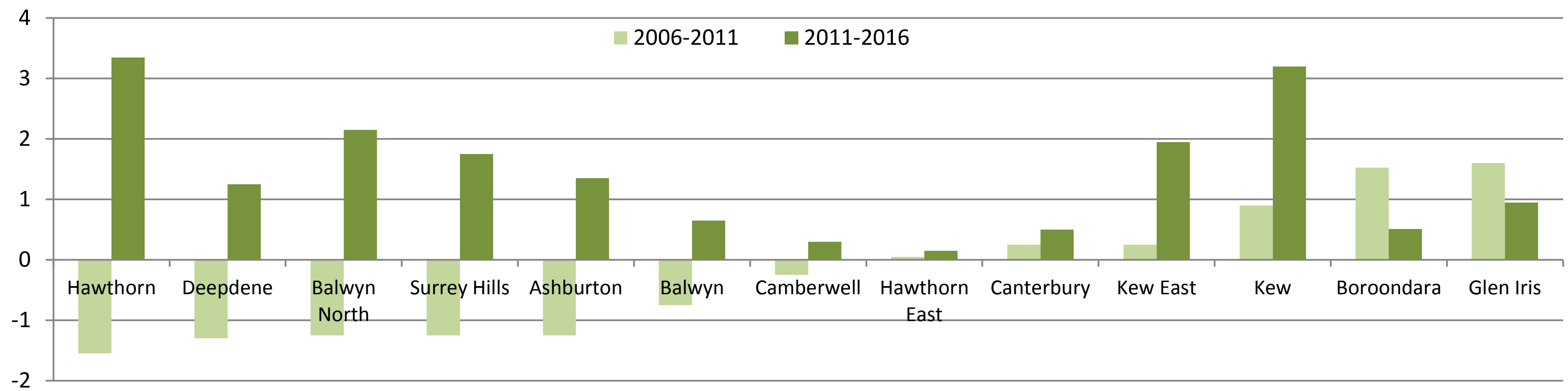
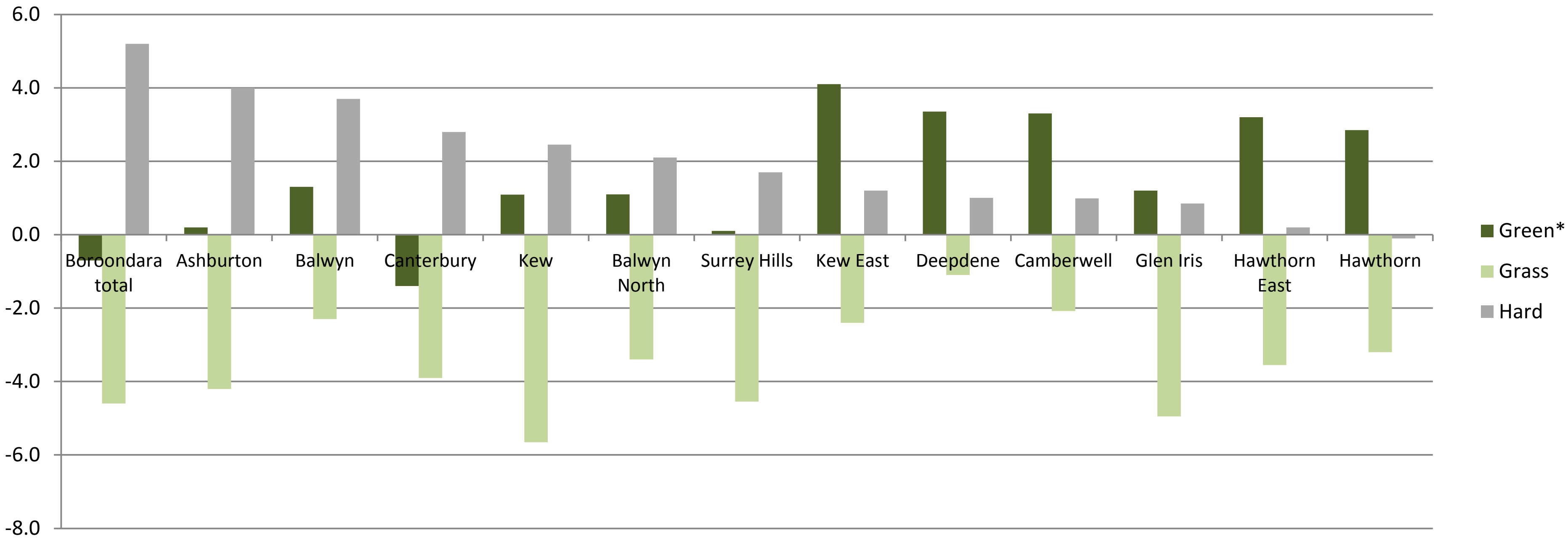


*Figure 2.6 Change in cover class between 2006 and 2016 by suburb*




* Tree canopy cover + shrub

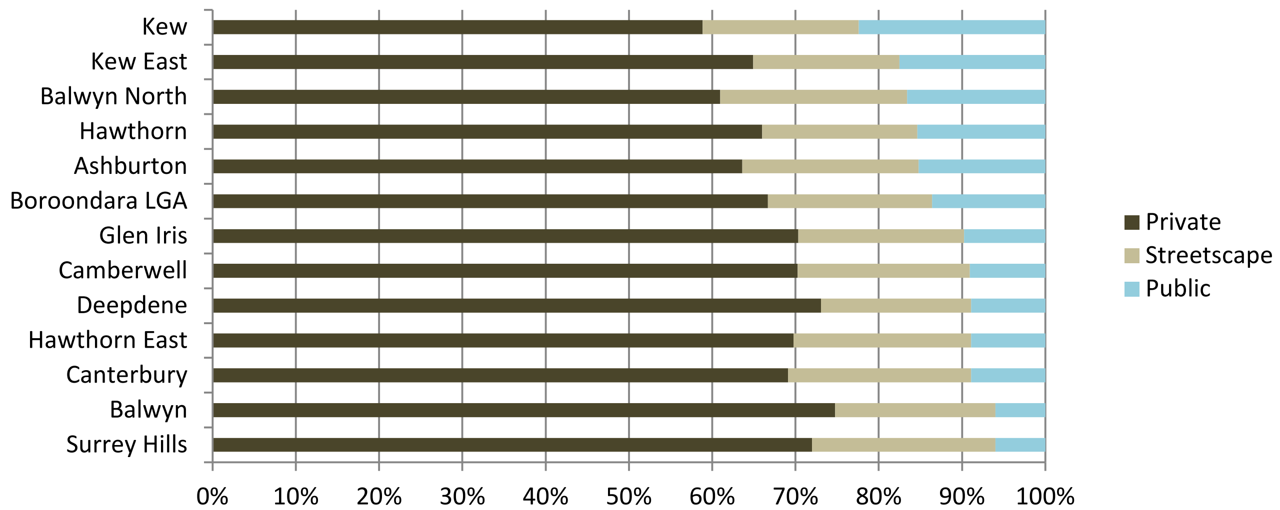
Most suburbs (8 out of the 12) recorded no significant change in canopy cover over the period between 2006 and 2016. Many suburbs experienced a decrease in canopy cover between 2006 and 2011, including Hawthorn (-1.5%), Ashburton (-1.3%), Deepdene (-1.3%), Balwyn North (-1.2%) and Surrey Hills (-1.2%), which then recovered by 2011-2016 so that no suburb had net significant canopy cover loss over the 10 year period. Some suburbs like Kew (+4.0%), Glen Iris (+2.6%) and Kew East (+2.2%) recorded net consistent and significant growth over the 10 year period (Figure 2.4 and Figure 2.5).

Many suburbs underwent significant change in cover class over the 10 year period. Suburbs such as Ashburton, Balwyn and Canterbury increased hard surfaces largely at the expense of bare earth/ grass (Figure 2.6). Suburbs such as Kew, Kew East, Deepdene, Glen Iris and Hawthorn East all increased the share of green space (Tree canopy + Shrubs) at the expense of bare earth/ grass (Figure 2.6).

*Tenure*

Each suburb had different proportion of land by tenure. The highest proportion of tenure for all suburbs was private ranging from 74.8% private land for Balwyn to 63.6% private land for Ashburton. Kew has the largest proportion of land that is public (22.4%) and Balwyn and Surrey Hills have the lowest (6% each). All suburbs had similar proportions of land as streetscapes ranging from 18-22% for each suburb.

*Figure 2.7 Percent land area by tenure and suburb, Boroondara LGA, 2016*



## Dynamic change and churn

Every suburb in Boroondara experienced dynamic change in the number of random points that were classified as tree canopy or not at each time point. This dynamic change is hidden in the net change statistic as there can be simultaneous significant loss and gain in tree canopy cover ('churn') that counterbalance one another, such that there is little, or no, significant net change over time. Some suburbs experienced more dynamic changes than others. The greatest churn in canopy cover between 2011 and 2016 was in Balwyn, where the small net change (+0.7%) was due to a large increase in canopy cover (+5.4%) accompanied by a large decrease (-4.7%) dominated by tree removal (-2.8%) and construction activity (-1.6%). In Hawthorn East, for example, there was a similar scenario where moderate tree growth (+4.1%) was largely offset by tree loss (-4.0%) for a stable net result of +0.2% growth in canopy cover.

*Change from shrub to tree - sapling growth*

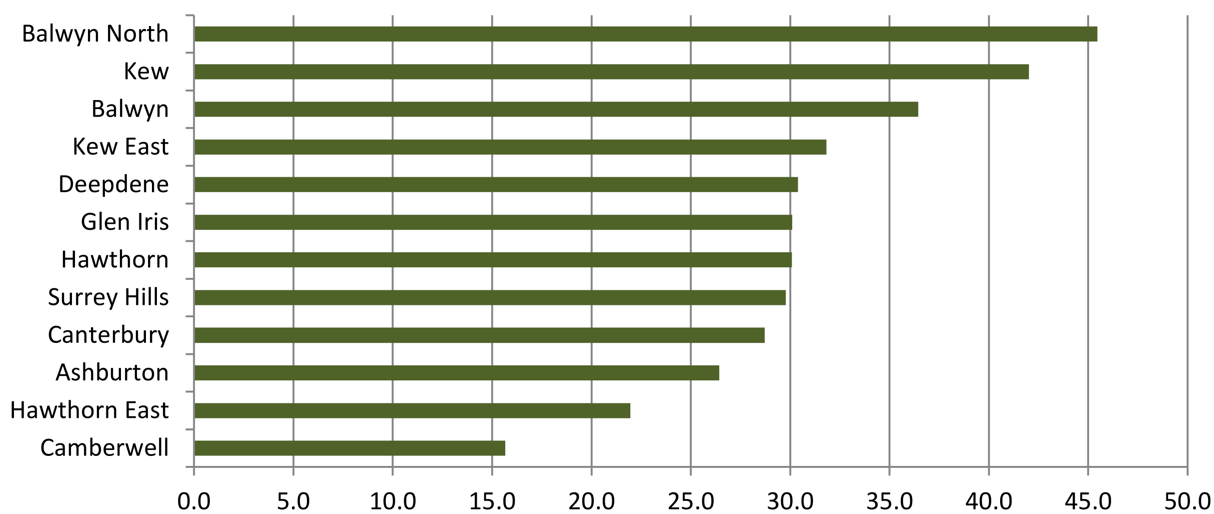
An example of the dynamic change that is experienced in each suburb is the transition of points that were classified as 'shrub' in 2011 (Time A) that were then classified as 'tree' in 2016 (Time B). The dependent sampling used for this study enables keeping track of changes in cover classes and thus tree canopy cover growth over each five year period.

