Analysis and Interpretation of Tree Audit Data For Cambridge City Council

Ref: CEN5002

Final Report

Date: 15 January 2013

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Executive Summary

Background

Research suggests that even moderate increases in canopy cover within cities can aid adaptation to the adverse effects of climate change. It is important to plan tree planting strategies within cities as early as possible in order for their full potential to be realised by the time the negative impacts of climate change are predicted to reach highs in the 2080s.

Objectives

The ultimate aim of this project was to provide Cambridge City Council (CCC) with an evidence base that can be used to enhance the benefits that urban trees in Cambridge can bring in helping the City and its residents adapt to the worst effects of climate change. This evidence base will be used to:

- Inform wider Council policy with regards to influencing desired canopy cover targets
- Add weight to any tree management policy that is developed for the City
- Enable the Council to cost-effectively target tree planting in areas of low canopy cover
- Identify areas where currently unprotected trees with large canopies are located
- Provide a baseline by which to measure future changes in tree stock quantity and quality
- Set measureable targets for canopy cover in the City
- Inform the Council on the health and fitness of its stock with respect to risks from climate change

Land-use classification

Land-use in Cambridge was classified based on the methodology in the *Trees in Towns II* report, a national survey published in 2008 which aimed to obtain a robust estimate of urban tree stock in England. Tree density and canopy cover varies significantly by land-use, therefore a simple method of classification of land into meaningful groupings for quantifying tree stock and prioritising tree planting was required. These land-use classes were *Town Centre and Commercial (TC)*; *Low Density Residential (LDR)*; *Medium Density Residential (MDR)*; *High Density Residential (HDR)*; *Industrial Areas (I)*; *Formal and informal open space (OS1)*; *Institutional open space (OS2)*; *Derelict, neglected and abandoned open space (OS3)* and *Remnant countryside (OS4)*. The majority of land in Cambridge was MDR, followed by OS4 and OS2.

Datasets

CCC owns a digital tree map layer (ProximiTREE) covering the entire City that details the spatial location, height and canopy area of individual trees as captured from aerial photography stereo images. This dataset forms the basis of most of the analyses in this study. CCC also uses the Ezytreev tree management software to map Council-owned tree stock in the City and collect attribute data on tree species and condition. Geographic boundaries of wards, CCC freehold land and Highways land were available for use in the

analyses. Land ownership was categorised into City Council land, Highways and privately owned/ other based on these boundaries. Conservation Areas and Tree Preservation Order areas/ trees were used to provide an assessment of canopy area in the City that is statutorily protected but privately owned.

Tree stock by ward

The mean number of trees per hectare across the City was estimated at 33.2. This varied from 17.2 trees ha^{-1} in Market ward to 52.1 trees ha^{-1} in West Chesterton ward. The mean canopy cover in the city was $1{,}700 m^2ha^{-1}$, ranging from $1{,}278\ m^2ha^{-1}$ in Cherry Hinton ward to $2{,}265\ m^2ha^{-1}$ in Newnham ward. Generally, tree stock and canopy cover in each ward were proportional to the land area that the ward occupies. Notable exceptions were Abbey ward, where canopy cover was lower than expected in relation to its land area; East Chesterton, where number of trees was higher than expected; Newnham, which had a higher canopy cover than expected and Trumpington, which had a lower number of trees than expected.

Tree stock by land-use

Tree density ranged from 13 trees ha^{-1} in OS4 to 61 trees ha^{-1} in OS3 (which only covered 1% of the land area). Densities of over 50 trees ha^{-1} were found in LDR and MDR. Canopy density ranged from $752\ m^2ha^{-1}$ in Industrial areas to $4{,}171\ m^2ha^{-1}$ in LDR. MDR and Industrial areas appeared to have trees with the smallest canopies. Land-use varied markedly between wards, which is likely to be the main reason for the variation in tree and canopy densities between wards.

Tree stock by ownership

The majority (77%) of land area in Cambridge was found to be privately owned[1]; City Council land comprised 13.5%, with Highways comprising the remainder. The numbers of trees and canopy cover were split in similar proportions, both at a City and ward level. Exceptions included Abbey and Cherry Hinton wards, where canopy cover in the City Council and Highways categories was higher than expected based on land area.

Height and canopy spread

Almost three-quarters of the trees in Cambridge were between 2.5 and 10m high. Fewer than 2% were over 20m tall. OS2 land-use had the greatest proportion of trees over 15m tall, which probably reflects the abundance of large mature specimens on college-owned land. Over three-quarters of trees had a canopy spread between 2 and 10m. Less than 2% had a canopy spread under 2m or over 20m. Open space categories had the greatest abundance of trees with canopies over 15m. MDR had the greatest proportion of trees with canopies of under 5m. Castle, Newnham, Market and Trumpington wards had the highest proportions of taller trees.

Protected stock

Overall, 25% of the canopy in the City was in private ownership in conservation areas. There was great variation between wards, with four having no private conservation areas.

[1] The 'Private Ownership' category also encompasses a small proportion of publically-owned land which has not been strictly categorised as under City or Council ownership.

On average across the City, 4% of the canopy cover was within TPO areas and 9% was associated with trees with individual TPOs. There were a number of wards in which the majority of the canopy cover had a protection status. Within conservation areas, 75% of trees were over 5m high c.f. ~60% in the City as a whole. Of the City trees over 20m high, 56% were in privately owned land in conservation areas. Of the City trees with a canopy spread over 20m, 31% were in privately owned land in conservation areas.

Council stock

The most common tree family in the council-owned stock was Rosaceae (33%), followed by Betulaceae (14%) and Aceraceae (12%). The most common genus was *Prunus* (14%). The majority of the council-owned stock with a condition assessment was in good (56%) or fair (36%) condition. Condition varied with land ownership, for example county highway and City council other categories had a greater proportion of trees in good condition than City public open space. There was also great variation in tree condition between wards, with Romsey and Coleridge having trees in the best condition and West Chesterton having the highest proportion of dead trees.

Ground survey

A ground-survey of trees within 24 200x200m (4ha) plots selected to be representative of the land-use classes within the City was carried out. The objectives of the ground survey were to provide some validation of the ProximiTREE data in terms of tree densities and canopy spread/height splits; to obtain robust estimates of the characteristics of the tree stock in the City (species, age, maturity and condition) and to provide a baseline against which future changes in the tree population can be assessed.

A total of 4,639 trees were surveyed within an area of 74.2ha, resulting in a density estimate across the City of 58.5 ± 8.3 ha^{-1}. Highest tree densities were found in the Industrial, OS2 and OS4 land-use classes. Counts for the same land areas from the ProximiTREE data were within 5% of survey counts for Industrial, MDR and HDR land-use classes and were slightly less accurate but moderately similar for LDR. In TC, ProximiTREE estimates were twice as high as ground-survey counts, possible due to the classification of shrubs as trees. In the OS classes there were three to four times more trees counted during ground survey than were estimated in the ProximiTREE dataset. This appeared to be due to under-estimation of the numbers of trees in very densely wooded areas by the ProximiTREE method. It was concluded that ProximiTREE estimates of tree density were relatively robust apart from these heavily wooded areas.

Surveyed trees tended to be taller than those in the ProximiTREE dataset, particularly in the middle height classes. This may be due to the four years' worth of growth between the date of the aerial photography and the time at which the ground-survey was carried out. Surveyed trees tended to have smaller canopies than ProximiTREE trees, which may be an artefact of the fewer trees estimated in the OS categories covering a similar area in terms of canopy.

The most common tree family for surveyed trees was Rosaceae (28%), followed by Olaceae (21%). The most common genus was *Fraxinus* (>20%) followed by *Prunus* (>15%). Of the surveyed trees, 71% were found to be in good condition and only 2% in poor condition or dead. The majority (38%) of surveyed trees had a stem diameter of 10-20cm. Forty percent of surveyed trees were estimated to be 5-10 years old and 32% between 25 and 50 years old. Forty percent were classed as semi-mature and 32% as young. A list of all tree species surveyed is available in Appendix 6.

Comparison with Trees in Towns II results

*Trees in Towns II (*Britt and Johnston 2008*)* was a national survey aimed at obtaining a robust estimate of the urban tree stock in towns and cities of England. It comprised a stratified sample of land-use classes for which a ground-survey and/or data capture from aerial photography was carried out. The tree density in Cambridge estimated from ProximiTREE data was lower than tree densities estimated by the *TTII* study for other large towns, the East of England and England. Canopy density was higher in Cambridge compared to the *TTII* sample. In Cambridge, a greater proportion of trees were in the upper height bands compared to the *TTII* sample. There were fewer trees in the lower canopy spread groups in Cambridge and more in the upper groups compared to the *TTII* sample. These results indicate that Cambridge has a more mature stock compared to other English towns and cities. Similarities between the Cambridge tree audit and *TTII* results include highest tree densities and canopy cover in LDR, similar tree densities for MDR, LDR and TC and shorter, smaller trees in Industrial areas. The main difference is the low tree density in Open Space land-uses compared to the *TTII* sample, explained by under-counting of trees in dense groups and large areas of arable remnant countryside in Cambridge that are relatively sparsely populated with trees.

Comparison with initiatives in other cities

Tree canopy cover in the East of England, across England and internationally is as varied as the efforts and funds put into increasing it, although drivers are primarily rooted in the understanding that an increased canopy cover plays a significant role in increasing resilience and adaptation to climate change. Canopy cover in the cities identified varies from 6.75% in Brighton and Hove to 42% in Annapolis, USA; while the spatial distribution of cover is not easily comparable due to differences in data collection methods and land use definitions, tree stock is predominantly under private ownership. As a likely result of this distribution (and similarly, limited funding), many councils have acknowledged the need to increase the public's awareness to the benefits brought by trees and similarly to encourage tree planting initiatives by communities and organisations alike. However, while UK examples are focused mainly on adapting to *future* climate change, the international examples also highlight the role that canopy cover plays in reducing risk to *current* climatic threats. In particular, each of the international examples identifies the significant role of canopy cover in stormwater management and flood risk mitigation at present. Finally, while the aim to increase both a city's understanding of the spatial distribution of its canopy cover and initiatives to increase the canopy cover itself are often hindered by limited funds, it was found that the ability to quantify the economic benefits of canopy cover in terms of ecosystem services and structural value (through use of the i-Tree Eco software, in the cases of Toronto, Annapolis and Torbay) often increase the likelihood of funding being allocated to arboricultural goals.

Implications of results for climate change adaptation in Cambridge

The vast majority of land in Cambridge is privately owned, which has implications for the design of local policies for tree planting. The focus will need to be on partnerships with institutions such as the University and guidance and schemes advising local residents on how they can increase canopy cover.

Industrial land had one of the lowest tree densities in Cambridge. There may be scope for increasing tree density in this land-use by encouraging boundary planting – for example Highways land could be targeted to reduce the effects of traffic pollution. Planting on more centrally located industrial land would be beneficial for reducing the urban heat island effect and modifying airflow.

Council-owned OS1 land, particularly in central wards, could also be targeted for tree planting. This land-use category includes amenity areas and parks, and planting in these areas would greatly increase the health benefits to members of the public.

Canopy cover plays a large part in providing the majority of benefits for climate change adaptation in an urban setting, particularly reducing the heat island effect, intercepting precipitation and removing urban pollutants. Maximising the canopy cover provided by a specified number of trees is therefore a good strategy if the land-use type can support larger trees. Selection of appropriate species should be encouraged, both by the City Council and County Council and by home owners. Tree species diversity should be encouraged to lessen the potential impact, of an increased risk from pests and disease, due to climate change. If variation in species is low, then the potential impact on the tree populations is increased.

In terms of protecting tree stock, a more targeted approach than that which has been applied to date could be considered, namely, by assessing those trees with greater potential to offset the effects of climate change.

Conclusions for policy inception

Canopy growth over future years was predicted for four different scenarios[2] using a growth model. The results of this process were used to calculate the number of trees that would need to be planted each year over five years in order to attain canopy cover targets for each scenario. These targets were set to be equal to the City average for each land-use category. Achieving the targets for the recommended scenario (Scenario 2, canopy cover increase by land-use and ward) would result in a 2% increase in canopy cover (from 17.1% to 19.1%) across the City's land area within 30 years. The level of planting that would be required to achieve this increase was estimated at over 3,000 trees per year over a 5 year period.

These targets could be achieved through a combination of initiatives which fall under four broad categories, addressing all aspects of tree management. These include:

- **Strategic management** focused at policy level to harmonize arboricultural activities and goals specifically related to climate change, mainly by embedding tree management within wider policy targets.
- **New planting** to increase canopy cover by establishing partnerships and engaging with the community to promote the wider benefits of urban trees; and encouraging and incentivising tree planting.
- **Protection** of the existing tree stock and canopy cover through policy and best practice in design and service provision.
- **Maintenance** of tree stock through proper management and increased replacement of failed tree stock where tree removal is necessary.

[2] Scenarios included canopy cover increase by: (1) Ward, Land-use and Ownership; (2) Ward and Land-use; (3) Ward & Ownership; (4) Ward only.

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1 Introduction

1.1 Background

Research suggests that even moderate increases in canopy cover within cities can help the city to adapt to some of the adverse effects of climate change. These include direct and indirect cooling effects, for example reduction of the urban heat island effect; shelter from harmful radiation; improvement of urban air quality; reduction of energy consumption from urban buildings; increasing soil water storage and absorption of atmospheric carbon. The negative effects of climate change are predicted to reach highs in the 2080s, which is the time it takes for many species of tree to mature. It is therefore important to plan tree planting strategies within cities now in order for their full potential to be realised within this critical time period, especially since large mature trees have greater benefits than smaller trees for climate change adaptation. Tree planting is a relatively cost-effective way of mitigating some of the adverse effects of climate change, whilst also providing many other benefits such as improvement of biodiversity and provision of amenity value for city residents.

1.2 National Policy Drivers

Heightened policy understanding of the importance of urban trees and their contribution to mitigating climate-induced effects was initiated following the publication of the Department for Communities and Local Government report *Trees in Towns II* in 2008. This study acknowledged the beneficial role that the urban forest plays in adaptation and carried out a national survey with the aim of obtaining a robust estimate of the urban tree stock and its management by local authorities in towns and cities in England. The findings of the study revealed an apparent lack of young trees and low numbers of large mature trees. Comparisons to earlier surveys showed a large reduction in the proportion of trees in the youngest age bands and an increase in trees aged 10-50 years, indicating that rates of urban tree planting were not maintained between the mid 1990s and mid 2000s. This has led to an unsatisfactory age structure which urgently needs to be addressed. It was suggested that the age structure could be improved by planting more young trees and retaining more old trees; however, the type of new trees planted requires careful consideration, as the replacement of large species with smaller-growing trees raises concerns about the increasing abundance of so-called 'lollipop landscapes'. The study concluded that whilst the integrated management of the urban forest is primarily a local government function, the local authorities should undertake the required work in partnership with other organisations. The study identified a need for all tree-related activities to be incorporated in a coherent and coordinated management plan, and local authority tree officers were encouraged to recognise the wider context and indirect benefits of urban green space and the environment.

Defra (2007) published a Delivery Plan for England's trees, woods and forests for 2008-2012, which explains how the Forestry Commission and Natural England will turn the government's Strategy into action on the ground. The Plan includes actions to help trees and woodlands adapt to climate change and mitigate its effects, including the creation of habitat networks and the provision of more shade in our cities. The Plan also highlights the importance of incorporating trees, woodlands and forests into regional and local strategies and engaging people with the benefits that trees provide the local environment and local communities. This is to include activities to embed trees and woodland in plans that cover the adaptation of the urban environment to climate change.

In 2009, an independent assessment (Read, 2009) was commissioned by the Forestry Commission to examine the potential role the UK's trees and woodlands can play in mitigating and adapting to a changing climate. The aim was to provide a better understanding of how improvements can be made to UK forestry to enhance its contribution to climate change mitigation. In relation to urban trees, the assessment concluded that trees play an important role in helping society adapt to climate change in the urban context through the provision of shelter, cooling, shade and control of run-off. It recommended that tree planting should occur in places where people live and gather, particularly those that currently have low tree cover. They recommended that policy incentives should be re-designed to give adequate reward to the non-market benefits of trees and woodland, especially those relating to climate change adaptation. The report noted that most UK local authorities lack the basic inventories describing the nature and extent of urban trees and woodlands in their districts and recommended that these gaps in information need to be urgently addressed.

The Government published the Natural Environment White Paper in 2011. This paper recognises the importance of trees and woodlands in providing valuable ecosystem services. It identifies that the health of trees is essential for societal wellbeing and the highlights the ambition for a major increase in the area of woodland in England, as well as better management of existing woodland, was stated. As a step towards attaining this ambition, the authors highlighted a need to create more opportunities for planting trees in our towns, cities and villages, helping mitigate and adapt to future climate change and increase resilience. The Government welcomed the case that Read (2009) set out with respect to tree planting rates, and asked the Independent Panel on Forestry to provide advice on the appropriate level of ambition for woodland creation and management. The Panel's report was published in July 2012, and the creation of opportunities for woodland and tree planting within the urban environment was reported as particularly important in order to improve the quality of towns and cities. Comment from the Government on this report is expected in early 2013.

The National Planning Policy Framework was published by the Department for Communities and Local Government in March 2012. It sets out the Government's planning policies for England and how these should be applied. It identifies three dimensions to sustainable development: economic, social and environmental. One of the roles of the planning system in the social dimension is to create a high quality built environment that supports the health, social and cultural wellbeing of its inhabitants. In the environmental dimension, the planning system needs to help improve biodiversity and mitigate and adapt to climate change. Green infrastructure is a key element of sustainable development and urban forest a key component of green infrastructure. A large body of research and policy supports the social, environmental and economic roles of trees, for example references to the economic benefits of trees are incorporated in the National Ecosystem Assessment and the Natural Environment White Paper.

National policy specifically targeted at climate change adaptation and mitigation is also a key driver for this research. The Government commissioned the UK Climate Change Risk Assessment (CCRA) in 2012 that aims to improve our understanding of changing climate risks and where the focus of our attention should be. They are initiating work with businesses, civil society and local government to develop the UK's first National Adaptation Programme (NAP) to maintain and enhance resilience to the changing climate. The evidence report for the NAP is split into themes including: Agriculture and forestry; Built environment; Infrastructure; Business and services and Health and wellbeing. The CCRA carried out a detailed analysis of the risks and opportunities presented by climate change in each of these themes, including their potential magnitude and how risks may change with time up to the 2080s. These analyses will help to develop the NAP in consultation with wider stakeholders. This research will set out adaptation opportunities for urban trees through planting, enhancement and protection of the urban forest that will directly and indirectly address some of the risks identified in the CCRA. The magnitude of many of the identified risks related to trees and forestry are expected to increase over time and peak in 2080, which will be the time it will take for many trees planted now to mature and thus achieve maximum benefit.

The Government published a white paper on health and wellbeing in 2011 and a subsequent policy statement (*Healthy Lives, Healthy People: Update and way forward*) set out the progress made in developing the vision for a reformed public health system in England. Part of this new approach is to give new responsibilities for public health to local authorities, which will have the advantages of embracing the full range of local services in development of holistic solutions to health and wellbeing. Trees have clear health benefits and urban trees will be of increasing importance to public health as the climate changes. This research will help Cambridge City Council to plan its public open space to bring maximum health benefits to its citizens.

1.3 Local Policy Drivers

Cambridge City Council has been taking action to tackle climate change for over 15 years. Along with over 130 other local authorities, the City Council made a formal commitment to play a part in the international effort to address the causes and consequences of climate change by signing the Nottingham Declaration on Climate Change in September 2006.

The City Council published its first five-year Climate Change Strategy and Action Plan following public consultation in September 2008 (CCC, 2008). It set out a clear vision and framework for increased action and identified 92 actions, including a number relating to managing the risk posed by climate change. These include flooding; water supply; heat; and high wind speeds and subsidence. The stock of urban trees can provide benefits against most, if not all of these aspects.

The City Council is currently drafting its second Climate Change Strategy and Action Plan which will cover a four year period from 2012 to 2016. It will help deliver Cambridge City Council's vision of 'a City in the forefront of low carbon living and minimising its impact on the environment from waste and pollution.' The Strategy will be adopted in the Autumn of 2012, following public consultation in July and August 2012. It will again include a focus on managing the greatest risks to the City Council and the City of Cambridge from climate change, including flooding, increased summer temperatures and heatwaves, and water shortages and droughts. The draft Action Plan includes five key actions relating to the urban forest, as well as a number of other wider actions which aim to manage the impact of these risks.'

The Green Infrastructure Strategy for Cambridgeshire was published in 2011 and was designed to help shape and coordinate the delivery of Green Infrastructure in the county to provide social, environmental and economic benefits. Cambridge City is one of the target areas in the strategy and the importance of taking opportunities to enhance the green infrastructure in development localities is stressed. The importance of green space as part of the City's historic character is also noted as well as the promotion of the health, education, recreation and biodiversity benefits of such areas.

1.4 Objectives

The main objective of this project is to analyse the data captured from aerial photography by Bluesky on the extent of canopy cover in Cambridge City and to make recommendations that could influence Council policy on the prioritisation of future tree planting and the protection of existing trees. A measure of the accuracy of the collected data is important, since the validity of the results will depend on this. A ground survey of a statistically valid sample of the tree stock in Cambridge has therefore been undertaken and the results used to provide an estimate of the accuracy of the remotely collected data, as well as providing a baseline against which future changes in canopy cover and tree density can be measured.

The ultimate aim is to enhance the benefits that urban trees in Cambridge can bring in helping the City and its residents adapt to the worst effects of climate change.

Specifically, the data analysed will provide an evidence base that can be used to:

1. Inform wider Council policy with regard to influencing desired canopy cover targets by land use and ownership.
2. Add weight to any tree management policy that is developed for the City.
3. Enable the Council to cost-effectively target tree planting in areas of low canopy cover and to help them decide how best this is to be achieved.
4. Identify areas where currently unprotected trees with large canopies are located, as large trees are more beneficial in mitigating some of the adverse impacts of climate change.
5. Provide a baseline from which to measure future changes in tree density and canopy cover and hence the effectiveness of policy implementation.
6. Set measurable targets for canopy cover in the City.
7. Inform the Council on the health and fitness of its stock with respect to risks from climate change.

1.5 Report Structure

The report is divided into eight sections including the introduction.

- Section 2 provides details on the land-use classification used in the project and how the land use is distributed throughout the City.
- Section 3 details the methodology used in analysis of the tree stock data and the key results of this analysis. This includes analysis by ward, land-use class and ownership; by conservation area and TPO; and by species and condition for Council-owned stock.
- Section 4 details the methodology and results of the further research carried out to collect more detailed information about the tree stock in a stratified sample of plots throughout the City and to make an assessment of the accuracy of the remotely captured data. The results of this ground survey work will also provide a baseline against which future changes in tree stock can be assessed.
- Section 5 compares the results, where appropriate, with results of the national *Trees in Towns II* study, and discusses the implications of these comparisons for the City.
- Section 6 provides a summary and comparison of initiatives across the East of England, the UK and internationally, to identify measures and approaches other Councils are taking in relation to increasing tree canopy cover.
- Section 7 provides an interpretation of the results of the analyses in the context of implications for climate change adaptation. An assessment is made of whether or not the tree stock in different wards and land-uses are sufficient with respect to climate change adaptation, or if there are improvements that could be made. A short literature review is included to help with the interpretation.
- Section 8 provides conclusions for policy inception based on the analyses and interpretation. Targets for canopy cover for the City by ward and land-use class are suggested and methods are proposed for achieving this.

1.6 Assumptions and Limitations

This study has a number of assumptions and limitations that are referred to throughout the document, but the main ones are summarised here by report section for the purpose of convenience and transparency.

Section 2: Land-use classification

- Areas of land-use smaller than 200 x 200m in area were incorporated into an adjacent land-use class. This means that there will be some misclassification of small land parcels, however this should average out across the City.
- Classification of residential areas into a low, medium or high density category can be quite subjective, since the definitions are rather vague and classification can vary between cities. Checks were made of residential classifications by an independent quality assurer to minimise any bias.
- Land use may have changed since the 2008 aerial photography baseline, most notably the major growth sites currently being developed which occupy OS4 land to the south and west of the city.

Section 3: Analysis of tree stock data

- ProximiTREE data (tree points and canopies captured from 2008 aerial photography) were used for this analysis prior to any ground-truthing being carried out. The analysis therefore does not take account of findings from the ground-truthing exercise (Section 4), although implications of the results of the ground-truthing are discussed in Section 4.
- ProximiTree data measures all vegetation over 1m in height. No distinction between shrubs and trees has been made.
- TPO areas refer to groups and areas of trees protected by TPO. Not all individual trees in the polygons representing these areas are likely to be protected, which may lead to an overestimation of numbers.

Section 4: Ground-truthing of remotely captured data

- The main caveat for this part of the project is that 100% coverage of survey plots could not be achieved due to limited access to some areas, particularly residential and commercial land-use classes. This means that results should be interpreted with caution when scaling up estimates to a city level. It should not, however affect the comparison with remotely captured data, since data captured in inaccessible areas were excluded from the comparative analysis.
- Remotely captured data were from aerial photography dating from 2008, whereas the ground survey was completed in 2012. There are therefore likely to have been some changes in tree stock and land-use during that four-year period.

Section 5: Comparisons with Trees in Towns II

- Differences between the *Trees in Towns II* (TTII) methodology and the Cambridge City tree audit should be taken into account when drawing comparisons. These differences include;
    - TTII is a sample not a full survey.
    - TTII was a ground survey supported by data capture from aerial photography.
    - Transport corridor not included in TTII.
    - Areas of formal recreation, such as golf courses and sports complexes, were excluded from TTII.
    - Woodland was not included as one of the primary LU classes in TTII.

- For each land use class, up to four sample sites were taken from within a single land use class polygon, rather than scattered throughout the town.

- Results of ground-truthing should also be considered when interpreting the results of this analysis.

Section 8: Conclusions for policy inception

- Canopy cover has been used to measure tree stock and predict future targets. Tree canopy cover only measures the spread of a canopy across a land surface and does not account for the vertical height of a canopy, age diversity, tree health or species.
- In order to calculate canopy targets a figure of 25% has been used to estimate the loss of new tree planting. This figure is the upper limit of new planting mortality taken from Trees in Towns II (Britt and Johnston 2008). However, this figure relates to public planting of trees only. We can expect the addition of private planting within the strategies to decrease this figure due to different pressures on new planting in this sector.
- Targets for wards by land use assume that this land is available for new tree planting. In some areas there may be a legitimate reason for canopy cover to be lower than the City average e.g. airport, military land and landfill sites.

