Tree canopy cover in Cambridge between 2008 and 2018

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1 Introduction

Urban trees provide a wide range of benefits to cities, including improving air quality, providing shade and reducing the urban heat island effect, and providing important habitat for wildlife. To ensure that these benefits are sustained over the long term, it is important to effectively manage urban trees. This requires regular mapping of the extant tree stock. Cambridge City Council commissioned BlueSky to map all trees in Cambridge in 2008 and again in 2018. This report uses these data to assess the current tree stocks and the changes between 2008 and 2018.

This report focuses on two key metrics – canopy cover and mean canopy height. Canopy cover is defined as the proportion of the land area which is covered by trees, usually expressed as a percentage. Mean canopy height is the average height of this canopy cover. Tall trees usually have large crowns and therefore contribute disproportionately to canopy cover and mean canopy height. It is therefore particularly important to preserve these large trees wherever possible.

This report is structured around four main themes. Firstly, the differences between the 2008 and 2018 surveys are discussed (section 4.1). Second, canopy cover and mean canopy height are mapped for the entire city, for each ward and for each output area (sections 4.2-4.7). Third, canopy cover and mean canopy height are quantified for different land use, constraint and ownership types (sections 4.8-4.12). Finally, canopy cover is assessed in the context of indices of multiple deprivation, and areas of prioritization are discussed. Additional detailed maps and metrics can be found in the appendices.

2 Key findings

1. Overall canopy cover increased from 17.1 % in 2008, to 17.6 % in 2018. This increase was mostly due to the growth of medium and large trees, since young trees have smaller crowns.
2. The only wards to experience a decrease in canopy cover were Castle, due to the large construction projects, and Newnham, because of a substantial decrease in canopy cover in gardens. Nevertheless, Newnham remained the ward with highest canopy cover in 2018.
3. Gardens account for a high proportion of canopy cover, given their relatively small area. The area of land dedicated to gardens decreased in all wards between 2008 and 2018 due to densification. However, in some wards, the canopy cover in these gardens increased. This suggests that gardens are a potential target for tree planting and / or preservation.
4. Tree preservation orders are currently located mostly in the wards with high canopy cover, so targeting wards with lower canopy cover would be valuable.
5. Protected open spaces contain a high proportion of tree canopy cover, particularly for large and massive trees in those wards with lower total canopy cover. Therefore, protected open spaces are key for protecting and increasing tree canopy cover in the areas of Cambridge which need it most.
6. Between 2008 and 2018, canopy cover increased substantially in most parts of Cambridge with a high index of multiple deprivation. These areas now have canopy cover comparable to the rest of the city. To increase this further, efforts should focus on adding new tree preservation orders.

3 Methods

3.1 Converting 2008 trees to shapefiles

The 2018 ProximiTree data were provided as an analysis ready shapefile (QT-82010-2_Cambs_ProximiTREE_Crowns.shp). The 2008 data were provided as six csv files, which were converted into shapefiles in the following way.

a) The canopy and height csv files were loaded into R
b) The height information was joined to the canopy information using the tree_id.
c) A shapefile was created containing all trees as points at the given X and Y coordinates. This shapefile contains the attributes from the csv files.
d) The points were converted into circular polygons by applying a buffer equal to the crown radius.
e) The resulting file was saved so that it can be easily re-loaded and viewed in ArcGIS.

3.2 Calculating canopy area from overlapping tree crowns

Metrics concerning individual trees were calculated directly from the tree polygons (see

Table 1). These tree polygons were assigned entirely to the boundaries which contained the highest point (see Figure 1). This means that the number of trees within the boundary represents only those whose highest point is within it, not the trees whose crown overlaps the boundary but whose highest point is located in a neighbouring boundary area. This avoids double counting.

To calculate canopy area metrics, we first transformed the overlapping tree crown polygons to non-overlapping canopy rasters. All tree polygons are circular, with a radius as measured at the widest point. This means that the tree polygons overlap with each other (Figure 1). Part of this overlap may be real, since tall trees can overshadow shorter ones. However, a large part of this overlap is likely an artefact from the assumption that all trees are circular. Furthermore, the trees were mapped from aerial imagery, in which overlapping sections would not be visible. Including this overlap would therefore lead to an overestimate of the canopy area. For each case of overlap between two trees, the overlapping area was removed from the shorter tree but kept in the taller tree (Figure 1). This avoids double counting of the area, meaning that the total non-overlapping canopy area is lower than the total tree crown area. Canopy area was calculated for each boundary area on a pixel-basis, meaning that a tree crown which overlaps with the boundary between two areas contributes partially to both areas (Figure 1).

This distinction between area-based metrics and tree-based metrics is particularly important for height measurements. TreeHeight_mean_m is the mean height of all the trees in a given area, with all trees weighted equally. Since small trees are very common (particularly in the 2018 survey) they will strongly influence the TreeHeight_mean_m. CanopyHeight_mean_m is the mean height of the canopy cover in the area. Tall trees tend to have larger crowns and cover a larger area than small trees, so they will more strongly influence CanopyHeight_mean_m.

All of the analysis in the main body of the report focuses on tree canopy cover and mean canopy height, because these metrics can be most robustly compared between the surveys in 2008 and 2018 (section 4.1). Maps of additional metrics at the output area scale are provided in the appendix (5.4, 5.5, 5.6).

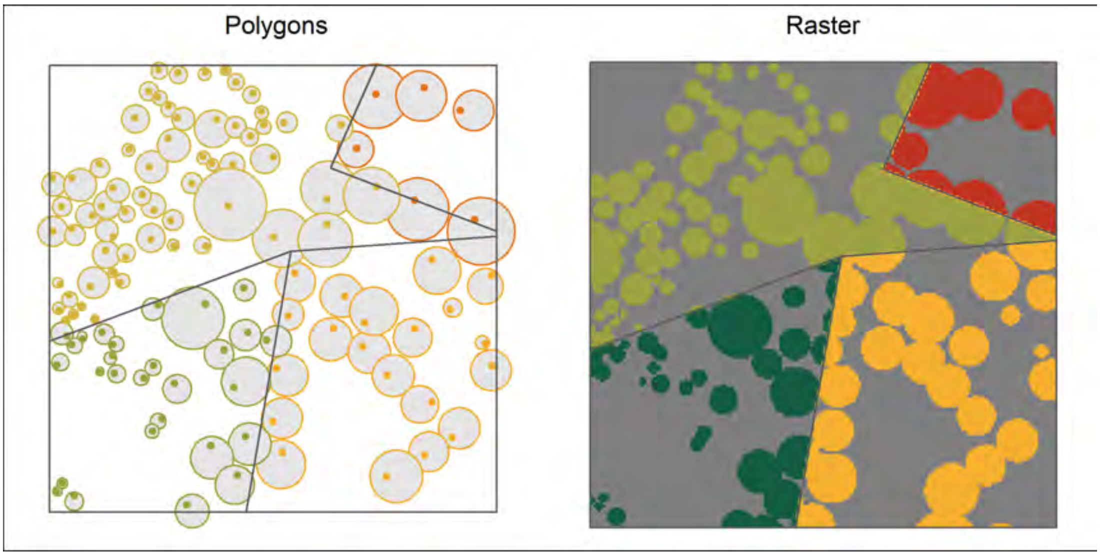

Figure 1 – Example of tree crown polygons (left) and non-overlapping canopy rasters (right). Colours show groupings into neighbouring output areas.

Metric	Units	Calculated from
TreeCount		Tree crown polygons
TreeDensity_ha	Trees ha^{-1}	
TreeHeight_mean_m	m	
CrownArea_mean_m2	m^2	
TreeCanopy_m2	m^2	Canopy raster
TreeCanopyDensity_m2ha	m^2 ha^{-1}	
TreeCanopyDensity_percentage	%	
CanopyHeight_mean_m	m	

Table 1 – Tree metrics calculated from tree crown polygons and canopy rasters.

3.3 Calculating tree metrics at each spatial scale

Our aim is to determine how tree stock varies across Cambridge. We mapped the variation in these metrics across the city at six spatial scales: output area, lower super output area, wards according to the 2004 boundaries, wards according to the 2021 boundaries, city-wide and city-wide with a 1km buffer (for the 2018 data only).

Overall metrics for all trees were calculated for each boundary area. Additionally, trees were grouped into four height classes: small (< 6 m), medium (6-12 m), large (12-18 m) and massive (>18 m). All metrics were calculated for each height class individually.

To highlight the changes in canopy cover between the surveys at the tree level we produced a ‘canopy cover change’ raster. This shows areas which have are covered by tree canopy in both 2008 and 2018, as well as the changes between them. An example of this can be found in figures Figure 6 and Figure 11.

3.4 Land use, ownership and constraints

Tree metrics were calculated for each land ownership, use and constraint class as shown in Table 2. This was done at each spatial scale, although only the ward level analyses are shown in the report as they provide a clearer overview. Maps of land use, ownership and constraints were provided by the Council, and are summarized in Table 2.

Some of the map data contained detailed information on the date a tree preservation order or conservation area was established. This data was simplified to areas in place before and after 2008 to match the dates of the tree surveys.

	Layer	**Source**	**Filtering**
Land ownership	Highways land	City_area_region.shp	Where highways overlap Council land it is classed as highways.
	City council land	terrier.shp	Type = CO
	Private / other	All other land	-
Land use	Manmade	Master map 2008 and 2018 versions used separately for these years.	Make = Manmade
	Natural		Make = Natural
	Gardens		Make = Multiple[1] Theme = Land DescGroup = General Surface
Constraints	Individual tree preservation orders	TPO_POINT_VIEW.shp	Points were buffered by 5 m to account for geolocation errors.
	Tree preservation areas	TPO_POLY_VIEW.shp	Overlap between TPO area and individual TPO assigned to individual TPO.
	Conservation areas	ConservationAreas.shp	Where conservation areas overlapped, the older one was used.
	Protected open space[2]	ProtectedOpenSpace.shp	-

Table 2 – Land ownership, use and constrain classes and sources.

[1] https://www.ordnancesurvey.co.uk/documents/os-mastermap-real-world-object-catalogue.pdf
[2] Reference Policy 67, page 196 for definition Cambridge Local Plan

4 Results

4.1 Assessing differences between 2008 and 2018 surveys

BlueSky stated that the 2008 and 2018 surveys are not directly *comparable 'due to the different times of day and year at which each was collected, the difference in photographic resolution, and the approach taken by different quality assessors'*. The total number of trees within Cambridge was 134,493 in the 2008 survey and 335,868 in the 2018 survey. If these data are to be used to understand the changes in tree canopy cover over time, we need to explore the differences between the two surveys in more detail. We do this by visualizing the trees in an example areas (Figure 2) and through direct comparisons of the two surveys at the output area scale (Figure 3, Figure 4).

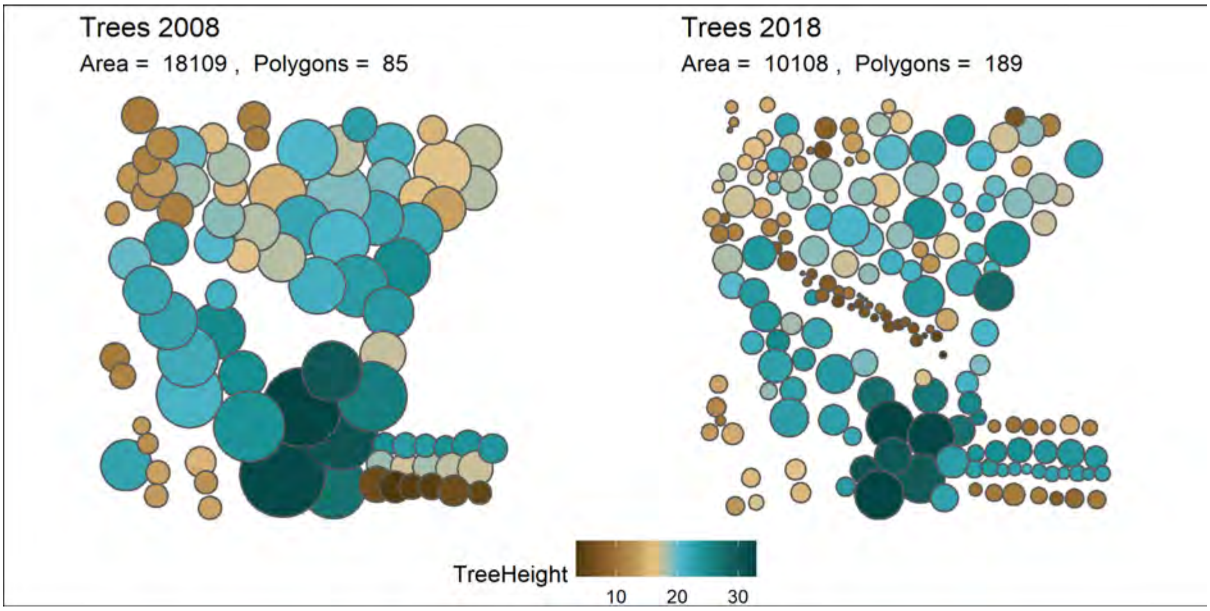

Figure 2 – Example area comparing the trees in the 2008 and 2018 surveys.

The main differences between the surveys are:

a) The 2018 survey contains approximately double the number of trees in the 2008 survey. This difference is consistent across the whole surveyed area. Most of these additional trees are very small, which presumably reflects the increased resolution of the 2018 survey enabling it to detect smaller trees.
b) The mean crown area of each tree in the 2018 survey is approximately half that of trees the 2008 survey. This is likely the result of the resolution of the imagery and the different approaches taken by the quality assessors.
c) In most areas, the total canopy cover is slightly higher in 2018 than in 2008. The canopy cover is related to both the number of trees (a) and their crown areas (b), so the differences between the surveys mentioned above balance out when calculating canopy cover.
d) Mean tree height is consistently lower in 2018 compared to 2008. This is presumably due to the large number of small trees which are present in the 2018 survey but not the 2008 survey.
e) Mean canopy height is slightly higher in 2018, compared to 2008. Canopy height is less sensitive to the number of small trees, since they occupy a small amount of space in the canopy. Canopy height is therefore more robust to the differences between the surveys.

In summary, the 2008 and 2018 surveys have very different characteristics at the individual tree level, but the canopy cover and canopy height metrics are quite consistent between the two surveys. Importantly, the systematic differences between the two surveys are consistent across their entire extents. Therefore, the magnitude of the changes between 2008 and 2018 may be affected by the survey characteristics, but the spatial variation across the city will be robust.