Tree canopy cover growth between two periods (time A and time B) arises from three possible scenarios:

1) An existing tree from time A growing into the sample point location in time B;
2) A tree being planted into the sample area after time A which then reached >3 meters in height before time B; or
3) A sapling that was previously classified as a shrub (<3meters) in time A, subsequently matures into a canopy tree (>3meters) by time B.

This research provides an opportunity to identify the extent of where the change from sapling to tree (scenario 3) occurs and can be used as an indicative measure of previous tree plantings over a five to ten year period.

*Figure 2.8 Percentage of tree canopy cover growth as a result of shrubs (saplings) maturing into trees, 2011-2016*



Balwyn North (45.5%) followed by Kew (42%) had the highest proportion of canopy cover growth as a result from shrubs (saplings) in 2011 transitioning to tree canopy cover in 2016, indicating that a significant number of young trees were planted between 2006 and 2011 in these two suburbs. Camberwell (15.7%) and Hawthorn East (22%) had the lowest proportion of tree canopy cover growth from shrub (sapling) growth which indicates that growth in canopy cover for these areas was primarily from already mature trees.

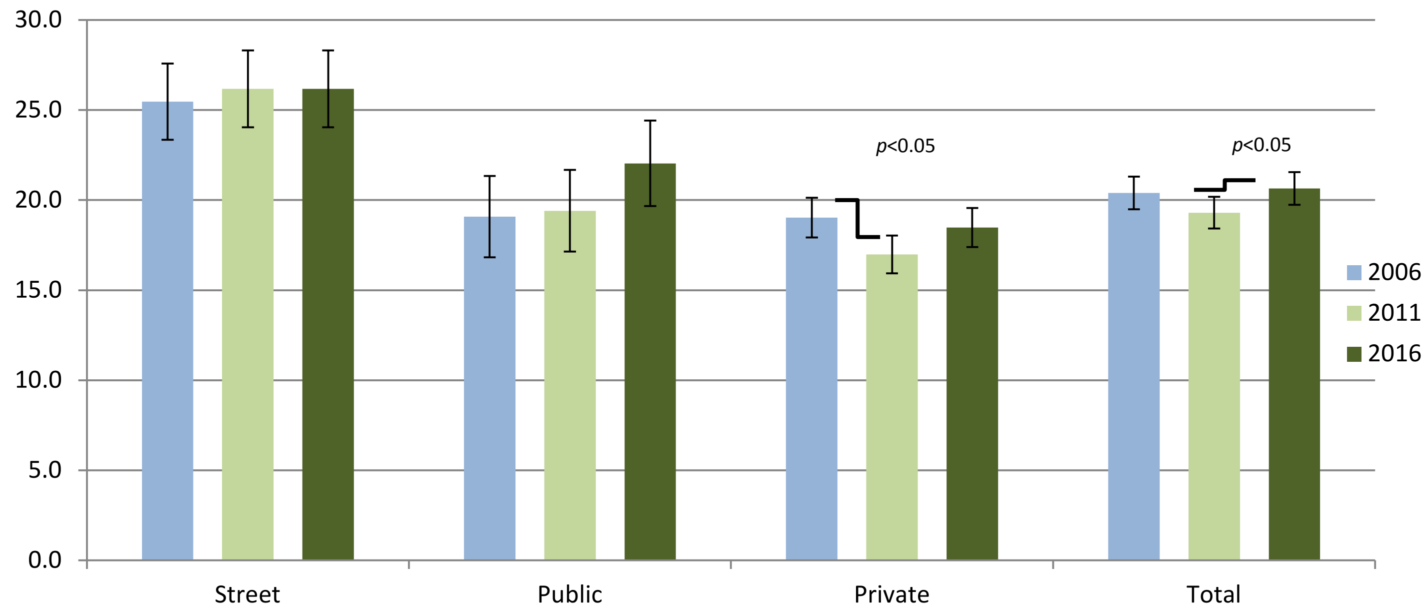
## Outcomes: By suburb

Each suburb in Boroondara experienced differing rates of growth and loss based on year, tenure and churn. This chapter will detail findings for each of the 12 suburbs of Boroondara LGA.

### Ashburton

Canopy cover for Ashburton was 20.7% of the suburb in 2016 and ranged from 18.5% for private areas, 22.0% for public areas and 26.2% for streetscapes.

*Figure 3.1 Ashburton canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

Considerable building activity in Ashburton between 2006 and 2011 resulted in a significant decrease -2.0% ($p$<0.05) in canopy cover for private areas (from 19.0% canopy cover in 2006 to 17.0% in 2011). The construction and tree removal activity between 2006 and 2011 however, did not result in a net loss of canopy cover for streetscapes and public areas. The significant loss in canopy cover for private areas between 2006 and 2011 did not result in a net significant decrease in canopy cover because of moderate growth in public areas and streetscapes. Between 2011 and 2016, the canopy cover for all Ashburton increased moderately from 19.3% (±0.8%) to 20.7% (±0.8%) and this was primarily due to increased canopy cover growth in private and public areas and a decrease in tree canopy loss for private areas (Figure 3.2).

*Figure 3.2 Percentage of canopy cover gain and loss in Ashburton by land tenure, 2006-2011 and 2011-2016*


* *p*<0.05 and change over the period was significant

A component to the significant change between 2006-2011 in Ashburton was that canopy loss (-5.8%) in private areas was also accompanied by lower tree canopy growth (+3.8%) to result in a net loss of -2.0%. A large part of the canopy loss in Ashburton between 2006 and 2011 was due to high removal and construction activity. Tree canopy cover growth between 2011 and 2016 however, was high and accompanied by lower tree loss which prevented further losses for the suburb.

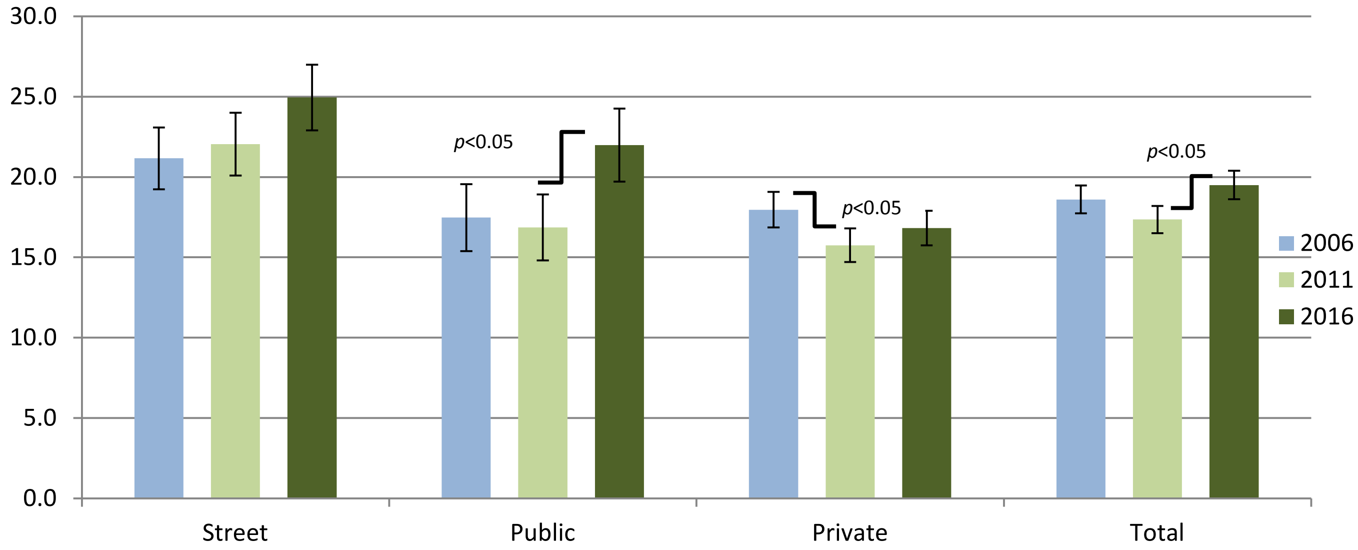
*Table 3.1 Ashburton: Cause of canopy cover loss in by land tenure, 2006-2011 and 2011-2016*

| Cover Loss | Removal | | Construction | | Parallax | | Total | |
|---|---|---|---|---|---|---|---|---|
| | 2006-2011 | 2011-2016 | 2006-2011 | 2011-2016 | 2006-2011 | 2011-2016 | 2006-2011 | 2011-2016 |
| **Street** | 3.3 | 2.4 | 1.2 | 0.5 | 1.9 | 0.7 | 6.4 | 3.5 |
| **Private** | 2.6 | 1.7 | 2.1 | 1.0 | 1.1 | 0.2 | 5.8 | 2.9 |
| **Public** | 2.6 | 1.6 | 1.0 | 0.7 | 0.0 | 0.3 | 3.6 | 2.6 |
| ***Total*** | 2.8 | 1.8 | 1.8 | 0.9 | 1.1 | 0.4 | 5.6 | 3.0 |

## Balwyn North

Canopy cover for Balwyn North was 19.5% (±0.9%) in 2016 ranging from 16.8% (±1.0%) for private areas, 22.0% (±2.3%) for public areas and 24.9% (±2.0%) for streetscapes.

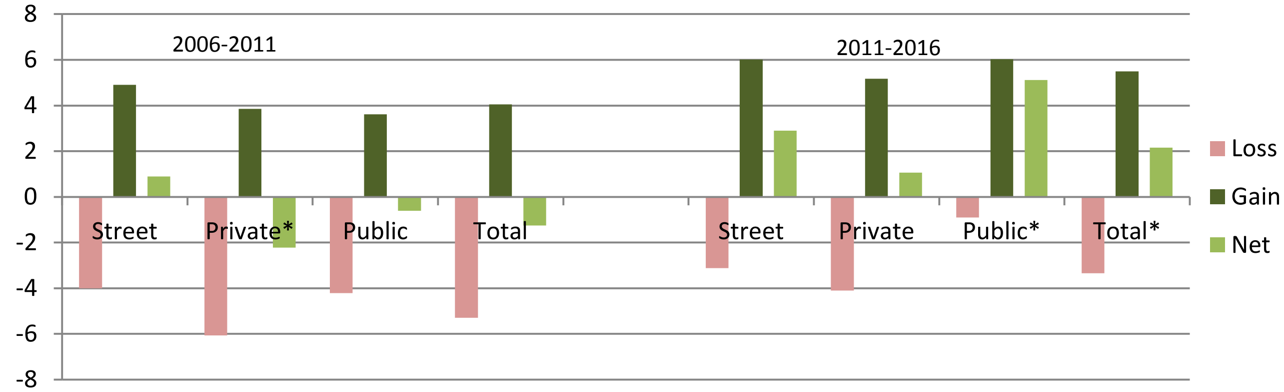
*Figure 3.3 Balwyn North canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

A large amount of construction between 2006 and 2011 resulted in a significant decrease -2.2% ($p<0.05$) in canopy cover for private areas (from 18.0% canopy cover in 2006 to 15.8% in 2011). Public areas experienced significant growth (+5.1%) between 2011 and 2016 increasing from 16.9% to 22.0% of the overall area. The growth in public areas and streetscapes between 2011 and 2016 resulted in canopy cover increasing 1.9% (from 17.4% to 19.5%).