2 Land Use Classification

2.1 Methodology

Land use in Cambridge was classified based on the *Trees in Towns II* methodology. As the *Trees in Towns II* survey sought to identify the condition and management of urban trees, the methodology was highly appropriate for the purposes of the Cambridge tree canopy assessment.

The land use categories comprise four principal classes:

- **TOWN CENTRE AND COMMERCIAL AREAS (TC)** incorporates a mixture of retail, commercial and residential properties in Cambridge's historic core. This classification also included areas containing trees of great age and stature, such as small parks and areas of paved open space, as well as car parks and the backyards of commercial premises. Also included in the classification are retail parks located on the outskirts of the City.
- **RESIDENTIAL AREAS**, which encompass three sub-categories:
    - **Low density residential areas (LDR)** cover a range of detached housing types from Victorian villas to generous plot-land developments. Garden size tends to be large enough to accommodate a small drive at the front of the house with extensive private grounds to the rear. Low density housing tends to be found near areas of open space, and both homes and associated grounds are predominantly mature.
    - **Medium density residential areas (MDR)** comprise the majority of housing areas in towns, including large Victorian terraced houses, inter-war and post war semi-detached houses, open-plan bungalow estates and modern housing developments. Many of these developments have relatively large front and back gardens, with significant numbers of trees.
    - **High density residential areas (HDR)** comprise flatted accommodation, high-rise blocks, and terraced housing. Flatted accommodation includes converted terraces, tenements and purpose-built blocks; high-rise blocks include landscape surrounds such as lawned areas with broadleaved native trees. Terraced housing areas are characterised by small or no gardens, and small back gardens or yards with few opportunities for planting trees.
- **INDUSTRIAL AREAS (I)** comprise both light and heavy industry. Light industry includes small factories and warehouses, generally located in separate plots within industrial estates, or inter-war industrial estates located on the town fringes. Heavy industry covers industrial processes requiring buildings and ample hard surfaced storage yards. Such sites tend to have limited open space, but may occasionally include large derelict areas that are now used for tree growth.
- **OPEN SPACE** encompasses a wide variety of uses ranging from formal gardens to abandoned land. Small areas of open space tend to form components of other urban land classes (e.g. small play areas in housing developments; landscaped gardens in retail parks), but larger areas of open space (often, but not exclusively, areas over 200 x 200m in size) are distinct from other land uses. Open space encompasses four sub-categories:
    - **Formal and informal open space and general amenity land (OS1)** covers all areas of open space subjected to management for amenity use, other than that which is classified as Institutional land. Management may range from manicured formal gardens and parks to occasionally mown areas for informal recreation such as sporting activities, as well as common land and greens.

- **Institutional open space (OS2)** comprises land associated with schools (playing fields and pitches), hospitals and churchyards (cemeteries and associated landscaping).
- **Derelict, neglected and abandoned open space (OS3)** covers land which is subject to little or no management. Included in this category is common land with little to no formal management, areas of remnant countryside which are cut off by development, and overgrown, disused agricultural land.
- **Remnant countryside (OS4)** often occurs on the fringes of medium-sized and large towns, where pockets of countryside have become surrounded by development. This category includes enclosed agricultural land for grazing which is subject to limited management, and tends to retain the original hedgerows and hedgerow trees.

Land use in Cambridge City was classified into the above categories primarily using the existing National Land Use Definitions (NLUD v 3.2), which formed the basis of the Cambridge City Land Use survey. These were mapped to the *Trees in Towns II* land use classes (Table 1) as a starting point. Ordnance Survey 1:10,000 base mapping and 2008 aerial photography supplied by Cambridge City Council were used alongside the NLUD GIS dataset to classify and delineate different land use polygons as accurately as possible. This was particularly important for classifying residential areas into density categories. Any parcels of land falling into one of the open space categories that were greater than 200 x 200m in area were classified as open space. Areas smaller than this were incorporated into the predominant surrounding or adjacent land use class.

Table 1. National Land Use Definitions of Land Use mapped to the *Trees in Towns II* classification

Trees in Towns classification	NLUD classification
Town Centre and Commercial (TC)	7. Recreation (within town centre only) 7.1 Indoor recreation 10. Community buildings (within town centre only) 10.1 Institutional buildings 10.2 Educational buildings 10.3 Religious buildings 11. Industrial and commercial 11.2 Offices 11.3 Retailing
Residential – Low Density (LDR)	9. Residential (also other Residential categories) 9.1 Residential 9.2 Institutional and communal accommodation
Residential – Medium Density (MDR)	7. Recreation 7.3 Allotments 9. Residential (also other Residential categories) 9.1 Residential 9.2 Institutional and communal accommodation
Residential – High Density (HDR)	9. Residential (also other Residential categories) 9.1 Residential 9.2 Institutional and communal accommodation
Industrial (I)	8. Transport 8.3 Railways 8.4 Airports 8.5 Docks 11. Industrial and commercial

	11.1 Industry 11.4 Storage and warehousing 11.5 Utilities
Open Space 1 (Formal and informal/amenity land)	7. Recreation 7.2 Outdoor recreation (also Open Space 2)
Open Space 2 (Institutional)	7. Recreation 7.2 Outdoor recreation (also Open Space 1) 10. Community buildings 10.1 Institutional buildings 10.2 Educational buildings (including College land) 10.3 Religious buildings
Open Space 3 (Derelict/neglected/abandoned)	12. Vacant land and buildings (Confirmed by inspection of recent aerial photography) 12.1 Vacant land previously developed 12.2 Vacant buildings
Open Space 4 (Remnant countryside)	1. Agriculture 1.1 Field crops 1.3 Fallow land 1.4 Horticulture and orchards 1.5 Improved pasture 2. Woodland 2.7 Land cultivated for afforestation 3. Unimproved grassland and heathland 3.2 Unimproved grassland 7. Recreation 7.3 Allotments 11. Industrial and commercial 11.6 Agricultural buildings
Assessed on a case-by-case basis (integrated with associated land use classes)	2. Woodland (all subclasses except 2.7 - Land cultivated for afforestation) 4. Water and wetland 4.2 Standing water 4.3 Running water 8. Transport 8.1 Roads 8.2 Public car parks 8.3 Railways 12. Vacant land and buildings (That have since been developed or are undergoing development as confirmed by inspection of recent aerial photography) 12.1 Vacant land previously developed 12.2 Vacant buildings

Results

Figure 1 shows the proportion of each type of land use in Cambridge City based on the applied classification scheme.

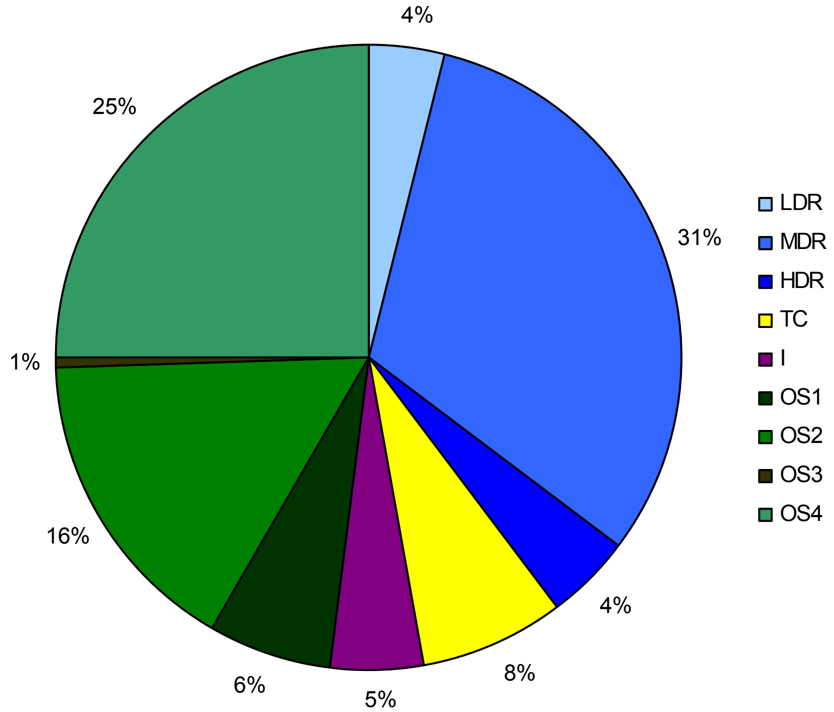

Figure 1. Land use class by proportion of the total area of Cambridge City

A map of the land uses in Cambridge according to the *Trees in Towns II* classification is shown in Figure 2.

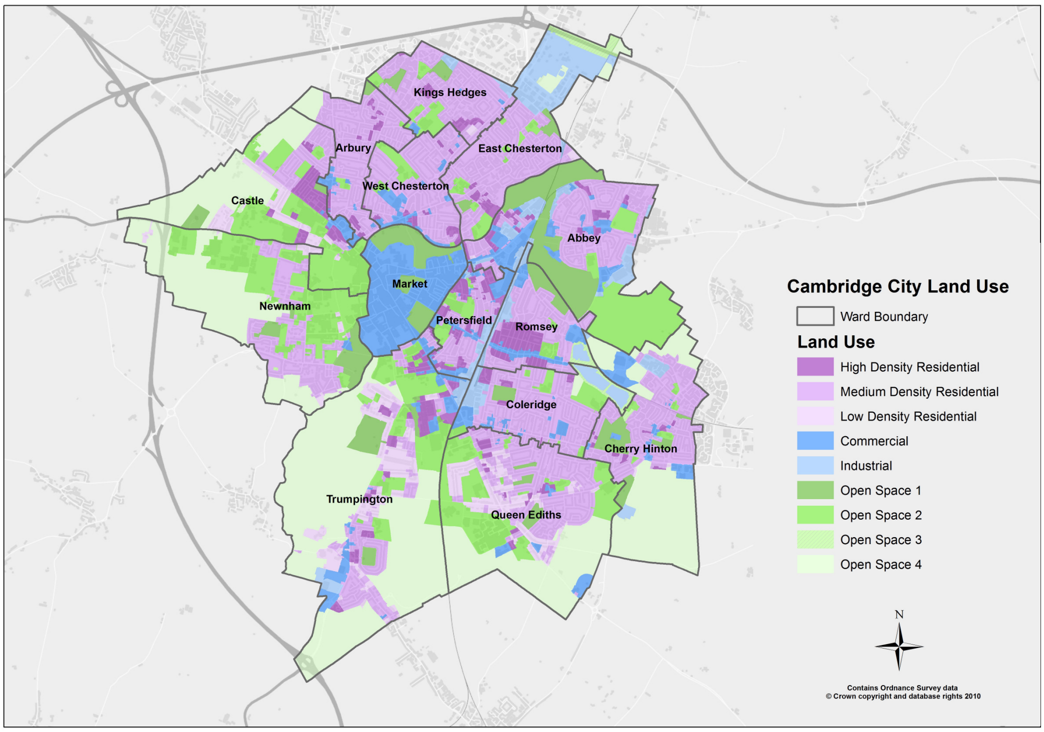

Figure 2. Cambridge City Land Use

2.1.1 Residential areas

Residential areas as a whole comprise 39% of all land uses in the Cambridge study area. Within this category, **Medium density residential** was by far the most common type of housing, making up 80% of the Residential category and dominating wards including Arbury, West Chesterton, Kings Hedges, East Chesterton, and Coleridge. Features typical of this category range from terraced housing with no front gardens or footpaths (particularly near the urban core in Petersfield, Colderidge and parts of Romsey) to larger homes within relatively close proximity to neighbours, such as those in West Chesterton and areas of Newnham. The category also encompasses one- and two-storey developments around the fringes of the city which are characterised by small gardens and large proportions of hard surfaces, including the preponderance of the Kings Hedges ward. This classification also frequently includes allotment gardens as well as smaller parcels of land which, if larger, would otherwise be classified as Open Space 1 or Open Space 3.

Low-density residential areas comprise only 10% of the Residential category and are mainly found in small clusters outside the urban core in the Castle, Trumpington and Queen Ediths wards. Low density housing tends to be adjacent to agricultural land (OS4) or institutional open space (OS2), and consists of both one-off examples as well as larger land parcels characterised by a small number of large dwellings.

High-density residential areas also comprise a small proportion (10%) of the Residential category, often occurring outside the urban core as multi-storey developments such as in Trumpington and Coleridge. In Cambridge, certain instances of Victorian terraced housing with no front gardens and very small back gardens were classified as high density, such as in parts of Romsey. This category tends to represent very small areas, and frequently encompasses land which would otherwise be classified as Open Space 1 or Open Space 3 if size merited this classification.

2.1.2 Town centres and commercial areas

Town centre and commercial areas make up a relatively small proportion of Cambridge's total land use, and include the entire historic town centre as well as mixed-use streets (e.g. residential/commercial) outside of the historic core, with Mill Road in Romsey Town serving as an example of the latter. Large areas of open space (Midsummer Common, Christ's Pieces and Parker's Piece) were omitted from this classification within the historic core as a result of their substantial land area. Industry is most predominant in East Chesterton as part of the Cambridge Business Park.

2.1.3 Industrial areas

Industrial areas are most predominant on the east side of Cambridge, where they are present in mid-sized clusters in Cherry Hinton and Kings Hedges and as both cluster and linear features (e.g. railroads) in Coleridge, Romsey, Petersfield and Abbey.

Large tracts of land used for light/heavy industry, other than business parks – e.g. rail infrastructure/rail stations, sewage works, warehouses etc. were also included in this land use class.

2.1.4 Open Space

Open Space comprises nearly half (48%) of Cambridge's land use. **Open space 1 (Formal and informal open space and general amenity land)** is frequently found near the urban core and is dominated by common areas, parklands and well-managed land. **Open space 2 (Institutional open space)** is also frequent and includes the both the grounds, green space and buildings associated with churches, schools, universities and hospitals. **Open space 3 (Derelict, neglected and abandoned open space)** is very infrequent, occurring in limited situations, often surrounding the perimeters of industrial features. **Open space 4 (Areas of remnant countryside)** abound on the southern and western fringes of the city, predominantly as agricultural land. Large allotments and areas of open space near industrial areas are occasionally classified as OS4 when they are adjacent to or surrounded by development.

3 Data Analysis

3.1 Datasets Used in the Analysis

3.1.1 **ProximiTREE** *data*

ProximiTREE™ is a digital tree map layer supplied by the data capture and remote sensing data specialists Bluesky. It was designed as a tool to aid decision makers, such as Local Authority officers and property developers, to detail the exact spatial location, height and canopy area of individual trees. The tree locations, heights above sea level and canopy areas are derived from aerial photography stereo images, and actual tree heights are determined using a Digital Terrain Model.

Individual tree locations along with their heights and canopies were provided in ArcGIS format for the whole of Cambridge City and formed the main component of the following analyses. The data were captured from aerial photography dating from 2008.

3.1.2 **Ezytreev** *data*

Cambridge City Council uses the ‘Ezytreev’ tree management software to map City Council owned tree stock in the City and attach attribute data on tree species and condition to the tree point locations. This dataset was provided in ArcGIS format plus an associated attribute table in order to evaluate species and condition splits for Council stock.

3.1.3 Boundaries

Geographic boundaries of the Wards within Cambridge City were provided in ArcGIS format as were polygons outlining Cambridge City Council’s freehold land. Boundaries of Highways and associated land were provided for Cambridge by the County Council. Land ownership within the City was categorised into City Council land, Highways (County Council responsibility) and privately owned/ other land on the basis of these boundaries.

Open spaces of environmental and recreational importance are protected by Cambridge City Council, and the boundaries of these protected areas were also provided. These areas include both private and publically-owned land and the GIS file has an attribute for whether it is private or public. The publically owned protected open spaces were used in the classification as Council-owned tree stock as City public open space.

3.1.4 Protected trees

Conservation Areas and Tree Preservation Order (TPO) areas as well as point locations of individual TPOs were provided by Cambridge City Council. These were used to provide an assessment of the canopy area in the City that is statutorily protected but privately owned. All TPO trees are private, whereas conservation areas cover both privately and Council owned land. Conservation areas are areas of ‘special architectural or historic interest’ that make them and the trees within them worth protecting and improving. Cambridge has eleven conservation areas at present. Cambridge City Council has specific powers to protect trees in the City by issuing Tree Preservation Orders. It is an offence to cut down, top, lop, uproot, wilfully damage or wilfully destroy a tree without the Council’s permission. An Order can cover anything from a single tree to woodland.

3.2 Methodology

3.2.1 By Ward, Land Use class and Ownership

The land use and ownership data were processed in a GIS to provide a spatial dataset in which any specific area, within each ward of Cambridge, had a land use class (defined in Section 2.1) and a land ownership class (City Council, Highways or private) assigned to it. The point locations of each tree in the ProximiTREE dataset allowed each individual tree to be assigned a ward, land use class and ownership class. This enabled analysis of the characteristics of trees and tree canopies in each land use and ownership class.

The total land area within each ward, land use and ownership class was also calculated using GIS, and from this the tree density (trees ha^{-1}) was derived for each group.

The canopy cover area was derived by merging the individual canopies in order to remove the overlapping area between separate canopies. The canopy cover density (m^2 ha^{-1}) was then calculated for each ward, land use and ownership group by intersecting the land classification layer with the merged canopy dataset.

The trees were further subdivided into height classes (0.0-2.4 m, 2.5-4.9 m, 5.0-9.9 m, 10.0-14.9 m, 15.0-19.9 m and 20.0+ m; as used in the *Trees in Towns II* study). The canopy spread of each tree was calculated from the area of each individual canopy by calculating the diameter of each circle representing individual canopies. The trees were then subdivided into canopy spread classes (0.0-1.9 m, 2.0-4.9 m, 5.0-9.9 m, 10.0-14.9 m, 15.0-19.9 m and 20.0+ m; as used in the *Trees in Towns II* study).

3.2.2 By Conservation Area and TPO

The canopy cover and tree density were also analysed by private protection status. This includes privately owned land in conservation areas, Tree Preservation Order (TPO) areas and individual TPOs. In order to include only the parts of the conservation areas containing privately owned trees, the Highways and council freehold land area was removed from the conservation area. The canopy cover (m^2) was then calculated for each type of protection status and summarised by ward. The canopy cover was also analysed for privately owned trees in each conservation area in Cambridge.

The number of trees found in conservation areas in each height and canopy spread group (as used in 3.1.1) was analysed by ward and conservation area.

3.2.3 By Species and Condition for Council Stock

In order to analyse the species and condition of the Council owned tree stock, the Council owned land was subdivided into three land ownership classes: County Highways, City public open space and other City Council land. Each tree in the Ezytreev dataset was assigned one of these three land ownership classes. The numbers of the most common species or groups of species were summarised for each county land use class by ward. The names of other species present in the city were also listed. The number of trees per genus and family were also summarised by council land ownership class and Ward.

For analysis of the condition of the council stock, the categories that were used were good, fair, poor or dead. All the remaining trees that did not have one of these four condition codes assigned were classified as ‘other’. The number of trees of each condition class were summarised by council land ownership class and Ward.

3.3 Results

3.3.1 By Ward, Land Use class and Ownership

3.3.1.1 Ward

The mean number of trees per ha across the whole of Cambridge was estimated at 33.2. However, this value ranges from 17.2 trees ha^{-1} in Market (city centre) to 52.1 trees ha^{-1} in West Chesterton, a largely residential ward to the north of Cambridge (Figure 3). The mean canopy cover density across Cambridge was estimated at ~1700 m^2 ha^{-1}, ranging from 1278 m^2 ha^{-1} in Cherry Hinton (south-east Cambridge) to 2265 m^2 ha^{-1} in Newnham in the west of the City (Figure 4).

Generally, the proportion of the tree stock and the proportion of the canopy cover observed in each ward were similar to the proportion of the land area that the ward occupies (Table 2). Notable exceptions were Abbey, where the canopy cover was lower than expected in relation to its land area (even though the number of trees was as expected if an even distribution of trees were to be assumed throughout the city); East Chesterton, where the number of trees was higher than expected in relation to its land area (9% vs. 6%); Newnham, which had a higher canopy cover than expected in relation to its land area (14% vs. 11%) and Trumpington, which had a lower number of trees than expected in relation to its land area (12% vs. 18%).

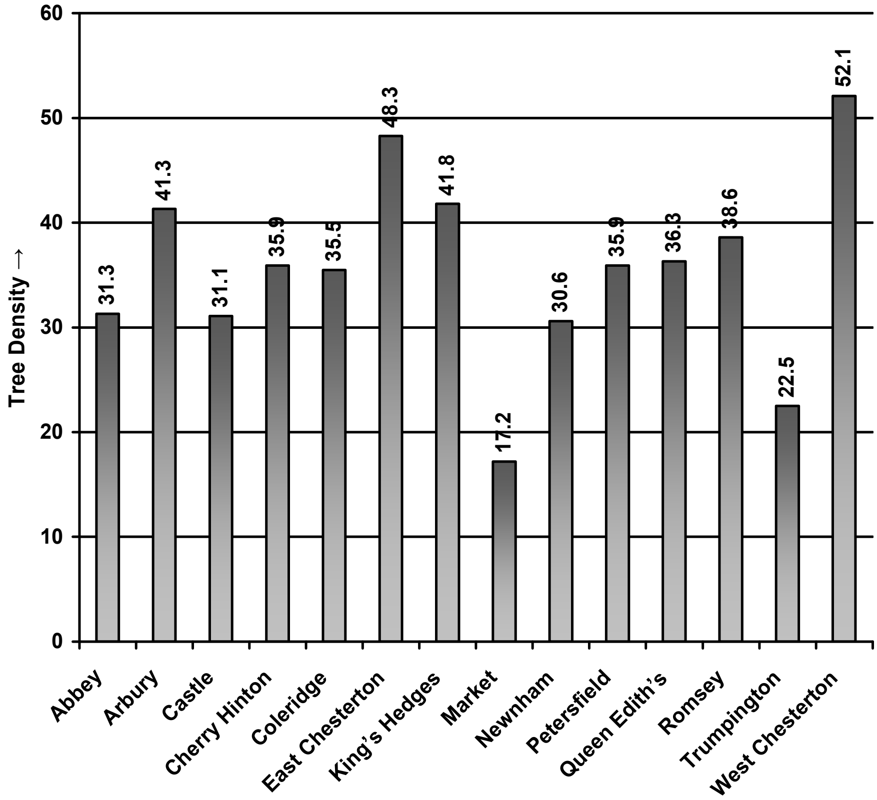

Figure 3. Tree density by Ward (Trees ha^{-1})

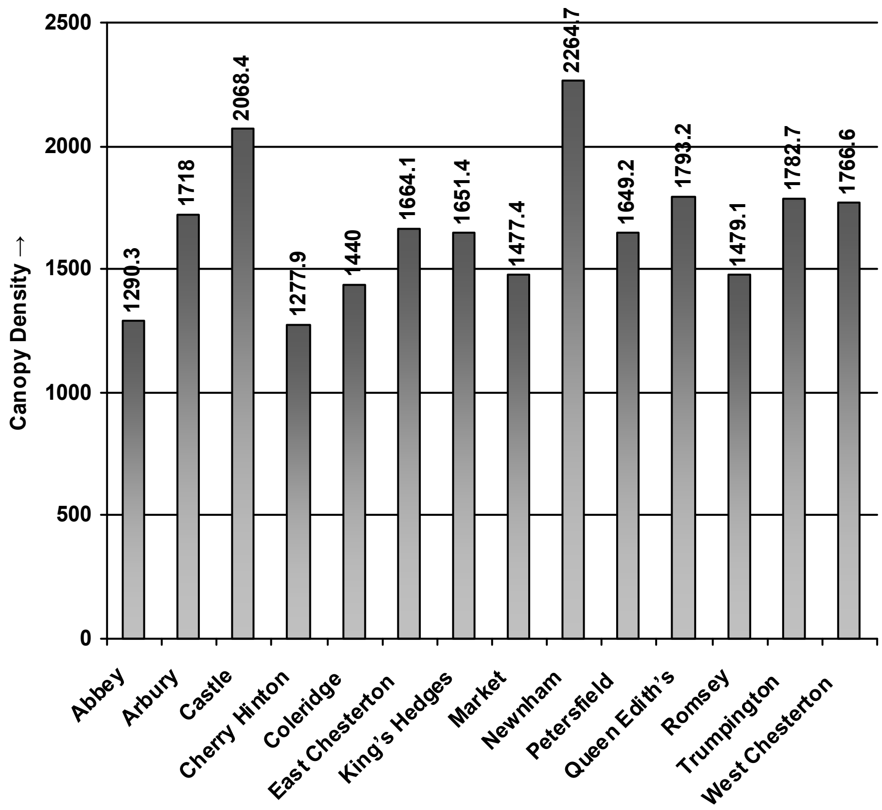

Figure 4. Canopy density by Ward (m^2/ha)

Table 2. Proportion of total number of trees, canopy cover and land area in Cambridge, by ward

Ward	Number of trees (%)	Canopy cover (%)	Land area (%)
Abbey	9.1	7.3	9.7
Arbury	4.6	3.7	3.7
Castle	7.8	10.1	8.4
Cherry Hinton	9.8	6.8	9.0
Coleridge	5.1	4.0	4.8
East Chesterton	9.3	6.3	6.4
King's Hedges	4.9	3.8	3.9
Market	2.2	3.6	4.2
Newnham	10.0	14.4	10.9
Petersfield	2.8	2.5	2.6
Queen Edith's	12.1	11.6	11.1
Romsey	4.2	3.2	3.6
Trumpington	12.2	18.8	18.0
West Chesterton	5.9	3.9	3.8

3.3.1.2 Land Use Class

Over half the trees in Cambridge fall into the medium density residential (MDR) land use classification (Table 3). This is to be expected, considering that it is the most common land use type in Cambridge; however it is still disproportionately higher than the proportion of the land area covered by this class. The proportion of the canopy cover in MDR (37%) is more similar to the proportion of the land area occupied by MDR (31%).

The results show that despite the areas covered by high and low density residential (HDR and LDR) land being similar (~4%), the LDR area has a greater proportion of the total trees (~7% compared to ~4% for HDR) and canopy cover (~10% compared to ~4%). This is to be expected since LDR areas consist of detached houses with large front and back gardens, which have space for large trees. Typically these houses tend to be older, with mature trees characterised by a large canopy area. This may be why the difference between these two land uses is more pronounced for the canopy cover than the proportion of the number of trees. HDR areas typically consist of small terraced houses with, at most, a small back garden or yard. The gardens have little potential for any significant canopy cover. The HDR land use class also includes blocks of flats, which often contain a number of trees in the surrounding open space. This is likely to contribute significantly to the proportion of trees found within the HDR land use class.

The Town Centre and Commercial (TC) and, in particular, Industrial (I) land use classes have a disproportionately small number of trees and canopy cover compared to the size of the areas they occupy. This is to be expected, especially for the industrial areas, in which the land area has a purely functional purpose with little planting.