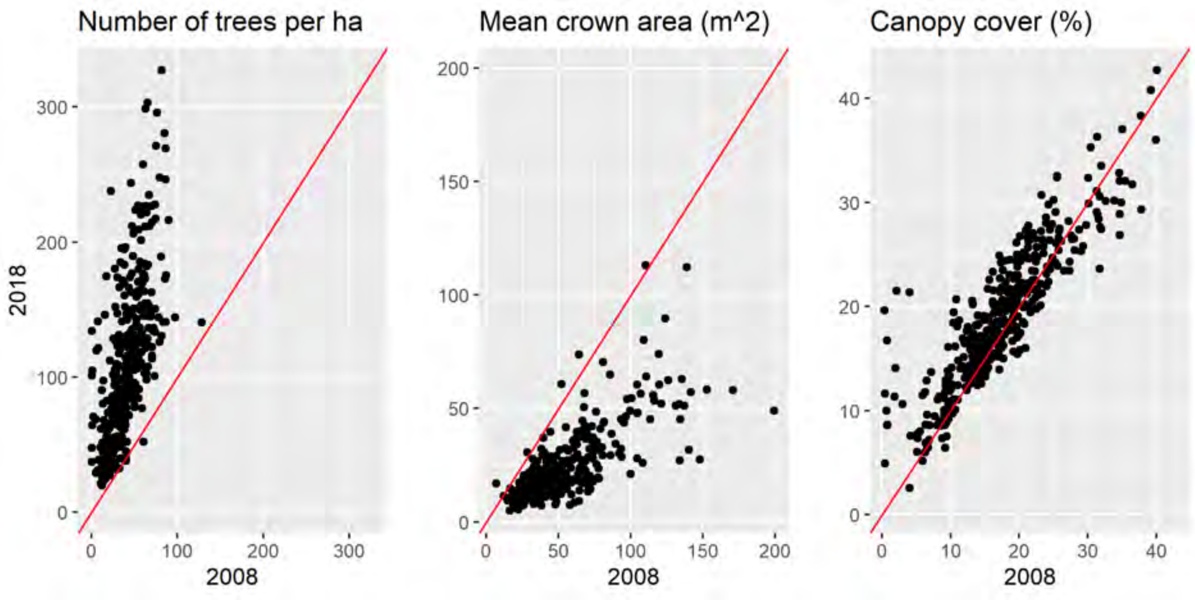

Figure 3 – Direct comparison between 2008 and 2018 summary data at output area level

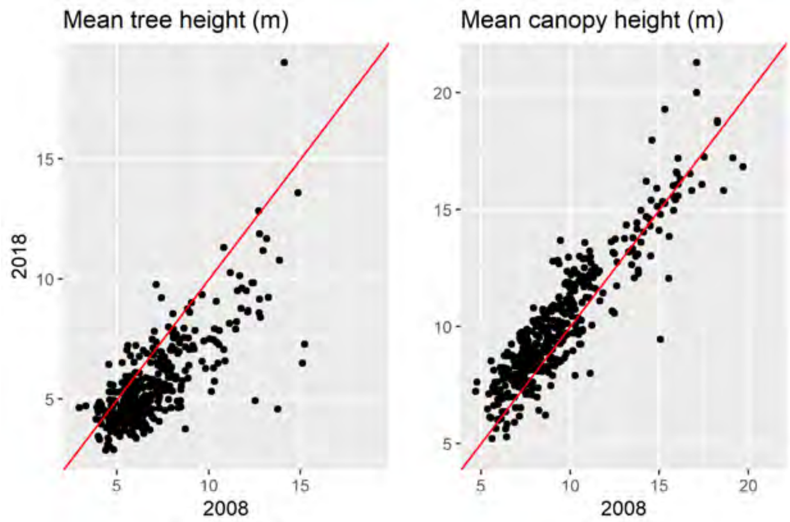

Figure 4 - Comparison of tree height and canopy height between 2008 and 2018 surveys at the output area level

4.2 City-level tree metrics (ownership, land use, constraints)

The mean canopy cover across Cambridge was 17.1 % in 2008 and 17.6 % in 2018. The 2008 survey covered a total area of 40.7 km^2, while the 2018 survey added a 1 km buffer around this area, increasing the total area surveyed to 75.9 km^2. The total number of trees detected in 2018 including this buffer was 483,951.

Tree height class	**City level (40.7 km^2)**				**Including buffer (75.9 km^2)**	
	# trees (thousands)		**Canopy cover (km^2)**		**# trees (thousands)**	**Canopy cover (km^2)**
	2008	**2018**	**2008**	**2018**	**2018**	**2018**
Small	72.1	235.0	1.5	1.6	326.2	2.4
Medium	44.5	72.1	2.6	2.4	111.8	3.9
Large	13.8	21.7	1.8	2.0	11.4	3.1
Massive	4.2	7.1	1.0	1.2	34.5	2.0
Total	134.5	335.9	7.0	7.2	484.0	11.4

Table 3 – City wide tree metrics for each tree height class.

Land use class	***Area (km^2)***		***Canopy cover (km^2)***		***# trees (thousands)***		***# massive trees***	
	2008	***2018***	***2008***	***2018***	***2008***	***2018***	***2008***	***2018***
Gardens	9.09	8.80	2.64	2.75	68.2	201.2	788	1373
Manmade	11.81	13.39	1.26	1.25	19.9	25.0	552	604
Natural	19.57	17.99	3.43	3.68	46.5	111.5	2806	5148
Total	40.46	40.18	7.33	7.68	134.5	337.7	4146	7125

Table 4 – City wide tree metrics for the different land use classes.

Land ownership class	***Area (km^2)***	***Canopy cover (km^2)***		***# trees (thousands)***		***# massive trees***	
		2018	***2008***	***2008***	***2018***	***2018***	***2008***
Council owned	5.54	1.18	1.30	19.8	45.9	691	1363
Highways	3.86	0.66	0.70	11.7	19.8	289	373
Other	31.32	5.25	5.34	103.0	27.0	3171	5338
Total	40.71	7.09	7.34	134.5	335.9	4151	7074

Table 5 – City wide tree metrics for the different land ownership classes.

TPO type	***TPO date***	***Inside conservation area?***	***Canopy cover (1000 m²)***		
			2008	***2018***	***Change***
Area	After 2008	Inside	19.9	19.4	-0.4
Area	After 2008	Outside	44.4	45.4	0.7
Area	Before 2008	Inside	108.7	103.5	-5.2
Area	Before 2008	Outside	149.9	129.9	-20.6
Point	After 2008	Inside	14.0	13.6	-1.0
Point	After 2008	Outside	14.5	16.2	0.6
Point	Before 2008	Inside	78.6	75.8	-3.0
Point	Before 2008	Outside	100.4	99.8	-2.1
Conservation areas not TPOs			2166.0	2115.9	-50.1
Not conservation area or TPOs			4323.5	4610.9	286.3
Total			7019.9	7230.5	205.2

Table 6 – City wide summary of canopy cover under tree protection orders

4.3 Ward-level tree metrics

Variation in canopy cover. In 2008, canopy cover varied across the wards from 12% in Cherry Hinton to 21% in Newnham (Figure 5). In 2018, canopy cover was more evenly distributed, with many of the lower canopy cover wards having experienced substantial increase growth.

Change in canopy cover. Canopy cover remained low in Cherry Hinton, Abbey and Market. Castle and Newnham experienced a substantial reduction in canopy cover, in part due to the new developments in this area. Figure 6 shows the canopy cover change raster for an area in west Cambridge which experienced a lot of building work in the period 2008 to 2018. Large areas where trees were removed are clearly visible. In addition, Figure 6 shows lots of trees which were newly planted trees or newly detected in 2018. However, these trees are all small and not yet at maturity and therefore do not compensate for the canopy cover loss from established trees. This analysis was repeated using the 2021 ward boundaries and the results were consistent, see appendix 5.1.

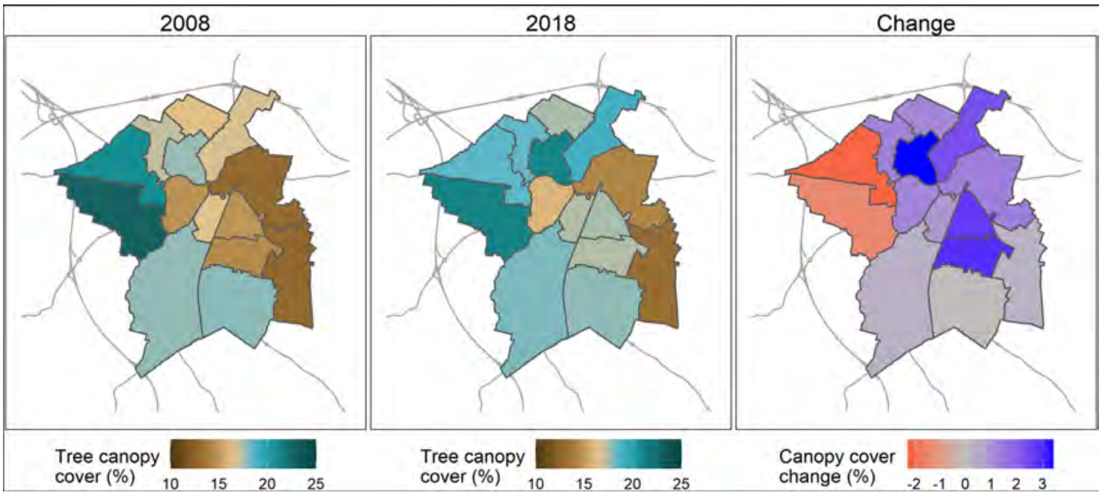

Figure 5 – Maps of tree canopy cover (%) at the ward-level.

Figure 6 – Example of canopy cover change around the University Sports Centre in West Cambridge.

Note that in Figure 6 some trees appear to have ‘moved’ slightly between the 2008 and 2018 surveys resulting in apparent canopy loss on one side and gain on the other. This is likely due to an issue with image geolocation, or the time of day causing different shadows. This is a very minor issue and, since it is consistent across the whole area, will not affect the results.

4.4 Size class distribution and change at ward level

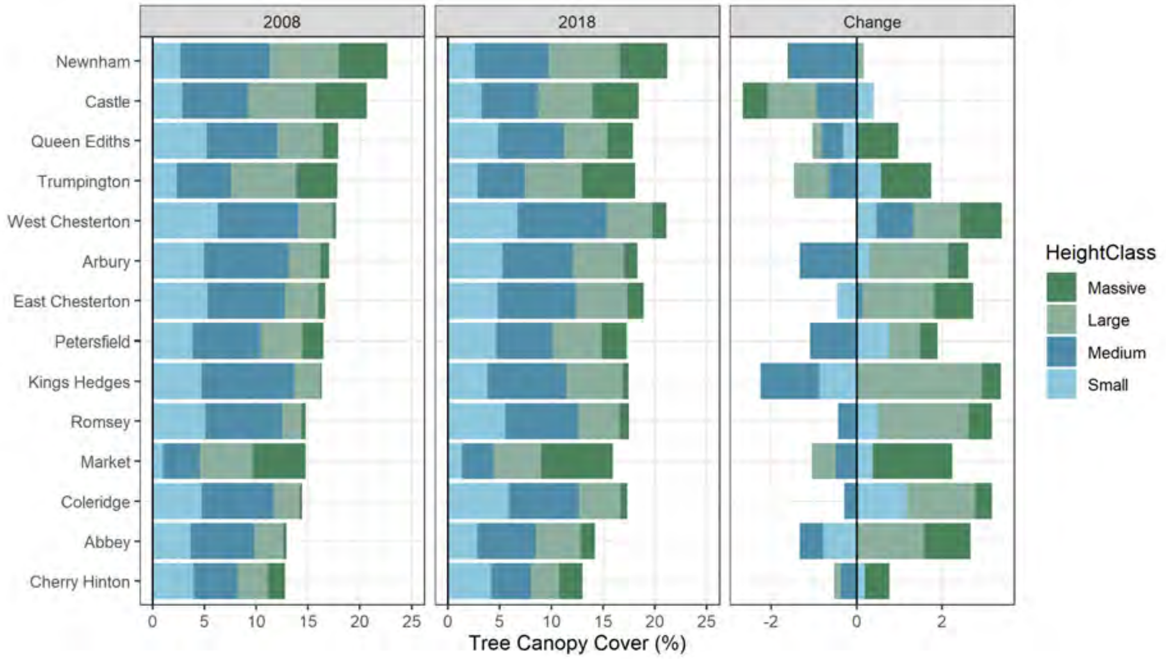

Figure 7 – Bar chart showing canopy cover (%) at the ward level subdivided by tree height class.

Note: This report contains multiple bar chart figures similar to (Figure 7). In all cases, the wards are arranged in descending order of canopy cover in 2008. The three panels show data from 2008, 2018 and the change between these years. The right hand panel showing the change in canopy cover always has a substantially smaller scale, because the change in canopy cover is small compared to the total canopy cover.

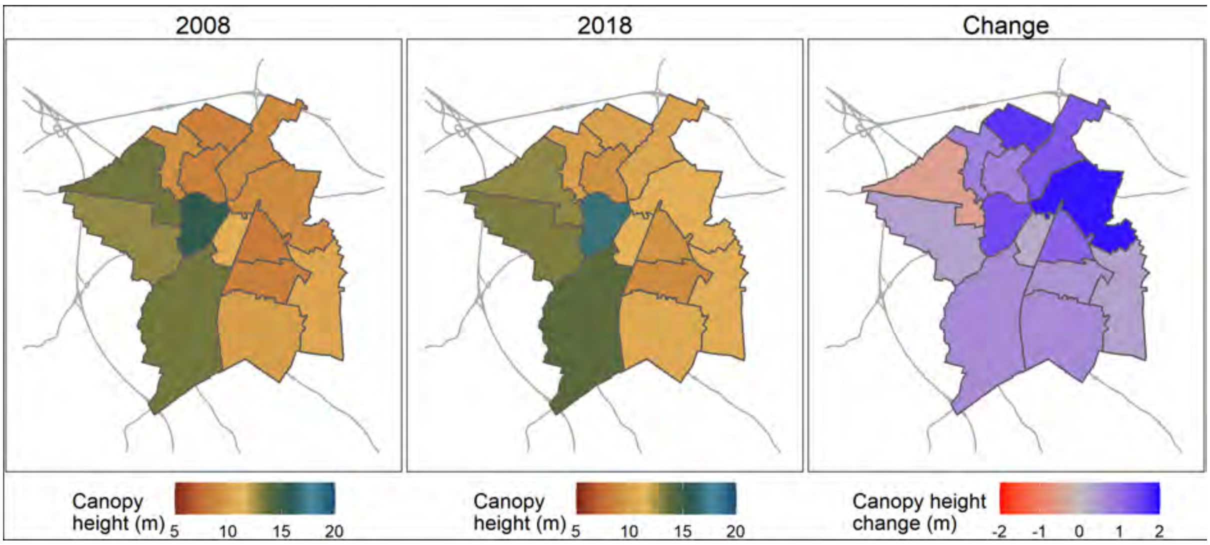

Figure 8 – Maps of mean canopy height (m) at the ward level.

Variation in canopy height. There was substantial variation in the contribution of trees of different sizes to the overall canopy cover between the 14 wards. The wards with the largest percentage canopy cover also had high proportions of tall trees (e.g Newnham and Castle). This is expected, as tall trees tend to provide larger canopy cover. This suggests that these wards have the most mature tree stock. The one exception to this trend was Market, which had a relatively low canopy cover comprised mainly of tall trees. This is presumably due to the college gardens, which contain a high number of large old trees.

Change in canopy height. 11 of the 14 wards experienced an increase in canopy cover between 2008 and 2018. This increased canopy cover is mainly in the taller trees, suggesting that it was mostly due to tree growth, rather than new planting. Newly planted trees are small, so they have a relatively low impact on total canopy cover in the short-term, although they may substantially increase canopy cover in the long-term. Only Castle experienced a substantial decrease in mean canopy height, presumably due to the construction works. Mean canopy height increased in Newnham, despite the decrease in canopy cover. This is because the decrease in canopy cover was due to almost entirely to the loss of medium sized trees, resulting a reduced remaining tree stock comprised of taller trees. In Castle, this decrease in canopy cover comprised trees of all sizes.

Caveats. Note that the systematic differences between the 2008 and 2018 surveys may influence the overall changes, but not the relative differences between wards. This means that the estimates for the change in canopy cover and canopy height may be biased by the systematic differences between the surveys. However, this bias is likely to be uniform across the city, so we can be confident that West Chesterton has had a higher increase in canopy cover than Trumpington.

4.5 Comparison of 2008 ward-level results with ADAS report

The Analysis and Interpretation of Tree Audit Data report (hereafter referred to as ADAS) used the same 2008 survey data as is used in the current analysis. This section provides a direct comparison with the ADAS report wherever possible.

The results of the current analysis align closely with those in the ADAS report. Specifically, the proportion of trees and canopy cover by ward in the current analysis is identical to that presented in the ADAS report (Table 7). Note that these values are proportions of city-wide tree cover (as given in the ADAS report), for absolute tree canopy cover values see the appendix (Table 11). Additionally, the proportion of trees and canopy cover by ownership class in this report is almost identical to those in the ADAS report (Table 8). The small discrepancy is likely due to the slight difference in definition of land ownership types. In this analysis, land which was classed as under both City Council and Highways ownership was classified as Highways only for the analysis.

The estimates for the proportion of tree canopy cover protected by tree preservation orders were higher in the ADAS report than the current analysis (Table 9). Nevertheless, the relative differences between wards were mostly consistent. This is likely due to methodological differences between the two approaches to analyse TPOs. In the current analysis, canopy cover protected by both a TPO area and an individual TPO was assigned solely to the individual TPO. Since individual TPOs were provided as points, it is uncertain which tree is covered by each individual TPO. Therefore, the TPO points were buffered by 5 m to allow for geolocation errors. This effectively increases the area covered by individual TPOs and, where they overlap, decreases the area covered by TPO areas.

The current analysis used a different land use classification to that used in the ADAS report, so these are not comparable.