*Figure 3.4 Percentage of canopy cover gain and loss in Balwyn North by tenure, 2006-2011 and 2011-2016*




* $p<0.05$ and change over the period was significant

The period between 2011-2016 had reduced canopy cover loss and increased growth which led to a greater net canopy cover growth. There was some evidence of replanting of trees around 2011, where saplings classified as shrubs (<3m tall) in 2011 were then consequentially classified as trees in 2016 due to significant growth over the 5 year period which was likely to have influenced the net growth between 2011 and 2016, despite the loss of many trees.

*Table 3.2 Cause of canopy cover loss in Balwyn North by land tenure, 2006-2011 and 2011-2016*

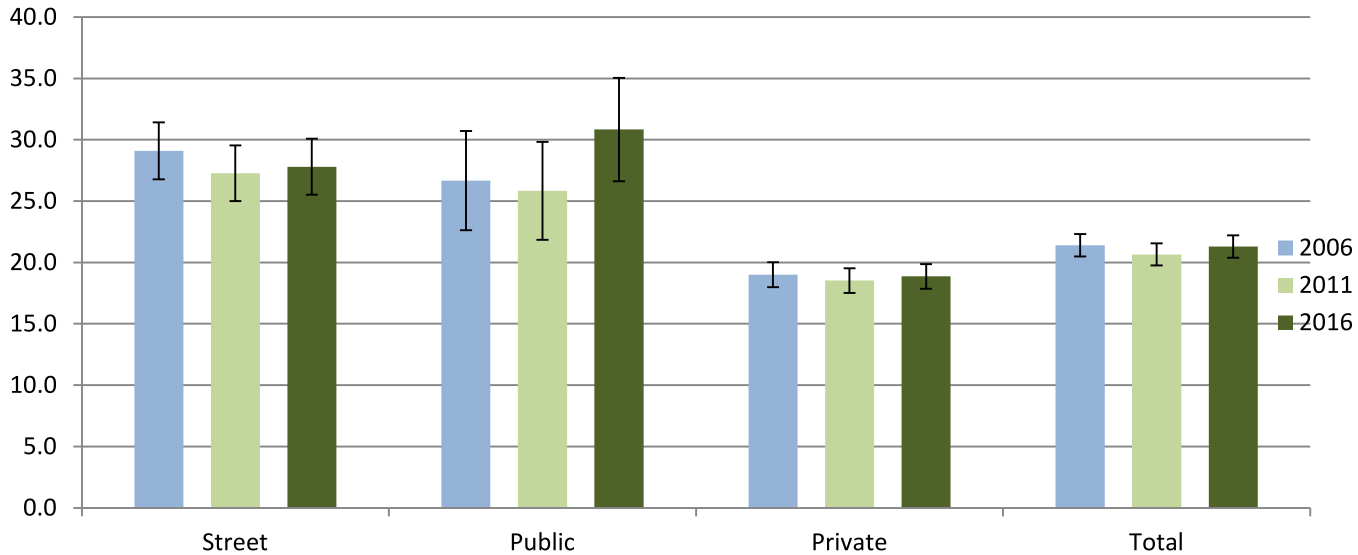
| **Cover Loss** | **Removal** | | **Construction** | | **Parallax** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** |
| **Street** | 1.8 | 2.7 | 0.9 | 0.4 | 1.3 | 0.0 | 4.0 | 3.1 |
| **Private** | 3.3 | 2.6 | 2.5 | 1.5 | 0.3 | 0.0 | 6.1 | 4.1 |
| **Public** | 2.4 | 0.6 | 1.5 | 0.0 | 0.3 | 0.3 | 4.2 | 0.9 |
| ***Total*** | 2.8 | 2.3 | 2.0 | 1.0 | 0.6 | 0.1 | 5.3 | 3.4 |

Removal was the largest factor in canopy cover decrease for 2006-11 and 2011-16. Construction activity was also considerable but decreased in impact on canopy cover between 2011 and 2016. Lower canopy loss from construction was accompanied by higher gains between 2011 and 2016 with an increase of 5.5% in 2016 compared to 4.1% in 2011.

## Balwyn

In 2016 Balwyn had 21.3% (±0.9%) of the suburb as canopy cover. Canopy by land tenure ranged from 18.9% (±1.0%) for private areas, 27.8% (±2.3%) for streetscapes and 30.8% (±4.2%) for public areas.

*Figure 3.5 Balwyn canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

There was a noticeable amount of construction of houses and pools between 2006-2011, however the net result was stable with no significant change between 2006, 2011 and 2016.

Despite having non-significant growth over the time period, there was considerable 'churn' for this suburb with high rates of canopy cover growth in all land tenures but also high corresponding canopy cover loss. The canopy cover loss was lower between 2011 and 2016, particularly for public areas.

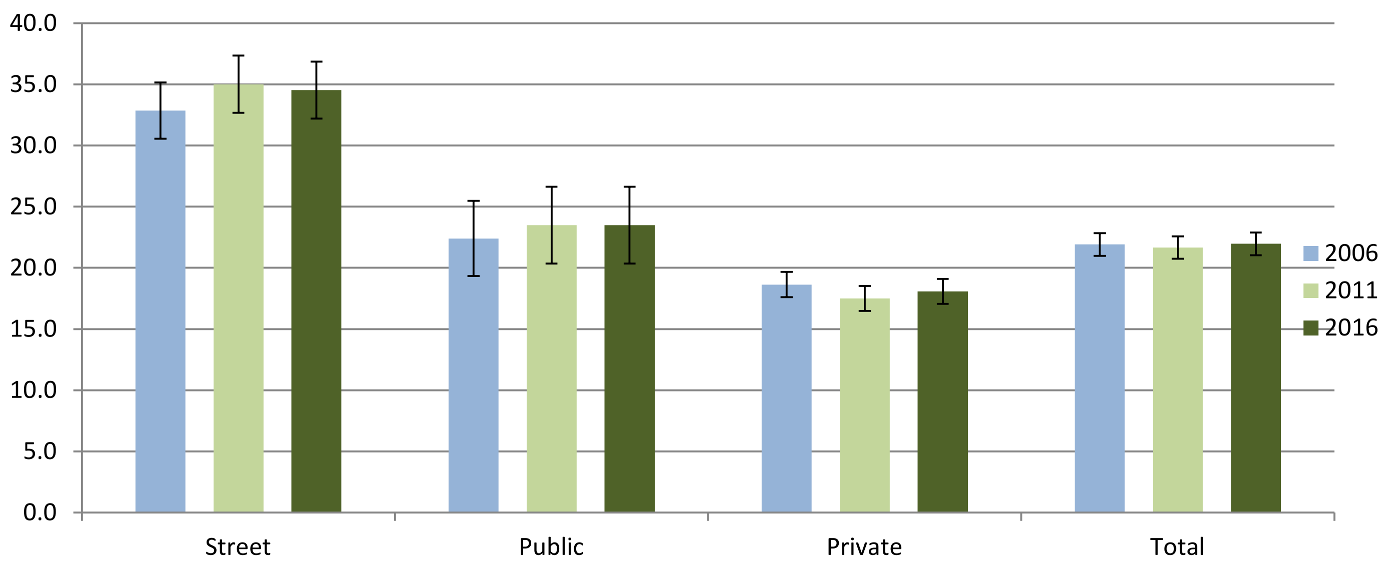
*Figure 3.10 Percentage of canopy cover gain and loss in Balwyn by tenure, 2006-2011 and 2011-2016*


* $p$<0.05 and change over the period was significant

## Camberwell

Canopy cover for Camberwell in 2016 was 22.0% (±0.9%), ranging from, 18.1% (±1.0%) in private land, 23.5% (±3.1%) for public areas and 34.5% (±3.1%) for streetscapes.

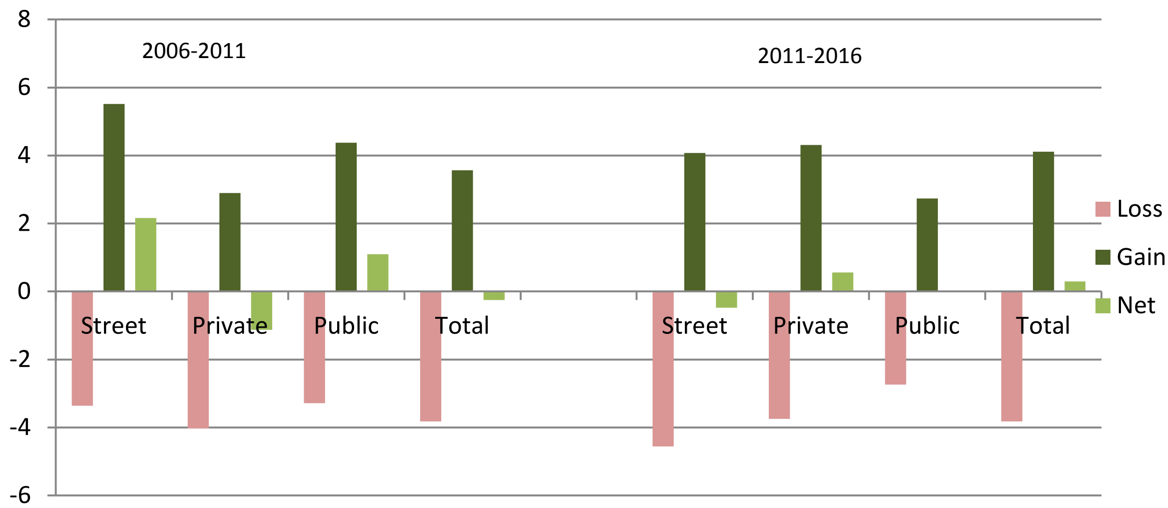
*Figure 3.11 Camberwell canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

There was no significant growth over the 10 year period for Camberwell. Between 2006-2011 and 2011-2016, the levels of canopy cover growth were offset by canopy cover loss to produce a net stable rate of canopy cover for the suburb with no significant change for any land tenure.