The Open Space 2 class (OS2; Institutional Open Space) covers a relatively large proportion of the Cambridge area and has the second greatest proportion of trees and canopy cover after MDR. This land use class includes the University colleges with grounds which typically contain mature trees with large canopy areas.

Despite 25% of the Cambridge area being classified as Open Space 4 (OS4; Remnant Countryside), it contains only ~10% of the trees and 14% of the canopy cover. This is because this land use class consists largely of big open arable fields, which often only have trees and shrubs at their boundaries.

Table 3. Proportion of total number of trees, canopy cover and land area in Cambridge, by land use class

LU class	Number of trees (%)	Canopy cover (%)	Land area (%)
LDR	6.9	9.6	3.9
MDR	53.3	37.6	31.4
HDR	4.3	3.9	4.2
TC	5.3	5.9	7.7
I	2.6	2.0	4.5
OS1	5.0	8.1	6.4
OS2	11.5	17.3	16.1
OS3	1.2	1.6	0.7
OS4	9.8	13.9	25.0

Calculated tree densities by land-use category are shown in Figure 5. Tree density ranged from 13 trees ha^{-1} in the OS4 category (Remnant Countryside) to 61 trees ha^{-1} in the OS3 category (derelict, neglected and abandoned land), although the latter covered a very small proportion (1%) of the City's land-use. Tree densities of over 50 per hectare were found in LDR and MDR.

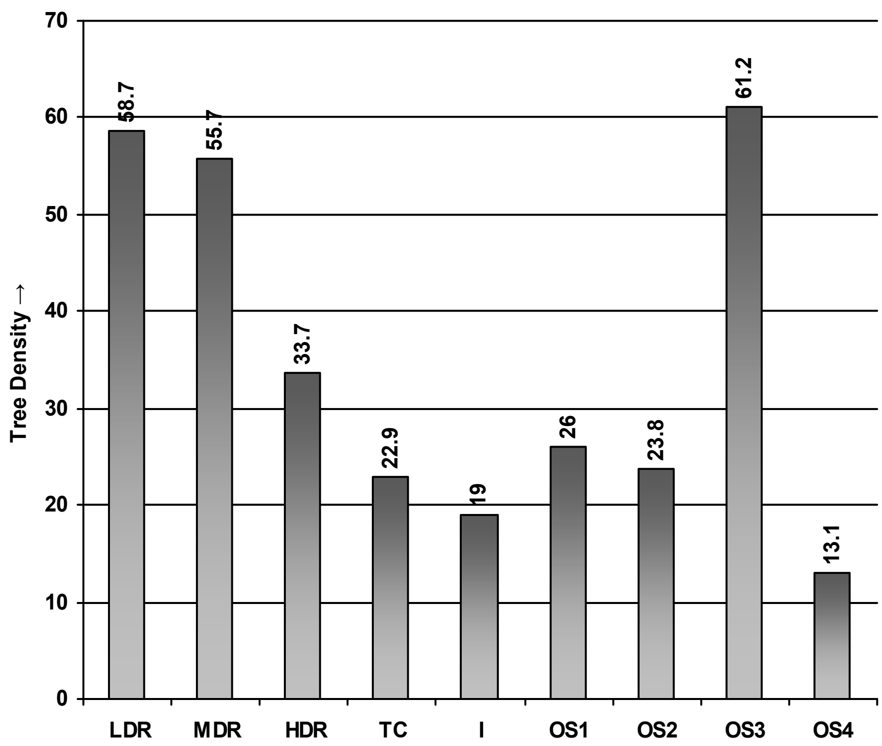

Figure 5. Tree density by land-use (Trees ha^{-1})

Calculated canopy densities by land-use category are shown in Figure 6. Canopy density ranged from 752 m^2 ha^{-1} in Industrial areas to 4171 m^2 ha^{-1} in LDR.

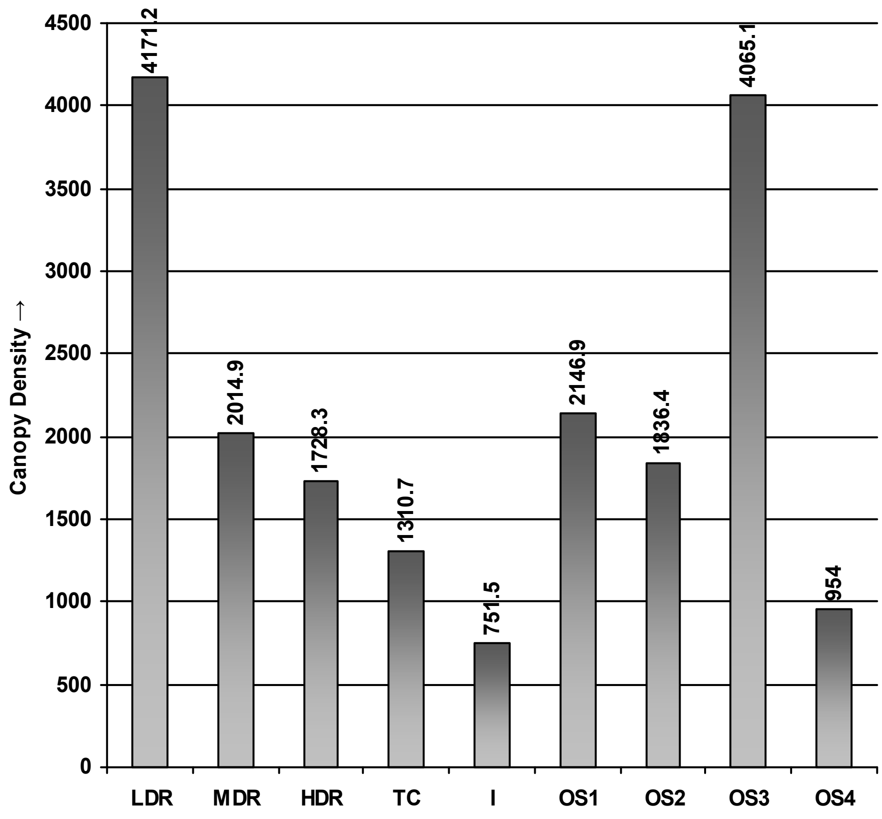

Figure 6. Canopy density by land use (m^2/ha)

Figure 7 illustrates an average canopy size within each land use type by using canopy density divided by tree density; this suggests that MDR and industrial areas have trees with the smallest canopies.

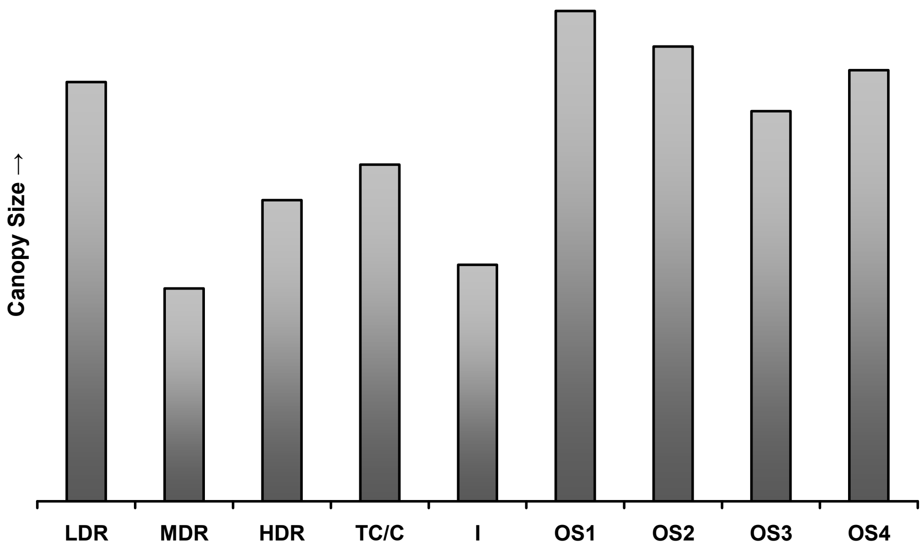

Figure 7. Representative tree canopy size by land-use (canopy density/tree density)

The distribution of land-use class by ward is shown in Figure 8. The distribution is markedly different between wards and because tree and canopy densities also differ markedly by land-use, it is expected that this is the main reason for the variations in tree and canopy densities between wards.

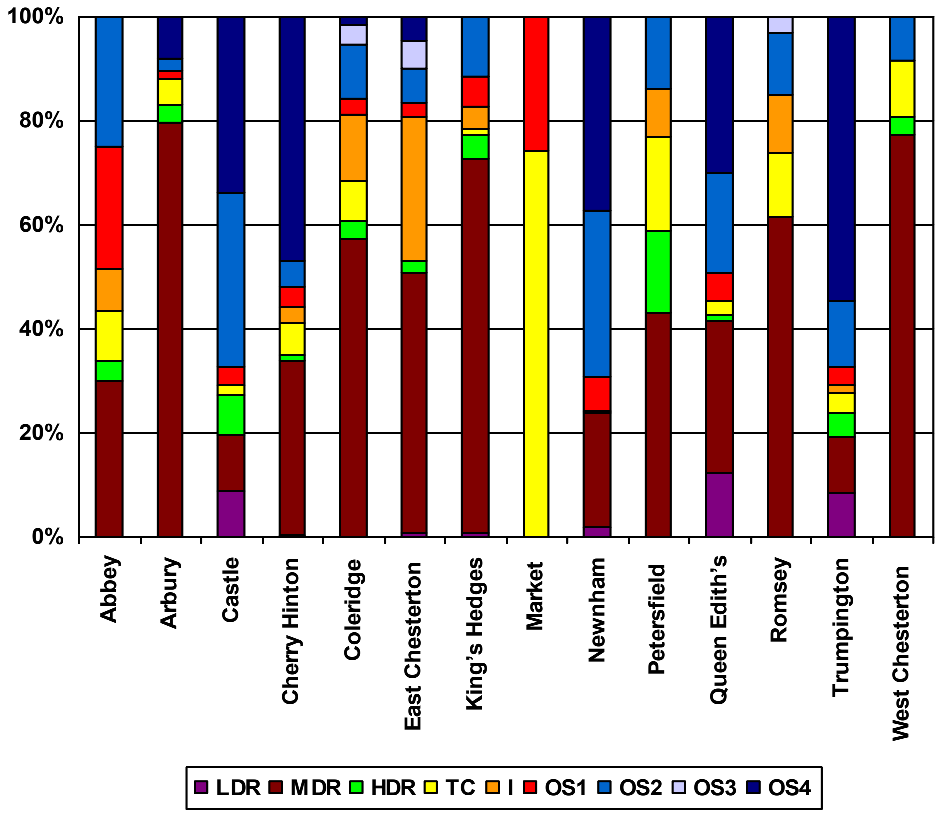

Figure 8. Land-use by Ward

Maps by each unique ward/ land-use classification of tree density and canopy density are shown in Figure 9 and Figure 10 respectively. These show that whilst the highest tree densities are scattered throughout the City, they are particularly concentrated in the northern and eastern parts. More specifically, East and West Chesterton have the highest tree densities and Market and Trumpington have the lowest. Conversely, canopy densities are markedly highest in the southern and western areas, with Newnham and Castle characterised by the highest canopy densities and Cherry Hinton and Abbey by the lowest. Comparing representative canopy size between wards goes some way to explaining the low tree density in Market and Trumpington, as it appears these wards hold the largest trees (Figure 11).

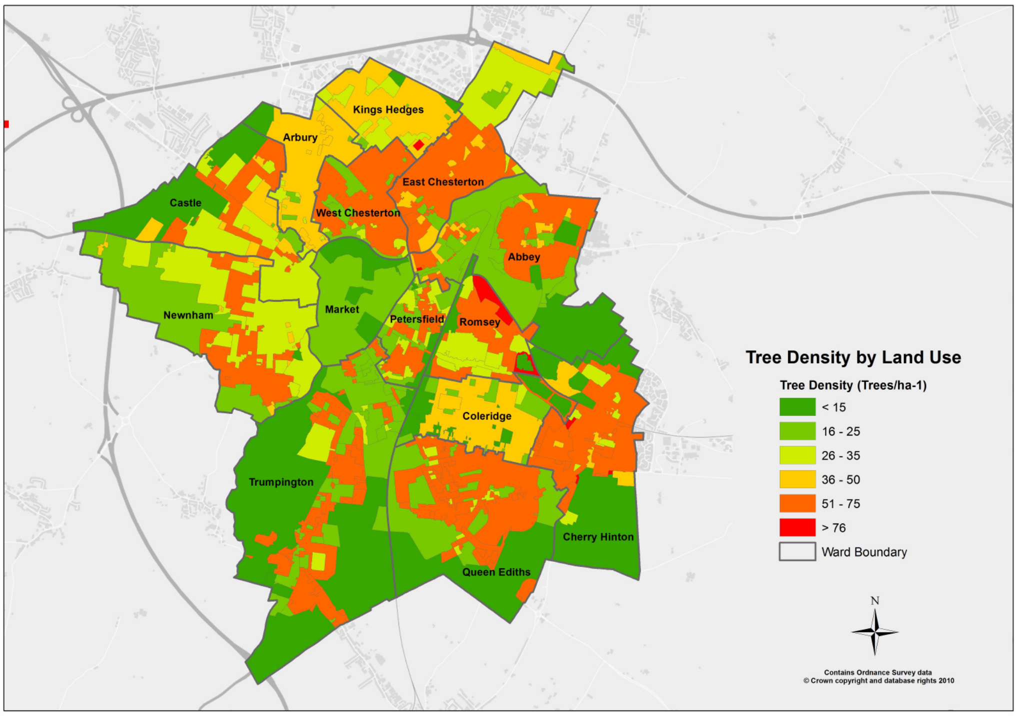

Figure 9. Tree density by ward and land-use in Cambridge City

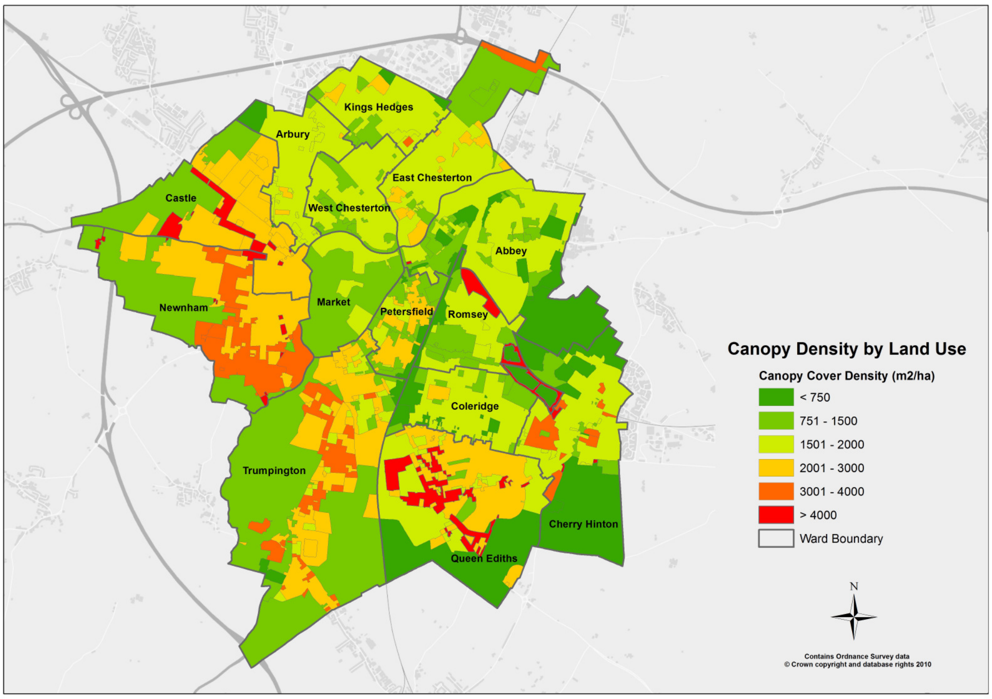

Figure 10. Canopy density by ward and land-use in Cambridge City

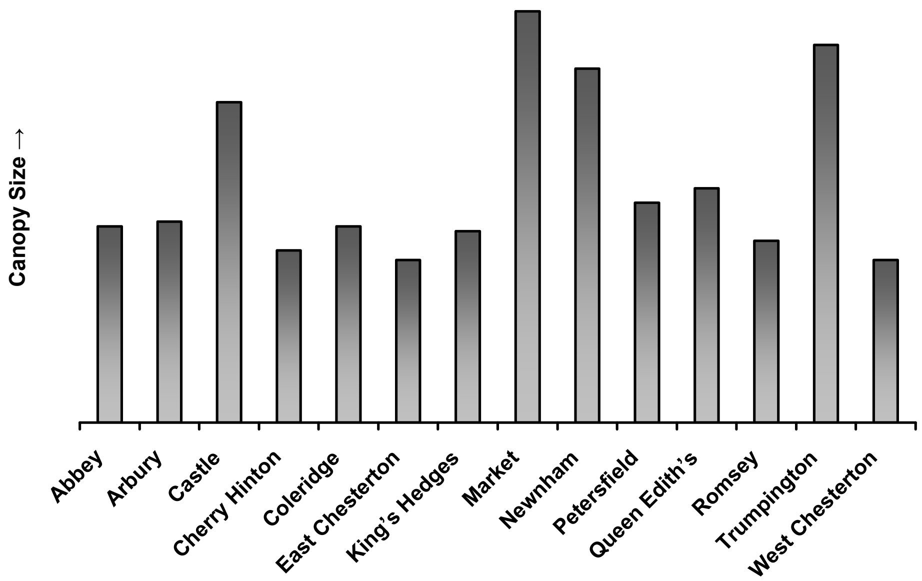

Figure 11. Representative tree canopy size by ward (canopy density/tree density)

3.3.1.3 Ownership

The majority (77%) of the land area in Cambridge is under private ownership, though it should be noted that public land which is outside of City and Council ownership comprises a small proportion of this total. The City Council owns 13.5% and the remaining 9.5% is Highways land. The number of trees and canopy cover area are split in similar proportions (Table 4). The City Council land has a slightly higher tree density (36 trees ha^{-1}) than the private and highway areas (~33 trees ha^{-1}). Land classed as private/other has the lowest canopy cover density (1640 m^2 ha^{-1}), which is marginally less than the highway land (1720 m^2 ha^{-1}). City Council owned land has a canopy cover density of 2070 m^2 ha^{-1}. The differences in densities between the ownership categories are greater for different land uses. For example within the residential land uses, the areas belonging to Highways have a much lower canopy cover density than private/other (e.g. 1490 m^2 ha^{-1} compared to 2240 m^2 ha^{-1} for MDR).

Table 4. Proportion of total number of trees, canopy cover and land area in Cambridge, by ownership

Ownership	Number of trees (%)	Canopy cover (%)	Land area (%)
City Council	14.6	16.3	13.5
Highway	9.3	9.6	9.5
Private/other	76.1	74.1	77.0

Land ownership is not equally distributed between wards (Figure 12), with more privately owned land in the southern and western wards and more City Council-owned land in the northern and eastern wards. Highways land is more evenly distributed between wards.

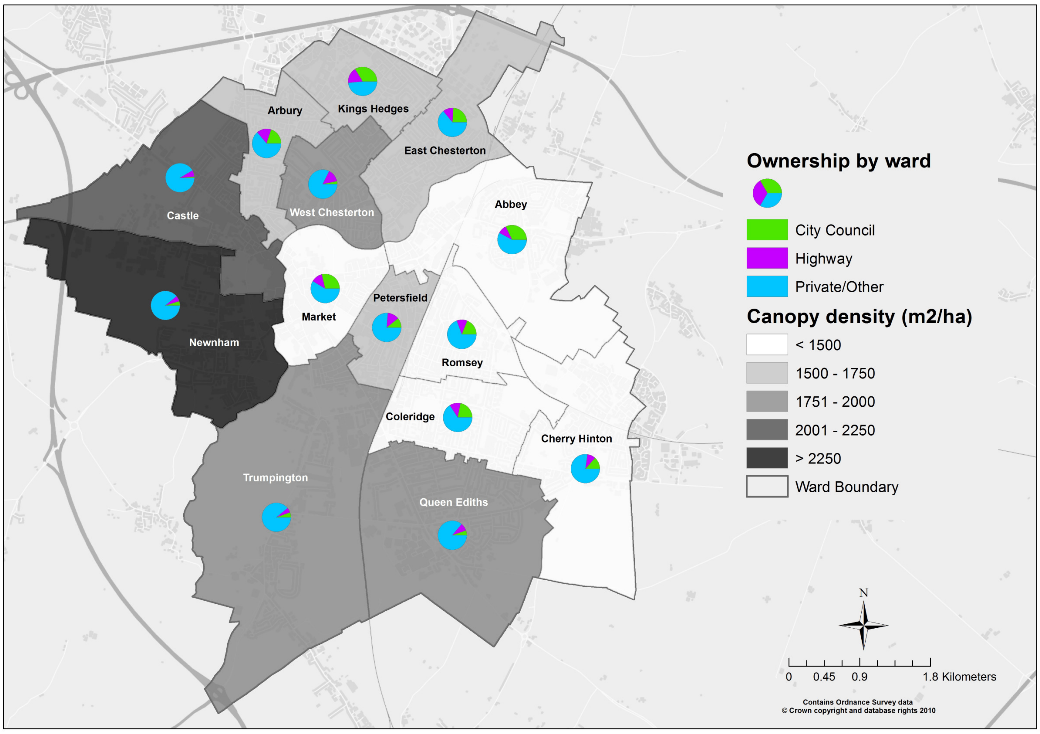

Figure 12. Land ownership split by ward overlaid onto map of canopy density at ward level

The canopy cover area by ownership split shows a similar distribution at ward level to the land area by ownership (Figure 13). Some wards in the north and east of the City have a higher proportion of canopy cover in the City Council and Highways categories than they do land area in these categories, most notably Abbey and Cherry Hinton.

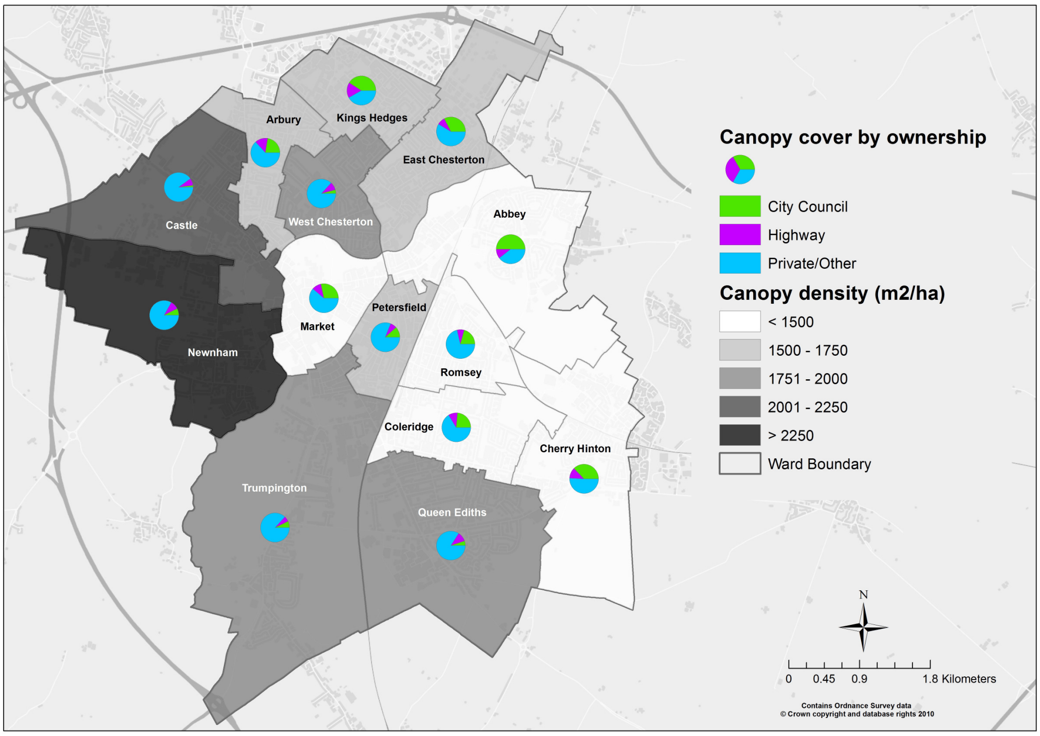

Figure 13. Canopy cover by ownership split by ward overlaid onto map of canopy density at ward level

3.3.1.4 Height and Canopy Spread

Almost three quarters of the trees in Cambridge are between 2.5 and 10 m high. Less than 2% of trees are over 20 m tall (Table 5). The land-use class with the greatest proportion of trees over 15m tall (>18%) is Open Space 2 (institutional open space). This probably reflects the abundance of large mature specimens on college-owned land in the City. Medium density residential, industrial and Open Space 3 land-use classes have particularly low proportions of trees over 15m tall.

Table 5. Proportion of trees in each height class by land use class in Cambridge

Land-Use class	Tree height group					
	0.0-2.4 m	**2.5-4.9 m**	**5.0-9.9 m**	**10.0-14.9 m**	**15.0-19.9 m**	**20+ m**
LDR	3.3	21.9	43.7	19.6	9.1	2.4
MDR	7.2	41.9	39.4	8.9	2.1	0.5
HDR	4.7	30.1	45.0	13.8	5.2	1.2
TC	6.0	29.1	36.7	17.4	8.4	2.4
I	4.0	35.3	45.8	13.5	1.4	0.1
OS1	2.5	18.2	45.2	21.0	9.4	3.8
OS2	3.2	21.1	37.5	19.9	12.6	5.7
OS3	2.7	28.8	53.7	12.9	1.5	0.4
OS4	5.6	37.6	31.7	15.5	7.1	2.5
Total	**5.8**	**35.0**	**39.4**	**13.0**	**5.1**	**1.7**

NB. rows sum to 100%

Over three quarters of the trees in Cambridge have a canopy spread of between 2 and 10 m (Table 6). Less than 2% of the trees have a canopy spread of <2m and less than 2% have a canopy spread of >20m. The land-use classes with the greatest abundance of trees with a canopy spread of over 15m are Open Space 1, Open Space 2 and Open Space 3. Medium density residential has the greatest proportion of trees with a canopy spread less than 5m.