Ward	***Land area (%)***	***This analysis***				***ADAS***	
		# trees (%)		***Canopy cover (%)***		***# trees (%)***	***Canopy cover (%)***
		2008	***2018***	***2008***	***2018***	***2008***	***2008***
Abbey	9.7	9.1	8.5	7.3	7.9	9.1	7.3
Arbury	3.7	4.6	4.5	3.7	3.8	4.6	3.7
Castle	8.4	7.8	6.4	10.2	8.8	7.8	10.1
Cherry Hinton	9.1	9.6	10.3	6.8	6.7	9.8	6.8
Coleridge	4.7	5.1	6.3	4.0	4.7	5.1	4
East Chesterton	6.4	9.3	8.6	6.3	6.9	9.3	6.3
Kings Hedges	3.9	5.0	4.1	3.7	3.8	4.9	3.8
Market	4.2	2.2	1.7	3.6	3.8	2.2	3.6
Newnham	10.9	9.9	8.4	14.5	13.1	10	14.4
Petersfield	2.6	2.8	3.2	2.5	2.5	2.8	2.5
Queen Ediths	11.1	12.1	13.6	11.6	11.3	12.1	11.6
Romsey	3.6	4.3	4.9	3.2	3.6	4.2	3.2
Trumpington	18.0	12.2	13.2	18.8	18.5	12.2	18.8
West Chesterton	3.7	5.9	6.2	3.9	4.5	5.9	3.9

Table 7 - Proportion of total number of trees and canopy cover by ward. Comparison with ADAS report, table 2, page 26

Land ownership	This analysis					ADAS analysis		
	Land Area (%)	# trees (%)		Canopy cover (%)		Land Area (%)	# trees (%)	Canopy cover (%)
		2008	2018	2008	2018			
City Council	13.6	14.7	13.6	16.6	17.8	13.5	14.6	16.3
Highways	9.5	8.7	5.9	9.4	9.5	9.5	9.3	9.6
Other	76.9	76.6	80.5	74.0	72.8	77	76.1	74.1

Table 8 - Proportion of trees and canopy cover by land ownership class. Comparison with ADAS report, table 4, page 32.

Ward	Canopy cover in TPO areas (%)		Canopy cover near individual TPOs (%)	
	This analysis	ADAS	This analysis	ADAS
Abbey	0.03	0.3	0.88	5.4
Arbury	1.56	2.1	1.52	3.6
Castle	3.27	3.2	3.34	10.4
Cherry Hinton	0.00	1.9	1.04	3.1
Coleridge	0.93	0.9	0.75	2.1
East Chesterton	2.87	3.8	1.54	5.7
Kings Hedges	1.84	1.8	1.21	2.4
Market	0.23	0.2	1.61	7
Newnham	3.61	3.1	3.16	11.4
Petersfield	2.00	4.6	7.44	30.4
Queen Ediths	5.23	9.8	5.49	21.2
Romsey	0.48	0.5	2.93	11.1
Trumpington	9.48	9.6	1.72	6.7
West Chesterton	0.29	0.3	2.29	6.2

Table 9 – Proportion of trees and canopy cover protected by tree preservation orders and conservation areas. Comparison with ADAS report, table 7, page 36.

4.6 Output Area change assessment

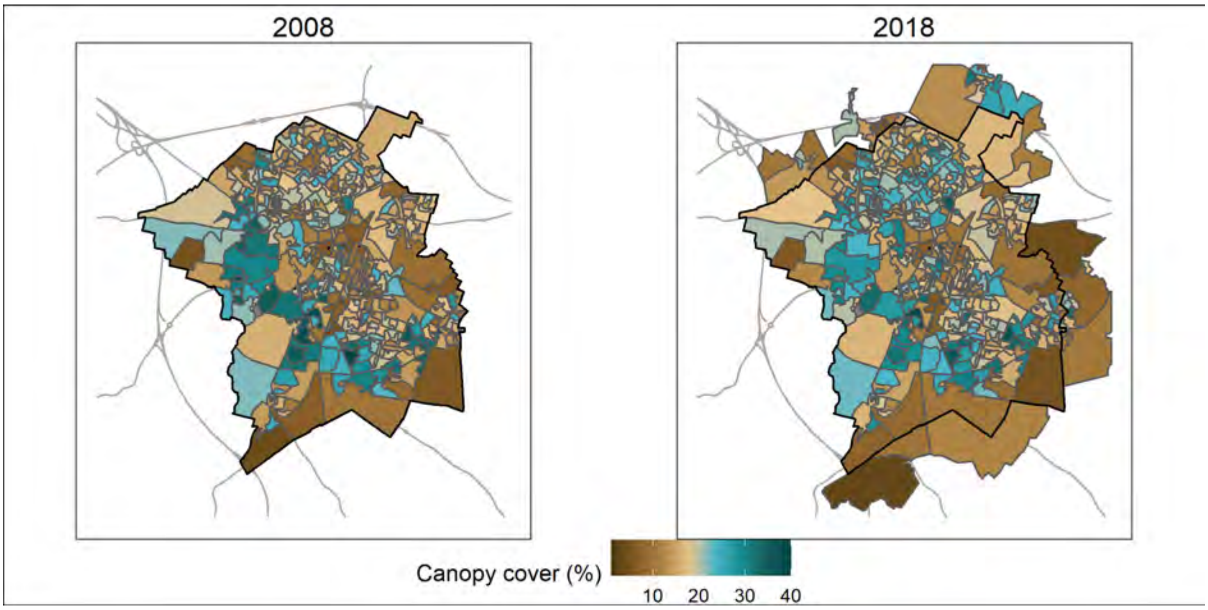

Figure 9 – Maps of tree canopy cover (%) across all output areas in Cambridge in 2008 and 2018.

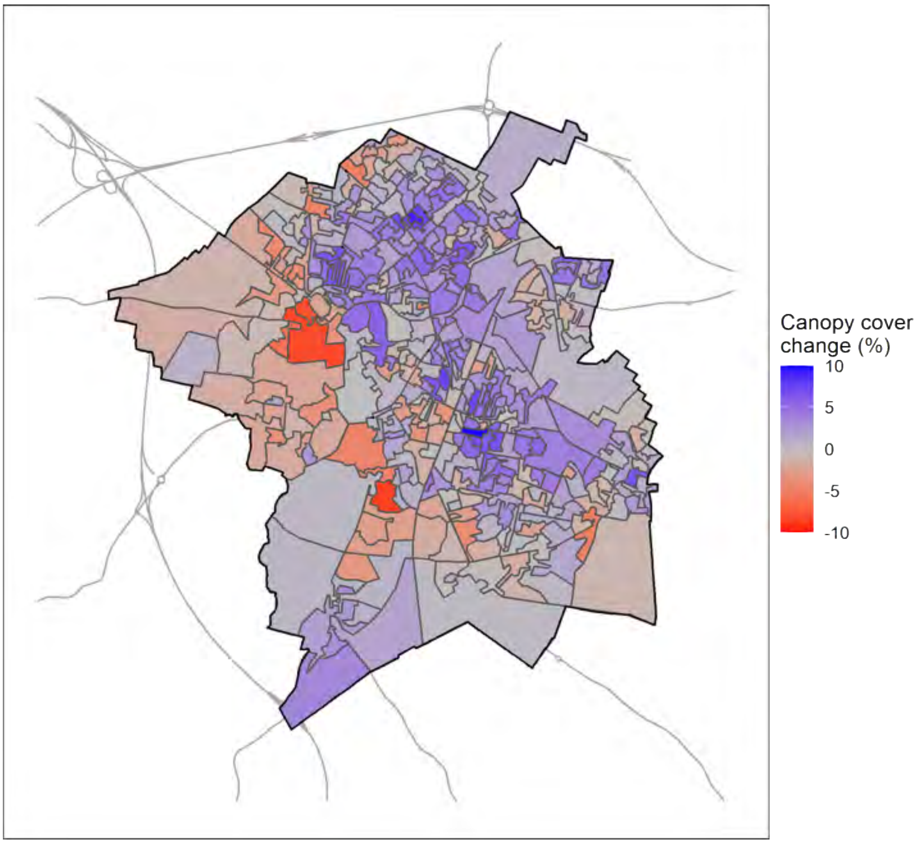

Figure 10 – Map of change in tree canopy cover between 2008 and 2018 across Cambridge at the output area scale.

Variation in canopy cover. The output area analysis shows that a ring of high canopy cover (>25%) around the western and southern edge of the city centre. All other areas have lower canopy cover.

The low canopy cover in the city centre is presumably due to the high density of commercial buildings.

Change in canopy cover. Canopy cover decreased in the western part of the city but increased in the central and eastern parts of the city. This is exemplified by the growth of the large trees in Jesus Green (Figure 11), where the green areas represent canopy cover in both 2008 and 2018 and the blue areas represent canopy cover increase. There was also an increase in canopy cover in the far southern sections of the city. This increase in canopy cover was mostly driven by tree growth, rather than planting, except in the southern tip (Great Kneighton) where this increase was almost entirely due to tree planting. Note that the changes refer to percentage canopy cover within each output area, so smaller output areas will be more sensitive to changes than large output areas.

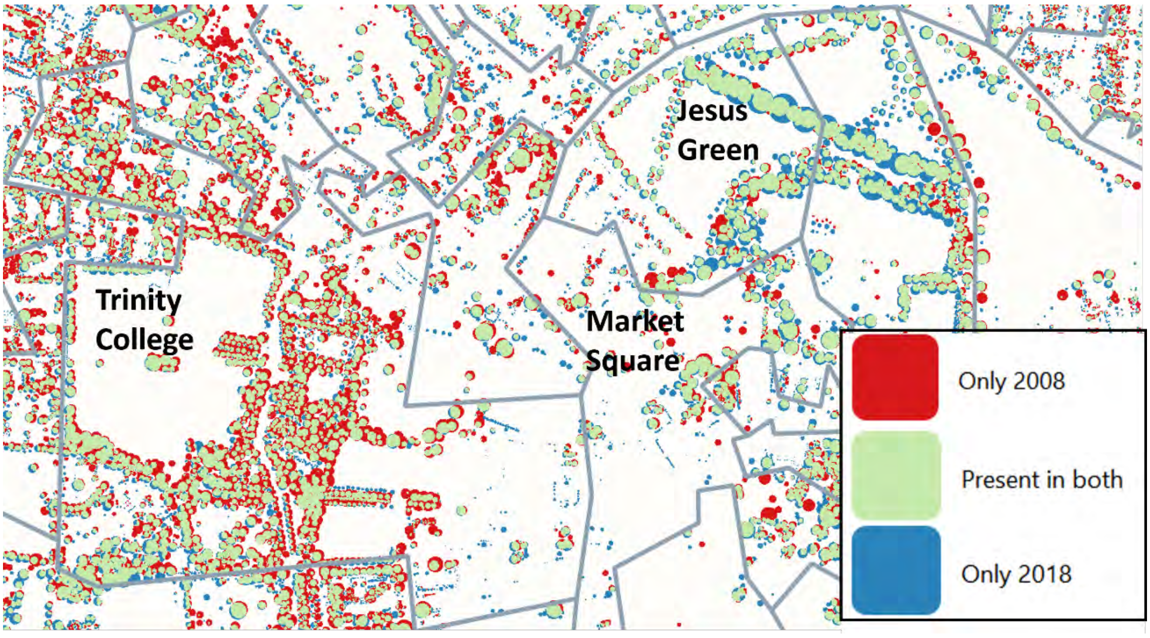

Figure 11 – Change in canopy cover at the output area level. This map focuses on a central area of Cambridge which has large negative changes in the western side (Trinity College) and large positive changes in the eastern side (Jesus Green).

4.7 Size class distribution & change at OA level

Variation of mean canopy height. Canopy height was highest in the western part of Cambridge, areas which also had the highest canopy cover. Interestingly, canopy height was also high in central Cambridge, which had low canopy cover. This shows that the central areas are characterized by a low number of large trees, presumably in college gardens.

Change in canopy height. Canopy height increased across most of the city between 2008 and 2018. The output areas in which canopy height decreased, or did not change, were those which had the tallest trees and the highest canopy cover in 2008. This shows that the increase in canopy height was due to the growth of small and medium sized trees in the areas of Cambridge which previously had low canopy cover.

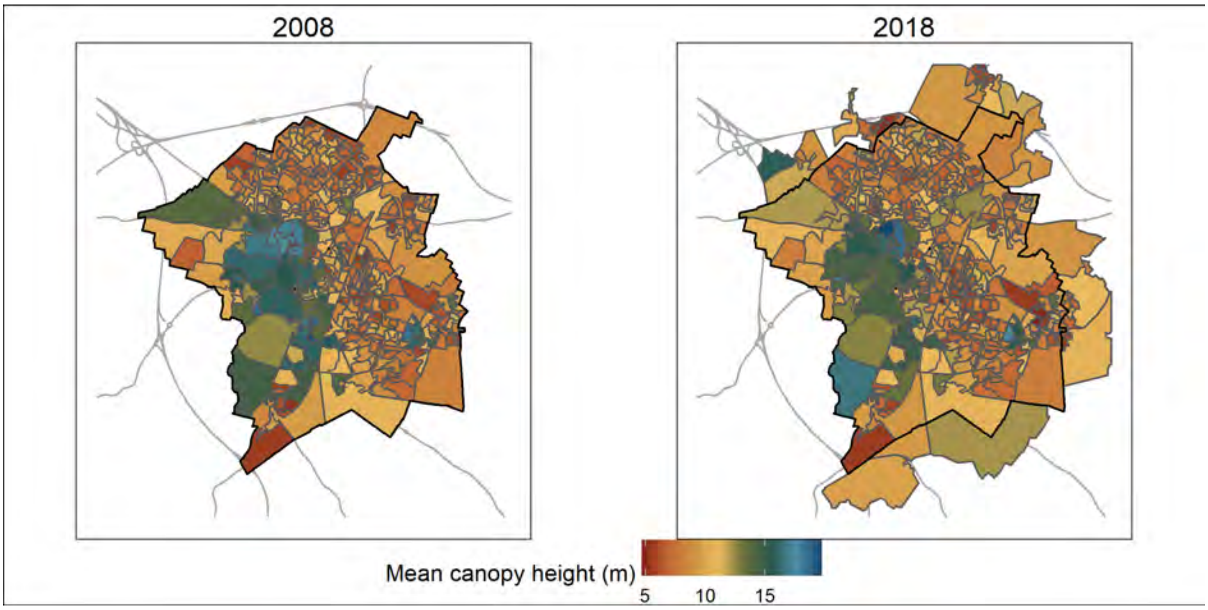

Figure 12 – Maps of mean tree height (m) for each output area in Cambridge in 2008 and 2018

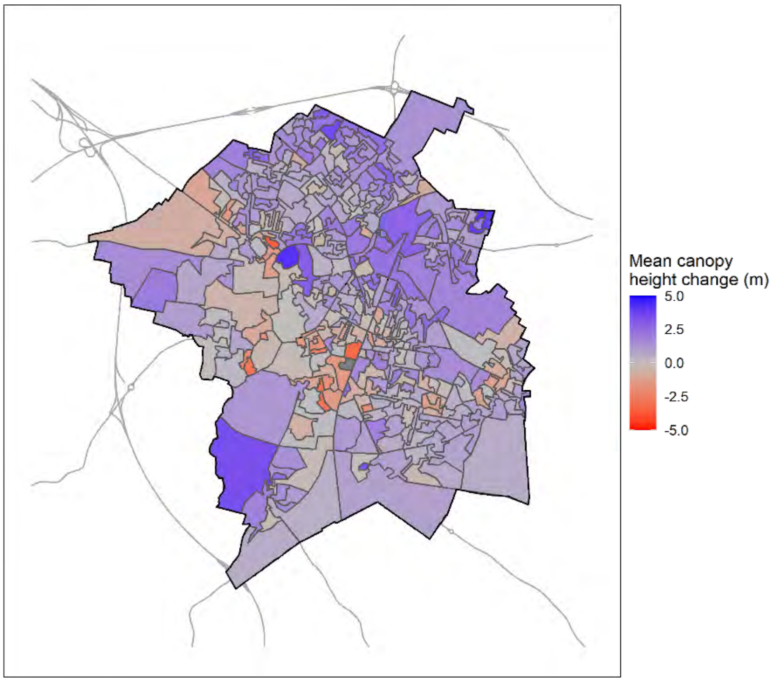

Figure 13 – Map of change in mean canopy height (m) for all output areas in Cambridge.