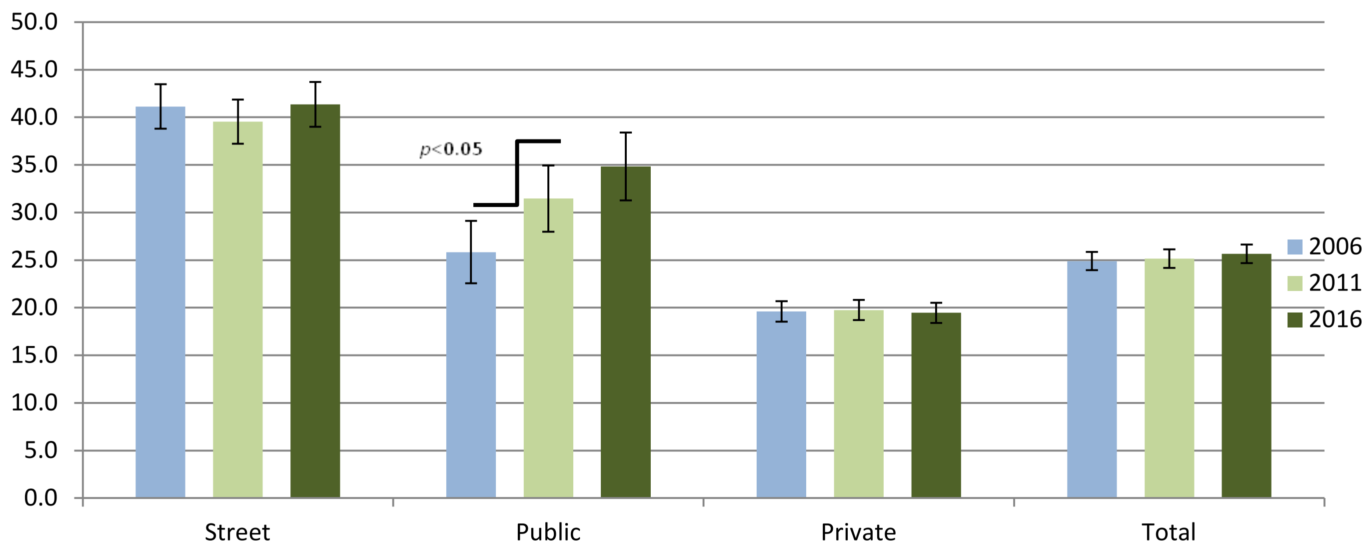
*Figure 3.12 Percentage of canopy cover gain and loss in Camberwell by tenure, 2006-2011 and 2011-2016*




## Canterbury

Total canopy cover for Canterbury was 25.7% (±1.0%) of the suburb in 2016 with differences by tenure ranging from 19.5% (±1.1%) for private land, 34.8% (±3.6%) for public areas and 41.4% (±2.3%) for streetscapes.

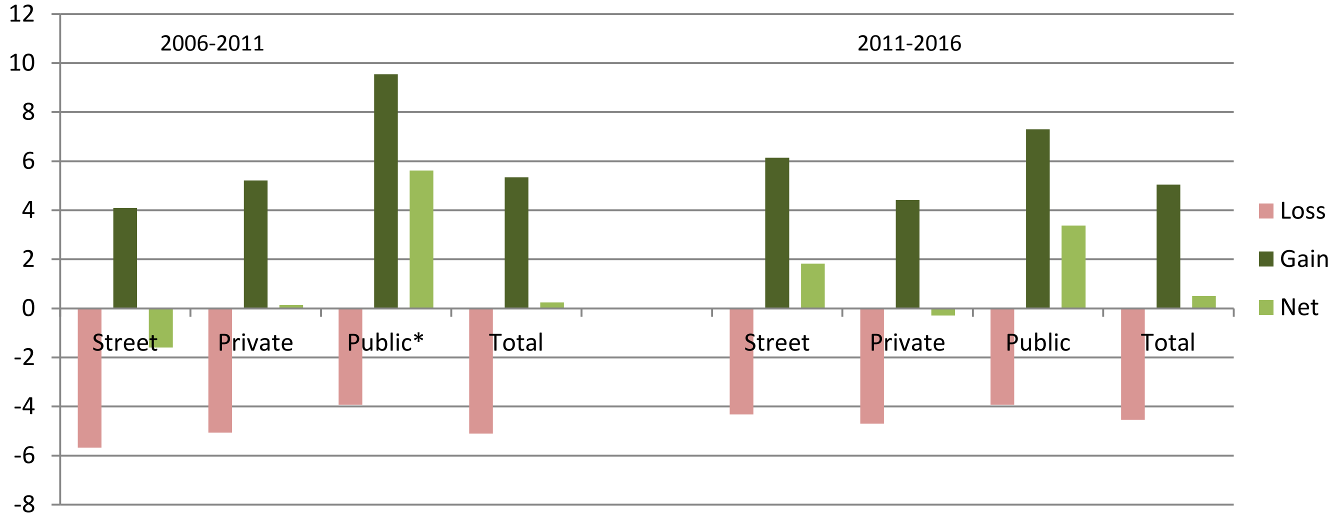
*Figure 3.14 Canterbury canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

Public areas, primarily dominated by parklands, had consistent growth over the 10 year period (+9.0%, $p<0.05$) increasing from 25.8% in 2006 to 34.8% in 2016. There was no significant growth or loss over the 10 year period for both streetscapes and private areas.

*Figure 3.15 Percentage of canopy cover gain and loss in Canterbury by tenure, 2006-2011 and 2011-2016*



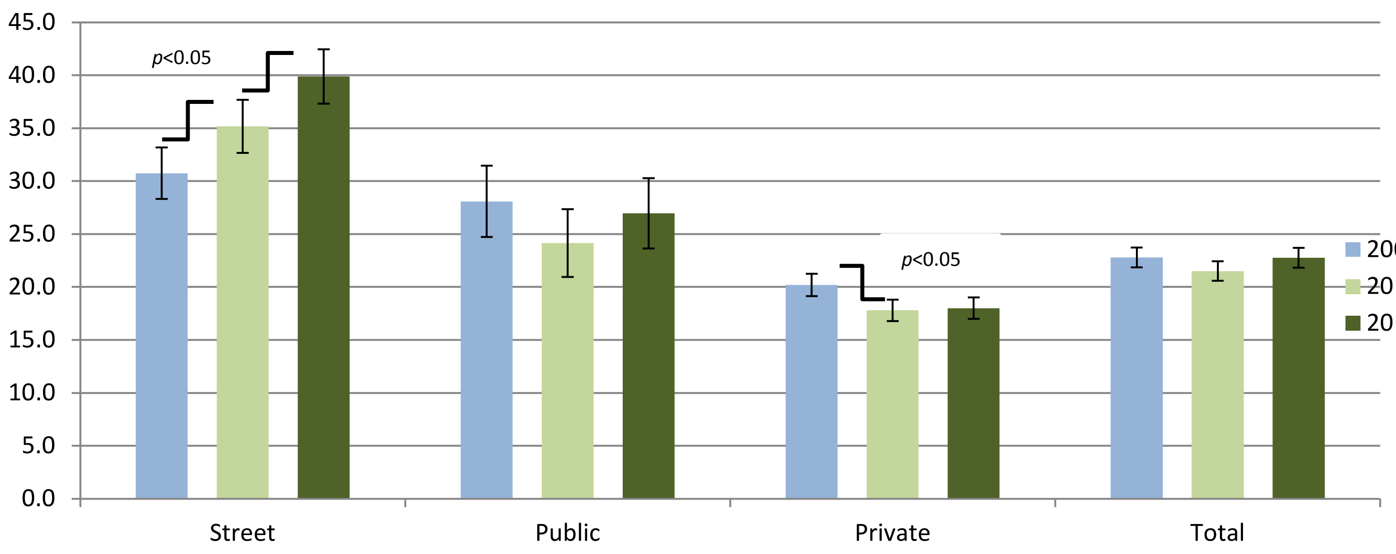

* $p<0.05$ and change over the period was significant

The high level of canopy cover growth in public areas for Canterbury was also accompanied by slightly lower canopy cover loss due to removal.

## Deepdene

Canopy cover for Deepdene was 22.8% (±0.9%) of the suburb in 2016. Canopy cover ranged from 18.0% (±1.0%) for private land, 27.0% (±3.3%) for public areas and 39.9% (±2.6%) streetscapes.

*Figure 3.16 Deepdene canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

Streetscapes increased canopy cover over each of the 5 year periods ($p<0.05$) increasing by 4.4% and 4.7% in 2011 and 2016 respectively. Private land tenure experienced significant (-2.4%, $p<0.05$) decline in canopy cover between 2006 and 2011. High canopy cover growth in streetscapes and moderate canopy cover decline in private areas resulted in a net stability in canopy cover over the 10 year period with no significant change for the total.

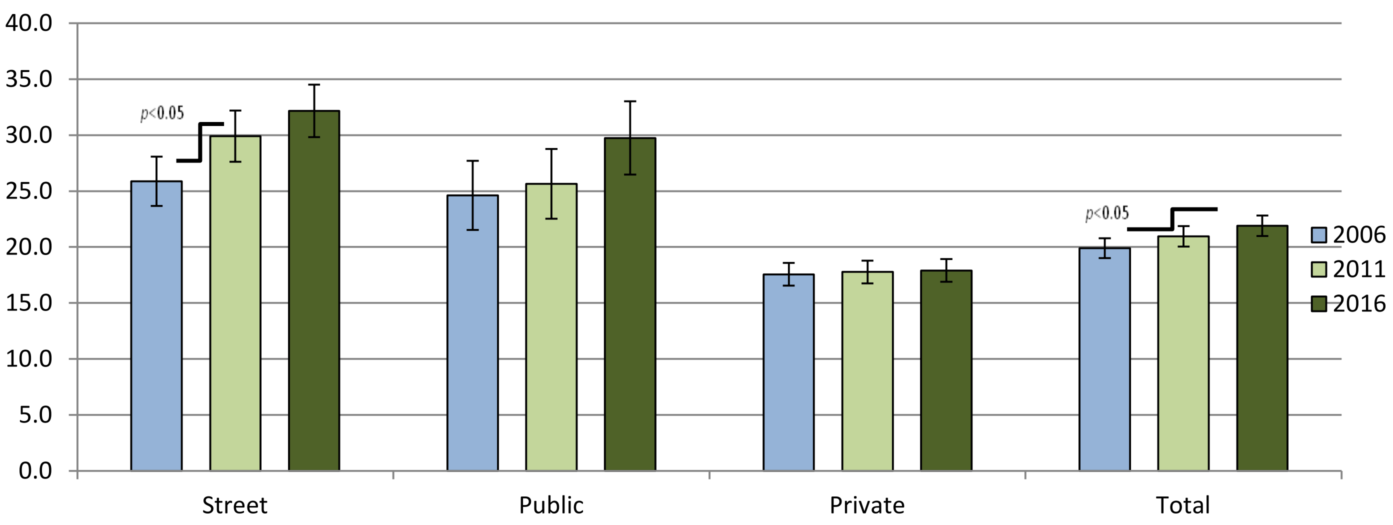
*Figure 3.17 Percentage of canopy cover gain and loss in Deepdene by tenure, 2006-2011 and 2011-2016*


* $p<0.05$ and change over the period was significant

## Glen Iris

Canopy cover for Glen Iris was 21.9% (±0.9%) of the suburb in 2016. Canopy cover ranged from 17.9% (±1.0%) private land, 29.7% (±3.3%) for public areas and 32.2% (±2.3%) streetscapes.