Table 6. Proportion of trees in each canopy spread group by land use class in Cambridge

Land-Use class	Canopy spread group					
	0.0-1.9 m	**2.0-4.9 m**	**5.0-9.9 m**	**10.0-14.9 m**	**15.0-19.9 m**	**20+ m**
LDR	0.1	14.7	48.5	26.4	8.4	1.8
MDR	2.1	38.7	47.2	9.9	1.8	0.3
HDR	0.7	30.8	50.6	14.0	3.2	0.8
TC	1.7	29.7	42.2	19.4	5.5	1.4
I	0.8	36.1	47.5	13.0	2.4	0.3
OS1	0.3	16.1	41.7	26.8	11.8	3.3
OS2	0.6	20.0	39.5	26.0	10.8	3.0
OS3	0.2	11.0	52.2	27.6	7.7	1.2
OS4	0.4	22.5	41.3	19.8	10.6	5.5
Total	**1.4**	**30.9**	**45.5**	**15.7**	**5.0**	**1.4**

NB. rows sum to 100%

Maps showing pie charts of tree height and canopy spread splits at ward level are shown in Figure 14 and Figure 15. These show that the wards of Castle, Newnham, Market and Trumpington have the highest proportions of taller trees, and the trees with the largest canopy spreads. Interestingly, canopy density is relatively low in Market ward, yet it has the greatest proportion of larger trees.

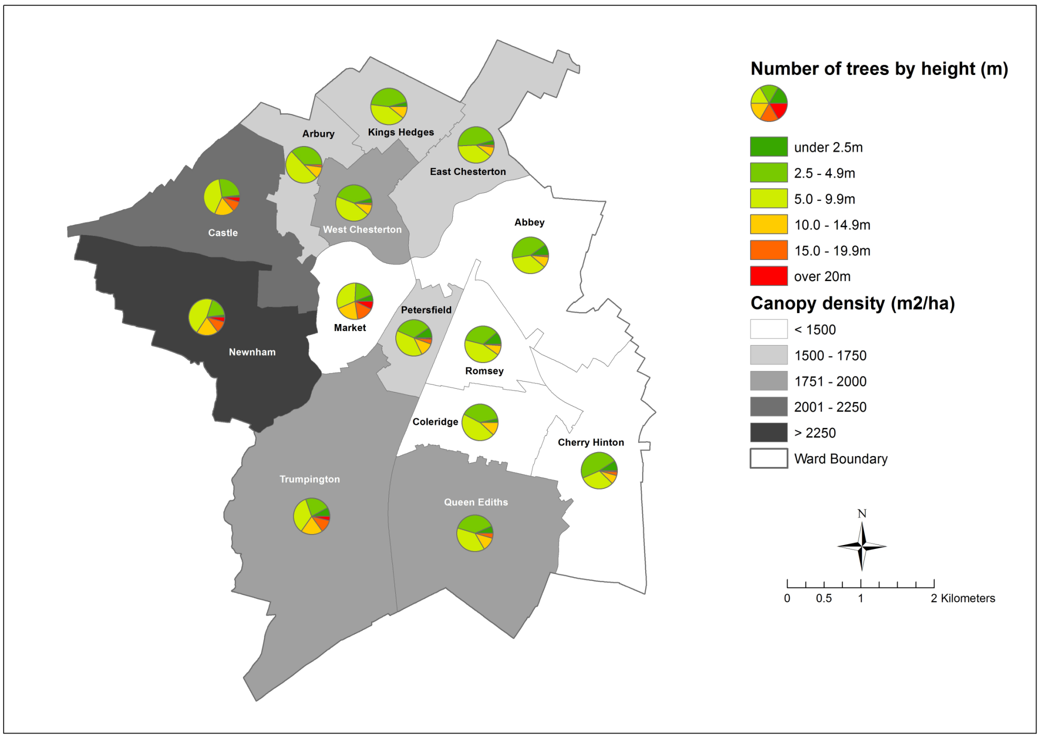

Figure 14. Map of canopy density by Ward, with pie charts showing the tree height split for each Ward

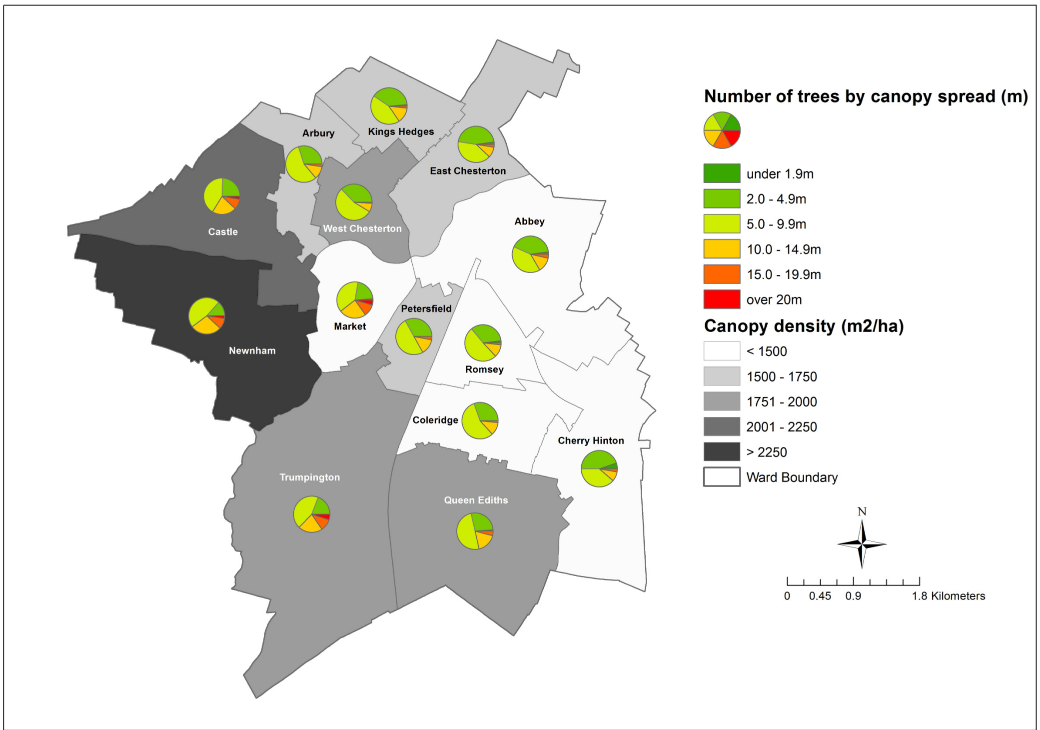

Figure 15. Map of canopy density by Ward, with pie charts showing the canopy spread split for each Ward

3.3.2 By Conservation Area and TPO

Overall, 25% of the canopy cover in Cambridge is in privately owned land in conservation areas (Table 7). There is great variation between the wards, depending on the location of the eleven privately owned land in conservation areas found within Cambridge. Four of the wards (Cherry Hinton, Coleridge, King's Hedges and Queen Edith's) have no private conservation areas (Figure 16). The proportion of tree canopies with TPO status and those which are located within TPO areas also vary between the wards (Table 7). In Queen Edith's for example, despite there being no private conservation areas, ~10% of the canopy cover is within TPO areas and ~21% belongs to trees with TPO status. On average across Cambridge, 4.4% of the canopy cover falls within TPO areas, and 9.3% of the canopy cover belongs to trees with individual TPOs.

There are a number of wards in which the majority of the canopy cover has a protection status. For example, 70% of the canopy cover in Petersfield falls within privately owned land in conservation areas and 30% of the canopy cover belongs to trees with individual TPO status.

There is some overlap between the categories of protection status, so the total percentage of protected canopy in a ward cannot be interpreted from the values in Table 7.

Table 7. The percentage of total canopy cover, by ward, which falls within protected areas (private conservation areas and TPO areas) and which belong to trees with individual TPO status

Ward	% of canopy cover in conservation areas (privately owned)	% of canopy cover in TPO areas	% of canopy cover that is associated with individual TPOs
Abbey	2.2	0.3	5.4
Arbury	2.6	2.1	3.6
Castle	50.3	3.2	10.4
Cherry Hinton	0.0	1.9	3.1
Coleridge	0.0	0.9	2.1
East Chesterton	6.5	3.8	5.7
King's Hedges	0.0	1.8	2.4
Market	60.5	0.2	7.0
Newnham	52.5	3.1	11.4
Petersfield	70.0	4.6	30.4
Queen Edith's	0.0	9.8	21.2
Romsey	19.8	0.5	11.1
Trumpington	37.1	9.6	6.7
West Chesterton	13.9	0.3	6.2
Total area	**25.4**	**4.4**	**9.3**

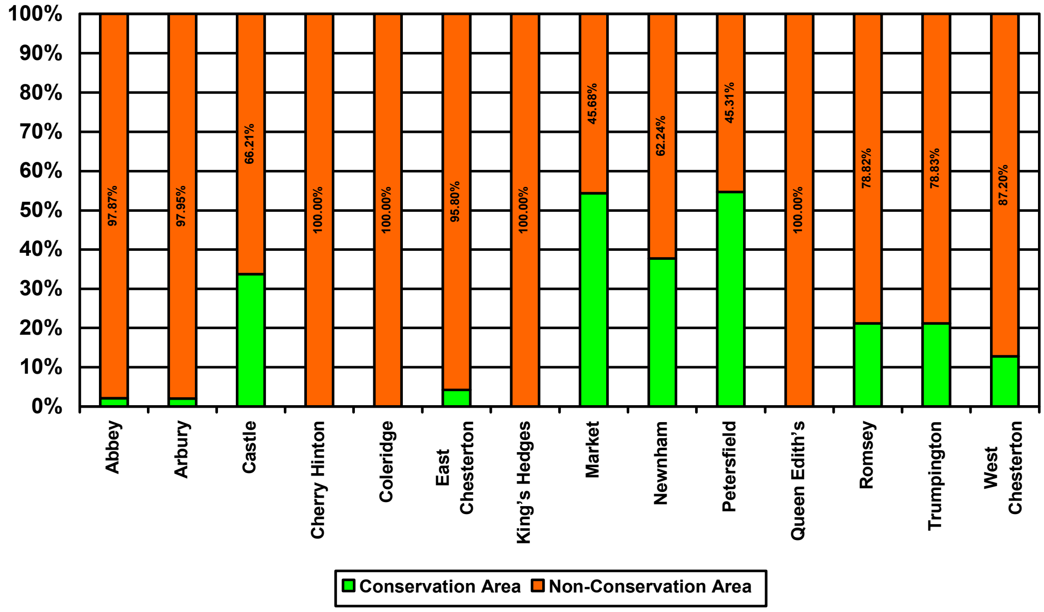

Figure 16. Conservation land area by Ward

Within the privately owned land in conservation areas, 75% of the trees are greater than 5 m high; whereas across Cambridge, roughly 60% are taller than 5 m (Figure 17). In total 17% of all trees in Cambridge are located within privately owned land in conservation areas. Of the tallest trees in Cambridge (taller than 20 m), 56% of these trees are within the privately owned land in conservation areas. For trees in Cambridge between 15 and 20 m high, 43% of the trees are within these conservation areas.

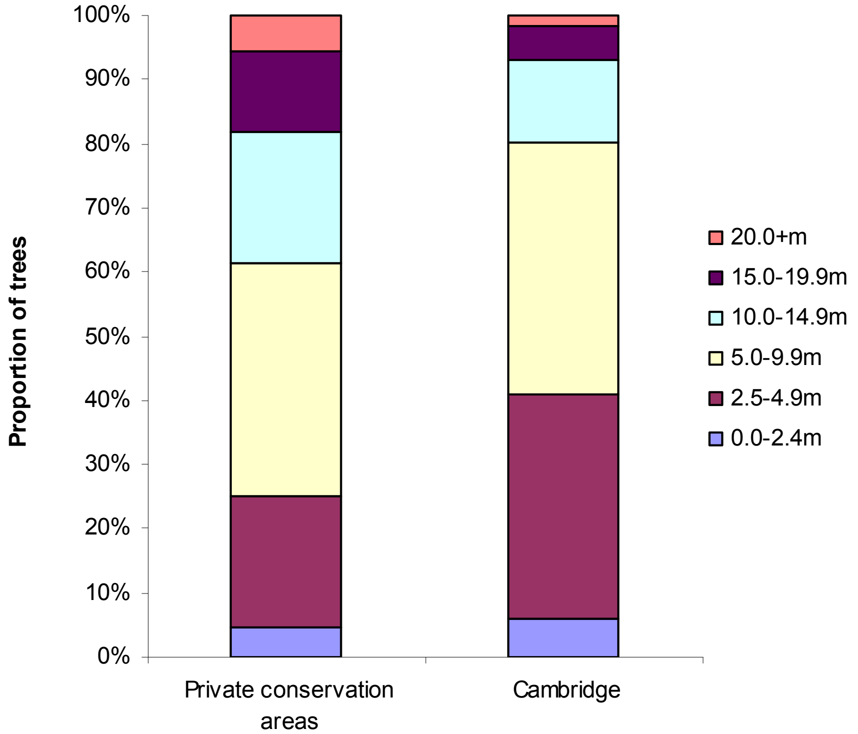

Figure 17. Proportion of trees by height group, for private conservation areas and Cambridge as a whole

The conservation areas also have a greater proportion of trees in the higher canopy spread groups than Cambridge as a whole (Figure 18). Of all the trees in Cambridge that have a canopy spread greater than 20 m, 31% are within conservation areas.

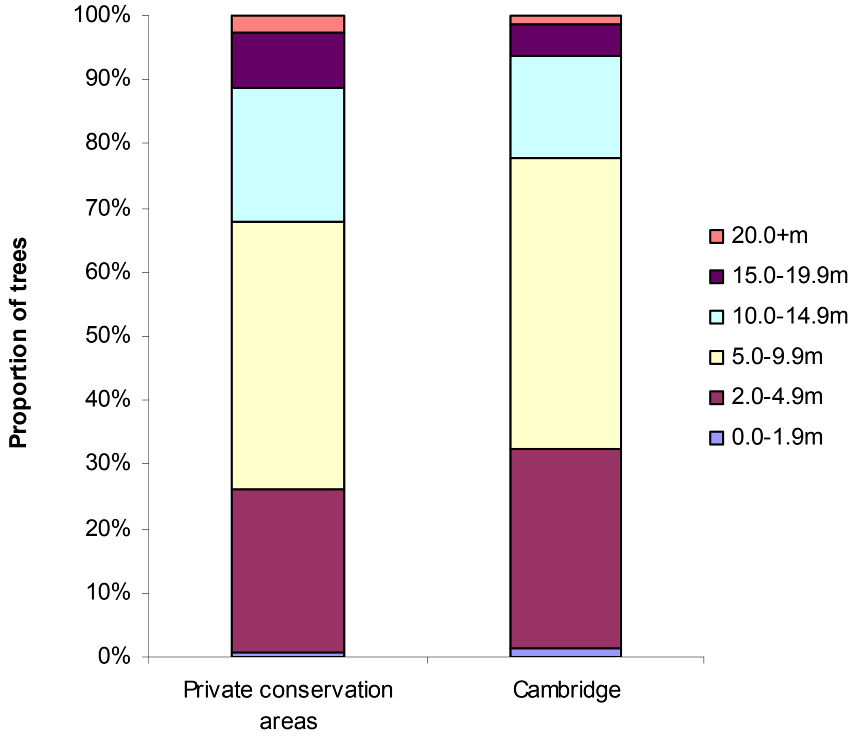

Figure 18. Proportion of trees by canopy spread group, for private conservation areas and Cambridge as a whole

3.3.3 By Species for Council Stock

In the county Highways land, the most common tree species were cherry species (9%) and silver birch (8%). In city public open space, 9.5% of trees were lime species, with other dominant species including cherry species, chestnut species, common ash and sycamore. Across the rest of the council stock (the city council other class), 9% were Norway maple and other dominant species include cherry species, common ash and silver birch.

Across all the council tree stock, the most common family was Rosaceae (33%), followed by Betulaceae (14%), Aceraceae (12%) and Tiliaceae (9%) (Figure 19). The most common genus was *Prunus* (14% of all trees), followed by Acer (12%), Tilia (9%), Betula (8%), Sorbus (8%) and *Fraxinus* (7%) (Figure 20). The most common species across the whole of the council tree stock were cherry (7.5%), silver birch (6%), lime (5%), common ash (4%) and Norway maple (4%).

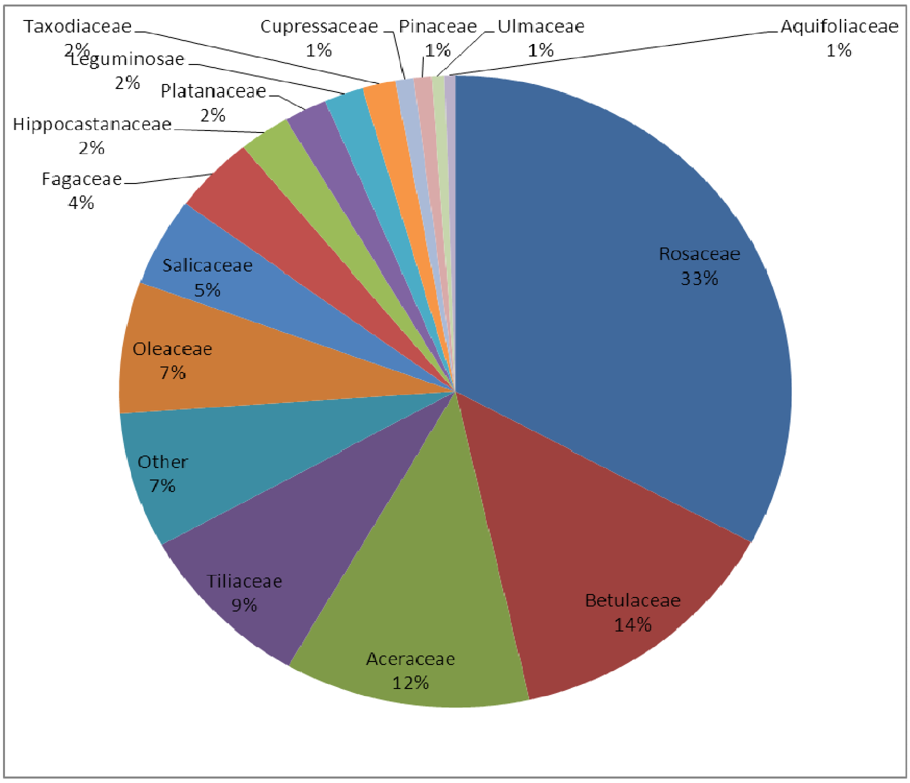

Figure 19. Family splits across all of the council-owned tree stock

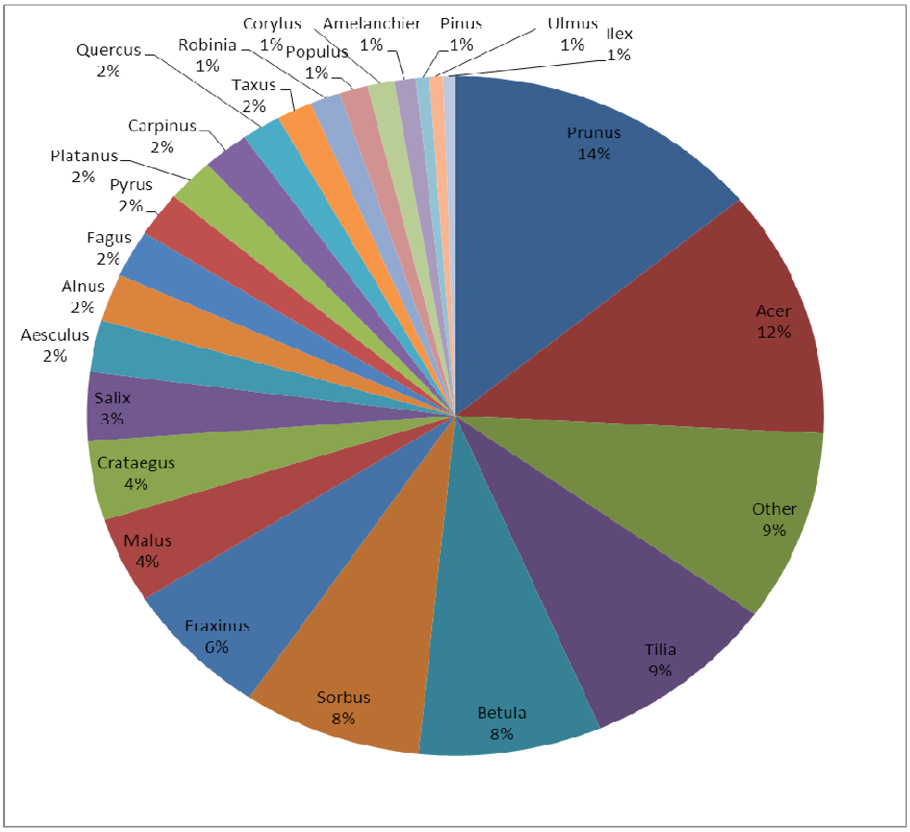

Figure 20. Genus splits across all of the council-owned tree stock

3.3.4 *By Condition for Council Stock*

The majority of Council-owned trees across Cambridge City which have been assessed for condition are of good (56%) or fair (36%) condition. Trees in poor condition and dead trees represent 4% and 3% of Council stock, respectively. The condition of Council-owned tree stock varies with land ownership type (Figure 21). For example, county highway trees and City Council other have a greater proportion of trees in good condition (~29%), compared to city public open space (15%), and a lower proportion of dead trees (an average of 0.6% compared to 2.8% in city public open space).

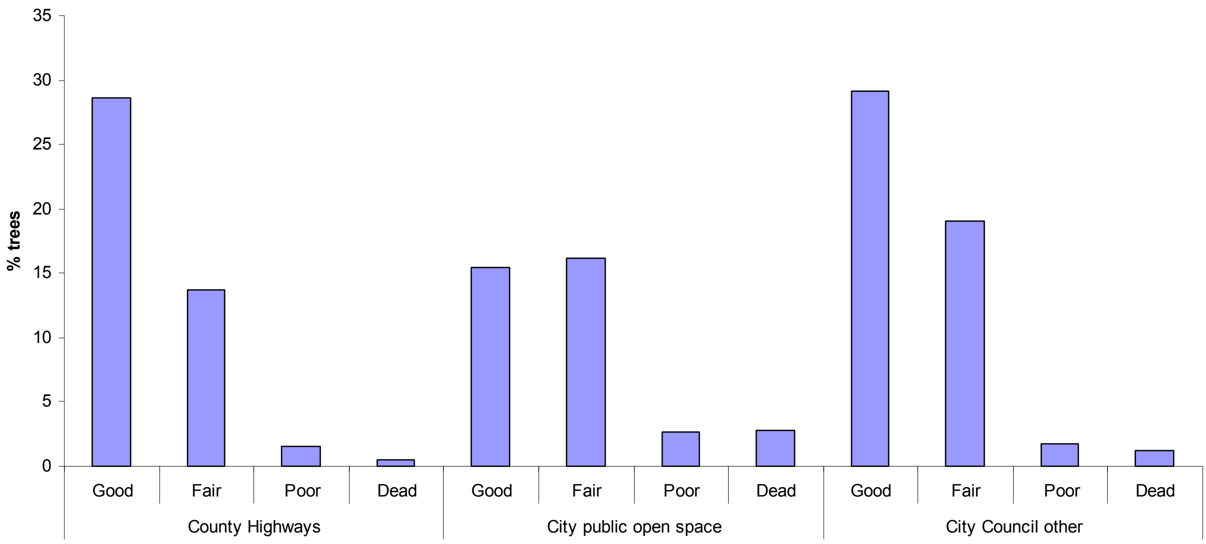

Figure 21. The percentage of trees with specific conditions (good, fair, poor or dead) assigned to them, in each of the three city council land use types

Figure 22 shows the condition of assessed trees by ward. When analysed by ward, the percentage of dead county Highways trees is at most 2.6%, whereas in city public open space in West Chesterton, 21% of trees are dead. In general, there is great variation in tree condition between the wards. The wards with the council owned trees in the best condition are Romsey and Coleridge (65% and 54% of trees are in good condition, respectively). Romsey and Coleridge have had approximately 70% and 80% of their trees assessed for condition status respectively, and therefore we can assume that in these more central areas tree condition is generally better. The other two central wards of Petersfield and Market have had around 30% and 50%, respectively, of their trees assessed. West Chesterton has the highest proportion of dead trees (2.5%) within the total council land area; it also has low percentages of good and fair condition trees (5.5% and 1.6%, respectively), though a large amount of the ward's trees have not been assessed, which may skew figures to some extent. Similarly, the challenge remains that a large proportion of trees across all wards have not been assessed for condition. In fact, less than 20% of the trees have been assigned a condition status – so the drawing accurate conclusions regarding the overall condition of the Council's tree stock is a complex matter.