4.8 Land ownership: Tree canopy cover between highways and council land

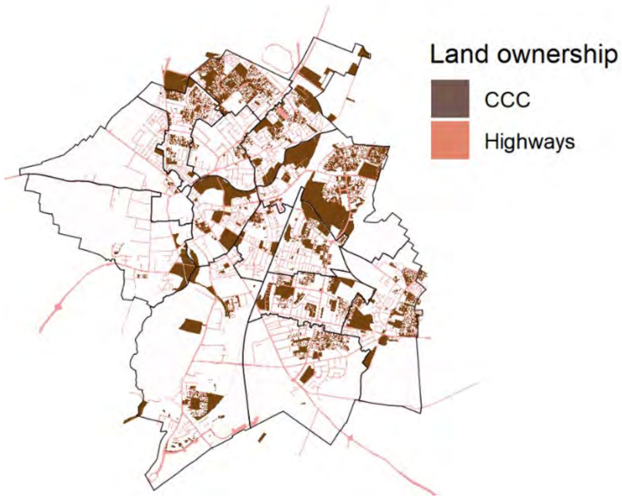

Figure 14 – Map of land ownership across Cambridge

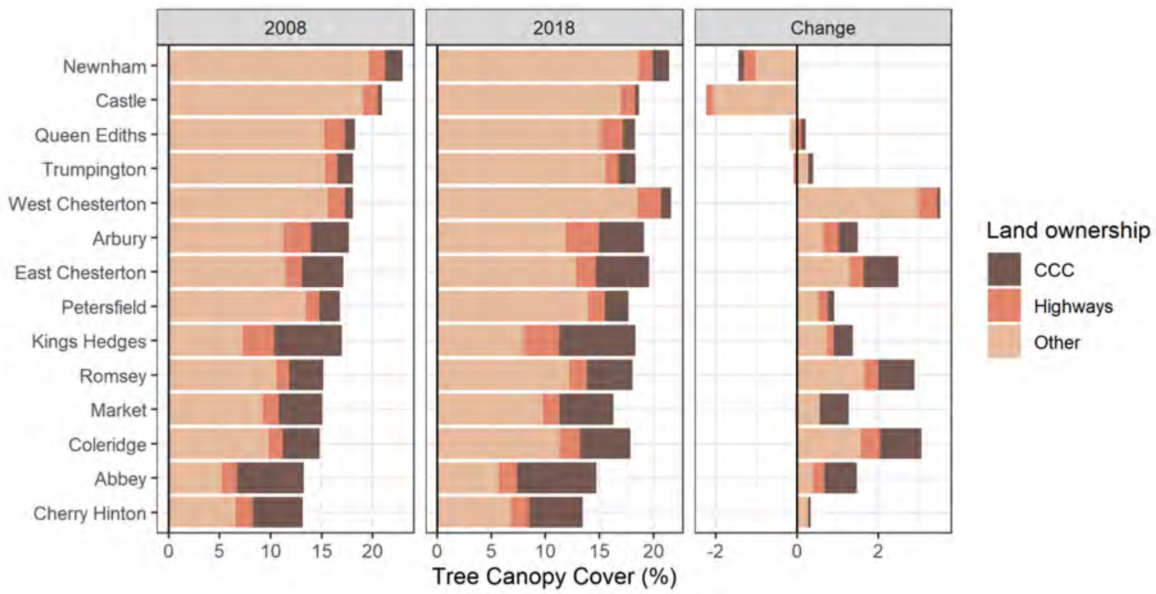

Figure 15 – Bar chart showing canopy cover (%) at the ward level subdivided by land ownership class.

Variation of canopy cover by land ownership. Highways land is evenly distributed across the city (Figure 14). Council owned land is mainly located in the northern and eastern parts of Cambridge, which tended to have the lowest canopy cover. The largest proportion of land is neither highways nor council owned land and it contains the majority of tree canopy cover in all wards except Abbey and Cherry Hinton. This land, which we assume is mostly privately owned, therefore has the largest opportunities for tree planting.

Change in canopy cover by land ownership. The changes in canopy cover on highways land follows the city-wide trend of increasing canopy cover, except in Newnham and Castle. Canopy cover increased on council land in Queen Ediths, Trumpington, West Chesterton, Arbury, East Chesterton, Petersfield, Kings Hedges, Romsey, Market, Coleridge, Abbey and Cherry Hinton. We found no notable differences between council owned land and highways land in terms of canopy cover change.

4.9 Land use: Manmade, natural and gardens, tree canopy correlations

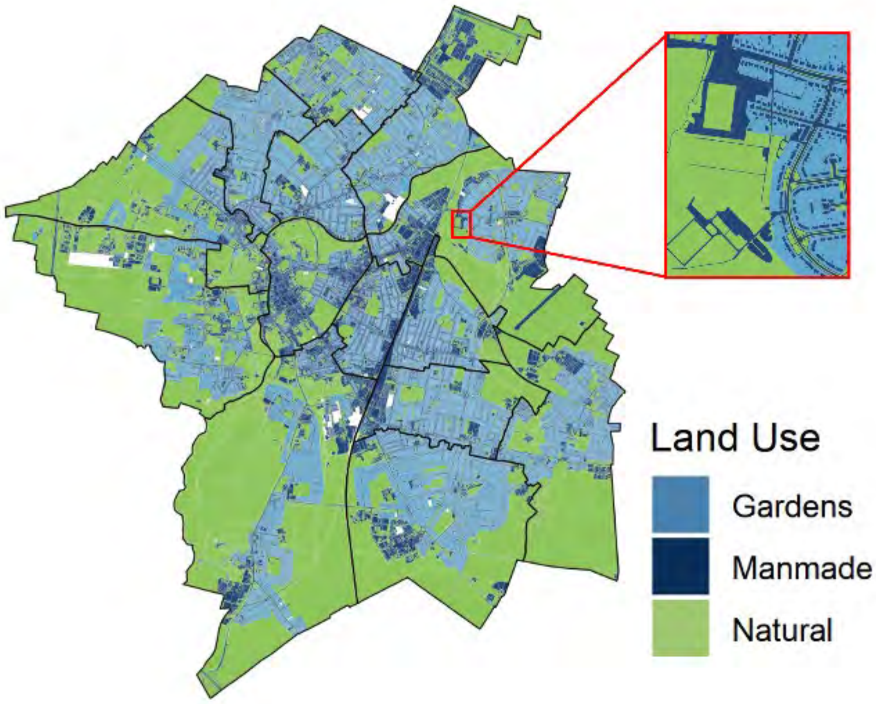

Figure 16 – Map of land use types in Cambridge from Mastermap 2008.

Land use distribution. The ratio of natural, gardens and manmade land areas varied substantially across the wards. Natural land use accounted for over 50% of the land area in only 6 of the 14 wards. Interestingly, these were the four wards with highest canopy cover (Newnham, Castle, Queen Ediths and Trumpington) and the two with lowest canopy cover (Abbey and Cherry Hinton). This is likely because Abbey contains Cambridge Airport while Cherry Hinton is dominated by farmland. The remaining 8 wards had higher proportions of gardens and manmade land uses, due to a higher proportion of residential areas. Note that these three land use classes do not account for 100% of the land area in some wards. This is because there are other land use classes which have not analysed here. These are the white areas in the map (Figure 16). These areas are mostly small and will not influence our overall analysis of tree canopy cover in gardens, natural and manmade land use classes.

Changes in land use. Overall, land use was relatively stable between 2008 and 2018. Three wards (Castle, Queen Ediths and Trumpington) saw a substantial (approximately 10%) reduction in the 'natural' land use type. This was partially accounted for by a relative increase in 'manmade' land area in these wards. These wards had substantial construction in this period, such as the Great Kneighton and Eddington projects. The other wards experienced smaller changes in land use types, with a consistent decrease in garden area and increase in manmade areas, characteristic of urban densification.

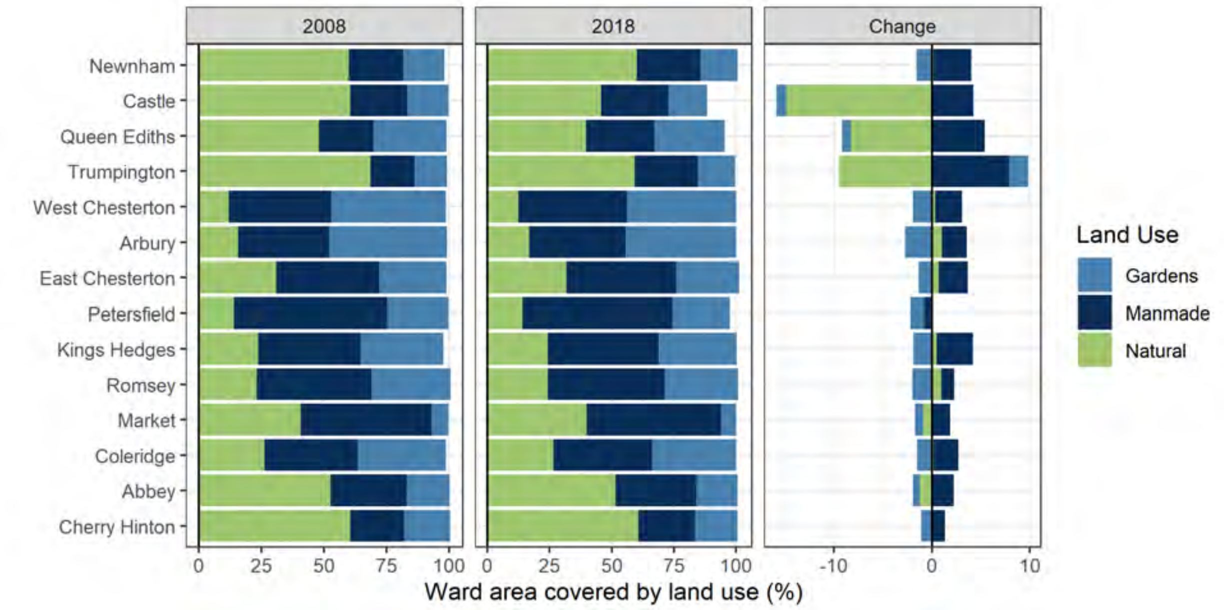

Figure 17 – Bar charts showing proportion of land area (%) in manmade, gardens and natural land use classes at the ward-level.

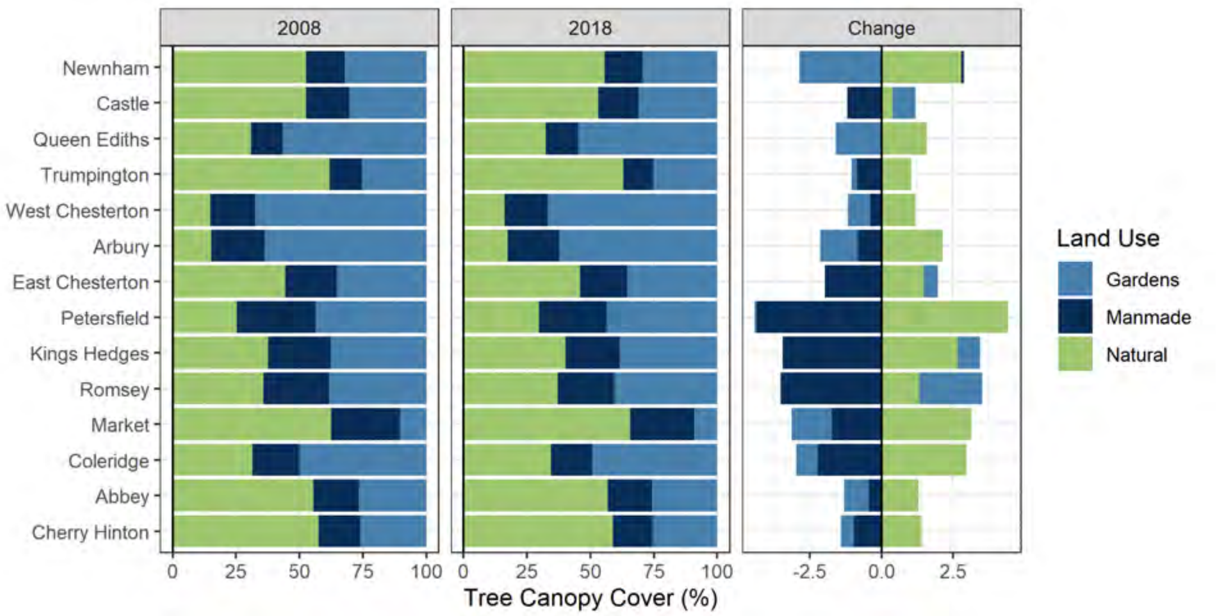

Figure 18 – Bar charts showing proportion of canopy cover (%) in by manmade, gardens and natural land use classes at the ward level.

Canopy cover by land use. As expected, the ratio of tree canopy cover by land use class (Figure 18) reflects the proportion of land area covered by each land use class (Figure 17). Land classified as manmade land use accounts for a small proportion of tree canopy cover (Figure 18). Conversely, gardens and natural land use contain a high proportion of tree canopy cover across all wards. Queen

Ediths is an exception to this pattern, with a low canopy cover on the natural land use class, despite having a relatively high proportion of this land use class.

Canopy cover change by land use. The overall tree canopy cover ratio between different land use types remains relatively consistent from 2008 to 2018 across all wards, with changes on the order of 1-2.5 %. The change in tree canopy cover by land use is a combination of both the changes in land area covered by each land use and the actual changes in canopy area. We find a very clear pattern across 12 of the 14 wards with a reduction of tree canopy cover on the manmade land use class, balanced by an increase of tree canopy cover on the natural land use class. This is despite the decrease in natural land use area. In particular, Castle, Queen Ediths and Trumpington experience an increase in canopy cover on natural land despite large decreases in natural land area in these wards.

Focus on gardens. The change in the proportion of tree canopy cover in gardens was highly variable across the wards. This is despite the fact that garden area decreased in all but one ward (Trumpington). This suggests that there remains considerable opportunity for increasing canopy cover in gardens, despite the fact that garden area is decreasing. In particular Romsey experienced a large increase in the canopy cover in gardens, despite decreases in the total land area of the garden. An example of this is shown below Figure 19. On the other hand, Newnham saw a substantial decrease in the amount of tree cover contained in gardens, and this is one of the main reasons for the overall decrease in canopy cover in this ward.

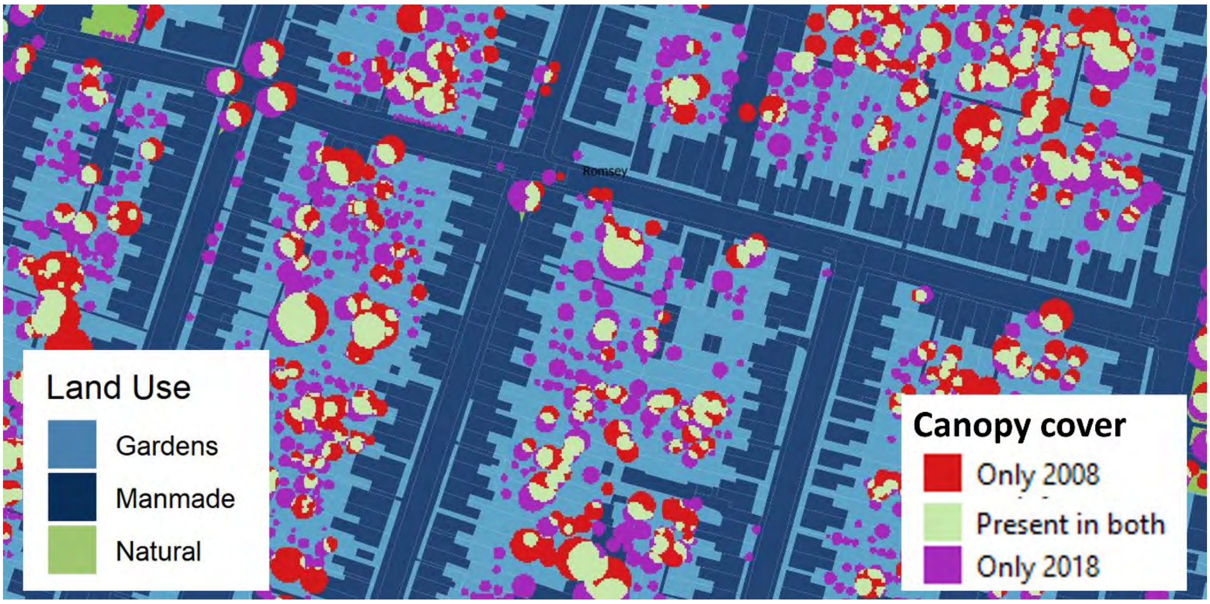

Figure 19 – Example of change in canopy cover in a residential area in Romsey. Note that the colour scheme has been changed for greater contrast.