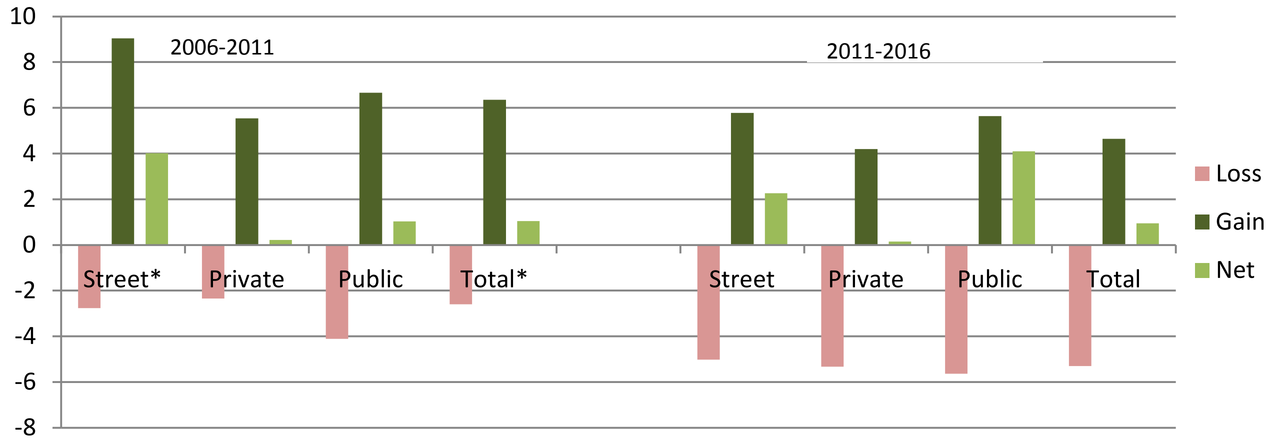
*Figure 3.18 Glen Iris canopy cover by land tenure, 2006, 2011 and 2016*



*Change between 2006 and 2016*

Streetscapes increased canopy cover between 2006 and 2011 (+4.0%, $p<0.05$) increasing from 25.9% to 29.9%. Consistent high growth in streetscapes and public areas resulted in a significant increase in total tree canopy cover for the suburb over the 10 year period increasing from 19.9% to 21.9%.

*Figure 3.19 Percentage of canopy cover gain and loss in Glen Iris by tenure, 2006-2011 and 2011-2016*

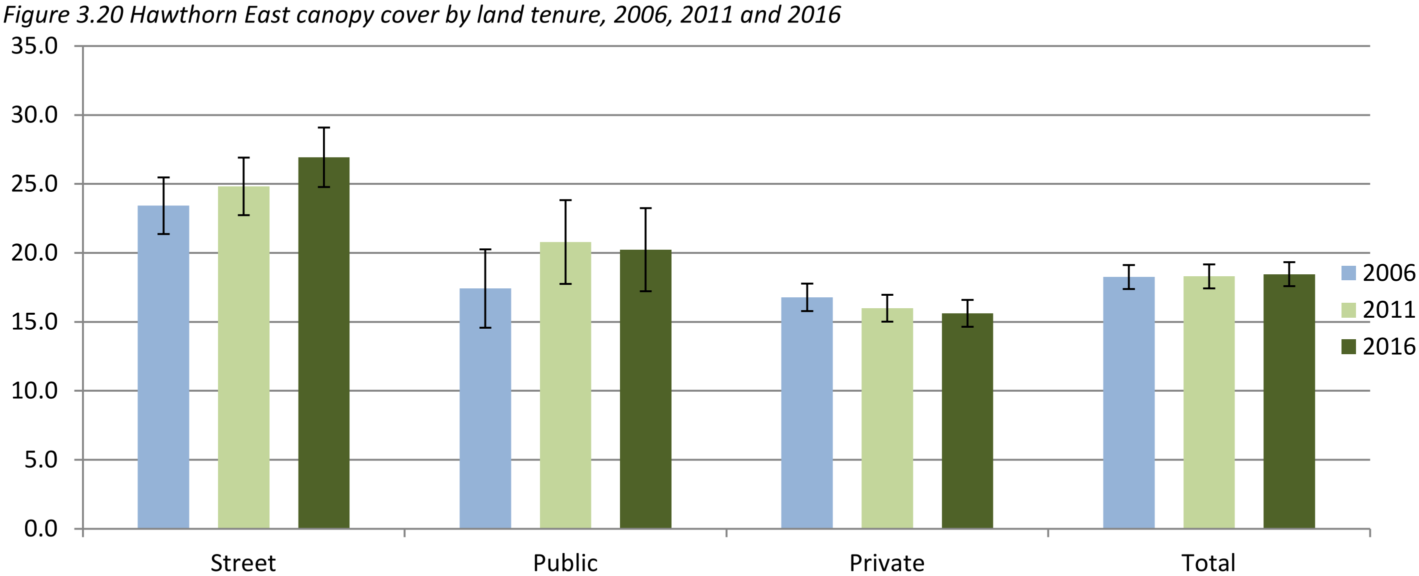



* $p<0.05$ and change over the period was significant

## Hawthorn East

Canopy cover for Hawthorn East was 18.5% (±0.9%) of the suburb in 2016. Canopy cover ranged from 15.6% (±1.0%) private land, 20.2% (±3.0%) for public areas and 26.9% (±2.1%) streetscapes.

*Figure 3.20 Hawthorn East canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

There was no significant growth over the 10 year period for Hawthorn East. In the periods between 2006-2011 and

2011-2016 the levels of canopy cover growth were offset by canopy cover loss to produce a net stable rate of canopy cover with no significant change by any land tenure.

*Figure 3.21 Percentage of canopy cover gain and loss in Hawthorn East by tenure, 2006-2011 and 2011-2016*

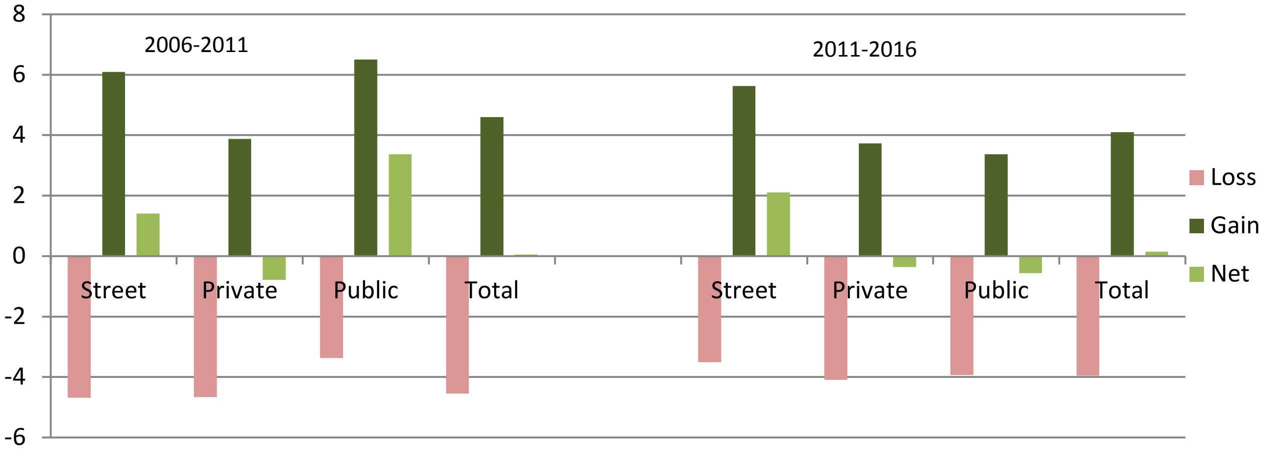



Figure 3.21 shows that high canopy cover growth was also accompanied by high canopy cover loss and suggests that a lot of tree growth and planting was also accompanied by tree loss through removal and construction between 2006 and 2016 in the suburb despite the stable net canopy cover percentage over the ten years.

*Table 3.3 Hawthorn East: Cause of canopy cover loss in by tenure, 2006-2011 and 2011-2016*

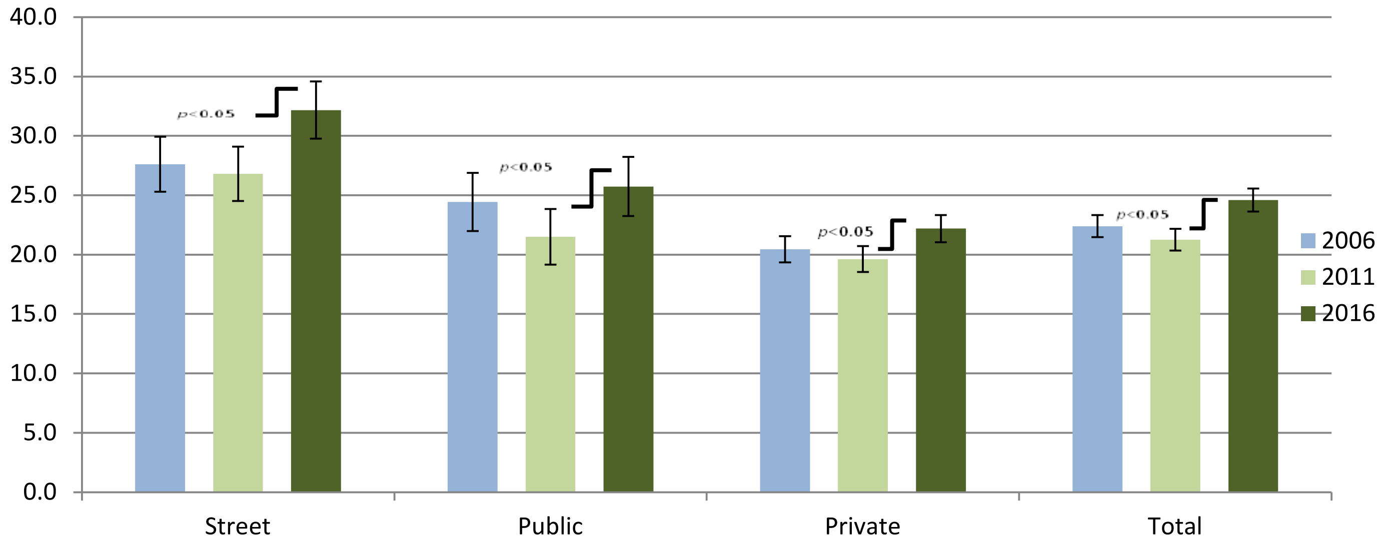
| Cover Loss | Removal | | Construction | | Parallax | | Total | |
|---|---|---|---|---|---|---|---|---|
| | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** | **2006-2011** | **2011-2016** |
| **Street** | 4.0 | 2.1 | 0.7 | 0.2 | 0.7 | 1.2 | 4.7 | 3.5 |
| **Private** | 3.0 | 2.7 | 2.1 | 0.9 | 0.7 | 0.5 | 4.7 | 4.1 |
| **Public** | 2.8 | 2.2 | 1.0 | 0.6 | 0.6 | 1.1 | 3.4 | 3.9 |
| ***Total*** | 3.2 | 2.5 | 1.8 | 0.8 | 0.7 | 0.7 | 4.6 | 4.0 |

The lack of growth in canopy cover for Hawthorn East was not primarily caused by heavy construction activity as tree removal was the primary cause of loss (63-70%) for the suburb.

## Hawthorn

Canopy cover for Hawthorn was 24.6% (±0.9%) of the suburb in 2016. Canopy cover by tenure ranged from 22.2% (±1.1%) private land, 25.7% (±2.5%) for public areas and 32.2% (±2.4%) streetscapes,.