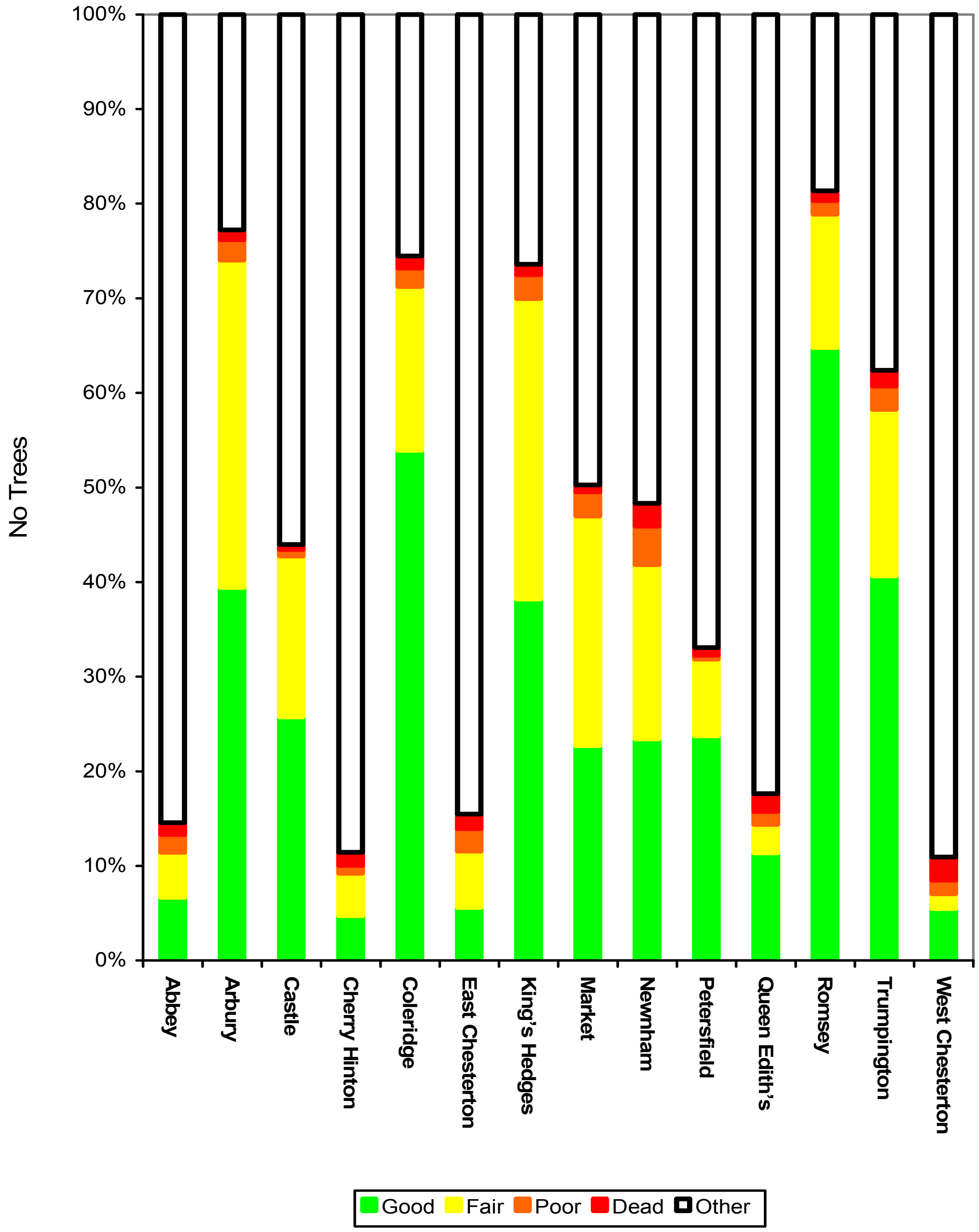

Figure 22. Tree condition across wards (trees with condition status only)

4 Ground Survey

4.1 Introduction

A ground survey of trees within a sample of plots throughout the City was carried out, the aims of which were threefold:

1. The first objective of the ground survey was to obtain an estimate of the tree stock in the sample plots that can be compared with the ProximiTREE results, stratifying the sample by land-use class so as to be representative of the City stock. Whilst the ProximiTREE method allows for capture of canopy extent and tree densities across the whole of the City, no information is provided on the level of confidence in these data. By ground-truthing a sample that is in proportion to the abundance of each land-use class in the City, we can go some way to validating the estimates that have been obtained using the ProximiTREE data in terms of tree densities and canopy spread/ height splits. Limitations to this approach include the date of the aerial photography from which trees were captured using ProximiTREE (2008) when compared to the date of survey (2012), since changes in tree stock and land-use may have occurred over this time.
2. The second objective was to obtain statistically robust estimates of the characteristics of the tree stock in the City, including species, age, maturity and condition.
3. The third objective was to provide a baseline from which future changes in the tree population and its composition at a land-use class level can be assessed.

Since the ground survey provides an estimate of tree density rather than an exact count, it is important to know how reliable the estimate is. Confidence limits provide an estimate of the reliability of the estimate; in other words if the 95% confidence limits of a population size estimate are between two values, the chance that the true population size lies between these values is 95%.

4.2 Methodology

4.2.1 Stratification and sample selection

A total of twenty four 4ha plots (200x200m) were selected for ground survey to be representative of the land-use classes within the City. Plot sizes of 4ha were used in the Trees in Towns survey, and were chosen here to cover an area per plot that was expected to be large enough to be representative of the tree stock within the land-use class whilst remaining economically viable to survey. The ProximiTree data covers the City of Cambridge (approx. 40 km^2) and some 135,000 individuals. This equates to an average of 33 trees per ha. The sample of twenty four 4ha plots (96ha total) throughout the City was therefore expected to contain approximately 3168 trees (~2.3% of total).

It was important that the sample was representative of the land-use classes within the City since it is known that tree densities and attributes vary over different land-use classes. Stratification allows separate estimates of the means and variances to be made for each stratum, but also allows the overall mean to be estimated with much greater precision. A stratified random approach to sample plot selection was therefore taken. The area of the City within each land-use class was calculated from the GIS data, and expressed as a proportion of the total area of the City. These proportions were then multiplied by the total number of survey plots (24) to determine the stratification, which is shown in Table 8.

Table 8. Survey plot stratification by land-use class

Land-use Class	***Area (ha)***	***Proportion***	***Survey Plots***
Commercial	314	0.08	2
Industrial	186	0.05	1
Low density	160	0.04	1
Medium density	1281	0.31	8
High density	173	0.04	1
OS1	263	0.06	1
OS2	657	0.16	4
OS3	28	0.01	0
OS4	1018	0.25	6
Total	**4080**	**1.0**	**24**

Plots were randomly selected within the land-use class in a GIS, whereby a 2x2km grid was overlaid onto the land-use class map and grid cells with at least 90% of their area within one land-use class identified for possible selection. Possible sample plots were numbered and then selected at random from within the land-use class until the sample quota was met for that land-use class. In cases where the area of the land-use class within the City was relatively small (e.g. high density residential), the grid was shifted to optimize the coverage of the land-use class within a single grid cell. The final locations of the 24 sample plots are shown in Figure 23 and Figure 24.

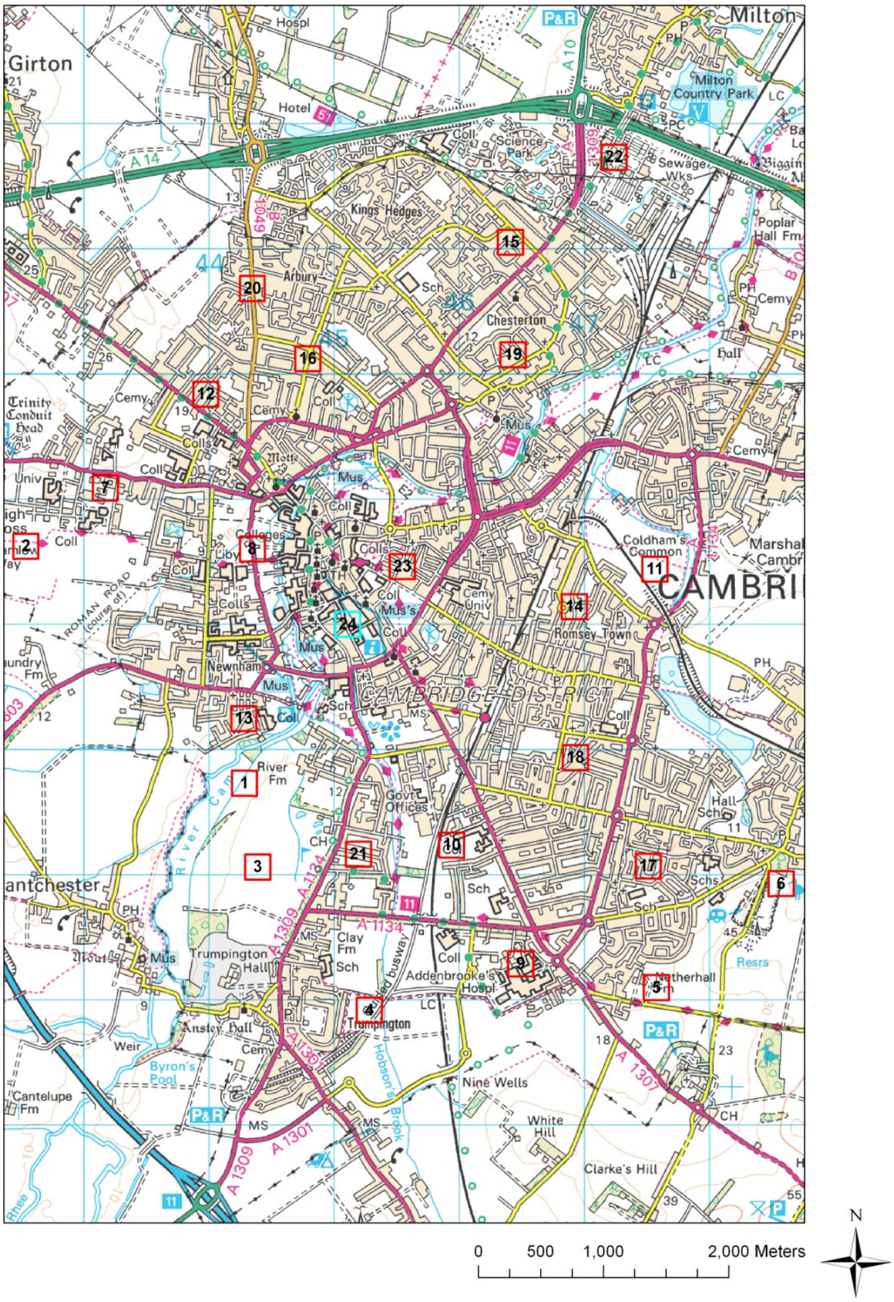

Figure 23. Locations of sample plots within the City of Cambridge

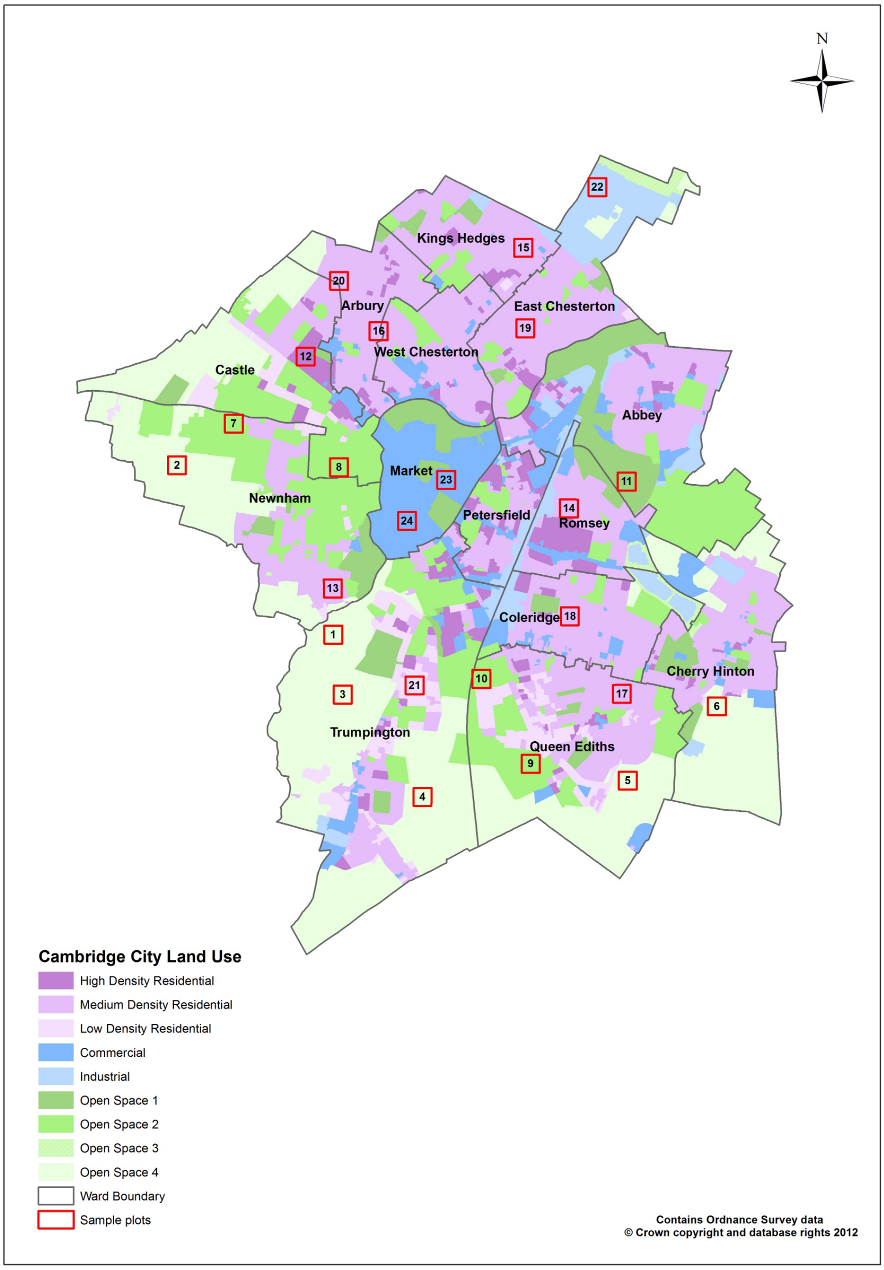

Figure 24. Locations of sample plots in relation to the land-use classes in Cambridge

To calculate the confidence limits of the estimate of mean tree density at City level, the mean and variance of tree density were first calculated independently per stratum. The overall mean was then estimated by summing the products of the stratum mean and 'weight' (i.e. the proportion contribution to the overall area). The variance of the estimate was calculated and subsequently the approximate 95% confidence limits.

4.2.2 Field survey methodology

All surveyors were experienced Arboriculturists qualified to level 5 or above of the National Qualifications Framework.

4.2.2.1 Equipment

Each surveyor was provided with a hand-held computer (Panasonic Toughbook) with integrated GPS, trunk diameter tape, waterproof clipboard and high visibility vest. They were also given a map and aerial photographs for each sample plot, showing the precise location and grid references for every plot to be surveyed.

4.2.2.2 Procedures in the field

Data were recorded on every clearly visible tree, or group of trees, within each selected plot, using Panasonic Toughbooks. All visible shrubs greater than 2.5m tall were also recorded. Surveyors were not expected to seek access to back gardens or other small plots of private land; although every reasonable effort to view the trees was expected.

Permission for access to industrial sites, hospitals, utility owned land or other larger plots of private land was sought in every case.

4.2.2.3 Survey Data

An excel spreadsheet was used to record data on each tree or group of trees.

Trees were assessed as follows:

4.2.2.3.1 Location

The GPS Northing/Easting value was recorded.

4.2.2.3.2 Groups

Surveyors were asked if the tree(s) in question formed a group. Groups were defined as "*two or more trees that clearly form a single entity of mutual benefit*" i.e. where their value to the amenity and landscape of the area was as a group rather than as individuals. A group of trees could be in a line or in a cluster. If trees were considered to form a group, then the surveyor would estimate the number of trees and species in that group.

4.2.2.3.3 Tree number

Each tree or group of trees, within the plot was uniquely numbered.

4.2.2.3.4 Ownership

The apparent 'status' or ownership of the land upon which each tree or group was located was recorded. Trees were placed in one of the following three categories:

Public: Trees that stand within public ownership – either within the roadside verge, pavement, central reservation, parks or open space that can be clearly seen and readily accessed.

Private: Trees in gardens, churchyards, schools, allotments, private parking areas etc.

Unknown: Trees on land where ownership is not clear.

4.2.2.3.5 Species/variety

A list of common tree species was embedded within the excel spreadsheet. If the species was not within the list then they would manually make a note of it in the spreadsheet.

4.2.2.3.6 Stem Diameter

Stem diameter was measured at 1.5 m above ground level using a diameter tape. If not on level ground, diameter was measured from the upper side of the tree. For multiple-stemmed trees surveyors were instructed to either measure the diameter of all stems and record the average, or (if more appropriate) measure around the base of the tree below all branches forks. The trunk/stem diameter was entered as being within one of the following five bands:

- 0.0-4.9 cm
- 5.0-9.9 cm
- 10.0-29.9 cm
- 30.0-59.9 cm
- 60+ cm

4.2.2.3.7 Height

Tree or shrub height was estimated from the ground to the top-most shoot-tip, and recorded in one of the following six bands:

- 0.0–2.4 m
- 2.5–4.9 m
- 5.0–9.9 m
- 10.0–14.9 m
- 15.0–19.9 m
- 20.0+ m

4.2.2.3.8 Crown spread

The maximum diameter of crown spread was estimated, regardless of orientation, and entered in one of the following six bands:

- 0.0–1.9 m
- 2.0–4.9 m
- 5.0–9.9 m
- 10.0–14.9 m
- 15.0–19.9 m
- 20.0+ m

4.2.2.3.9 Age

Age was estimated in years, and recorded in one of the following six bands:

- 0-5 years
- 5-10 years
- 10-25 years
- 25-50 years
- 50-100 years
- 100+ years

4.2.2.3.10 Maturity

Tree maturity was estimated and entered in one of the following five categories:

• Young, obviously planted within the last three years (unless as a heavy or extra-heavy standard).

• Semi-mature recently planted and yet to attain mature stature; up to 25% of attainable age.

• Early mature almost full height, crown still developing and seed bearing; up to 50% of attainable age.

• Mature full height, crown spread, seed bearing; over 50% of attainable age.

• Late mature, full size, developing early signs of decline.

• Over mature, full size, die-back, small leaf size, poor growth extension.

4.2.2.3.11 Condition

Trees were allocated to one of four tree condition categories, taking into account, health, vigour, local environment, vandalism, pathogenic attack, etc.:

• Good no evidence of disease or damage. Full leaf, no die-back, good branch structure.

• Fair minor evidence of disease/damage. Minor deadwood. Not life threatening.

• Poor condition extensive evidence of disease or damage. Life threatening. Dieback in crown, poor callus growth on wounds.

• Dead/Dying obviously moribund, severely diseased.

4.2.3 Comparison to ProximiTREE data

As discussed in section 4.2.2, not all of the areas in a sample plot could be accessed to adequately survey trees. In order to make valid comparisons between ground survey data and ProximiTREE data, the ‘no access’ areas were digitised as polygons and any ProximiTREE tree points falling within these polygons excluded from the analysis. The corresponding ProximiTREE canopies for the remaining tree points were selected based on their unique ID.

Counts of trees within each land-use class were compared for ground surveyed trees and ProximiTREE trees. The distributions in height class and crown spread class were also compared between the two samples.

4.3 Results

A total of 4639 trees were surveyed within an area of 74.2 ha. Of the surveyed trees, 1123 were surveyed as individuals and 3516 as groups. The calculated average tree density and 95% confidence level for the City based on this stratified sample was 58.5 ± 8.3 ha^{-1} (with the caveat of the surveyed residential and commercial areas not being fully representative due to the inaccessible areas). The numbers of surveyed trees, the land area surveyed (i.e. accessible) and the resulting estimate of tree density per land use class are shown in Table 9. Highest tree densities (>80 ha^{-1}) were found in the Industrial, Open Space 2 (institutional) and Open Space 4 (remnant countryside) land use classes. Densities were also high (>60 ha^{-1}) in Low Density Residential and Open Space 1 (amenity land). The lowest density was recorded in the Town Centre & Commercial land use class. The 95% confidence levels (for land use classes with more than one plot surveyed) show that the largest variation in density between sample plots, and therefore the lowest confidence in the estimate at land use class level, was for the Open Space 2 class.

Table 9. Numbers and densities of surveyed trees by land use

Land Use	*Surveyed Trees*	*Surveyed Area (ha)*	*Density (Trees ha^{-1})*	*95% CL*
Commercial	42	5.9	7.1	1.6
Industrial	189	2.3	80.5	-
Low density	42	0.7	63.7	-
Medium density	657	20.0	32.8	9.4
High density	61	2.6	23.7	-
OS1	247	4.0	61.8	-
OS2	1352	15.5	87.2	286.4
OS4	2049	23.2	88.4	41.6

4.3.1 Comparison to ProximiTREE data

The numbers of surveyed trees compared to the numbers of trees estimated by ProximiTREE for the same land areas are shown in Figure 25. Counts were very similar in the Industrial and all of the Residential land use classes (ProximiTREE counts within 5% of survey counts for Industrial, Medium and High density). In the Commercial & Town Centre land use class, ProximiTREE estimated there to be over twice as many trees than recorded during ground survey. In the Open Space classes, there were three to four times more trees recorded during ground survey than were estimated in the ProximiTREE dataset for the same areas. Overall, there were over twice as many trees identified by ground-survey (4639) than by the ProximiTREE method (2215) for the same area.

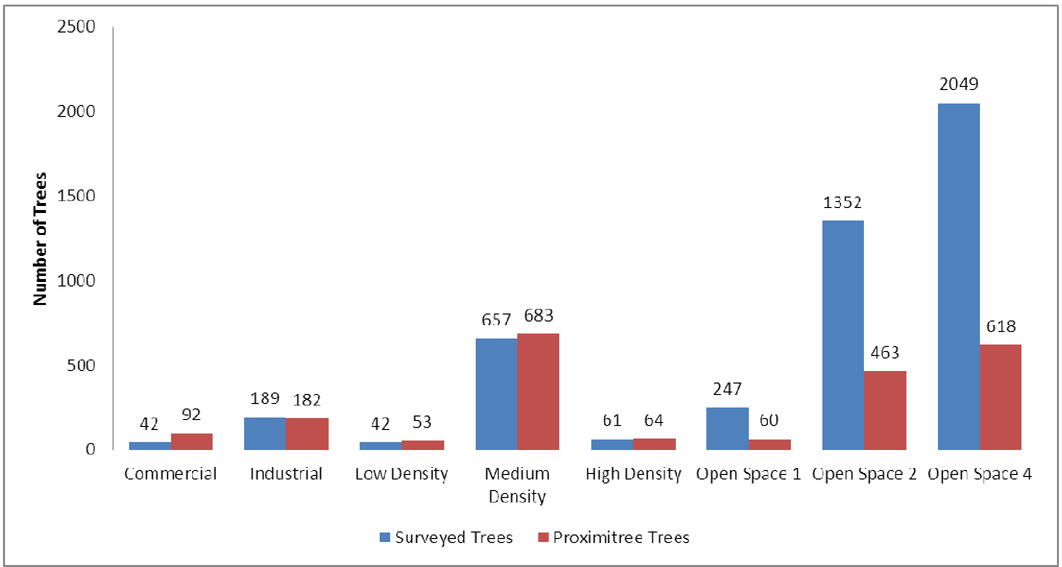

Figure 25. Estimates of numbers of trees from ground survey and from ProximiTREE capture from aerial photography by land-use class for surveyed areas

The distribution between height classes of ground-surveyed trees compared to ProximiTREE trees for the total surveyed area is shown in Figure 26. There were more trees in the 10.0–14.9m class and fewer in the 2.5-4.9m class in the ground-surveyed sample compared to the ProximiTREE sample.

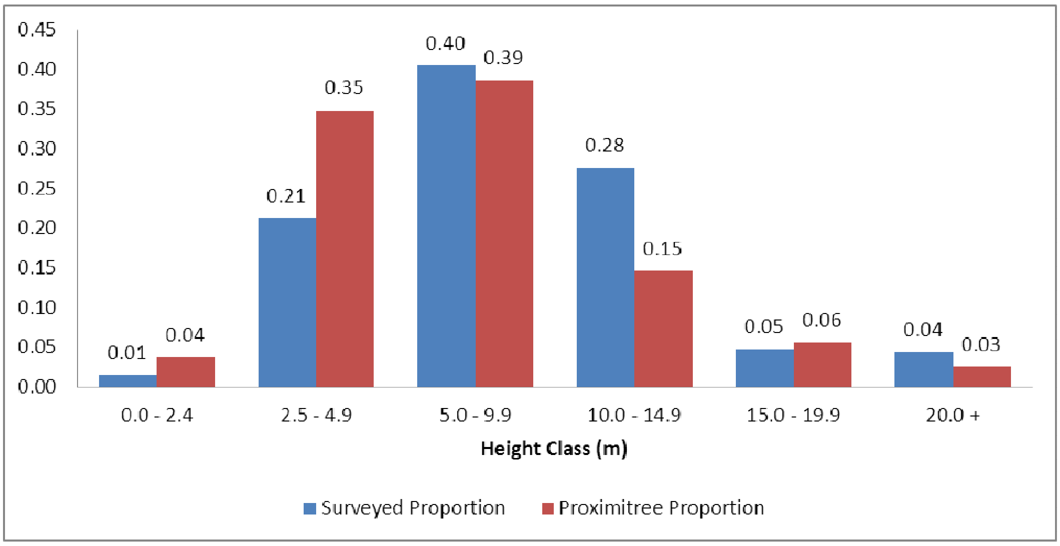

Figure 26. Proportional distribution of ground-surveyed and ProximiTREE trees between height classes for the total surveyed area

The distribution between crown spread classes of ground-surveyed trees compared to ProximiTREE trees for the total surveyed area is shown in Figure 27. There were more trees in the 0.0-1.9m and 2.0-4.9m classes and fewer in the larger classes in the ground-surveyed sample compared to the ProximiTREE sample.

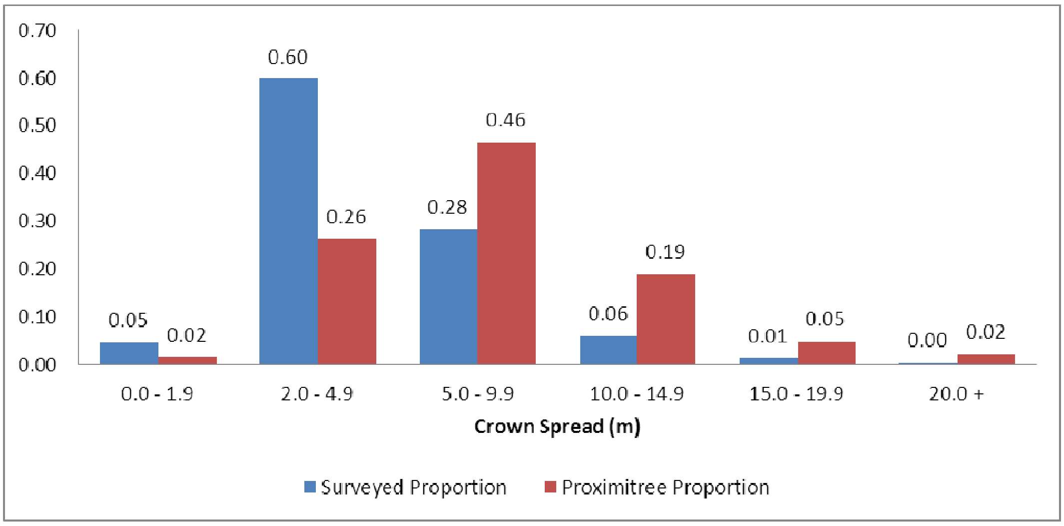

Figure 27. Proportional distribution of ground-surveyed and ProximiTREE trees between crown spread classes for the total surveyed area

4.3.2 Characterisation of City stock

4.3.2.1 Taxonomy

The percentage of surveyed tree stock by genus is shown in Figure 28. Over 20% of surveyed trees belonged to the *Fraxinus* genus, all of these being common Ash species. Over 15% belonged to the *Prunus* genus, mostly cherry species. The next most common of the surveyed trees were *Tilia* (lime species), *Malus* (apple/pear) and *Cupressus* (Leyland cypress).