4.10 Land constraints: Conservation areas

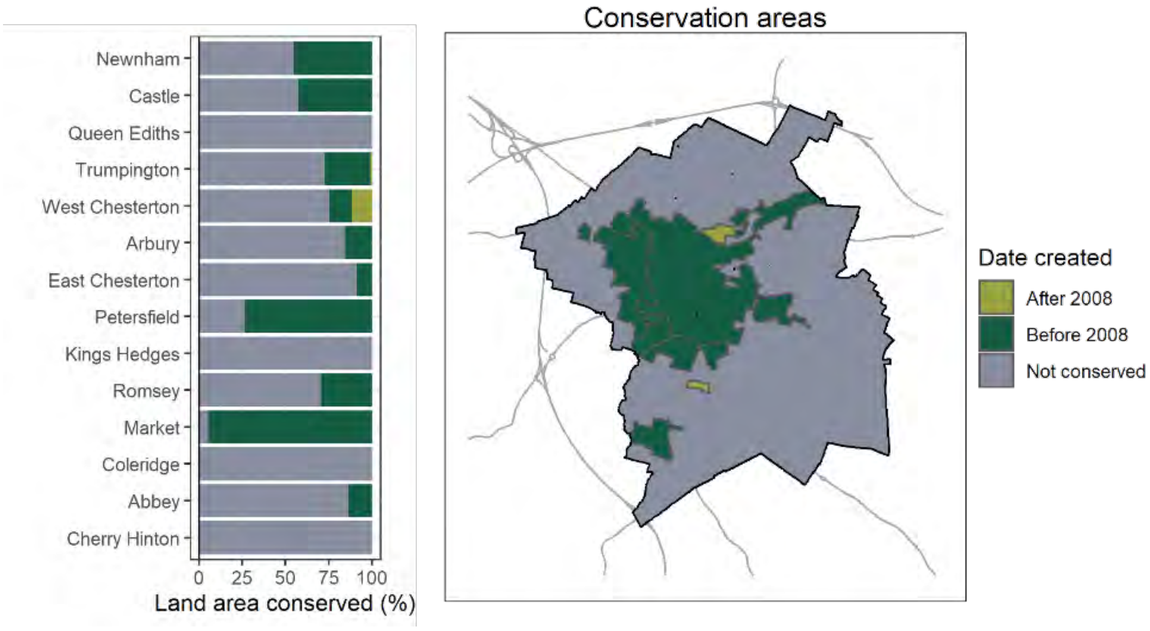

Figure 20 – Left – Bar chart showing proportion of land area in conservation areas at the ward level. Right - map of conservation areas created before and after 2008

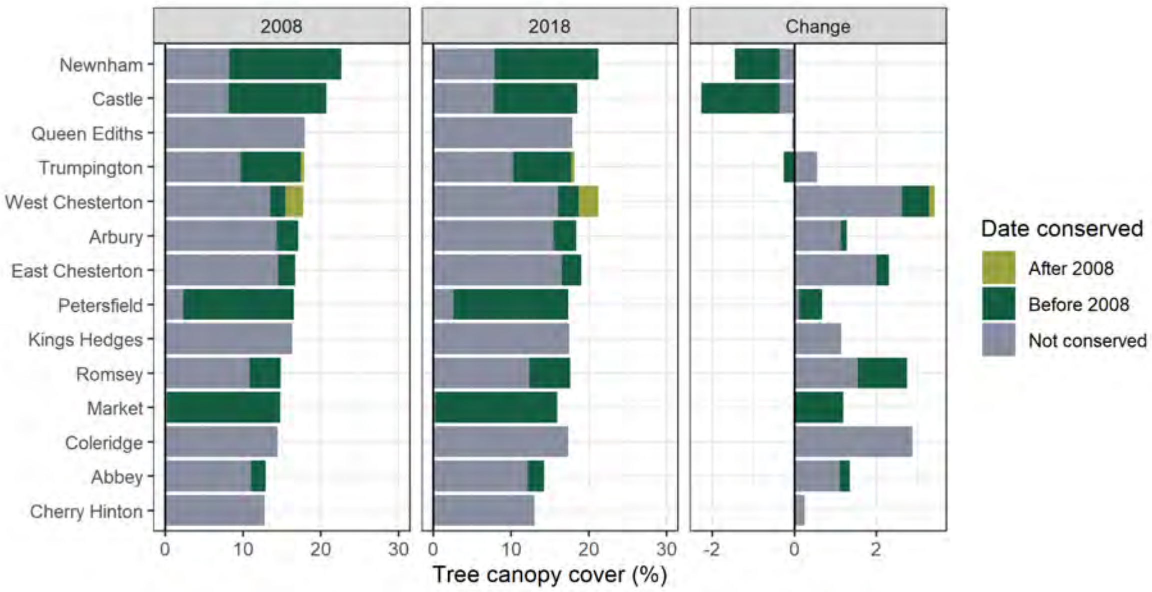

Figure 21 – Bar charts showing tree canopy cover (%) at the ward level subdivided by conservation status..

Distribution of conservation areas. Conservation areas are focused on the city centre, and all were in place prior to 2008. Small sections of Trumpington and West Chesterton have been designated as conservation areas since this date.

Canopy cover by conservation area. The two wards with highest canopy cover (Newnham and Castle) had the majority of their canopy cover located in conservation areas in both 2008 and 2018. However, these conservation areas experienced a substantial decline in canopy cover between 2008 and 2018. Market and Petersfield were almost entirely covered by conservation areas, and therefore their canopy cover is located almost entirely in these conservation areas.

4.11 Land constraints: Tree preservation orders and needs assessment.

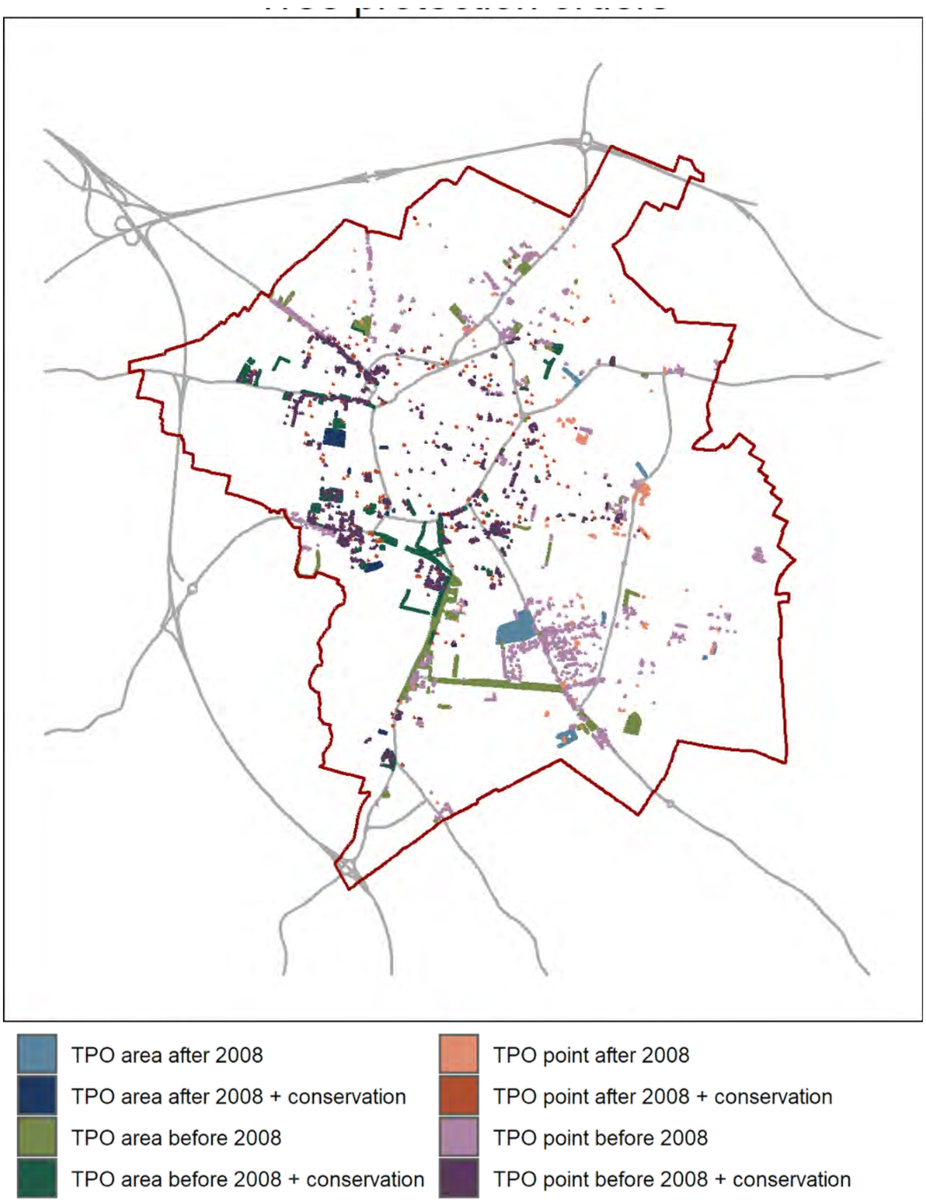

Figure 22 - Map of TPOs across Cambridge.

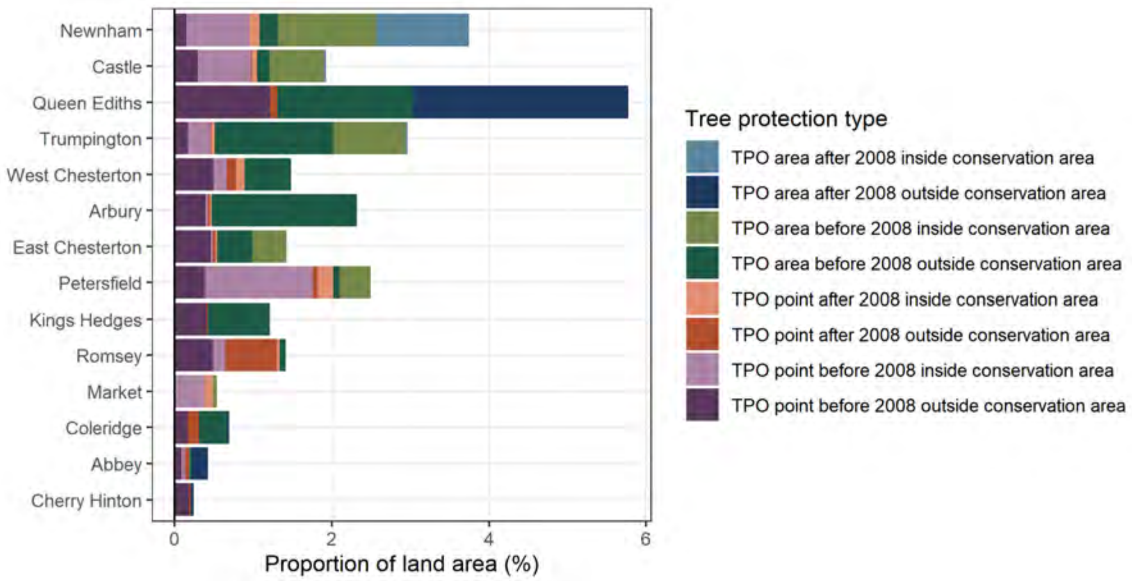

Figure 23 – Bar chart showing proportion of land area (%) covered by each TPO type at the ward level.

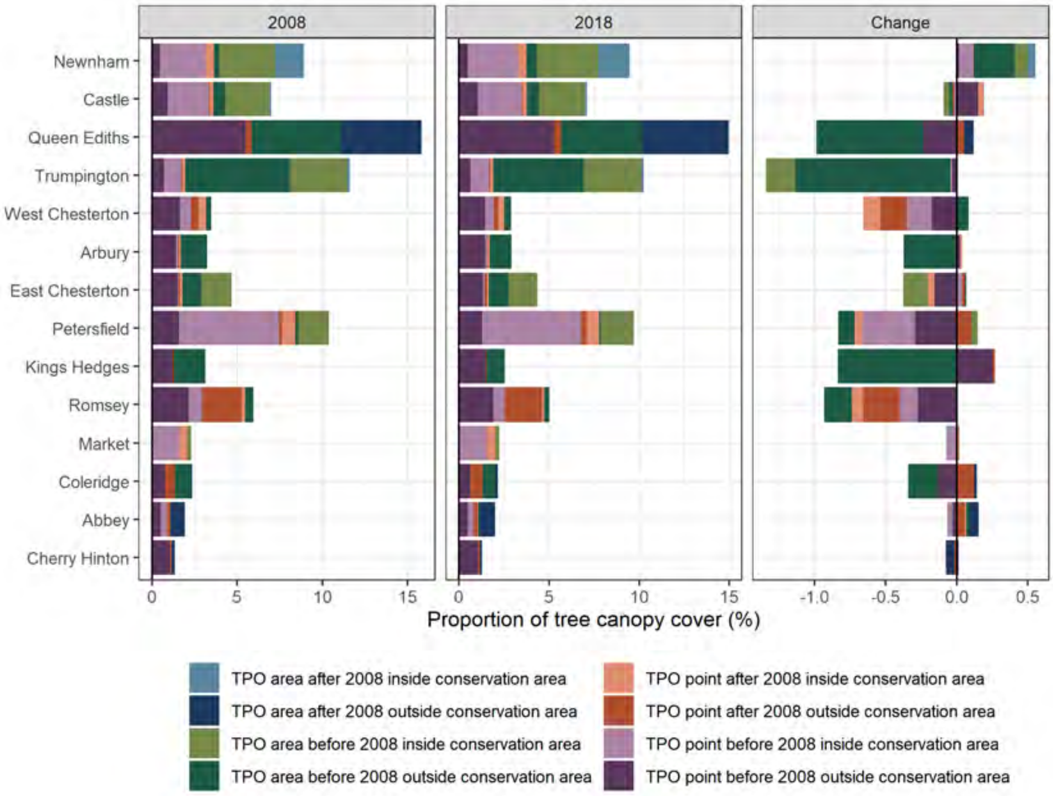

Figure *24* – Bar chart showing proportion of tree canopy cover protected by TPOs at the ward level.

Distribution of TPOs. Less than 6 % of each ward was covered by an area-based TPO or within 5 m of a point-based TPO (Figure 23). Point-based TPOs are widely distributed across 11 of the 14 wards in Cambridge. Coleridge, Abbey and Cherry Hinton have a low proportion (by canopy area) of point-based TPOs and area-based TPOs. Area-based TPOs are concentrated in the wards with the highest tree cover (Newnham, Castle, Queen Ediths, Trumpington, and Arbury).

Tree canopy cover by TPO. The proportion of tree canopy cover in an area-based TPO or within 5 m of a point-based TPO ranged from under 2 % (Cherry Hinton) to over 15 % (Queen Ediths), reflecting the amount of land covered by TPOs in these wards (Figure *24*). Large and massive trees were more likely to be protected by TPOs than small or medium sized trees (over 30% in Queen Ediths, Figure 25). Nevertheless, Figure 25 shows that the vast majority of large and massive trees are not protected by TPOs, particularly in the wards with lower tree canopy cover. This is also clear from the city-wide summary of TPOs (Table 6).

Note that the bar charts show the proportion of tree canopy cover protected by TPOs for each ward. For example, Cherry Hinton had the lowest proportion of tree canopy cover protected. Cherry Hinton also had the lowest tree canopy cover of all the wards (Figure 7). This suggests that Cherry Hinton should be a priority area for TPOs in the future. The same is true for Abbey and Coleridge.