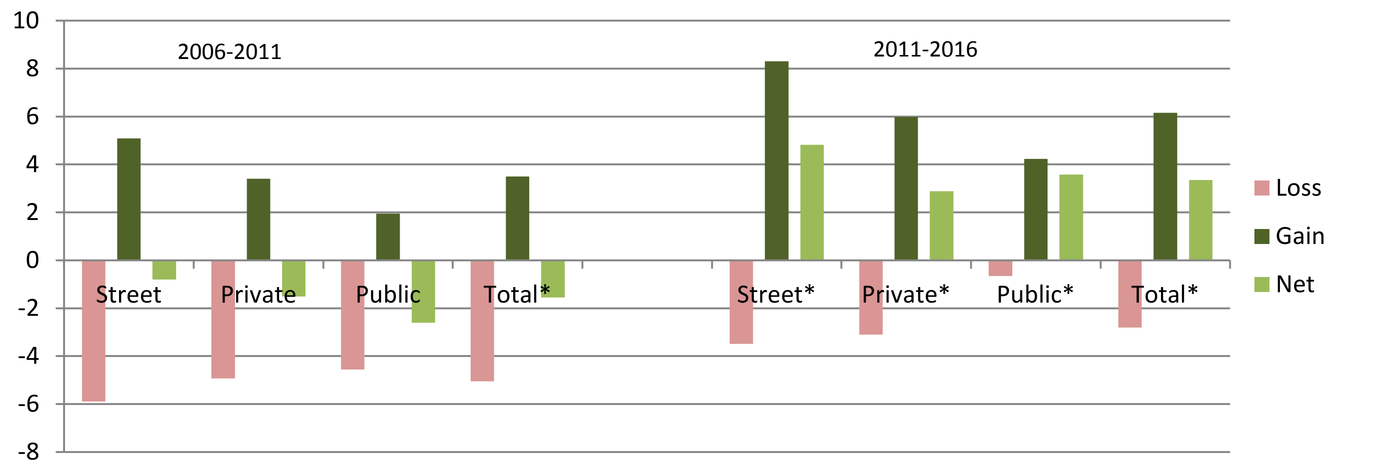
*Figure 3.22 Hawthorn canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

Canopy cover was stable in Hawthorn between 2006 and 2011, with the suburb experiencing a non significant decline over the period. Canopy cover increased significantly (*p*<0.05) however, for each of the land use areas in Hawthorn between 2011 and 2016 (private +2.9%, street +3.8% and public +3.6%).

*Figure 3.23 Percentage of canopy cover gain and loss in Hawthorn by tenure, 2006-2011 and 2011-2016*



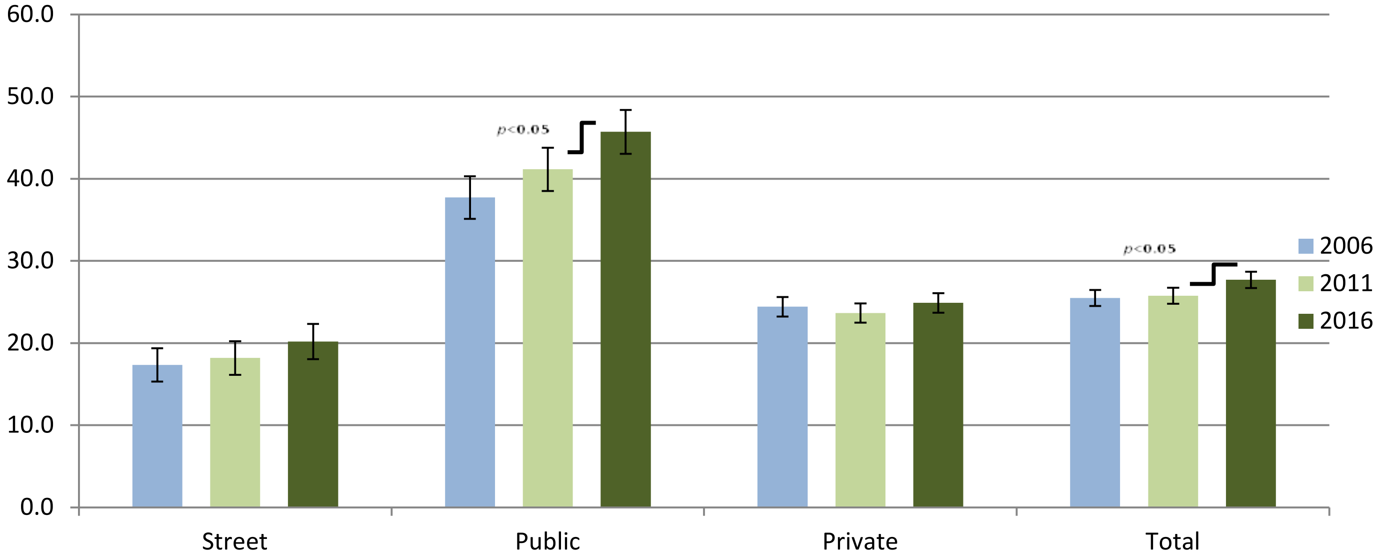

* *p*<0.05 and change over the period was significant

The significant growth between 2011 and 2016 was primarily due to higher growth rates in canopy cover and lower canopy cover loss throughout the suburb.

## Kew East

Canopy cover for Kew East was 27.7% (±1.0%) of the suburb in 2016 and ranged from 20.2% (±2.1%) streetscapes, 24.9% (±1.2%) private land and 45.7% (±2.7%) for public areas.

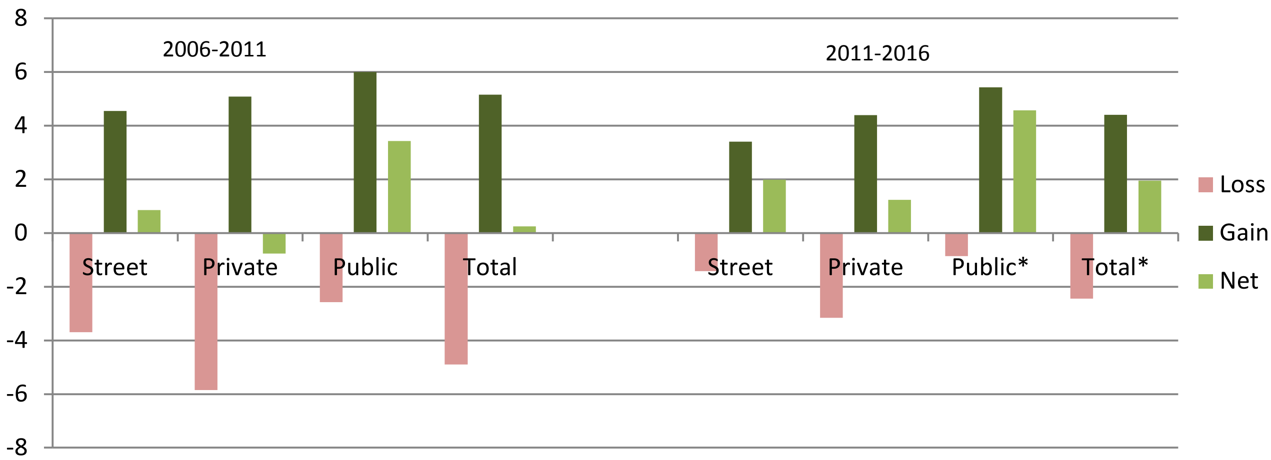
*Figure 3.24 Kew East canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

There was significant growth ($p<0.05$) between 2011 and 2016 for public areas from 41.1% to 45.7%, this significant growth accompanied by stable canopy cover in streetscapes and private areas brought the total estimate for Kew East to a significant increase (+2.0%, $p<0.05$).

*Figure 3.25 Percentage of canopy cover gain and loss in Kew East by tenure, 2006-2011 and 2011-2016*



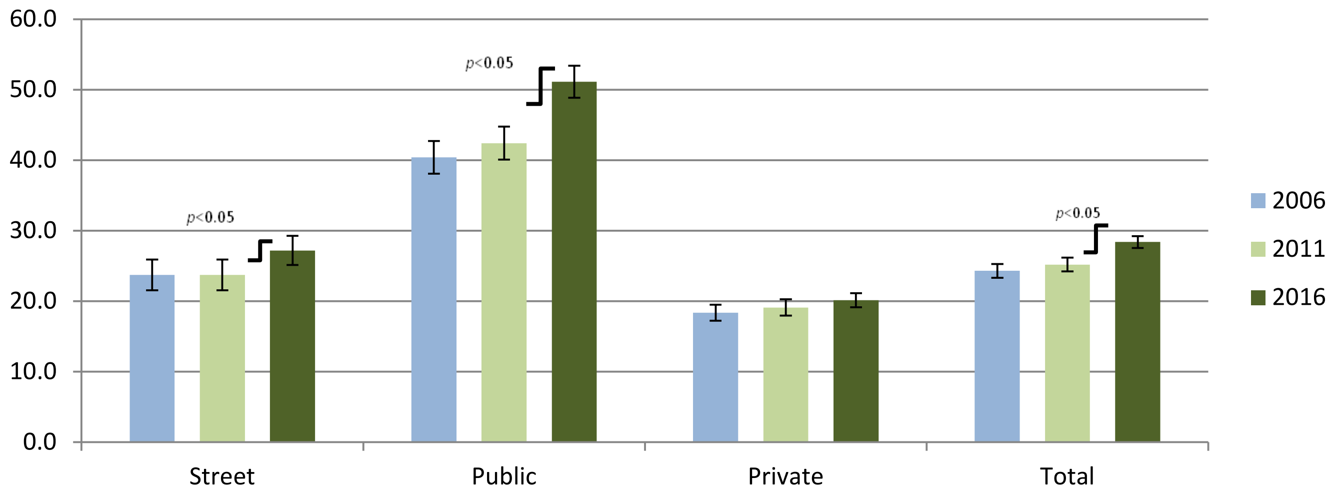

* $p<0.05$ and change over the period was significant

A major factor in the significant increase in canopy cover between 2011 and 2016 was due to the reduced loss of tree canopy cover and not an increase in canopy cover growth.