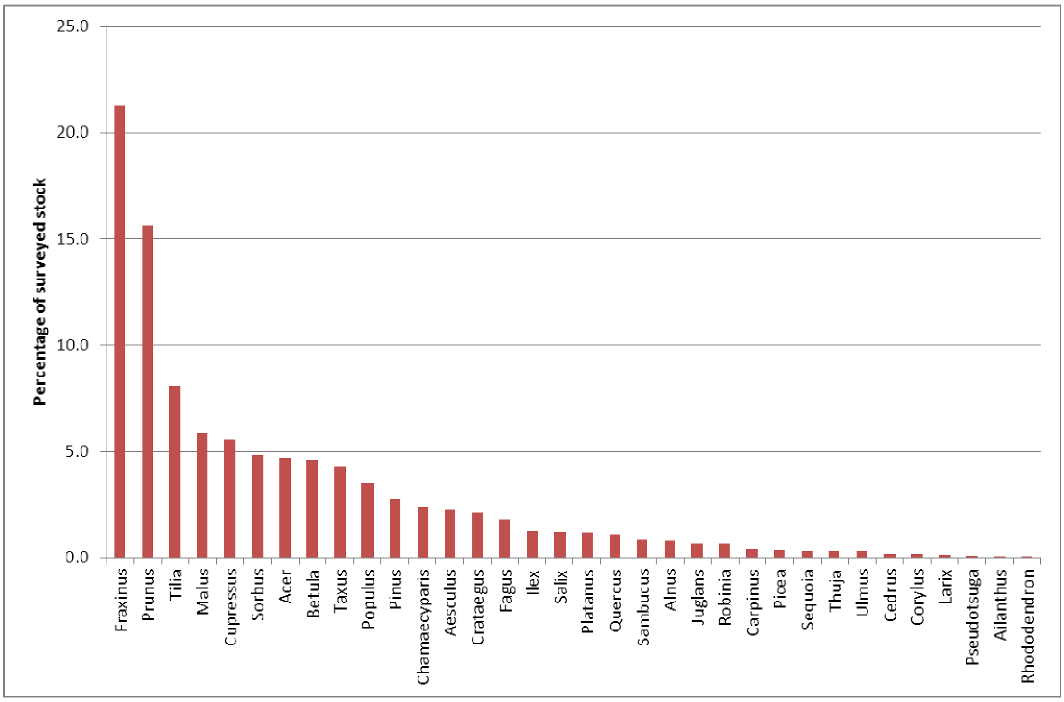

Figure 28. Percentage of surveyed tree stock by genus

At a family level (Figure 29), the most common amongst the surveyed trees were Rosaceae (28%), followed by Oleaceae (21%), with these two families making up almost half of the surveyed tree stock.

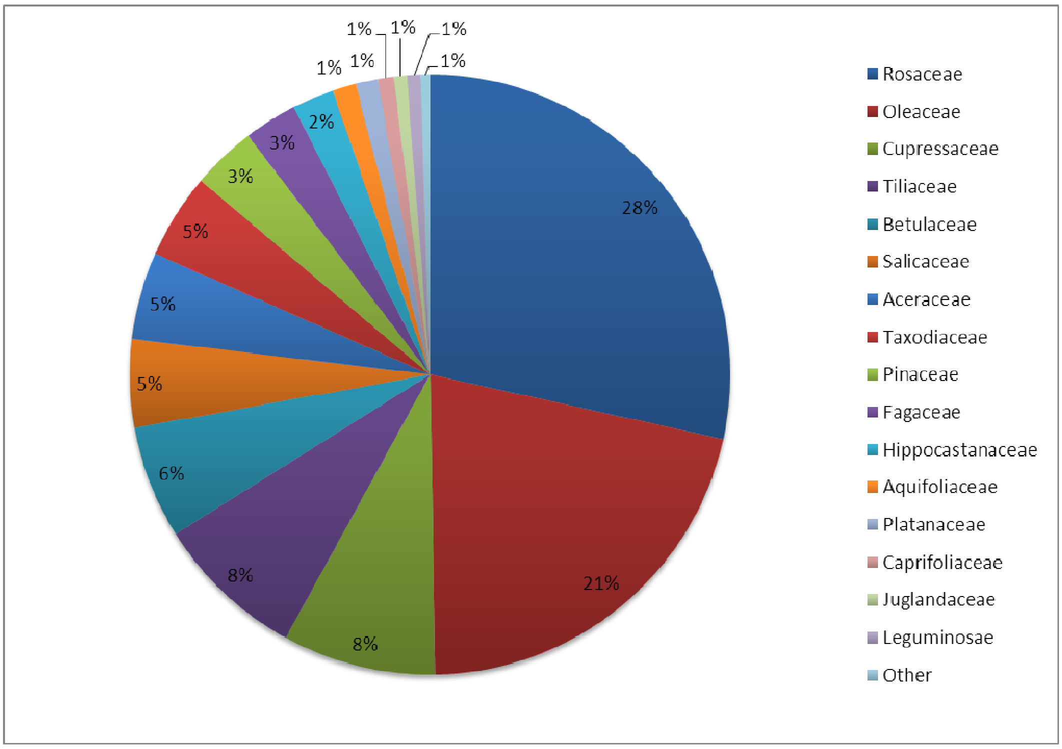

Figure 29. Percentage of surveyed tree stock by family

4.3.2.2 Condition

The distribution between condition categories of surveyed trees is shown in Figure 30. The vast majority (71%) were in good condition. Only 2% of surveyed trees were in poor condition or dead/ dying.

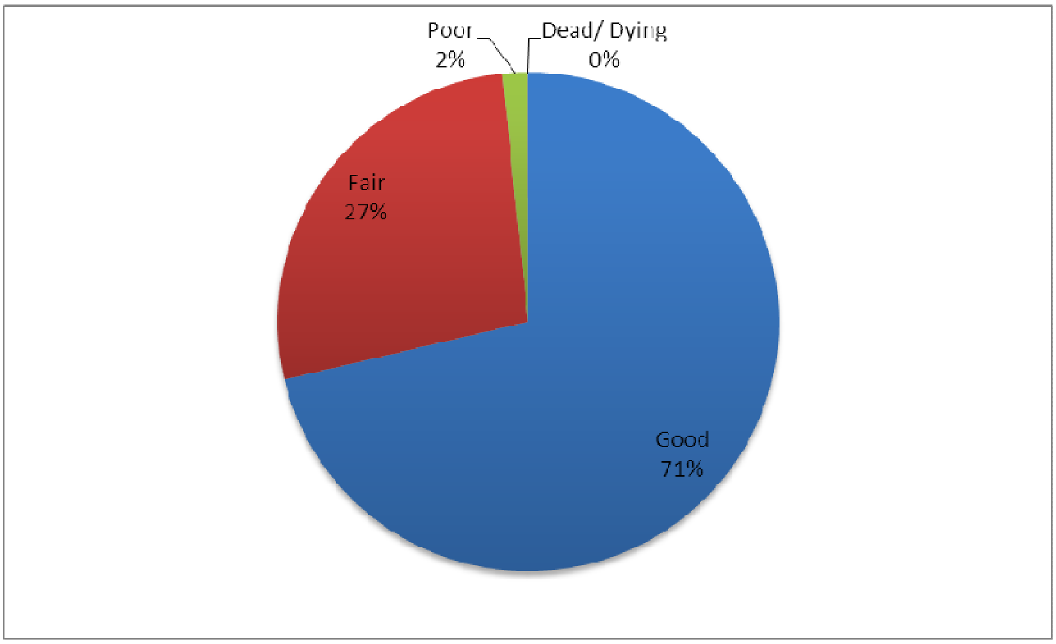

Figure 30. Percentage distribution amongst condition categories for surveyed trees

4.3.2.3 *Stem diameter*

The distribution in stem diameter amongst the surveyed trees is shown in

Figure 31. The majority (38%) of surveyed trees had a stem diameter of 10.0-19.9cm. Twenty-seven percent had a stem diameter of 20.0-29.9cm.

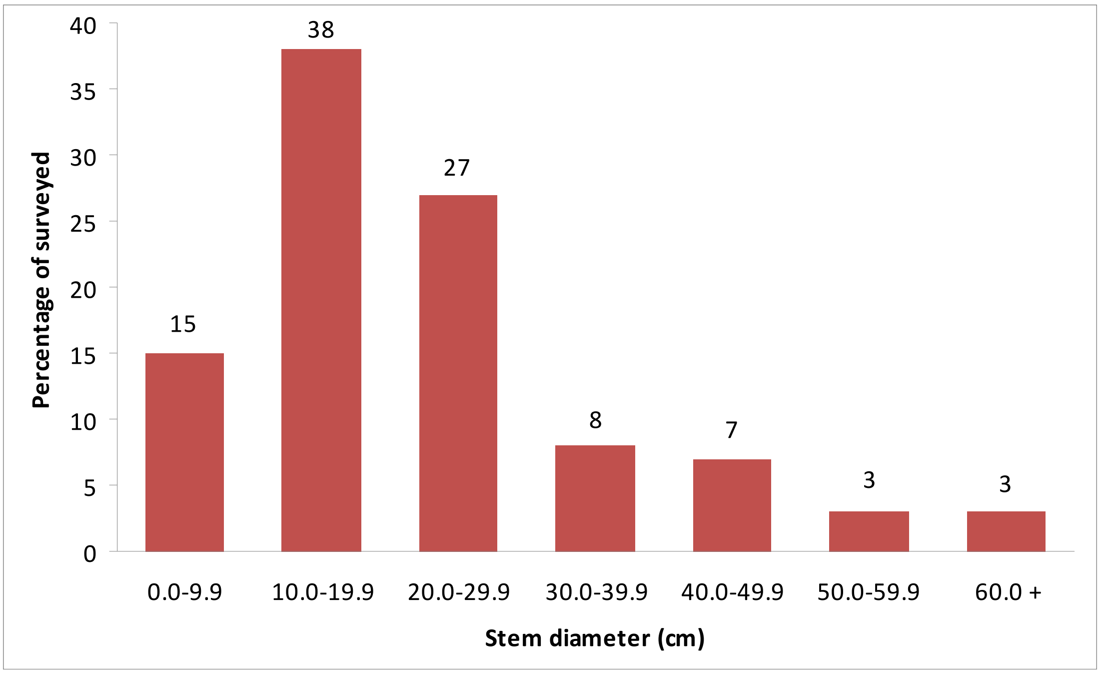

Figure 31. Percentage distribution amongst stem diameter classes for surveyed trees

4.3.2.4 *Age & Maturity*

The distributions between age and maturity classes of surveyed trees are shown in Figure 32 and Figure 33 respectively. Forty percent of trees were estimated to be between 5 and 10 years old, with 32% estimated at between 25 and 50 years old. Forty percent of trees were classed as semi-mature and 32% as young.

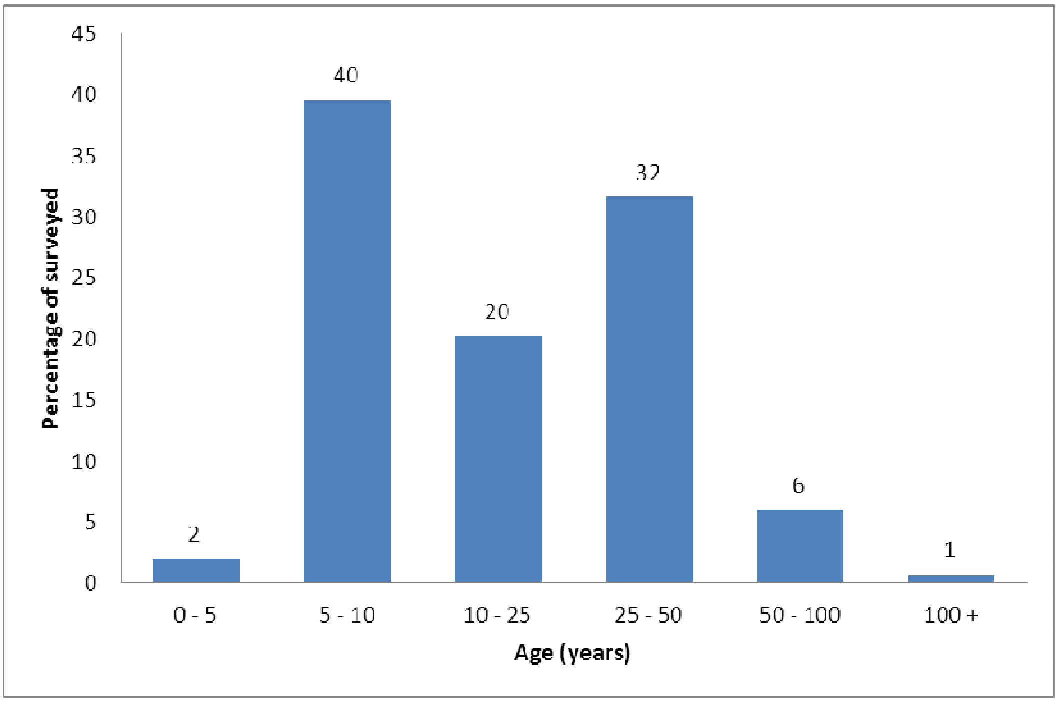

Figure 32. Percentage distribution amongst age classes for surveyed trees

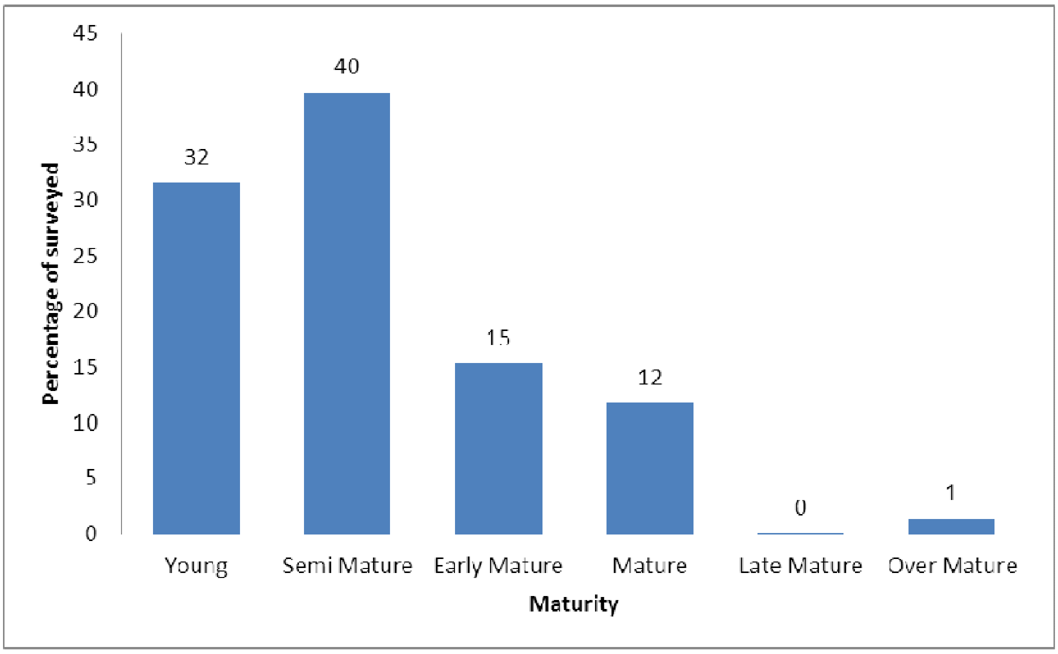

Figure 33. Percentage distribution amongst maturity categories for surveyed trees

4.4 Discussion

The calculated average tree density and 95% confidence level for the City based on the ground-survey sample was 58.5 ± 8.3 ha^{-1} compared to the density of 33.2 ha^{-1} estimated by the ProximiTREE data. Whilst the estimate from the ground-survey is biased towards accessible land, the direct comparison of counts from the two methods at a land-use level indicates that the remotely captured data is significantly under-estimating tree densities where there are areas of dense woodland, particularly in the open space land use categories. In other land-use classes, counts for the same areas were approximately similar. Higher counts using the ProximiTREE method in some land-use classes, particularly Town Centre & Commercial, may be due to the mis-classification of shrubs as trees.

The discrepancy in density estimates for the Industrial land-use class (ground-survey estimate approximately four times higher) is probably due to the sample plot containing dense groups of trees.

It is concluded, from comparison of ground-survey results with ProximiTREE data in the equivalent areas, that the ProximiTREE estimates of tree density for all land-use classes apart from the Open Space categories are relatively robust. Where dense woodland is present, estimates may be 3-4 times lower than they should be, and this should be taken into account in any interpretation of analyses using tree densities. It is recommended that canopy densities are used as the main metric for setting tree planting targets (McPherson et al 1998, see section 5.3).

Surveyed trees tended to be taller than ProximiTREE trees, particularly in the middle height classes. This could be explained by four-years' worth of growth between the date of the aerial photography from which the ProximiTREE data were captured (2008) to the date of ground survey (2012).

Comparisons can be made of the taxonomy of surveyed trees to those of the Council-owned stock. The most common family of trees in both samples was Rosaceae (28% of trees in the ground survey sample and 33% of Council trees). Betulaceae and Tiliaceae also appeared in the top four for both samples. Olaceae and Cupressaceae were more common in the ground survey sample than in the Council stock, whereas Aceraceae were more common in the Council stock. At a genus level, *Prunus* represented approximately 15% of trees in both samples. *Fraxinus* was the most commonly represented genus in the ground-survey sample (20%) but made up only 7% of Council-owned stock. Tilia was well represented in both samples. Malus and Cupressus were in the top five of the ground-survey sample but not the Council-owned stock, and Acer, Betula and Sorbus were in the top five for the Council-owned stock but not the ground-survey sample.

Comparisons of tree condition can also be made between ground survey results and assessed Council-owned stock. Whilst the majority of trees from both samples were in good condition, a higher percentage (71%) were assessed as being in good condition in the ground-survey sample compared to 56% of Council-owned stock. Seven percent of assessed Council trees were found to be in poor condition or dead, whereas only 2% of ground-surveyed trees fell within these categories.

The results of the ground-survey provide a baseline against which future changes in the City tree stock and its characteristics can be assessed. It is recommended that accessible surveyed areas are re-surveyed every year or two years in order to monitor effects of implementation of local policy with respect to improving both the quantity and quality of the tree stock in the City. Field maps showing the sample plots and approximate locations of surveyed trees and the final data from the tree surveys are provided in Figures 23 and 24 to assist in this process. It is also advised that access is gained to a sample of back gardens by Council Arboriculturists, since gardens were under-represented in the ground-survey in this study due to lack of easy access.

5 Comparison with Results from *Trees in Towns II*

5.1 Introduction

This study has used some of the same classifications as the *Trees in Towns II* study for analysing tree stock. Therefore some basic comparisons can be made between them, in order to determine the similarities and differences between the urban tree stock in Cambridge and the *Trees in Towns II* sample areas across England. Comparisons are made between Cambridge and the results from other large towns (population > 800,000), the East of England and England as a whole.

The *Trees in Towns II* sample was stratified by English region; size of town/ city (small, medium and large); land use (low density residential, medium density residential, high density residential, town centre/ commercial, industrial, open space). One 200x200m (4ha) plot was selected for field survey within each stratum. Where possible, up to three further replicate sites per land use type per town were remotely surveyed using aerial photography.

For the field survey, data were recorded on every clearly visible tree, or groups of trees, within each plot. This included all visible shrubs >2.5m tall. Height and crown spread of individual trees were recorded. For the aerial photograph survey, the vegetation canopy associated with any individual trees or clusters of trees was digitised. No attempt was made to count trees from the imagery or use height criteria in the definition of a tree. It is therefore likely that errors of omission and co-mission were made.

Differences between the *Trees in Towns II* (TTII) methodology and the Cambridge City tree audit that should be taken into account when drawing comparisons include;

- TTII is a sample, not a full survey
- TTII was a ground survey supported by data capture from aerial photography
- Transport corridor was not included in TTII
- Areas of formal recreation, such as golf courses and sports complexes, were excluded from TTII
- Woodland was not included as one of the primary LU classes in TTII
- For each land use class, up to four sample sites were taken from within a single land use class polygon, rather than scattered throughout the town

It is assumed that the data capture from aerial photography for estimation of canopy cover produced similar degrees of error as those expected from the ProximiTREE data.

5.2 Tree Densities

The average number of trees per ha in Cambridge as estimated from ProximiTREE data is similar to the *Trees in Towns II* results (England average) for medium and high density residential areas (~60 and ~30 trees ha^{-1} respectively) and town centre/commercial areas (~25 trees ha^{-1}). However, for the low density residential, industrial and open space land use classes, the number of trees per ha in Cambridge was found to be considerably lower than in the respective land use classes surveyed in the *Trees in Towns II* study (Figure 34). Across all land use classes, tree density in Cambridge was calculated to be 33 trees ha^{-1}, whereas the average density of trees and shrubs recorded in the East of England in the *Trees in Towns II* survey was 74.7 ha^{-1}. The ground-survey completed as part of the current study estimated tree density in the City to be intermediate between these two densities at 58.5 ha^{-1}.

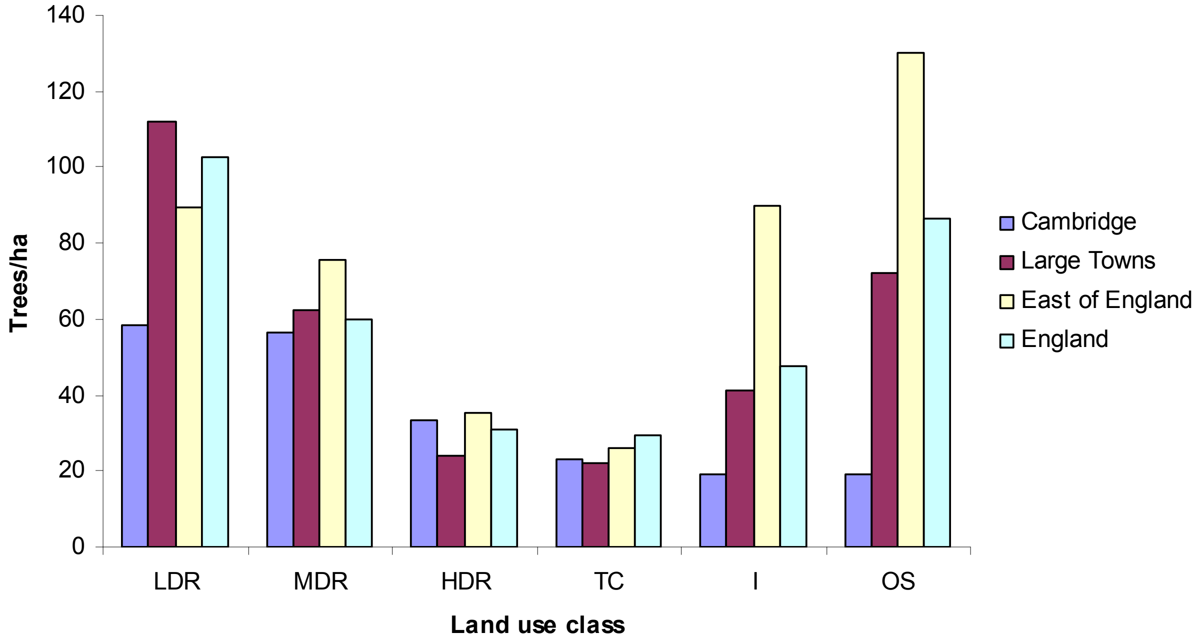

Figure 34. Mean number of trees per ha for each land use class in Cambridge estimated from ProximiTREE data; and in the *Trees in Towns II* sample for large towns across England, towns in the East of England region and for all urban areas across England

The variation in the number of trees per ha between the different land use classes was less pronounced in Cambridge compared to the *Trees in Towns II* areas. This may be due to difference in sampling and surveying techniques between the two studies. Whereas the entire area covered by Cambridge city council was classified and surveyed in this study, the *Trees in Towns II* study relied on surveying sample plots of a designated size and shape. This will have produced sampling errors associated with the use of a sample rather than a census. This is backed up by results of the ground survey sample, which shows that there can be large variation in tree densities between sample plots within the same land-use class.

The number of trees in Cambridge was captured from aerial photography. Therefore some individual trees may have been missed due to their size or because, in areas with many trees grouped together, not all the trees were captured. We have evidence from the ground-truthing that this was the case, certainly for some of the Open Space land-use classes. This will have resulted in an underestimation of the number of trees per hectare in certain land-use classes, particularly where a number of trees are likely to be grouped together, such as in open spaces (OS) and gardens associated with low density housing (LDR).

In Cambridge, large areas were classified as remnant countryside open space. These areas are large agricultural fields mostly devoid of trees. This is likely to have contributed to the great difference in open space tree density in Cambridge, compared to the *Trees in Towns II* areas.

5.3 Canopy Densities

Tree canopy cover can be defined here as the proportion of land covered by the canopy area of trees. While canopy cover can only provide two-dimensional insight and is not necessarily suitable to predicting future trends without supporting data, it is nonetheless a valuable metric by which to measure urban tree characteristics. In particular, McPherson *et al*. (1998) identify canopy cover's usefulness as a metric as stemming from the potential to use it for comparison across and between cities, regardless of size of total land cover. Similarly, canopy cover allows for identification of change over space and time at a relatively low cost in comparison to field sampling.

Based on ProximiTREE data, calculated canopy density in Cambridge was considerably higher than the Trees in Towns estimates for large towns, the East of England and England as a whole for all land use classes apart from Open Space 1 and Open Space 4 (Figure 35). Over the whole of the City, the canopy cover estimate was approximately 17% of the total land area. The overall mean canopy cover, derived from aerial photography, of the plots in *Trees in Towns II*, was 8.2%.