Change in tree canopy cover by TPO. The changes in the proportion of tree canopy cover protected by TPOs were all less than 1.5 %. We previously showed that the area of canopy cover increased in most wards between 2008 and 2018 (Figure 7). Against this overall trend, the proportion of canopy cover protected by TPOs decreased in most wards. This means that the canopy cover protected by TPOs did not increase as much as the canopy cover in the rest of the ward. In particular, the area-based TPOs established prior to 2008 in Queen Ediths, Trumpington, Arbury and Kings Hedges had substantial decreases in the proportion of tree canopy cover. This is likely because the trees in these areas are mature and therefore not growing as quickly as the overall growth rate in these wards (or have been lost or pruned).

The proportion of large and massive tree canopy cover protected by TPOs also decreased between 2008 and 2018. There is more variability in these trends because large and massive trees are less common (Figure 7), so a small change can have a big impact on the proportion of large and massive tree canopy cover.

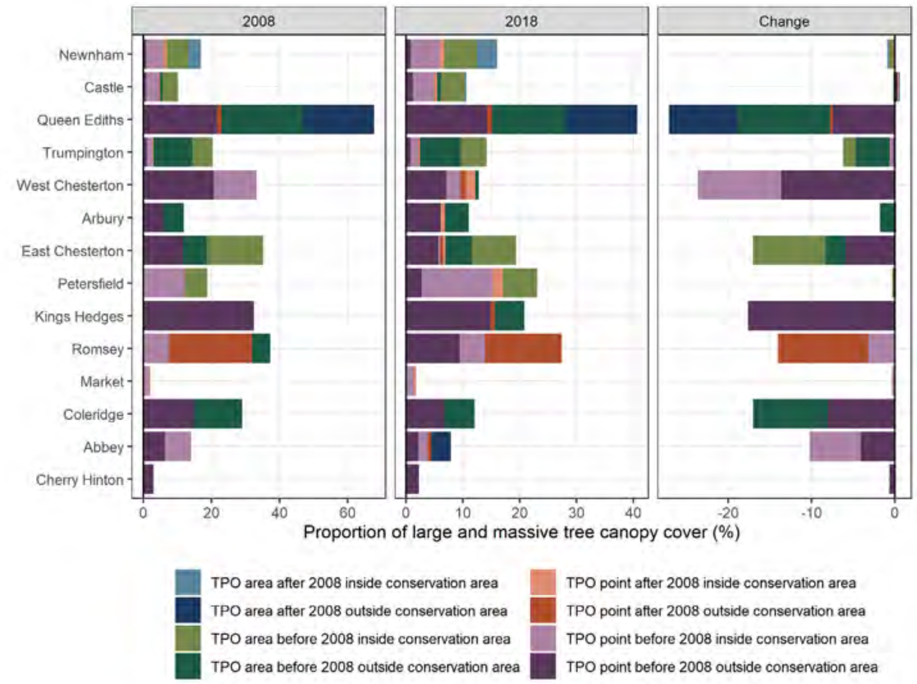

Figure 25 - Bar chart showing the proportion of large and massive tree canopy cover protected by TPOs at the ward level.

4.12 Land constraints: Protected open space

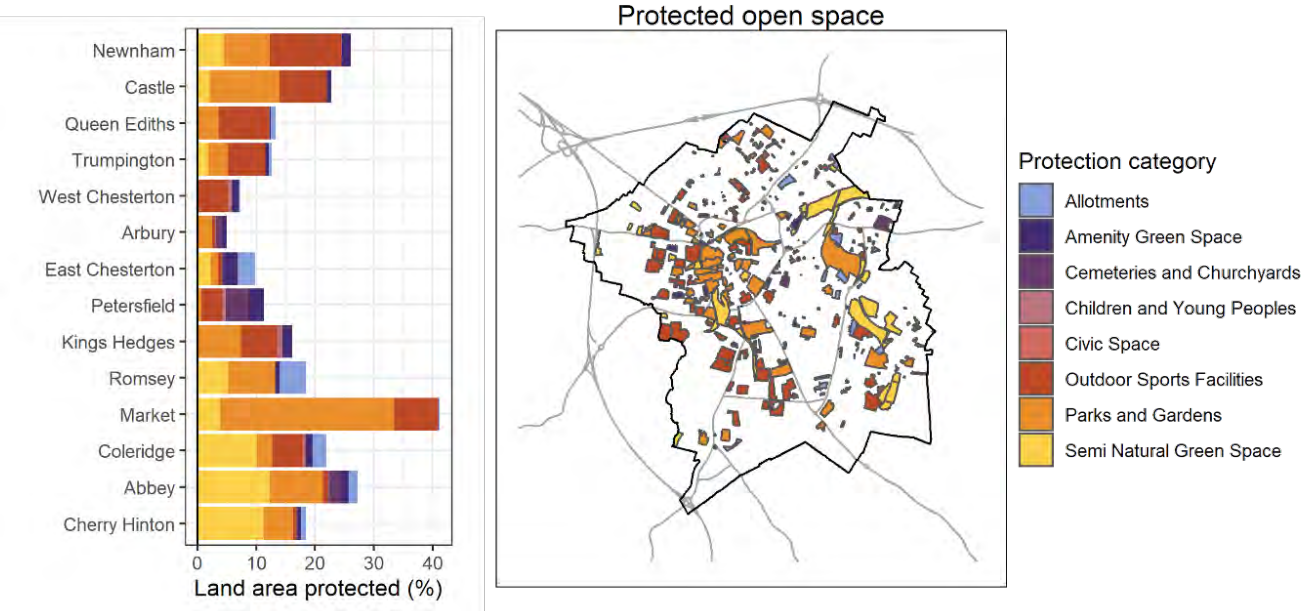

Figure 26 – Left – Bar chart showing the proportion of land area (%) in protected open spaces at the ward level. Right - Map of protected open space across Cambridge.

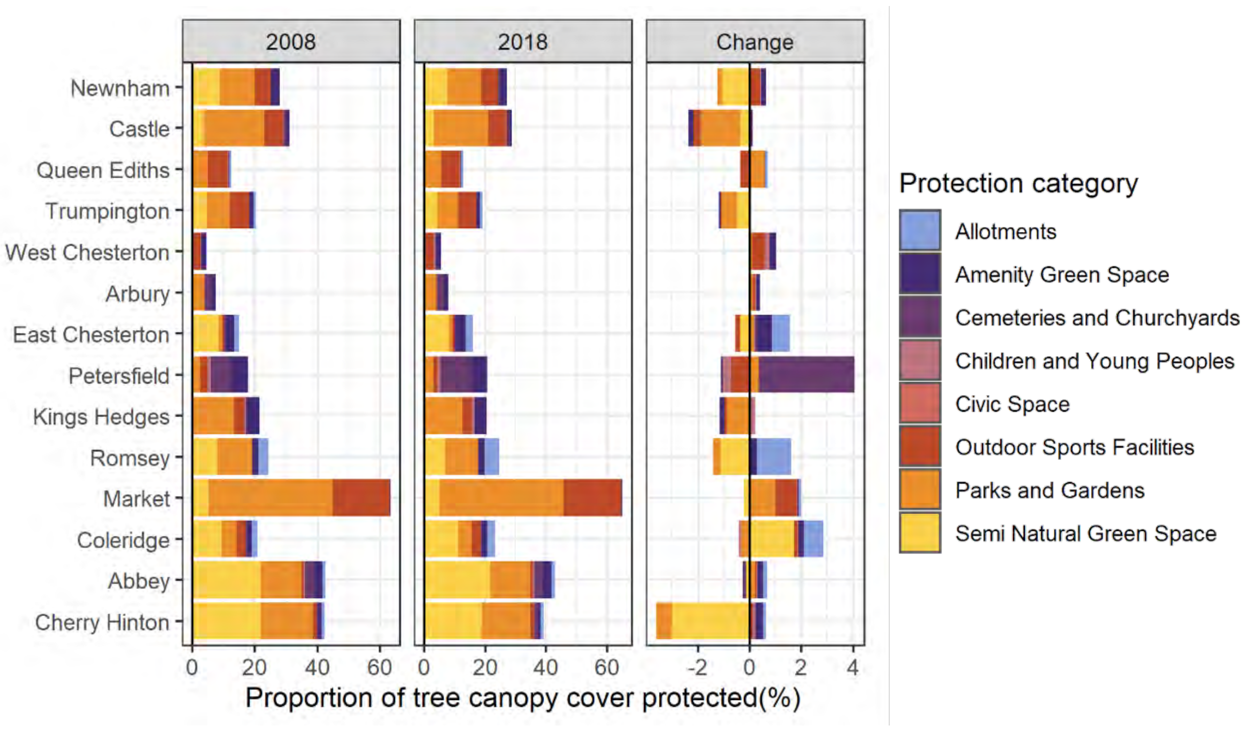

Figure 27 – Bar charts showing the proportion of tree canopy cover (%) in protected open spaces at the ward level.

Distribution of protected open spaces. Most wards had 10-20 % of their land area protected (Figure 26). Market had the highest proportion of land area protected (over 40 %), while Arbury and West Chesterton had the lowest (under 10 %). This distribution of protected open space does not reflect the level of tree canopy in these wards. It is the wards with medium levels of tree canopy cover which have the lowest proportion of their land protected. Note that the bar chart (and all bar charts in this report) is arranged by decreasing 2008 canopy cover, where Newnham has the highest and Cherry Hinton has the lowest.

Canopy cover in protected open spaces. The proportion of tree canopy cover in protected open spaces ranged from under 10 % in West Chesterton, to over 60 % in Market. This reflects the area of land protected in these wards. The majority of this canopy cover was in 'semi natural green spaces', 'parks and gardens and 'outdoor sports facilities'. The majority of canopy cover was located outside of protected open-spaces..

Change in tree canopy cover by protection. The change in tree canopy cover in protected open spaces reflects the broader trends discussed above. Interestingly, in Cherry Hinton the protected spaces (Semi Natural Green Space) lost canopy cover. Additionally, this analysis shows that the increase in tree canopy cover in Petersfield was almost entirely within a single churchyard. Figure 29 shows a detailed map of canopy cover change in this churchyard, showing large amounts of canopy growth (blue) and very little canopy loss (red) compared to the areas outside the churchyard.

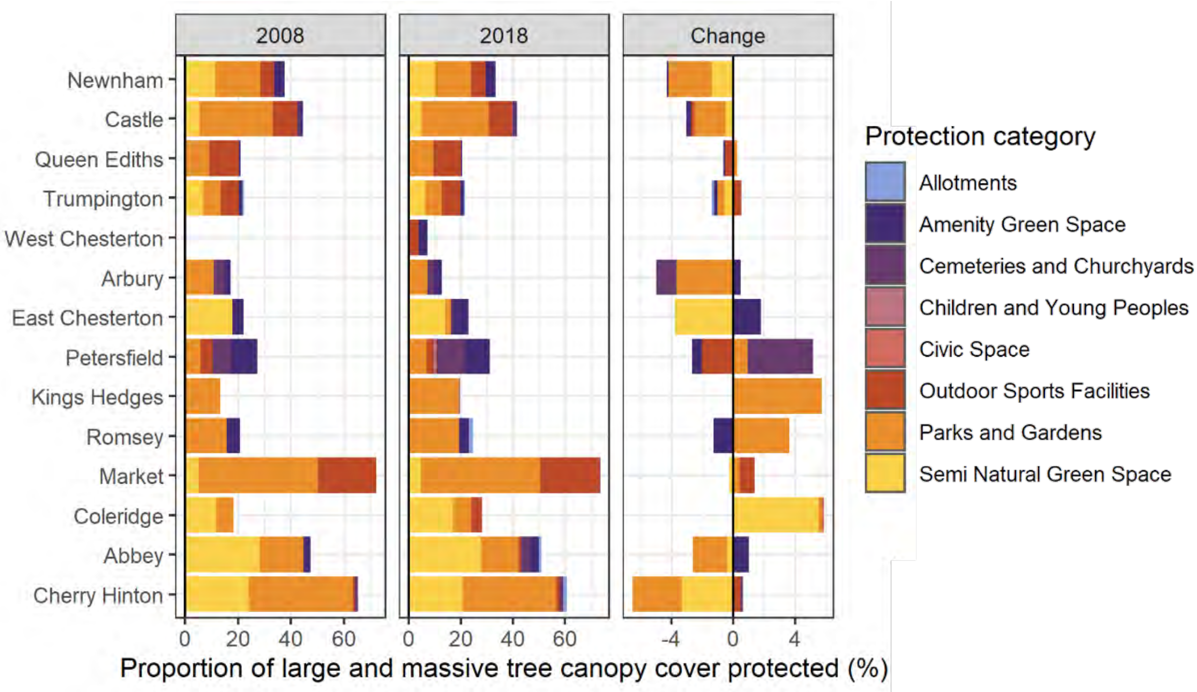

Figure 28 – Bar chart showing proportion of canopy cover (%) of large and massive trees in protected open spaces, at the ward level.

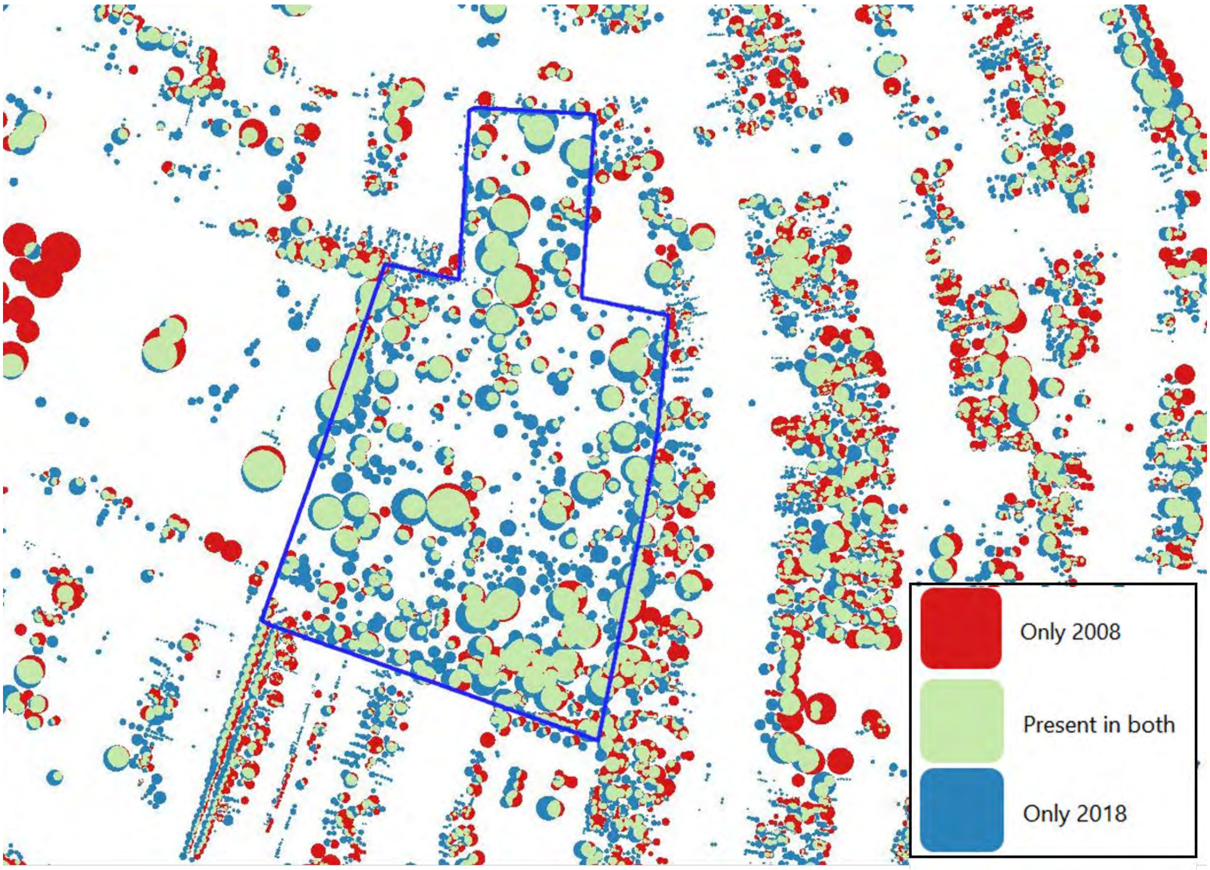

Figure 29 – Example of change in canopy cover between 2008 and 2018 in the churchyard in Petersfield.

4.13 IMD & tree canopy correlations and planting assessment

The areas with the highest index of multiple deprivation (IMD) are in the north-east of the city (Figure 30). We focus our analysis on the nine LSOAs with index of multiple deprivation higher than 25 (Table 10).