## Kew

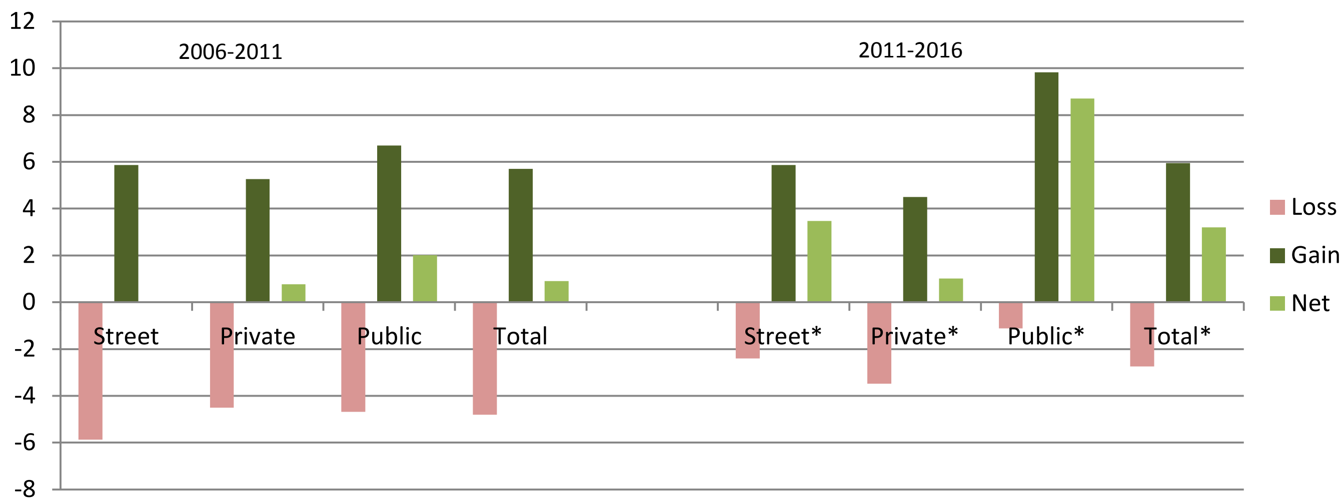
Canopy cover for Kew was 28.4% (±1.0%) of the suburb in 2016, which was the highest in Boroondara. Canopy cover ranged from, 20.1% (±1.2%) private land, 27.2% (±2.3%) streetscapes and 51.1% (±2.4%) for public areas.

*Figure 3.26 Kew canopy cover by land tenure, 2006, 2011 and 2016*




Canopy cover increased significantly ($p<0.05$) for streetscapes (+3.5%), public areas (+8.7%) and for the total suburb (+3.2%) between 2011 and 2016.

*Figure 3.27 Percentage of canopy cover gain and loss in Kew by tenure, 2006-2011 and 2011-2016*



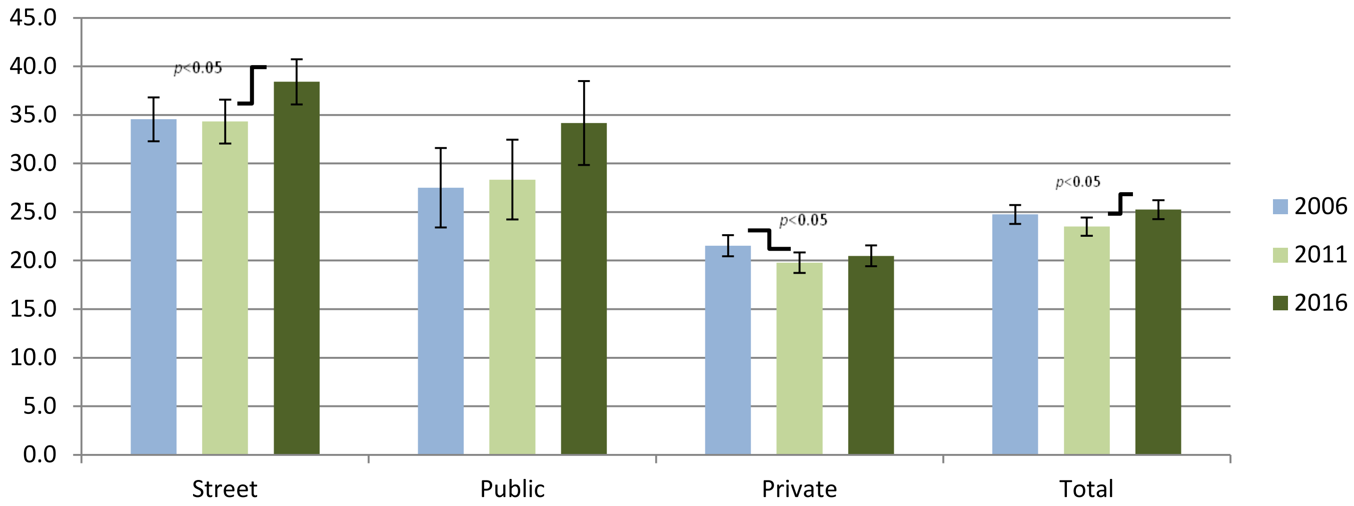

* $p<0.05$ and change over the period was significant

An important factor in the significant increase in canopy cover for Kew between 2011 and 2016 was the reduced loss of tree canopy cover accompanied by a very large increase in canopy cover growth particularly in public areas along the Yarra River.

## Surrey Hills

Canopy cover for Surrey Hills was 25.3% (±1.0%) of the suburb in 2016. Canopy cover ranged from, 20.5% (±1.1%) private land, 34.2% (±4.3%) for public areas, 38.4% (±2.3%) streetscapes.

*Figure 3.28 Kew canopy cover by land tenure, 2006, 2011 and 2016*




*Change between 2006 and 2016*

Streetscapes increased canopy cover over the 5 year period between 2011 and 2016 ($p<0.05$) increasing by 4.1% from 34.3% to 38.4%. Private tenure however, experienced a significant (-1.7%, $p<0.05$) decline in canopy cover between 2006 and 2011. Growth in streetscapes and public areas resulted in a net increase for canopy cover between 2011 and 2016 (+1.8%, $p<0.05$) with the suburb increasing canopy cover from 23.5% to 25.3%.

*Figure 3.29 Percentage of canopy cover gain and loss in Surrey Hills by tenure, 2006-2011 and 2011-2016*


* $p<0.05$ and change over the period was significant

## Evaluation and discussion

In 2016 Boroondara LGA had 25.0% (±1.0%) canopy cover and experienced no statistically significant change between 2006 and 2016. However, over the ten year period there was considerable fluctuation in canopy cover over time and by different land tenures in the suburbs. Tree canopy cover increased significantly ($p<0.05$) for four suburbs (Kew, Kew East, Hawthorn, Glen Iris) over the ten year period and many suburbs had tree canopy cover increasing or decreasing depending on land tenure (private, public, streetscape) and between 2006-2011 and 2011-2016.

*Change in canopy cover by suburb*

Different suburbs had different rates of growth and loss by tenure and year, depending on development and construction activity, tree planting and tree growth. Between 2006 and 2016 there was a consistent trend in change for canopy cover for many suburbs in Boroondara with canopy loss between 2006-2011 and canopy growth between 2011-2016. The suburbs that experienced canopy cover loss between 2006 and 2011 included Ashburton, Balwyn North, Surrey Hills, Hawthorn and Balwyn. The canopy cover losses between 2006 and 2011 were primarily driven through construction and tree removal activities in private areas and low tree growth rates. In the time period between 2011 and 2016 however, all the suburbs previously affected either by low growth rates and high loss had stable canopy cover or significant ($p<0.05$) increase, particularly in Hawthorn, Balwyn North, Ashburton, Surrey Hills, Kew East and Kew. This upsurge in canopy cover growth and reduction in loss resulted in a net stable canopy cover estimate between 2006 and 2016 for most suburbs in Boroondara with some suburbs such as Kew, Kew East, Hawthorn and Glen Iris all increasing canopy cover fractions significantly ($p<0.05$) over the 10 year period.

*Tenure and change*

In every suburb of Boroondara the estimated canopy cover on public land and in public streetscapes was greater than that on private land. This is consistent with previous studies showing that public owned land is the main contributor to canopy cover in urban areas (Kaspar et al. 2017; Dobbs et al. 2013; City of Sydney, 2012). Even though public land and streetscapes comprise 33% of the area of Boroondara, they contributed to 39% of the total canopy cover. More importantly, when testing for net significant change over the 10 year period, public land and streetscapes were the only land tenures to have net canopy cover growth in Boroondara between 2006 and 2016. Similarly, all significant declines in canopy cover were only experienced in private tenures. Suburbs including Ashburton, Balwyn North, Surrey Hills and Deepdene all experienced significant decline in canopy cover by private tenure between 2006 and 2011, only to have that decline stabilize between 2011 and 2016.

*Factors in 2006-2011 loss and 2011-2016 growth*

Canopy cover change is dynamic, with canopy cover increasing and decreasing simultaneously over any time period and thus the net result can potentially conceal some of the 'churn' in canopy cover change that unfolds in an area. Many of the suburbs that did experience canopy loss in private areas over 2006-2011 period such as Camberwell, Ashburton and

Balwyn did experience higher canopy loss from construction, however tree removal without subsequent construction was still the primary mechanism for canopy cover loss. What was particularly important for the net canopy cover loss in these suburbs was low canopy cover growth rates. The particularly low growth rates and high removal between 2006 and 2011 points to the millennium drought which did not end until 2010 as a likely key factor in change in canopy cover for that period (van Dijk et al. 2013). During the millennium drought, many trees throughout South East Australia died or ceased growing due to water stress and this was particularly relevant for trees away from rivers (van Dijk et al. 2013) or watered gardens and parks. Similarly, a key component to the high canopy cover growth rates over the ten year period for Kew, Kew East, Hawthorn and Glen Iris is that public land comprises a high fraction of these suburbs, particularly for Kew (22.4%) and Kew East (17.5%) and the public land in these suburbs contain a significant amount of native trees on public reserves near rivers such as the Yarra (Kew, Kew East and Hawthorn) and Gardiners Creek (Glen Iris).

Ageing trees can also be a factor in slower growth rates as single age stands of trees reach the end of their life span, stabilize growth or die and get replaced. The aging street tree population in suburbs such as in Canterbury (City of Boroondara 2017) and Balwyn for example could also be a factor that those two suburbs experienced the lowest growth in streetscape canopy cover, despite having high canopy cover overall.

Tree planting in private and public areas can also influence growth rates significantly. Balwyn North (45.5%) followed by Kew (42%) had the highest proportion of canopy cover growth as a result from shrubs (saplings) in 2011 transitioning to tree canopy cover in 2016, indicating that a significant number of young trees were planted between 2006 and 2011 in these two suburbs.

*Development and hard surfaces*

There is much research to show that local tree loss is one of the negative consequences of urban densification as trees are removed to make way for buildings and other impervious surfaces (Brown et al. 2013; Hostetler et al. 2013; Hall 2010; Brunner & Cozens 2013; Davies et al. 2008). However, what this research has shown (Figure 2.6) is that the large amount of development that occurred from 2006 to 2016 relates to an increase of hard surfaces and the loss of bare earth/ grass and not to a significant net reduction in canopy cover.

*A growing public good*

Despite the initial negative trends in private area loss during 2006-2011 which was most likely aggravated by the millennium drought, this study has shown that Boroondara has a stable canopy cover and that in many suburbs there have been consistent trends for growth, particularly in public areas and streetscapes. The fact that all significant growth in canopy cover came from public areas and streetscapes indicate that the City of Boroondara has successfully compensated for potential canopy cover loss from development and environmental stress by managing the relatively smaller component of canopy cover on streetscapes and public land.

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# Appendix: Statistical tests, data quality and limitations

Sample based methods invariably rely on sampling design and statistical inference to arrive at an estimate of total canopy cover. Two types of error can occur in data resulting from samples: *non-sampling error* and *sampling error*.

*Non-sampling error*

Non-sampling error can occur at any stage of data collection and is primarily a result of processing error through incorrect coding, time period bias for the aerial imagery, image parallax or inconsistency of the classification of points. These issues can be mitigated through checking, careful assessment of points and improving image time consistency however, some non sampling errors are unavoidable. An additional subsample for each time point (2011 and 2016) was reassessed to check for errors in coding.