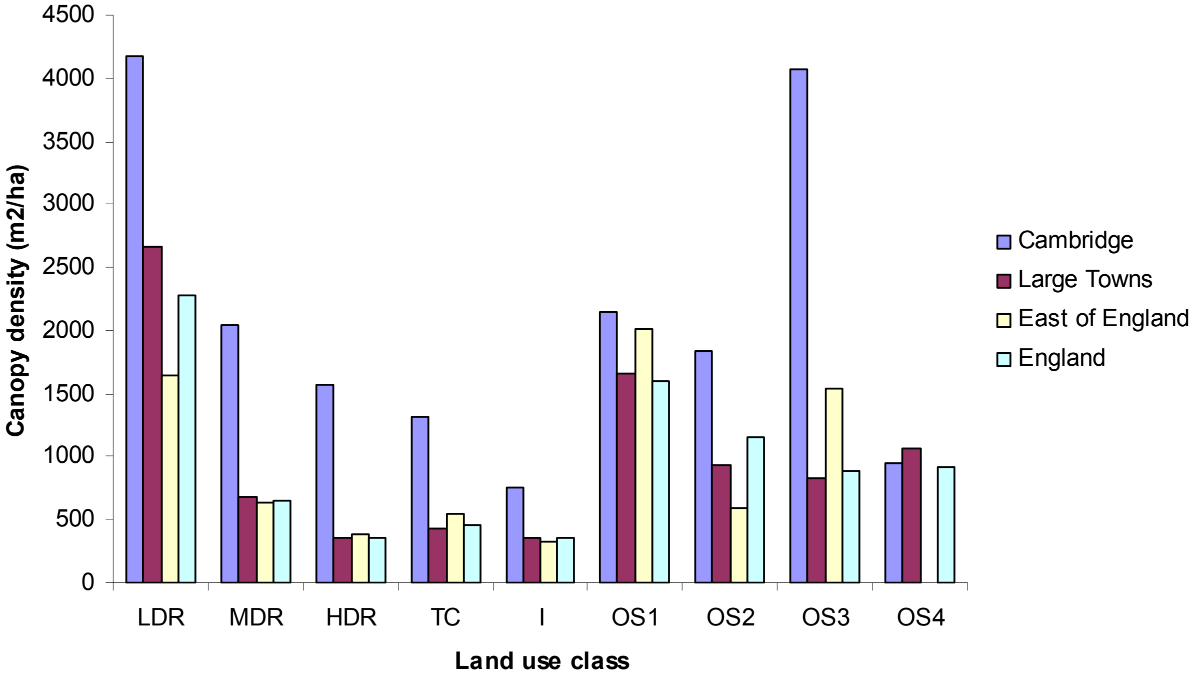

Figure 35. Canopy cover density (m^2 per ha) for each land use class in Cambridge (ProximiTREE data); and in the *Trees in Towns II* sampled large towns across England, towns in the East of England region and for all urban areas across England[3]

This is an unexpected result for Cambridge given the lower estimates of tree density compared to the *Trees in Towns II* results, albeit likely not as low as estimated by the ProximiTREE method. Perhaps the most obvious explanation is that for certain land use classes, Cambridge may have fewer yet older trees, which have much larger canopies.

The relatively high canopy cover value for Open Space 3 (derelict, neglected and abandoned open space) in Cambridge may be due to this land use class being severely unrepresented in Cambridge (see Figure 1). The small land area that does fall into this class includes areas densely populated with trees, surrounding the reservoirs. Therefore these areas are not easily comparable to what would typically be considered derelict, neglected or abandoned open space within other urban areas.

[3] Canopy density of OS4 (Remnant Countryside) land for East of England is not available.

Land associated with University colleges, surrounding Cambridge town centre, was classified as institutional open space (OS2). However, the land belonging to the University of Cambridge within the historic centre of the city was classified as town centre (TC). Generally this land is more built up than the colleges outside of the main commercial centre of Cambridge. However, there is still a higher tree density than what is perhaps typical of other town centres. This may be a contributing factor to the high canopy cover density in the TC land use classification in Cambridge, compared to the *Trees in Towns II* results.

5.4 Height and Crown Spread Groupings

Generally, in Cambridge there are markedly fewer trees ha^{-1} that fall into the lower height bands, compared to areas surveyed across the East of England as well as the average across England as a whole (Figure 36). However this difference becomes less pronounced in the higher groups.

The TTII study shows there is a great regional variation. For example in the 5.0 – 9.9 m height group, the mean number of trees was ~15 ha^{-1} across England, which is in line with what was found in Cambridge (~13 trees ha^{-1}); however, across the areas surveyed in the East of England, the number of trees ha^{-1} is approximately double. In the highest two bands (15.0 – 19.9 and 20+ m), the tree density in Cambridge are very similar to the East of England, although less than the average across the whole of England.

Overall the number of trees per ha recorded from aerial photography in Cambridge by ProximiTREE are lower than the TTII results (as discussed in Section 5.2). From these results it appears likely that the capture of trees from aerial photography may have missed smaller trees, resulting in the trees in this height group being under represented.

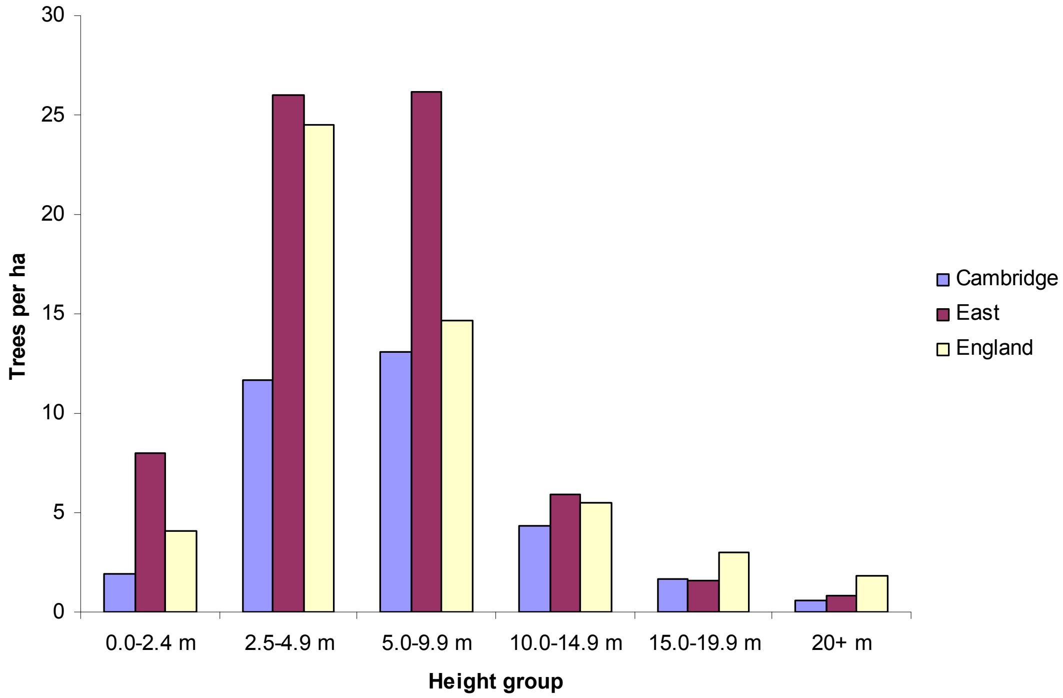

Figure 36. Mean number of trees per ha in each height group for Cambridge (ProximiTREE data), compared to TTII surveyed areas in the Eastern region and across England

A similar relationship between the lower and higher bands was found between the canopy spread groups. Cambridge appears to be severely under represented in the lower bands (i.e. a canopy spread of < 5.0 m), yet over represented in the higher bands, in comparison to the Eastern region and England (Figure 37).

Similarly to the difference in height group, the under representation in the lower groups may be due to smaller trees, with a small canopy spread, being 'lost' in the capture from aerial photography. However, it is apparent that Cambridge has a relatively high density of trees with a larger canopy spread, particularly compared to the rest of the East of England. This supports the hypothesis that Cambridge has a larger density of more mature trees with larger canopies compared to other towns and cities.

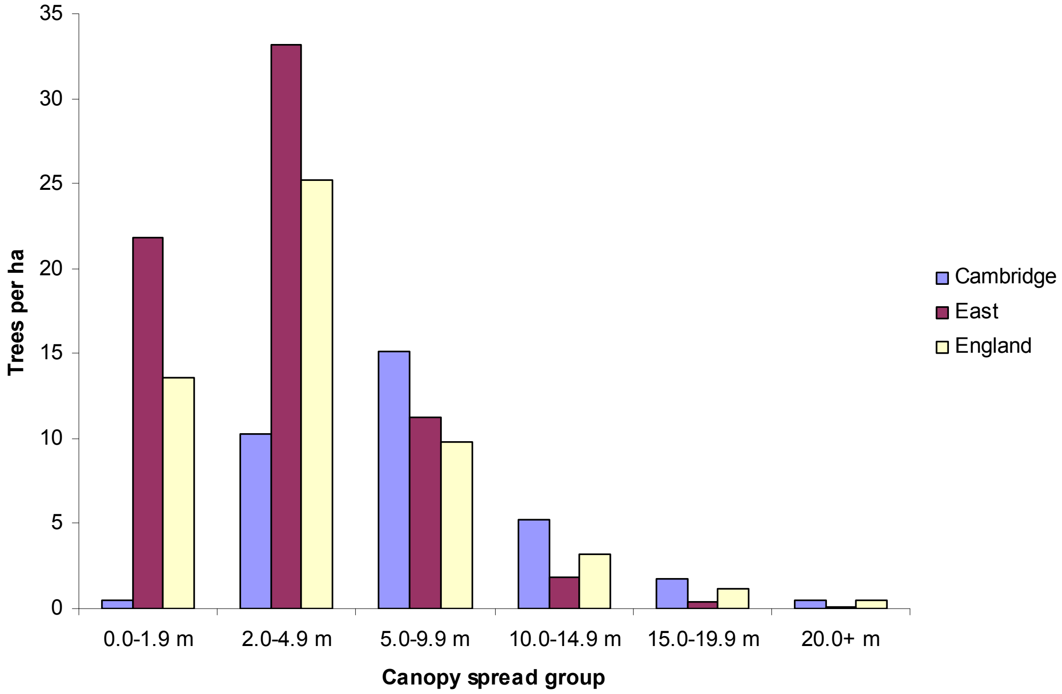

Figure 37. Mean number of trees per ha in each canopy spread group for Cambridge (ProximiTREE data), compared to TTII surveyed areas in the Eastern region and across England

There are a number of similarities and differences between the height group divisions by land use in the TTII study and Cambridge (

Table 10). Similar to TTII, the low density residential (LDR) areas in Cambridge have the highest density of trees in the taller height groups compared to other land use classes. In the TC class, Cambridge has similar tree densities in all the height groups, compared to TTII. This is also true for MDR and HDR; although Cambridge has a higher density of trees between 5 and 10 m and a lower density of trees less than 5 m, compared to TTII.

Table 10. Average number of trees per ha in each height class by land use in Cambridge (ProximiTREE data) and for all the sample areas across England in the TTII study

Land-Use class	Tree height group											
	0.0-2.4 m		2.5-4.9 m		5.0-9.9 m		10.0-14.9 m		15.0-19.9 m		20+ m	
	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII
LDR	1.9	4.4	12.9	34.9	25.6	21.5	11.5	11.4	5.4	9.0	1.4	4.4
MDR	4.0	5.6	23.4	30.3	22.0	15.6	4.9	4.9	1.2	1.2	0.3	0.6
HDR	1.6	2.0	8.8	17.5	15.2	7.2	5.3	2.4	2.2	1.0	0.5	0.3
TC	1.4	0.9	6.7	12.6	8.4	8.5	4.0	3.9	1.9	1.4	0.5	0.9
I	0.8	2.2	6.7	20.1	8.7	16.3	2.6	3.1	0.3	0.7	0.0	0.4
OS	0.7	11.2	5.1	31.1	7.2	19.9	3.5	7.4	1.8	5.7	0.8	5.5
Mean	**1.9**	**4.1**	**11.6**	**24.5**	**13.1**	**14.7**	**4.3**	**5.5**	**1.7**	**3.0**	**0.6**	**1.8**

Within Cambridge, densities of trees with a very small crown spread are much lower than those in the *Trees in Towns II* sample across all land use types (Table 11). Similar to the *Trees in Towns II* results, for crown spread classes greater than 5m, the low density residential land use class have more trees per ha than any other land use class. However, whereas open space surveyed by TTII also had a large share of the trees with a wide canopy spread, in Cambridge open space has a modest share of larger trees. In both Cambridge and the TTII sample areas, industrial areas have the lowest density of trees, demonstrated by the preponderance of this group having a canopy spread of less than 10 m.

Table 11. Average number of trees per ha in each canopy spread class by land use in Cambridge (ProximiTREE data) and for all the sample areas across England in the TTII study

Land-Use class	Canopy Spread group											
	0.0-1.9 m		2.0-4.9 m		5.0-9.9 m		10.0-14.9 m		15.0-19.9 m		20.0+ m	
	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII	Cam	TTII
LDR	0.1	18.1	8.6	37.3	28.5	18.1	15.5	7.7	4.9	3.1	1.1	1.3
MDR	1.2	18.7	21.6	28.0	26.3	9.1	5.5	1.6	1.0	0.5	0.1	0.2
HDR	0.2	8.9	9.4	14.3	16.9	5.5	5.4	1.2	1.4	0.4	0.3	0.2
TC	0.4	4.8	6.8	13.6	9.7	7.3	4.5	1.9	1.3	0.6	0.3	0.2
I	0.2	9.8	6.9	25.2	9.1	6.5	2.5	1.2	0.5	0.3	0.1	0.002
OS	0.1	22.1	3.8	33.4	7.8	13.1	4.6	7.0	2.1	3.6	0.7	1.6
Mean	**0.5**	**13.6**	**10.3**	**25.2**	**15.1**	**9.8**	**5.2**	**3.2**	**1.7**	**1.2**	**0.5**	**0.5**

5.5 Conclusions

Following on from analysis and comparison of tree characteristics, a number of conclusions can be drawn:

- Generally, the tree density in Cambridge as estimated using the ProximiTREE data is lower than the tree densities recorded during the TTII survey. However, the canopy cover density is higher in Cambridge, compared to the sample squares in TTII.
- For tree height, in Cambridge a greater proportion of the trees are in the upper bands, compared to the TTII survey results. The number of trees per ha in the lower height bands, is considerably less in Cambridge compared to the TTII results, especially in the East of England.
- There is an under representation of trees in Cambridge in the lower canopy spread groups (less than 5 m), but over representation in the upper bands (canopy spread greater than 5 m).

These results indicate that Cambridge has a more mature stock compared to other English towns and cities. Therefore, while there are typically fewer trees per ha, these trees have a greater canopy spread, and as a result a higher canopy cover density. It is also likely that the differences between Cambridge and the TTII results are due to differences in survey methodology and sample technique.

When considering the tree stock by land use class, there are a number of similarities between Cambridge and the TTII study:

- Low density residential areas tends to have the greatest number of tree per ha as well as the greatest canopy cover density. These trees also tend to be taller, with a greater canopy spread.
- The number of trees per ha for the medium and low density residential and town centre/commercial land use classes in Cambridge are similar to the sampled areas in the TTII study.
- Trees in industrial areas tend to be shorter with a smaller canopy spread.

There are also a number of differences, the most noticeable of which is that the tree density in open space areas in Cambridge appear to be low compared to the rest of England. Explanations for this are that (i) the method of data capture tends to under-count trees in dense groups, and (ii) the open space in Cambridge consists of large areas of remnant arable countryside, which are sparsely populated with trees, apart from hedgerows and woodland along field boundaries.

6 Comparison with initiatives in other cities

Cambridge City is not alone in assigning a level of importance to urban tree populations in order to mitigate the future effects of climate change. There are numerous studies and policies which have been undertaken and continue to be commissioned across the developed world. The common theme of these studies is to understand the current resource and subsequently enhance this resource to ease the effects of climate change which is generally believed to be a real future threat to urban environments.

The following section offers a comparative illustration of both the distribution of tree stock and the respective arboricultural strategies for a variety of cities and towns in the East of England, across the UK and internationally. For comparative purposes, it should be noted that Cambridge's population stands at nearly 120,000 inhabitants and encompasses a total geographic area of approximately 4070 hectares (Cambridge City Council 2011, Cambridgeshire County Council 2009). The comparison below highlights the characteristics of past, current and future canopy cover (where available) for each example and outlines the key strategies associated with each area. In the UK, attention has primarily been focused on the importance of trees vis-à-vis increasing resilience to future climate change; however more recently, attention has begun to shift towards estimating the current financial and environmental value of a city's tree stock, which has occurred for some time in North America. Perhaps as a result, the North American examples highlighted here are as focused on increasing resilience to *current* weather patterns as to adapting to future climate scenarios, particularly as far as the benefits of canopy cover for stormwater retention could be derived.

6.1 East of England

6.1.1 Ipswich

Area: 4000ha

Population: 138,000

Trees in Towns II canopy cover: Not assessed

Current canopy cover: Around 13%; approximately 100,000 trees on 669ha of council-administered land, figure for non-council owned land not available.

Geography of current canopy: Not available.

Canopy cover goal: 22% by 2050.

Annual planting rate: Not available.

Initiatives, partners and funding: Ipswich's Tree Management Policy was created in 2010 with the aim of supplementing existing tree-focused planning statements and documents to protect the existing stock and plant new trees. A good deal of the report is focused on the importance of understanding the composition and spatial distribution of woodlands and Ipswich's tree stock and points to a gap in information, particularly as far as privately owned trees are concerned. Similarly highlighted is the need to better understand the types of management that take place, the threats and pressures to the urban forest and the need to raise awareness among the community in terms of the value of woodlands and trees in contributing to health benefits and encouraging sustainable communities. The policy also highlights the need to continue increasing the proportion of the budget spent on proactive tree management, and sets out various action points for future management. Action points include, inter alia, encouraging the natural regeneration of canopy cover, managing replacement of dead tree stock by replacing two trees for each council-owned tree which is removed, and establishing different sources of funding for maintaining arboricultural activities.

6.1.2 Norwich

Area: 3900ha

Population: 250,000

Trees in Towns II canopy cover: 11.16%

Current canopy cover: Not available, but there are approximately 750,000 trees in the city area.

Geography of current canopy: Council managed trees comprise just under half the city's tree stock (300,000 total); 11,000 of which are street trees.

Canopy cover goal: No specific canopy targets.

Annual planting rate: Norwich City Council's Tree Strategy aims to plant 450 trees annually in streets and Council land and 500 trees in woodland areas, with specific targets including the planting of a variety of tree species to increase biodiversity.

Initiatives, partners and funding: The City's Tree Strategy covers a number of strategic objectives with specific and pre-determined targets used to quantify success. These objectives include increasing planting and the biodiversity of tree stock, coordinating tree management initiatives by establishing a database of the council's tree stock, and engaging the community on tree-related activities by improving communication and involving locals on various activities, with a continued aim to increase the spend on proactive tree management.

6.2 Rest of UK

6.2.1 Torbay

Area: 6300ha

Population: 131,000

Trees in Towns II canopy cover: Not assessed.

Current canopy cover: 11.8% comprised of 818,000 trees.

Geography of current canopy: Not specifically stated, although the plots that were used to derive the 11.8% total comprised primarily residential land (42%), agricultural land (20%), parks (13%) and commercial/industrial areas (12%). No breakdown of the distribution of trees is given for land use, however.

Canopy cover goal: Not strictly part of the assessment, though up to 8% of Council owned land could be planted.

Annual planting rate: Not available.
Initiatives and partners: Torbay is the first UK-based case study to use the i-Tree Eco tool (www.itreetools.org), a free, peer-reviewed software suite from the USDA Forest Service which has primarily been used in North American cities to quantify the monetary value and ecological services of areas of tree stock. Using UK-specific information (including weather, pollution and phenology datasets) and additional local tree survey data to enhance the assessment, the project valued the structural (replacement) cost of Torbay's tree stock at £280 million, and estimated that the Borough's trees remove approximately 50 tonnes of particulate air pollution annually. Similarly, the tree stock was found to store approximately 98,000 tonnes of carbon annually, equating to a monetary value of about £5 million; carbon sequestration was estimated at 3320 tonnes of carbon per year with an associated value of £200,000. Estimations of energy reduction resulting from tree shading were omitted from the study as available datasets for the US were not compatible for use with the UK scenario, however if these were to be collated, they could be incorporated in future assessments. Crucially, the Borough used this piece of work to justify substantial increases in spending in the existing tree management budget.

6.2.2 Manchester

Area: 11,600ha

Population: 500,000

Trees in Towns II canopy cover: Not assessed.

Current canopy cover: 15.5% (60% of which is on Council-owned land).

Geography of current canopy: 60% on City Council land – approximately twice the national average. Leisure land comprises the majority of Manchester's tree cover at 30.38%, followed by private Gardens (21.7%), Green Space (18.64%) and Street Trees (9.68%).

Canopy cover goal: Not available.

Annual planting rate: Not available, but the Red Rose Forest project aims to plant 25 million trees over 40 years in the Greater Manchester Area (Red Rose Forest, n.d.).

Initiatives, partners and funding: In addition to the Red Rose Forest project, which is targeted at Great Manchester, the city of Manchester was subject to a tree audit in 2007. *Valuing Manchester's Trees: An Audit of Tree Data and Tree Cover in the City (Part I and II*) (Manchester City Council 2008) aimed to compile the existing datasets related to the city's arboricultural characteristics and to identify the distribution of trees and woodlands in Manchester at ward level. In addition to exploring total canopy cover, which differed greatly by ward (from 3.96% in the City Centre to 24.57% in Higher Blackley in the North West), the study also identified canopy cover distribution by ward *excluding* green areas and open space land, with a city average of 11.34%. The study also identified distribution of canopy cover over a variety of land use types and explored links between canopy cover and health. Recommendations included targeting hard-standing areas for planting, particularly in buffer zones near infrastructure corridors (rail, roads and canals), as well as obtaining information on the status of trees managed by Housing Trusts and on private land, as there is currently a lack of information available on trees under both types of management. The study also identified the need to create and maintain a GIS-based Central Tree Database which could be managed and used by a cross-section of stakeholders within the City Council.

6.2.3 Bristol

Area: 11,000ha

Population: 428,000

Trees in Towns II canopy cover: 12.96%

Current canopy cover: 14% (2011) - about 100,000 trees, equating to 324ha of woodland area.

Geography of current canopy: Street trees (10%), Park trees (35%), Housing open space trees (15%), Education sites trees (7%).

Canopy cover goal: 30%

Annual planting rate: Not available; but 3080 trees planted since 2005, over 1,000 of which were planted between April 2011 and March 2012. Provisional plans exist to plant up to 2,000 street trees by 2015 (Horsey, n.d.).

Initiatives, partners and funding: Bristol City Council's TreeBristol scheme (initiated in 2005) is underway to plant trees across the city with the aim of achieving their target canopy cover by allowing individuals to sponsor trees to be planted. The Bristol Tree Forum is a separate initiative under Bristol City Council which aims to bring together a number of stakeholders (neighbourhood partnerships, University staff, City Council officers, arboricultural officers, conservation groups, residents association, city design officers) to protect and enhance Bristol's trees, establish funding to ensure planting can continue in order to meet canopy targets, and provide an open forum for discussion and consultation on tree issues. The forum recognises the value of trees in adapting to and mitigating climate change, and a portion of activities are based around design principles: in particular, establishing a more sustainable ratio of tree canopy cover to hard surfaces in the City. Bristol City Council is also in the process of establishing a Tree Planting Design Guide, which encompasses a number of factors including function, diversity, design, species, support (of residents, for planting) and placement.

6.2.4 Brighton & Hove

Area: 8380ha

Population: 257,000

Trees in Towns II canopy cover: 6.75%

Current canopy cover: Not available; but there are approximately 13,000 street trees and over 500 ha of woodland in Brighton & Hove.

Geography of current canopy: Not specifically available, but categorised as four main elements, including 1) street trees, 2) woodlands (504ha of which are open to public access), 3) trees in parks and open spaces, and 4) trees in housing areas (noted as the smallest of the four in terms of tree stock as little replacement of felled trees has occurred).

Canopy cover goal: Increase tree cover in housing areas and expand plans for tree planting in general to increase urban woodland cover. Aim to replace mature and over-mature trees where necessary and identify other avenues to supplement the Council's allocated budget with additional funding opportunities such as sponsorship, grant aid, and the City's 'Tree Trust' to ensure adequate funds are spent on arboricultural needs.

Annual planting rate: Not available; 3000 trees planted in Millennium Wood (2000) and 900 trees in East Brighton Park (2005), but both on a one-off basis.

Initiatives, partners and funding: Brighton and Hove City Council's Tree and Woodland Strategy (2004) introduces the importance of trees from a sustainability point of view, with an aim that the policy will guide long term management, care and protection of the City's trees and woodlands and with a number of achievable and measureable goals. Street trees are surveyed and record is kept in a tree management database (Arbortrack) and GPS devices are hoped to be used for arboricultural mapping in the future. Tree inspection and pruning for highways is done on a rotational basis (every 2-4 years), and arboricultural inspections in open space and parklands are surveyed and maintained regularly to minimize tree risk.

The City Council's 'Tree Trust' encourages citizens to sponsor a tree or contribute donations to plant trees in parks and open spaces and identifies sixteen such sites around the Council area. The Council also encourages street planting (subject to the appropriateness of the site).

Trees are also addressed in planning guidance through by SPD 06 'Trees and Development Sites' which encourages developers to take into consideration areas requiring maintenance of trees. The Council also provides a number of arboricultural information notes to assist the community with tree planting, including planting in smaller gardens, and to understanding the importance of trees for biodiversity.

6.3 International examples

6.3.1 Toronto, ON, Canada

Area: 63,000ha

Population: 2.6 million

Current canopy cover: 17-20% of the City of Toronto area (2007)

Geography of current canopy: 6% street trees, 34% city parks & natural areas, 60% private property.

Canopy cover goal: 30-40% canopy cover by 2057.

Annual planting rate: 84,000 trees (annual average between 2004 – 2009; this continues to be the annual goal into the future to achieve canopy targets).

Initiatives and partners: The City of Toronto works in conjunction with a number of local and national not-for-profit partners including LEAF (www.yourleaf.org), Evergreen (www.evergreen.ca), Toronto Parks and Trees Foundation (https://torontoparksandtrees.org/) and Trees Canada (www.treecanada.ca) who sponsor, either in full or in part, the city's tree planting activities. These organizations and entities are funded by a host of supporters including city councils, the Lottery Fund, charitable trusts, NGOs, businesses and multinational corporations as well as the federal and provincial government.

In 2007, the Toronto City Council made the expansion of the urban forest a priority, with the goal of increasing canopy cover to between 30-40% from the existing cover of 17-20%. This goal is partially based on the 40% canopy cover recommendation by American Forests (www.americanforests.org) which was derived based on the aim of sustaining the economic, social and environmental benefits of the urban forest. This target will be overseen by Toronto City Council in conjunction with the Parks, Forestry and Recreation Dept and will occur through the ongoing use of GIS and modeling tools such as the i-Tree Eco model (www.itreetools.org) and remote sensing techniques to help forestry managers better understand, inform and plan for the future composition of the urban forest. In particular, private land has been targeted to identify potential opportunities for increasing canopy cover through stewardship. City initiatives also include the goal of collaboration between forestry managers and other sectors and utility providers (water, transport, city planning) in achieving their objectives, and promote the ongoing maintenance and preservation of large trees whilst minimising tree mortality.