Area (LSOA)	IMD	Land area protected (%)	Land area covered by TPOs (%)
CA 001E-King's Hedges	27.3	1.0	0.0
CA 001D-King's Hedges	28.1	35.1	0.0
CA 003B-East Chesterton	28.2	5.6	0.0
CA 006B-Abbey	28.6	43.4	0.1
CA 002D-Arbury	29.3	9.7	0.0
CA 001C-King's Hedges	29.8	6.9	4.0
CA 001A-King's Hedges	30.0	31.4	0.0
CA 006D-Abbey	35.7	5.6	0.5
CA 006F-Abbey	36.6	32.7	0.3

Table 10 – LSOAs with high index of multiple deprivation and the proportion of land area which is protected and covered by TPOs.

Canopy cover by IMD. In 2008, we found that IMD was associated with lower canopy cover, although the correlation was very weak (Figure 31, first panel). By 2018, the tree canopy cover in the high IMD areas had increased, so there was no clear relationship between IMD and tree canopy cover. This was reflected by the increase in canopy cover, which was stronger for high IMD areas (Figure 31, third panel).

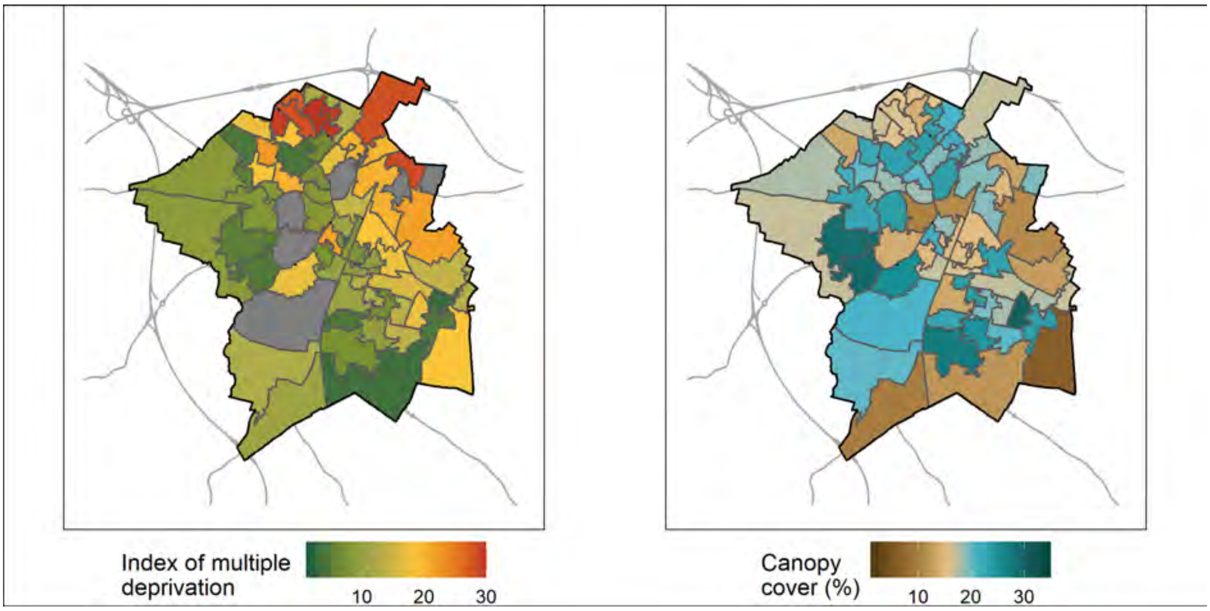

Figure 30 – Maps of index of multiple deprivations and canopy density at the lower super output area level. Note that grey areas in the left hand panel do not have summary IMD data.

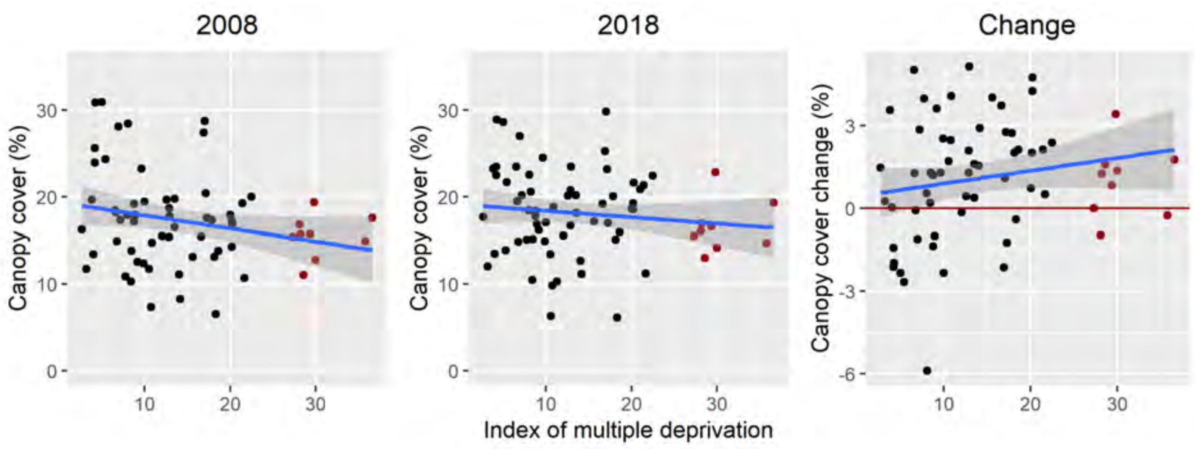

Figure 31 - Relationship between tree canopy cover and index of multiple deprivation. Each point represents an LSOA. The blue fit line was calculated by ordinary least squares regression and it represents the relationship of the two variables. Tthe grey shaded area represents the uncertainty in this relationship.

Land prioritization in high IMD areas. The nine LSOAs with high IMD had a relatively high proportion of Council owned land (Figure 32) but only one of these LSOAs contained a conservation area (CA 006B-Abbey). As a proportion of their total land area, these nine high IMD LSOAs had a low proportion covered by TPOs (Table 10), but a relatively high proportion covered by protected areas (Figure 33) compared to other LSOAs. This suggests that efforts to increase tree canopy cover in these areas should focus on adding new TPOs, while maintaining existing trees on Council land and in protected areas.

Note: in the following three figures, the left hand panel shows only the LSOAs with high IMD, while the right hand panel shows the remaining LSOAs

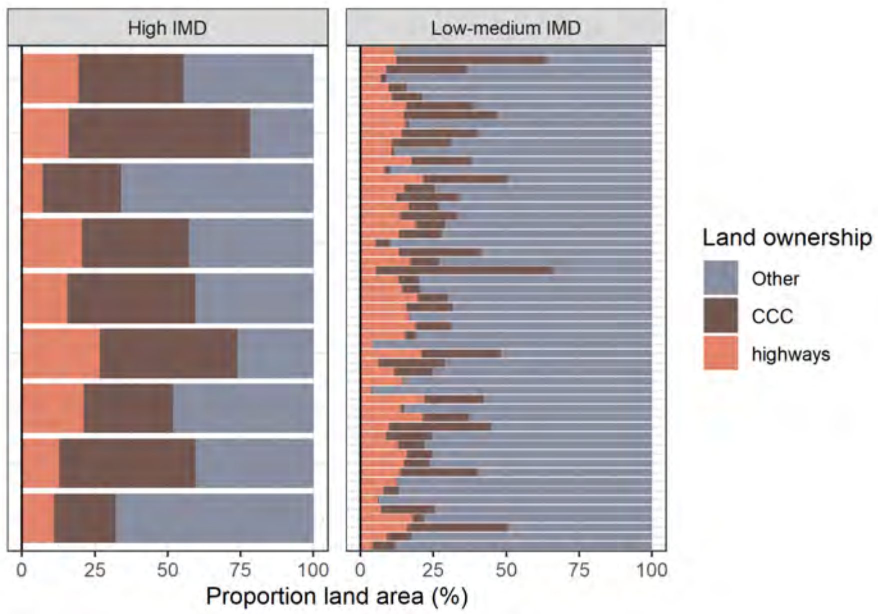

Figure 32 – Bar charts showing proportion of land area in each ownership type at the LSOA level.

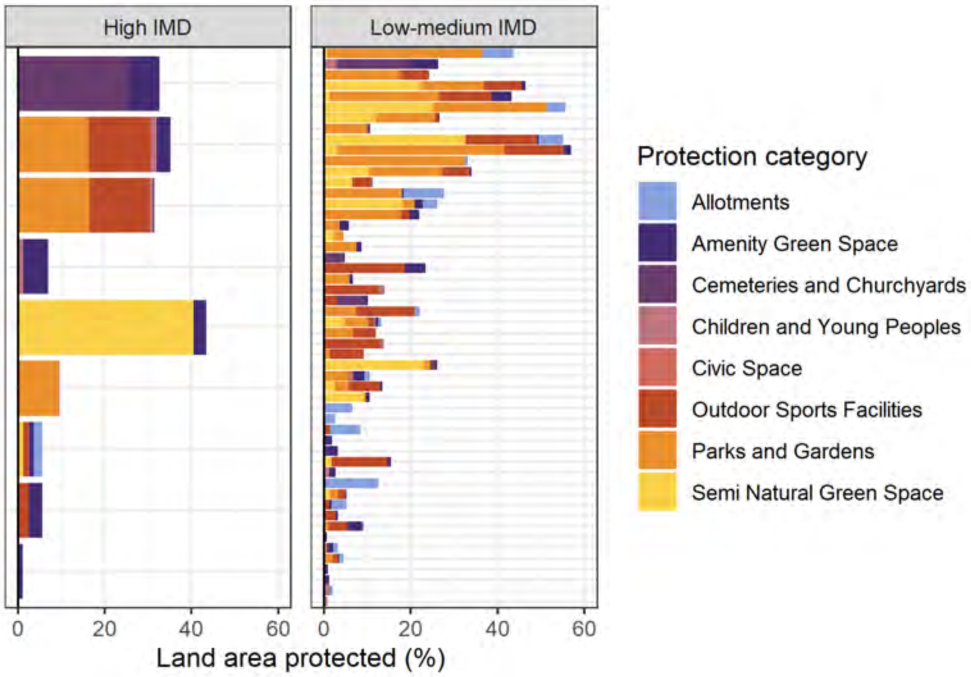

Figure 33 – Bar chart showing the proportion of land area covered by protected areas.

5 Appendices

5.1 Absolute values for ward level tree canopy cover

Ward (2004 boundaries)	Tree Canopy Cover (% land area)	
	2008	**2018**
Abbey	12.9	14.3
Arbury	17.1	18.4
Castle	20.7	18.4
Cherry Hinton	12.8	13.1
Coleridge	14.5	17.4
East Chesterton	16.7	19.0
Kings Hedges	16.4	17.5
Market	14.8	16.0
Newnham	22.7	21.2
Petersfield	16.5	17.3
Queen Ediths	17.9	17.9
Romsey	14.8	17.5
Trumpington	17.8	18.1
West Chesterton	17.7	21.1
Ward-level mean	16.7	17.7

Table 11 – Absolute values of tree canopy cover for each ward

5.2 Ward-level summary with 2021 boundaries

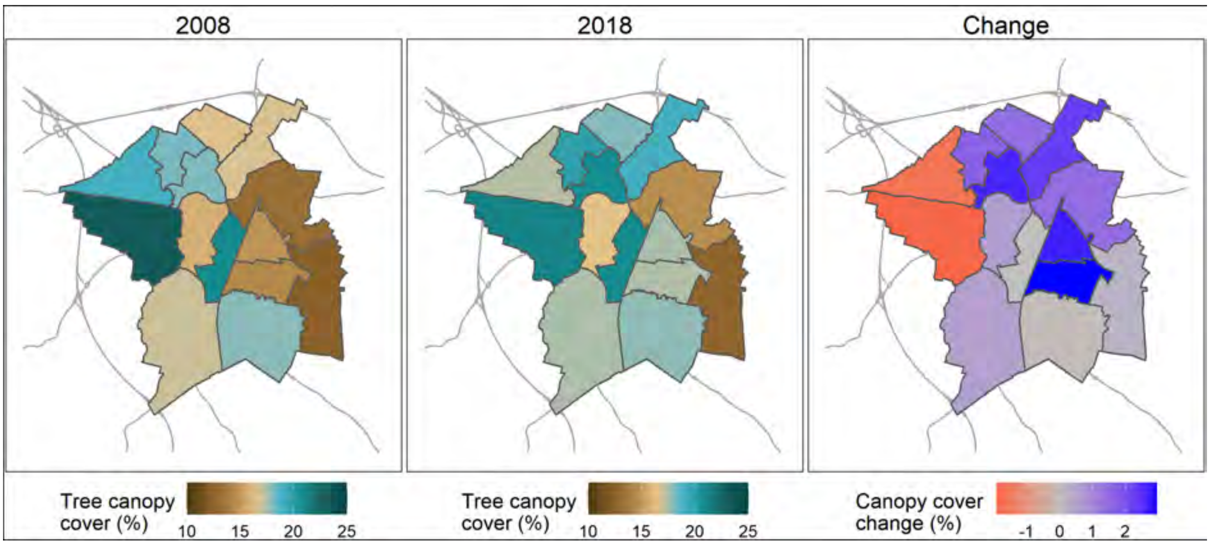

Figure 34 – Maps of tree canopy cover (%) at the ward level using the 2021 ward boundaries.

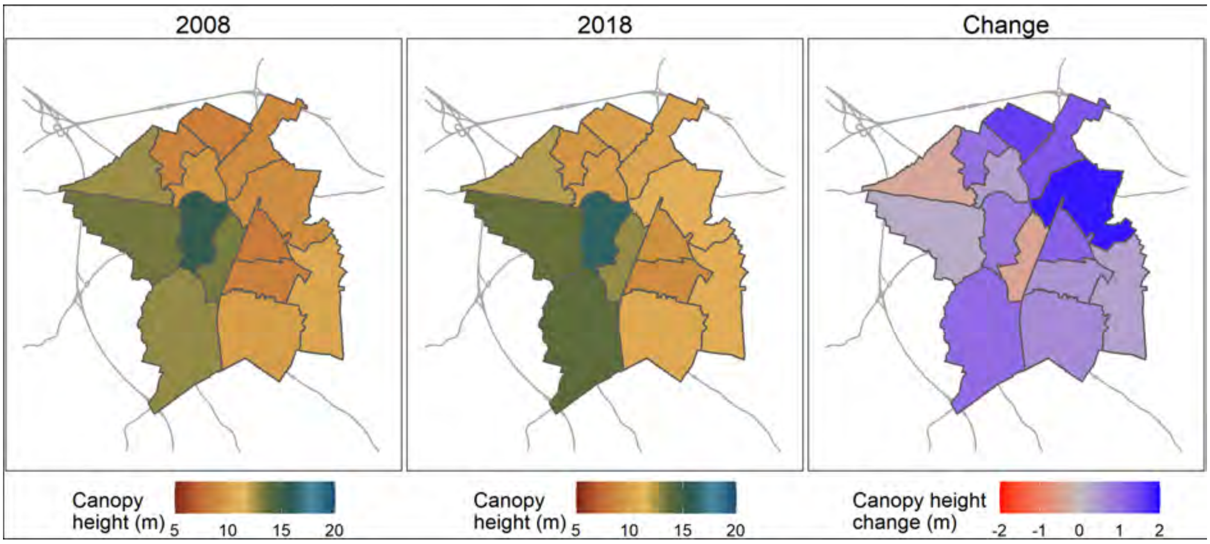

Figure 35 – Maps of canopy height (m) at the ward level using the 2021 ward boundaries.

Ward (2021 boundaries)	Land area (%)	# trees (%)		Canopy cover (%)	
		2008	2018	2008	2018
Abbey	9.6	9.2	8.6	7.4	8.0
Arbury	3.6	5.0	5.0	3.8	4.0
Castle	7.1	6.6	5.4	7.9	7.0
Cherry Hinton	9.4	9.7	10.4	6.8	6.7
Coleridge	4.7	5.1	6.3	4.0	4.7
East Chesterton	6.4	9.3	8.7	6.3	6.9
Kings Hedges	4.1	5.4	4.9	4.0	4.2
Market	5.3	2.8	2.3	4.9	4.9
Newnham	11.9	10.6	8.9	16.1	14.4
Petersfield	4.0	4.0	4.2	4.9	4.7
Queen Ediths	11.1	12.2	13.6	11.7	11.3
Romsey	3.6	4.2	4.9	3.2	3.6
Trumpington	15.2	10.2	11.3	15.1	15.1
West Chesterton	3.8	5.6	5.5	4.0	4.4

Table 12 – Proportion of trees and canopy cover in each ward, according to the 2021 boundaries. This table is directly comparable to Table 7, which uses the 2004 boundaries.