*Sampling error*

As data are collected from a sample but inferences are made about the whole area, the data are thus subject to 'sampling' error. Sampling error essentially reflects the difference between the estimate derived in the report from the sample and the 'true value' if a full mapping project of the canopy cover were actually to be conducted (McLennan 1999).

The two core factors affecting sampling error in this report include:

- Sample size: Larger samples give rise to smaller sampling error;
- Sample /canopy proportion ratio: The larger the sample is as a proportion of the actual canopy cover, the smaller will be the sampling error.

With minimal non-sampling error we can be confident that, if significant, the sample statistic within the standard error range will be within the actual 'true value' due to the central limit theorem.

## Estimating sampling error

In this report three core statistical tests were used to create and assess output data:

1) Create a simple random sample of 2000 points once for each suburb and assess each point by cover class for each time point (2006, 2011 and 2016);
2) Calculate the proportion of points on canopy cover as well as a standard error for each proportion for each suburb at each time point; and
3) Compare the sample derived canopy cover proportion from each time point using McNemar test and a second standard error of the difference between dependent samples.

*Measuring standard error and significance in the report*

Sampling error can be measured mathematically and in this report it is primarily presented through the standard error.

A standard error is used to present the range of values on the sample statistic that is expected to contain the 'true value' that is being measured by the sample, thus any estimate derived from a sample has a standard error associated with it (McLennan, 1999).

In this report, two slightly different types of standard error were measured:

1) The standard error of the canopy cover for each suburb as a result of a sample; and
2) The standard error of the difference between the canopy cover proportions from two different independent samples i.e. the 2011 report (P1) and the current 2016 report (P2).

*Comparisons between reports and the standard error of the difference*

If the proportion of canopy cover between reports is different for each suburb, this does not necessarily mean that there has been a change, the difference may be due to statistical error. For each time point the same sample was used within the same sample frame (i.e. suburb or land use area), thus each sample was considered a 'dependent sample'. When comparing the proportions between two dependent samples (i.e. P1 and P2) a hypothesis test should additionally be done to ascertain that there has in fact been a change (McNemar test). When describing the change between the reports a standard error of the difference should also be presented (Gravetter & Wallnau 2000).

## Non sampling error: data quality and data issues

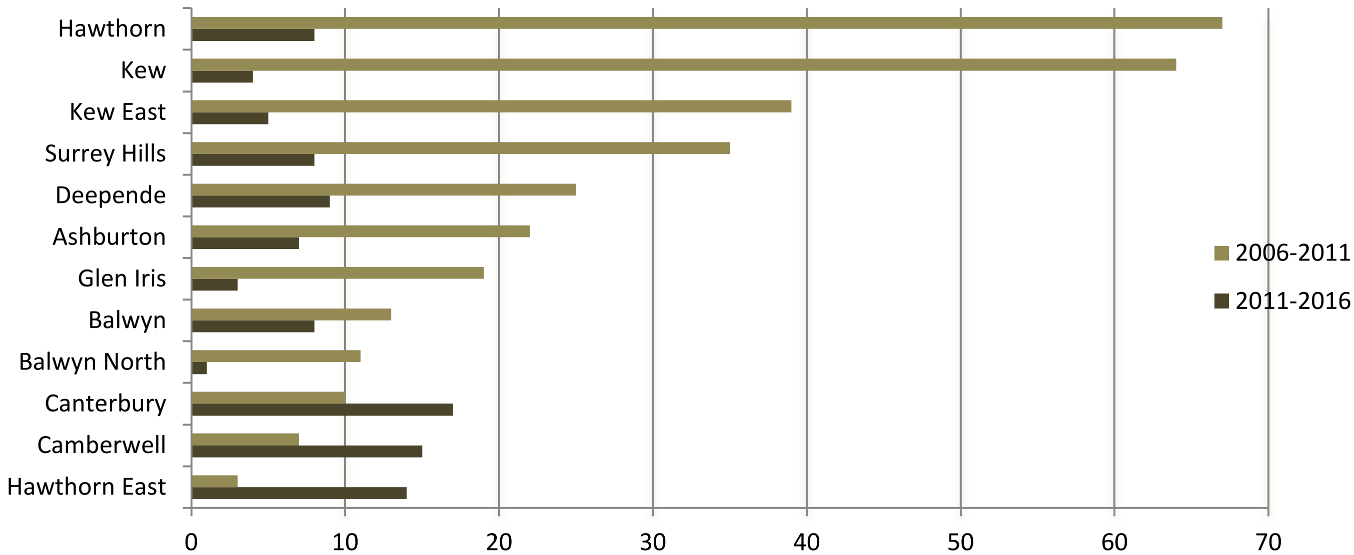
*Image timing*

It is important to ensure that a study such as this is conducted during full leaf to allow the full canopy cover to be estimated. This study was potentially restricted because the images were at sub optimal times particularly 2006 with images taken in winter (July) and to a lesser degree for images taken in 2011 (October). In general, studies of canopy cover in south eastern Australia are best taken from December to February as that is a time when deciduous trees will be in maximum leaf. To compensate for this, a sample point landing within the tree canopy orbit was classified as a point on canopy in 2006. To correct for potential errors each point in 2006 that landed on a canopy cover was cross checked with the image in 2011 and 2016, thus despite the timing of the aerial photographs, error in point classification was kept to a minimum and would unlikely have a significant effect on results.

*Parallax*

Vegetation height, coupled with the angle that the image was taken can potentially lead to image parallax errors where tall objects appear to lean and 'move' the point between the two time images (Nowak & Greenfield 2012). In some cases parallax errors were considerable in this research particularly between 2006 and 2011 images. To ensure that potential parallax error was estimated for change between each image an indicator variable was created and assessed for the cause of change variable.

*Figure 4.1 Number of points classified as canopy loss identified as parallax between images, 2006-11 and 2011-16*




Parallax was present in all images but was particularly high for Hawthorn, Kew, Kew East and Surrey hills between 2006 and 2011. The clustering of parallax error in the western part of Boroondara (Hawthorn, Kew, Kew East) may be due to the remote image being taken in two sections over 2 days and the angle of the aircraft taking the image may have been slightly off kilter. Further research on Glen Iris showed significant parallax for tree growth, particularly for tall street trees in 2006 and 2011 and comparisons between 2006 and 2011 for Glen Iris should be done with caution.

*Dealing with parallax effect in estimation*

Due to the way that the central limit theorem functions with such a large number of points (2000), the results of parallax between the two times should not affect the mean estimate for canopy cover. However, the method used for comparison between the time points (McNemar test, cause of change) requires a dependent sampling regime, thus the parallax between 2006 and 2011 is a significant problem when ascertaining the cause of change between the time points as well as testing for significance.

*Data Quality*

An additional subsample for each time point (2011 and 2016) was reassessed to check for errors in coding.

*Limitations and comparisons with other reports*

Canopy cover is an important policy and scientific indicator. However, it is important to note that canopy cover is just a two dimensional metric indicating the spread of canopy across an area and does not provide an indication of the composition, structure, diversity or the vertical extent of the urban tree canopy (McPherson et al. 2011). The sample statistics generated in this report largely mirror those from other research, with the sample statistic from Amati et al. (2017) exactly the same as that from this report. Other reports that used less similar imagery and sampling times or methods still had broadly similar estimates within the sample error.

*Table 4.1 Comparisons of canopy cover and year with Amati et al. 2017, Kaspar et al. (2017) and Jacobs et al.(2014)*

| | | | | ***Amati et al.*** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | **Report Year** | **%** | **se** | **Comparison Report year** | **%** | **se** | **Difference** | **Tree canopy + shrub** | **Difference** |
| **Boroondara LGA** | 2017 | 24.6 | (±2.0%) | 2016 | 24.9 | (±1.0%) | 0.0 | n/a | n/a |

| | | | | ***Jacobs et al.*** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | **Report Year** | **%** | **se** | **Comparison Report year** | **%** | **se** | **Difference** | **Tree canopy + shrub** | **Difference** |
| **Boroondara LGA** | 2009 | 28.1 | (±2.3%) | 2011 | 24.9 | (±1.0%) | -3.2 | 29.1 | 0.9 |

| | | | | ***Kaspar et al.*** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | **Report Year** | **%** | **se** | **Comparison Report year** | **%** | **se** | **Difference** | **Tree canopy + shrub** | **Difference** |
| *Hawthorn* | 2010 | 28.0 | (±1.0%) | 2011 | 21.3 | (±1.0%) | -6.7 | 27 | -1.0 |
| | 2015 | 30.6 | (±1.0%) | 2016 | 24.6 | (±1.0%) | -6.0 | 30.9 | 0.3 |
| *Ashburton* | 2010 | 30.8 | (±1.0%) | 2011 | 19.3 | (±0.8%) | -11.5 | 25 | -5.8 |
| | 2015 | 32.7 | (±1.0%) | 2016 | 20.7 | (±0.8%) | -12.1 | 26.3 | -6.4 |
| *Balwyn* | 2010 | 31.4 | (±1.0%) | 2011 | 20.7 | (±1.0%) | -10.8 | 29.3 | -2.1 |
| | 2015 | 32.1 | (±1.0%) | 2016 | 21.3 | (±1.0%) | -10.8 | 29.0 | -3.1 |

Comparisons between Amati et al. (2017) and this report have the same results for canopy cover despite different sample sizes largely because the same methodology was utilised and high quality remote imagery was used. Jacobs et al. (2014) and this report align within the standard error for both results with Boroondara 28.1% (±2.3) compared to 25.9%, (±1.0) however, it is important to note that Jacobs et al. (2014) used Google Earth images for canopy cover estimation, accompanied with lower sample size thus non statistical and statistical error will be higher.

The differences between Kaspar et al. (2017) and this report however are relatively high for the suburbs, with the differences in results for Ashburton and Balwyn for example, exceeding 10%. The differences in results can be attributed primarily due to slightly different classification of canopy cover. In Kaspar et al. (2017) points on trees estimated to be 2 metres in height were classified as on tree canopy cover, whereas in this report only points on trees 3 metres or higher were classified as 'canopy' and points on smaller trees and shrubs were classified as 'shrub'. To reveal the potential differences, if the tree canopy and shrub variables are combined (Table 4.1) to create a tree-shrub variable the results fall within the standard error (i.e. the range of possible results the true canopy cover could be compared to the sample canopy cover) between reports.

*Table 4.2 Comparisons in change over time between Kaspar et al. and this report*

| | **2010-2015** | **2011-2016** | **difference** |
|---|---|---|---|
| *Hawthorn* | 2.7 | 3.4 | 0.7 |
| *Ashburton* | 2.0 | 1.4 | -0.6 |
| *Balwyn* | 0.6 | 0.7 | 0.0 |

Similarly, table 4.2 shows that if the change in canopy cover over 5 years is compared between time points, the differences between studies are comparable and this indicates that the trajectory of relative change is still consistent between reports. For example, the canopy cover change percent of +0.6% between 2010 to 2015 in Kaspar et al. (2017) for Balwyn was equivalent to the results from this report between 2011 and 2016 (+0.7%); Ashburton and Hawthorn also show similar levels of growth over the same time period between both reports.