5.3 Sensitivity of tree metrics to treatment of overlapping crown area

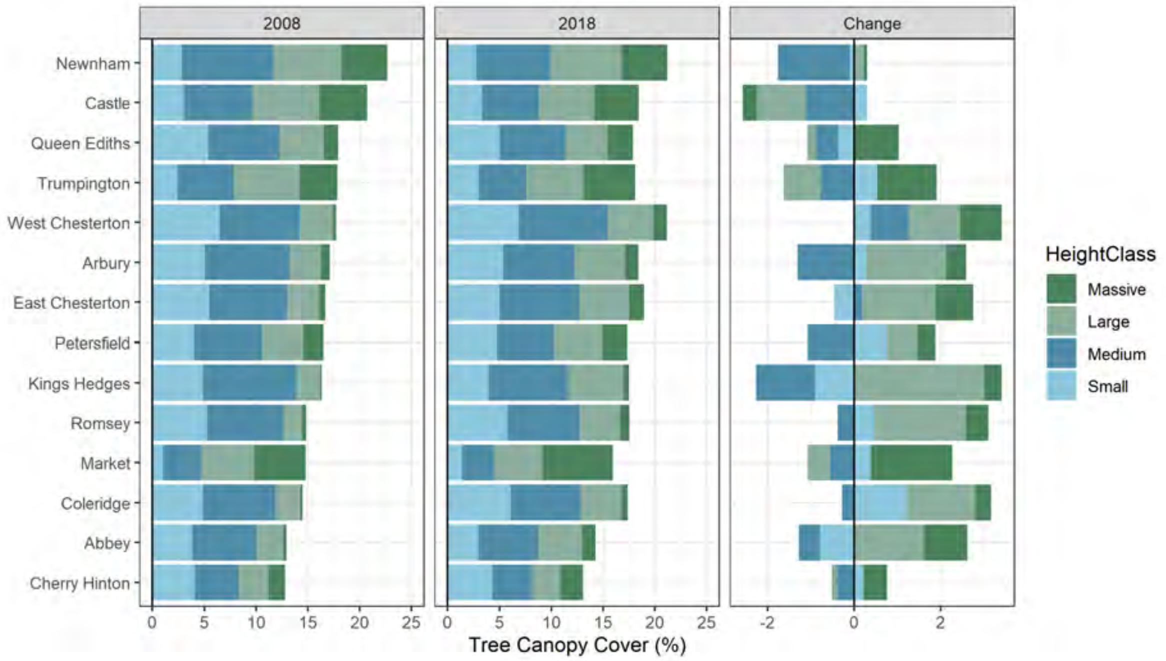

Figure 36 – Bar chart showing tree canopy cover at the ward level subdivided by tree height class.

In the main report, the overlapping area between trees were assigned to the taller tree as it is more likely to be dominant. In order to test the sensitivity of the results to this assumption, the overlapping areas were randomly assigned to either tree. The results (Figure 36) are highly similar to those in the main report (Figure 7), showing that our analysis is robust to this assumption.

5.4 Maps of mean tree height at the output area level

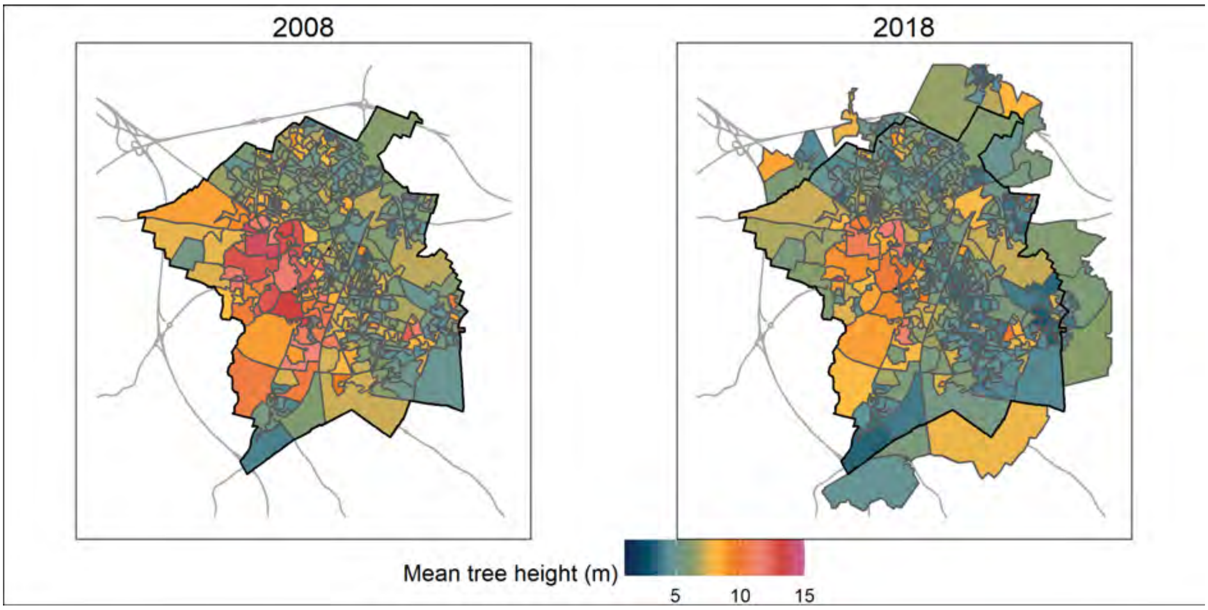

Figure 37 – Maps of mean tree height (m) for each output area in Cambridge in 2008 and 2018

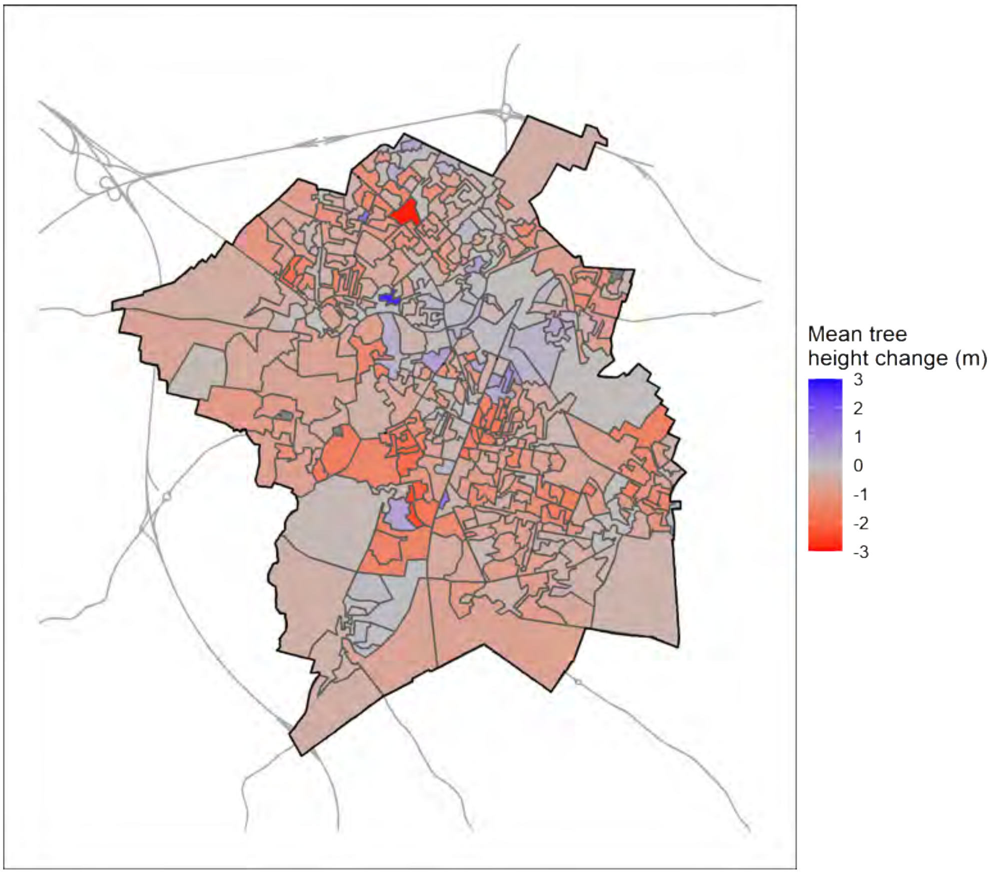

Figure 38 – Map of change in mean tree height (m) for all output areas in Cambridge.

5.5 Maps of mean crown area at the output area level

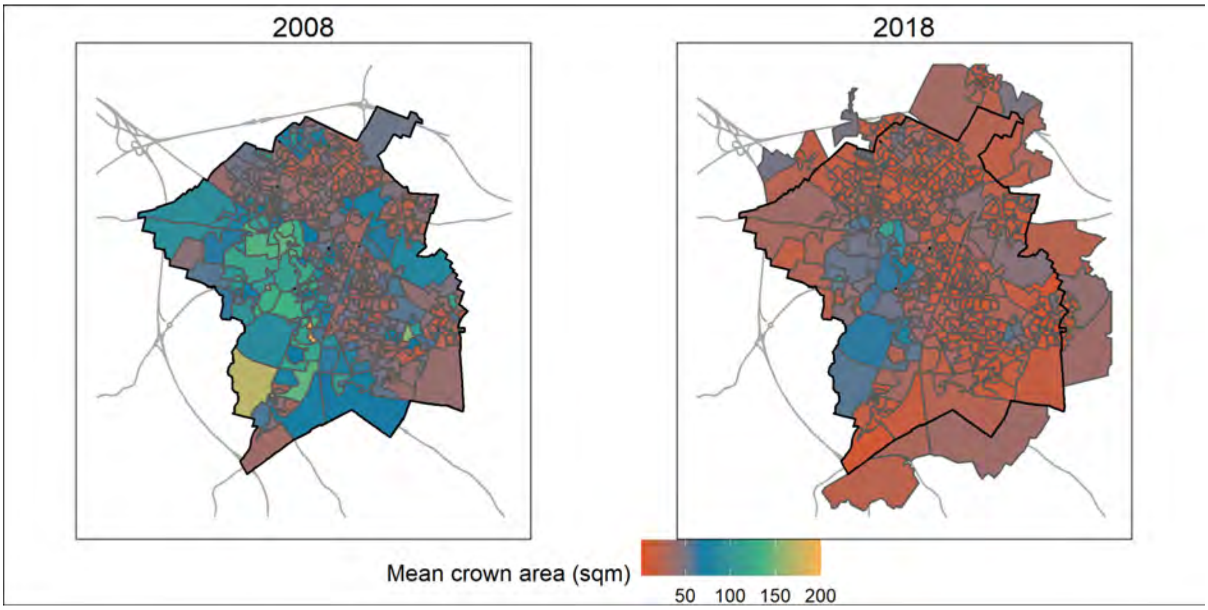

Figure 39 – Map of mean crown area at the output area level

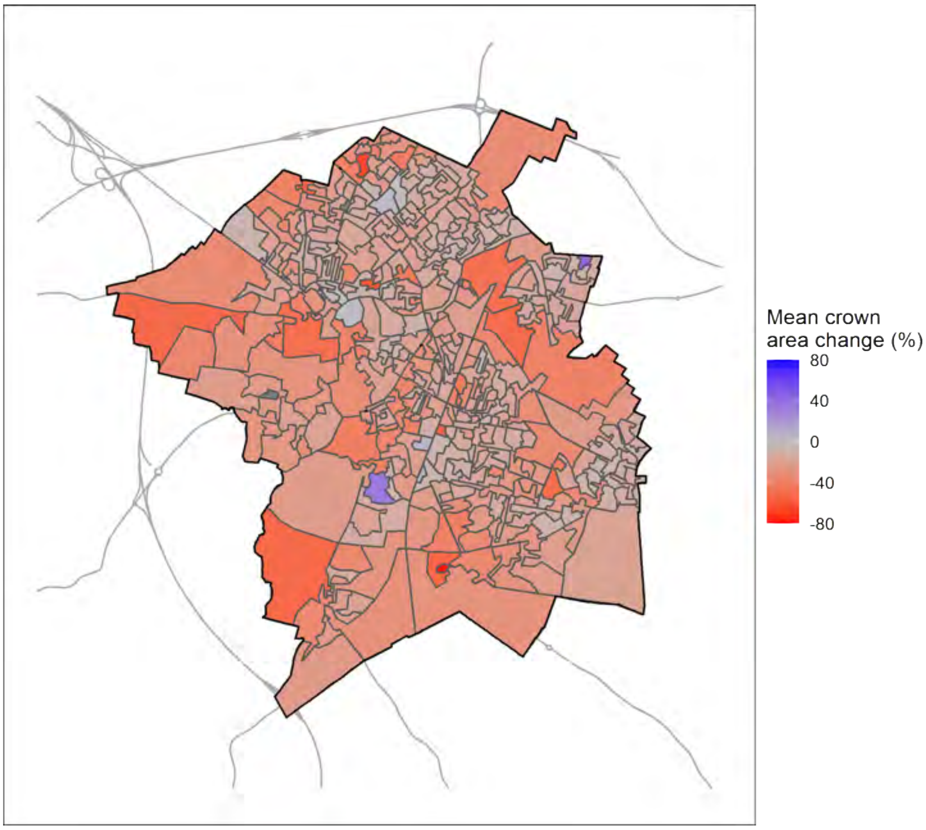

Figure 40 – Map of change in mean crown area at the output area level

5.6 Maps of tree density at the output area level

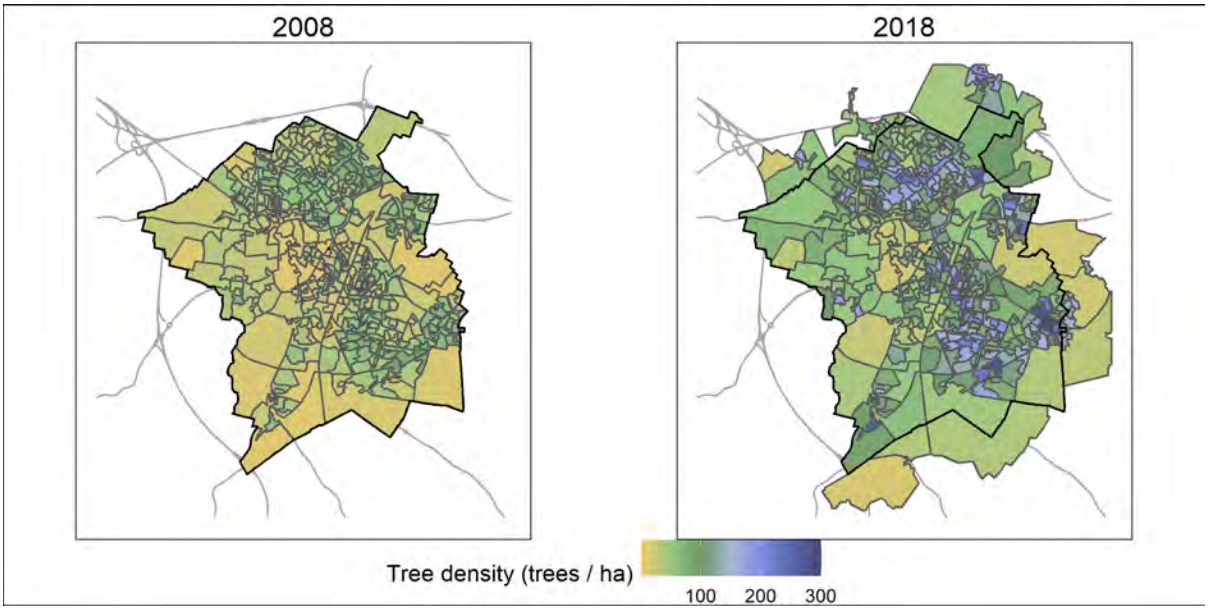

Figure 41 – Maps of tree density at the output area level

Figure 42 – Map of change in tree density at the output area level