The City of Toronto has quantified the benefits of trees with the use of i-Tree modeling software. Toronto's forests and urban trees have been estimated to provide around $60 million per year in ecological services, primarily around climate change, air quality, flood reduction potential and stormwater management and energy conservation; gross carbon sequestration is approximately 46,700 metric tons of carbon annually equating to a value of $1.3 million. Trees were also found to decrease utility bills by 8%. The city also identified the value of trees in increasing the value of houses and land, finding a correlation between the number of trees on a property and its market value, which increased by up to 18%. The City is also particularly interested in mature trees which have increased canopy cover in comparison to younger trees.

6.3.2 Annapolis, MD, USA

Area: 1721.47ha

Population: Approximately 39,000

Current canopy cover: 42% over 703 ha

Geography of current canopy: 37% on parcel lands, 4% on PROW (public road right-of-way, or non-parcel lands). Land use types with the highest canopy cover include Residential (23%), Exempt-Commercial (primarily federal, state, county and municipal lands and lands associated with non-profit entities, e.g. museums, colleges and churches) (5%) and PROW (4%).

Canopy cover goal: 50% canopy cover by 2036. Land use types with most potential for increasing canopy cover include Residential (potential for 15% increase), Exempt Commercial (8), Commercial (7%), Apartments (3%) and Unknown (3%). Maximum potential canopy cover within the city is 1,343 ha (3,318 acres) or 78% of the total City land area.

Annual planting rate: Not available.

Initiatives and partners: Annapolis is one of 26 communities in Maryland which have committed to increasing canopy cover through the Urban Tree Canopy (UTC) Goals strategy which aims to increase urban stormwater retention capacity by expanding the urban forested area. Resulting from this goal, a GIS-based assessment was carried out in 2006 which identified the extent of the existing and potential tree canopy cover in the city. Emphasis was also placed on *how* these targets could be achieved. Key findings in this respect included the importance of education and outreach in increasing canopy cover on private lands, which comprise a significant proportion of the city's total area. As a result, in November 2012, the city's Clean & Green initiative introduced an opportunity for residents to purchase a range of tree species at a reduced cost in order to meet canopy targets, through a partnership between the City and the Department Neighbourhood and Environmental Programs. Similarly, a long term focus was taken with the recommendation of conducting progress assessments at ten-year intervals and, in the interim, undertaking a combination of complimentary measures undertaken, including tree protection, maintenance and planting to ensure that goals are realized.

6.4 Conclusions

Although a number of cities and towns in the UK have identified the importance of maintaining, enhancing and increasing canopy cover in their respective areas, many Councils have stopped short of implementing strategies to increase canopy cover, primarily as a result of a limited arboricultural budget. It is often the case that while there is a general understanding of the spatial distribution and quality of their current tree stock through GIS-based surveys, data may be collected on an ad hoc basis, datasets may be not be up to date or may be incomplete depending on resources. Predictably, where additional funding exists (Manchester, Bristol and Torbay are the most obvious UK-based examples), datasets and strategies to increase canopy cover are more complete, arboricultural budgets are targeted at proactive rather than reactive spending, and Councils are further along to achieving their objectives. The international examples, whilst situated in locations with substantial tree canopy cover, nonetheless serve as illustrations of the importance of quantifying the financial and environmental benefits of trees in order to gather adequate funding for arboricultural initiatives – demonstrated by additional funding obtained by Torbay Borough Council subsequent to the valuation of its tree stock by the i-Tree Eco software in 2011.

7 Interpretation of the Results

Climate change, in the urban context, is of growing concern to those concerned with the welfare of inhabitants of urban areas. Increasingly, cities are attempting to quantify and qualify the environmental benefits of their tree stock in order to define the value of urban trees. Cambridge City is in a position to make use of the extensive quantitative data held on their tree stock. This data includes the location, quantity and characteristics (height and canopy spread) of trees, as well as information on ownership and land use, and for Council-owned stock, data on species and condition. Taken together, these quantitative datasets are a vital tool which can be used to target future tree management policy in order to adapt to climate change in the coming decades.

This section of the report discusses Cambridge City's urban forest in the context of adaption to future issues related to climate change in the urban environment following a review of the most current research and information on the significance of trees in the urban environment.

7.1 Background to the role of urban trees in climate change adaptation

The urban environment is increasingly important due to the fact that, for the first time in history, more people now live in towns and cities than in rural areas. Furthermore, according to The Office for National Statistics, over 90% of the UK population now have an 'urban' lifestyle. As a result of an increasingly urban population, the UK is likely to face significant challenges under future climate warming scenarios.

Brought about by global warming, climate change is now recognised as one of the most serious challenges facing us today (Whilby, 2007, Lindner *et al*. 2010) and the potential impacts for trees are well documented (Freer-Smith *et al*., 2007). The UK climate change scenarios indicate an average annual temperature increase of between 1 and 5°C by 2080 (UKCIP, 2009). These scenarios do not take urban environments into account which have the potential to further increase these temperatures due to what is referred to as the 'urban heat island effect' (Gill *et al*., 2007). This study estimated that, under high emissions scenarios, a 10% (absolute) increase in canopy cover in areas with limited green cover could decrease urban temperatures by up to 2.5 degrees by 2080.

Climate change forecasts predict that the UK will experience hotter, drier summers and warmer, wetter winters. Under medium emissions scenarios the East of England will see increases of 3^{o}C and 3.6^{o}C in winter and summer respectively, by 2080. Winter precipitation will increase by 20% and summer precipitation will reduce by 21% (UKCIP 2009). These changes will likely be more pronounced in urban environments.

7.1.1 Benefits of urban trees

The benefits of urban trees, in the context of urban climate change adaption, are widely recognised. Environmental benefits do not solely relate to areas of forest or woodland. Smaller groups, avenues and individual, isolated trees can equally improve environmental conditions in urban areas (Konijnendick *et al.* 2005).

Trees are one of the components used to green our urban environments. Recent years have seen an increasing drive to promote and incorporate 'green infrastructure' in urban areas. Green infrastructure can be thought of as an interconnected network of natural areas and other open spaces which collectively work to conserve natural ecosystem values and functions, sustain clean air and water, and provide a wide array of benefits to people and wildlife (Benedict *et al*. 2006). Green infrastructure also consists of shrubs, grass and other vegetation which interact with natural systems of air, water and soil.

Urban tree stock is increasingly perceived to be able to contribute significant benefits to the adaption of urban environments to the effects of climate change. However, in order to achieve maximum benefit from our tree stock we must be in a position to allocate resources to effectively manage trees in order to maintain and increase the potential benefits. Generous estimates suggest that the average lifespan of a typical urban tree is 32 years and that many newly planted trees do not survive their first year (Moll and Ebenreck, 1998).

Species selection in the urban environment is also becoming more significant. The relative aesthetic merits of a species are now in direct competition with attributes that could alleviate the effects of climate change. Trees that are more drought-tolerant or have larger mature canopies should be considered over those with more manageable attributes such as smaller size or public acceptance based on aesthetic qualities.

7.1.1.1 Reduction of air pollution

Pollutants such as nitrogen oxides and ozone are of increasing concern in the urban environment. Climate change is likely to enhance these pollutants due to rising temperatures: higher levels of radiation can lead to higher concentrations of ozone in the air; ultraviolet radiation is widely recognised as a cause of increased instances of skin cancer among human populations. Nowak (1994) showed that trees in the Chicago area were estimated to remove 6190 tonnes of air pollution per year, which equates to an average improvement in air quality of approximately 0.3%. Further improvement in air quality of 5-10% can be gained from increased tree cover. Tiwary et al. (2009) showed that trees reduce pollution through the deposition of particulate matter onto leaf surfaces. The structure of large trees and their rough surfaces cause interception of particulate matter of less than 10 microns in diameter (PM10) by disrupting the flow of air, and trees provide a surface area for capture that can be between 2 and 12 times the area of land they cover.

Air pollution from industry and transport is a major public health issue in urban areas (Beckett *et al*., 1998). Urban trees can make a significant contribution to the improvement of urban air quality by removing air pollution through dry deposition. Dry deposition describes how gaseous and particulate pollutants are captured on plant surfaces and are absorbed into the plant tissue through the stomata (Jim and Chen, 2008) or introduced to the soil through leaf fall. Trees can remove particulate matter of 10 microns or less. Trees alter the urban atmosphere by reducing levels of ozone, however some species can contribute to volatile organic compound (VOC) emissions, the cooling effect of trees on urban air temperatures more than offsets this effect by reducing ozone to a greater effect (Nowak *et al*., 2000). Attention should also be given to species that are known to produce significant levels of pollen. Pollen production can exacerbate the allergenic response due to reduced air flow patterns in the urban environment. Evergreen tree species, especially conifers, filter more dust than deciduous species; however conifers are more sensitive to damage caused by air pollution (Beckett *et al*. 1998).

7.1.1.2 Shade and cooling

Trees provide cooling benefits through direct and indirect cooling. The principal indirect benefit from trees is through reduction of the urban heat island effect, a phenomenon of warmer air occurring in city centres, compared to lower ambient temperatures in the surrounding countryside. Here, evapotranspiration processes release water vapour which absorbs heat directly from the air and cools it. Similarly, direct benefits come from the absorption of sunlight and shading. Shade provided by trees reduces the amount of sunlight reaching hard surfaces such as asphalt and brick which convert sunlight to heat.

Potcher *et al.* (2006) have shown that open spaces with a higher number or larger area of trees have been found to have lower temperatures than those with fewer trees.

The 'urban heat island' effect is identified as being a significant threat to urban areas (Climate Change Risk Assessment Report (Defra 2012), and is likely to become an increasingly common phenomenon in future years, putting pressure on urban infrastructures and increasing the need for cooling. Trees can play a major role in decreasing energy consumption by urban buildings resulting from their shading potential. In summer, shading from trees reduces the urban heat island effect which helps to reduce the amount of energy required to cool buildings. Recent work by the Commission for Architecture and the Built Environment (CABE) suggests that up to 3% of energy savings in residential properties within less than 10m of trees can be achieved by the shelter the tree canopy provides. Capon et al. (2012) suggest that a figure of 8% is achievable in commercial buildings 'less than 10m from trees (3% for heating and 5% for cooling).'

7.1.1.3 Increased carbon sequestration and reduction in air pollution

Urban trees play a role in mitigating climate change by acting as carbon pools, absorbing carbon and reducing the concentration of CO_2 concentrations in the atmosphere. This is accomplished directly through carbon sequestration and indirectly as a result of the reduced need to heat and cool buildings owing to an increased canopy cover (Jo and McPherson 1995). In comparison to other types of above-ground vegetation, trees are particularly good carbon reservoirs, with older trees able to absorb more carbon and younger trees able to sequester relatively more carbon dioxide. A recent study in Leicester identified that trees stored approximately 97% of the carbon stored in vegetation within the city (Davies *et* al. 2011), pointing to their potential to act as successful carbon pools within the urban environment.

7.1.1.4 Reduced flood potential

Trees draw water from the soil, therefore increasing soil water storage. Trees and soils function together to reduce storm water runoff. Trees intercept rainwater on leaves, branches and trunks, some of which will evaporate and some will soak into the ground. A typical medium sized urban tree can intercept as much as 9000 litres of rainfall per year (CUFR, 2002). When rainfall hits non-porous surfaces it increases the water temperature and picks up pollutants which are washed into natural water courses. In a study by Gill *et al*. (2007), increasing tree cover by 10% in areas with low proportions of green cover was modelled to reduce runoff from a 28mm rainfall event by 5.7% in these areas, contributing to a 1.9% overall reduction across the study area, specifically, the city of Manchester. Further storm water storage capacity may be gained by designing tree pits to take roof run-off as part of SUDS initiatives in hard urban landscapes and would help trees survive in times of drought. Carefully planned systems can offer many benefits to the urban tree and the wider urban environment (Stål 2009).

7.1.1.5 Human health and well-being

Urban trees also provide benefits as far as human health and well being are concerned, due to reductions in temperature derived from the shade that trees provide. There has been found to be a direct relationship between urban temperatures and heat related deaths: Armour *et al*. (2012) summarise the health benefits to the urban population as improvements in physical health, mental health and well-being, hospital recovery rates and childhood development. A review of research into the health benefits of trees has been released by Forest Research (Sarajevs 2011) which concludes by stating that there is a growing body of research generally, but not unanimously, confirming the health benefits of street trees in particular. The benefits considered during the review included reduced air pollution, provision of environments conducive to physical activities, reducing stress and improving mental health, reducing noise levels, cooling air in summer by giving shade (including associated savings to the National Health Service (NHS) from avoided heat stroke) and reduced ultraviolet radiation through shading (including associated savings to the NHS from avoided skin cancer). Lovasi et al. (2008) found that street trees have been associated with a lower prevalence of asthma in children, even after adjustment for potential confounding factors including socioeconomic characteristics, population density and proximity to pollution sources.

The canopy of an urban tree provides valuable shelter from radiation. Rising air temperatures and higher levels of radiation can lead to higher concentrations of ozone in the urban environment which in turn can lead to increased ultra-violet radiation, at street level, which is known to contribute significantly to skin cancer among human populations. As urban climates warm it is conceivable that there would be an increase in outdoor recreation. Shade from trees will become increasingly important to protect populations from increases in heat and radiation in those places most used such as children's play areas, parks and routes for joggers.

7.1.2 Threats to urban trees

The abiotic conditions for urban trees are complex. They are significantly different from natural growing conditions due mainly to changes in hydrology, soil and air pollution and the detrimental affects of increased interaction with humans, which at worst can manifest in severe damage through vandalism.

It is likely that climate change will increase the complexity of pests and diseases affecting trees and physiological response to the urban environment will become more complex as the expected climate change scenarios play out (Konijnendick *et al.* 2005).

7.1.3 Threats from urban trees

One of the key threats from urban trees in the coming decades is likely to come in the form of building subsidence as a result of water abstraction by tree roots (Capon and Oakley 2012, LAEC 2007). Trees are heavy water users and soil moisture content is reduced as tree roots take up water, which can result in destabilization and ground movement in certain circumstances. Cambridge lies upon predominantly shrinkable, clay soils which are more likely to be prone to subsidence especially as rising summer and autumn temperatures are likely to contribute to a deficit in soil moisture content in the coming years under future climate scenarios (Cambridge City Council 2008). While modern buildings with sound foundations are expected to be less vulnerable to subsidence, structures constructed prior to 1970 are likely to be increasingly at risk, particularly where soils are prone to frequent occurrences of shrinking and swelling (Defra 2012).

As a result, consideration should be given to the location and species of trees prior to planting, with the aim of minimising future damage. However, Biddle (1998) suggests that aesthetically suitable species should be identified and shortlisted for planting prior to considering their potential for future damage, arguing that past examples of subsidence may have been the result of poor tree management and/or proximity to neighbouring buildings rather than the result of poor species selection. Biddle also makes the point that the benefits of planting urban trees will greatly outweigh the potential negative consequences, and that a tree's suitability in the urban landscape can be reviewed on an ongoing basis. Similarly, he argues, it is important to consider that trees do not necessarily need to be grown to maturity in order for communities to reap the benefits associated with mitigating climate change.

7.1.4 Conclusions

The most beneficial attributes of trees in the urban environment are those that grow fastest to large mature size and are long lived. Large species trees convey the greatest financial, social and environmental benefits, and make a fundamental contribution to the well-being of almost 80 per cent of the UK population who live and work in urban conurbations (Armour *et al*. 2012). A recent study analysing the benefits of large tree species in the urban landscape (ibid. 2012) lists numerous financial, social and environmental benefits that larger trees species bring to the urban environment. These benefits include, but are not limited to: increased property and land values, reduced energy costs due to microclimate regulation, improved human physical health, improved workplace productivity, reduced flood damage and cleaner water. Trees that are fast-growing and are long-lived are rare, which is why the urban forester must consider the long term view. Trees that are fast-growing are important but one must take a wider view and look to incorporate those trees that will be of most benefit in the future. Consideration must also be given to the threats from trees in the urban environment; most significantly an increased risk of subsidence to properties in close proximity to current and future tree planting positions. Mitigation and management of this risk should be considered at all levels of future urban design.

7.2 The implications of the results for climate change adaptation in Cambridge City

7.2.1 Ownership

Cambridge City is estimated to be home to over 135,000 trees, the vast majority of which are privately owned (over 103,000). The remaining 32,000 trees are found on public land and are maintained by Cambridge City Council or Highways. The City has an area of just over 4000ha distributed among 14 wards ranging in size from around 100ha to 700ha. Across Cambridge, the vast majority of land is classed as privately owned.

This has implications for the design of local policies for tree planting, which will need to focus on partnership working with institutions such as the University, which own a large proportion of the private land and could represent valuable opportunities in the form of un-planted open spaces. Guidance and schemes advising local residents on what they could do to increase canopy cover on their properties would also be highly beneficial, particularly if targeted at those properties with larger gardens in the low and medium density residential areas. This could include advice on the best tree species to plant to attain maximum climate change adaptation benefits. 'Selling' the benefits of tree planting to local residents as a way of allowing them to contribute to climate change adaptation for a small one-off cost could potentially result in a big gain for the City as a whole.

7.2.2 Land-use

OS4 (remnant countryside) and Industrial land-use types have the lowest tree densities in Cambridge. OS4 includes a high proportion of large arable fields, which is likely to partly account for the low density. Industrial land-use includes Cambridge City's transport network and industrial buildings such as storage and warehousing which would account for lower density tree coverage due to less space available for planting. There may be scope for increasing tree density in these areas by encouraging boundary planting. For example, Highways land could be targeted to reduce the effects of traffic pollution and provide more shading where there are large expanses of black tarmac.

Owners of OS4 land could be encouraged to increase tree density on field boundaries or around agricultural buildings. OS4 land is generally found on the outskirts of the City; therefore increased tree density in these areas would have less impact on reducing the adverse effects of climate change. Industrial land-use is more centrally located within the city so an increase in canopy cover would be more beneficial in reducing the urban heat island effect and modification of airflow. In the long term, a reduction in energy consumption could be realised from shading effects as trees increase in size.

The City Council owns over 70% (40ha) of OS1 land-use (formal & informal open space) across Cambridge, yet tree density in these areas is relatively low. Almost 20ha are within the more central areas of Abbey and Market. Council-owned OS1 land-use in these areas, especially Market (around 7ha), could be targeted for increased tree density to alleviate the future effects of climate change. The outlying wards with high City Council-owned OS1 land should also be considered with a view to increasing tree density; these should include 4.5ha in Cherry Hinton, 2ha in East Chesterton, 2.5ha in Kings Hedges and 6ha in Newnham. Amenity areas and parks are included in the OS1 category and planting in these areas would greatly increase the health benefits to the public who use these open spaces, especially in the context of climate change and hotter summers. This land-use would also support the planting of larger tree species that would eventually provide greater canopy cover and therefore shading compared to smaller species. In the near future, local authorities will have a key role in improving the health of local residents and tree planting to provide shade and amenity value is a relatively cheap and easy way for local politicians to do so.

OS3 land, classified as derelict, neglected & abandoned open space, represents an appropriate land-use on which to increase tree cover. Current tree canopy density is high at $4000m^2$/ha but could be increased, especially in the central area of Romsey, where it appears that there are 2ha of this land use in private ownership. If the statistics are correct, there is an opportunity to fully occupy this area with tree cover, a possible 1.2ha of land in Romsey OS3 could be available. Coleridge and East Chesterton have a combined total of over 6.5ha of privately owned OS3 land-use which could release almost 4ha of space available for planting on the outskirts of central Cambridge. The issues associated with private ownership could be prohibitive, however further investigation would be worthwhile. These potential opportunities will be explored in more detail in section 8 of this report.

With regard to climate change adaption analysis, canopy cover plays a large part in providing the majority of benefits within an urban setting, most notably by reducing the urban heat island effect, interception of precipitation and removal of pollutants from the urban environment. Maximising the canopy cover provided by a specified number of trees is therefore a good strategy, as long as the land-use type can support the planting of larger trees.

Over 27% of MDR is owned by the City Council or Highways so there may be an opportunity to increase future canopy size by selecting appropriate species. Home owners could also be encouraged to plant species that have larger canopies if their garden size allows, and advice on the most appropriate species to plant dependent on garden size could be provided by the Council on their website.

Open space categories and LDR have trees with the largest canopies; the most likely explanation being that trees in these areas have the space to attain natural mature size and possibly that larger grown species are selected for planting in these land use types, again due to having the space to attain natural mature canopy spread.

7.2.3 Wards

The vast majority of land within wards is privately owned. More interesting is the varied land use type across wards, which is particularly useful in explaining the differences in tree density across wards within Cambridge and identifying opportunities for planting. The main opportunities for increasing canopy cover by ward are summarised below and expanded on in Section 8. Canopy cover has been used to measure tree stock and predict future targets; however, the opportunities identified below for planting assume that the land identified is both available for planting and more importantly, that it is suitable for new planting. In some wards, the area of canopy cover may legitimately be lower than the City average due to a conflicting land use – for example, airports, military land and landfill sites, or due to being otherwise unsuitable for planting.

Abbey is dominated by Medium Density Residential (MDR), Formal and informal/amenity land (OS1) and Institutional Open Space (OS2) land. There are therefore opportunities for increasing canopy cover in this ward by encouraging garden planting in MDR, planting tree species with larger canopy spreads in OS1 and encouraging institutions to plant larger trees in OS2.

Arbury consists largely of MDR land-use and there are therefore opportunities for increasing canopy cover by encouraging home owners to plant suitable tree species in their gardens.

Castle is dominated by OS2 and Remnant Countryside (OS4) land. Institutions and agricultural land owners should be encouraged to plant specimens that will have large canopies in these open spaces wherever possible. Castle ward already has one of the greatest representative tree canopy sizes in the City due to the abundance of OS2 and OS4 land, which also have high representative tree canopy sizes.

Cherry Hinton is dominated by OS4 and MDR land-uses. Home owners and agricultural land owners should be encouraged to plant appropriate species wherever possible.

Coleridge consists largely of MDR land-use and there are therefore opportunities for increasing canopy cover by encouraging home owners to plant suitable tree species in their gardens.

East Chesterton is dominated by MDR and Industrial land-uses. There are therefore opportunities for increasing canopy cover in this ward by encouraging garden planting in MDR and targeting Highways and City centre industrial sites for planting.

King's Hedges consists largely of MDR land-use and there are therefore opportunities for increasing canopy cover by encouraging home owners to plant suitable tree species in their gardens.

Market comprises Town Centre land-use and OS1. There are limited opportunities for planting in the City centre, although any trees planted here will have beneficial effects with respect to the urban heat island. There are opportunities to plant species with larger canopy spreads in OS1, however Market already has the highest representative tree canopy size of all the wards since OS1 has the highest representative tree canopy size of all land-uses.

Newnham largely consists of OS2 and OS4 land-use categories. Institutions and agricultural land owners should be encouraged to plant specimens that will have large canopies in these open spaces wherever possible. Newnham ward already has one of the greatest representative tree canopy sizes in the City due to the abundance of OS2 and OS4 land, which also have high representative tree canopy sizes.

Petersfield has the majority of its land in MDR, but also has fairly high representation of HDR, Town Centre, Industrial and OS2. Opportunities exist for increasing canopy cover particularly in High Density Residential (HDR) and OS2 land-uses.

Queen Edith's has the highest proportion of Low Density Residential (LDR) of any ward and the majority of the remainder is split between MDR, OS2 and OS4. The best opportunities for increasing canopy cover exist in the open space categories.

Romsey has the vast majority of its land area in MDR. There are therefore opportunities for increasing canopy cover by encouraging home owners to plant suitable tree species in their gardens.

Trumpington is dominated by OS4 land use. It also has one of the highest representative tree canopy sizes in the City because of this. There may be scope for encouraging land-owners to plant larger species at the boundaries of their agricultural fields.

West Chesterton consists largely of MDR land-use and there are therefore opportunities for increasing canopy cover by encouraging home owners to plant suitable tree species in their gardens.

7.2.4 Protected Tree Stock

Trees within conservation areas are given a degree of protection by means of a requirement to notify the planning authorities for any tree removals or work to trees. Within Cambridge City, the more central wards have the highest amount of conservation land area. Most notably; Market and Petersfield have over half of their land area within conservation areas. There is a noticeable lack of Conservation area land within the southern wards of Queen Edith's, Coleridge and Cherry Hinton. However, conservation areas can only be made in areas of 'special architectural or historic interest' so it may not be appropriate to extend into Queen Edith's, Coleridge and Cherry Hinton. It is important that replacement planting cannot be enforced unless a tree is removed or destroyed without prior notification or is removed under an exemption. Therefore where tree removals are being considered as part of a section 211 notification, TPOing the tree and conditioning a replacement should be considered to ensure continuity of tree cover is maintained. Enforcement of replacement planting as a result of removal under an exemption should be enforced where appropriate. Where TPO trees are removed, conditioning of replacement trees should be considered. Large species trees should be preferred where appropriate. The required replacement of trees should be enforced if not carried out. The replacement tree is not protected by the original TPO therefore consideration should be given to modifying the original Order to include the replacement. All this is likely to require increased resource to manage.

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In terms of the amount of canopy area protected by Tree Preservation Orders (TPOs), most notable is that over 20% of canopy cover within Queen Edith's is protected. Queen Edith's was systematically surveyed in the mid 1990's as part of a TPO review which would have increased the amount of trees, and therefore canopy cover, protected; this review was stopped due to lack of resources. A more targeted approach could be considered by assessing those trees with greater potential to offset the effects of future climate change. The review process should be prioritised in the following order:

1. Trees over 20m (20m+ trees are likely to be already supplying significant benefits and may be long lived species)
2. Trees over 15m
3. Large species trees under 15m (i.e. trees that can attain 15m+ at maturity)
4. Other where required.

Data is available showing the location of trees within the above categories. Areas containing 20m+ trees can be prioritised and assessed first but it is recommended that, when on site, all categories can be included in any resulting TPO

7.2.5 Species distribution

The most common tree species found amongst Council-owned stock in Cambridge City are Cherry spp. and Silver birch, amounting to 7.5% and 5.7% respectively. Cherry spp. are relatively short lived and only ever attain medium size. Silver birch, in an urban setting, are again relatively short lived with light canopies. A lighter canopy provides less benefit to the urban environment in the context of climate change. The ground survey indicates twice as many Cherry spp. (over 15%) which may highlight the popularity of this species within private ownership.

Ash and Norway maple have populations of approximately 4.5% amongst Council-owned stock in Cambridge City; the lime population (including Small-leaved lime) attains a healthy 6.6%. When mature, these species provide more benefit to the urban environment due to their larger mature size and dense canopies. During the ground survey over 20% of trees surveyed were Ash indicating a much higher level of non-council owned trees being of this species. Such a high percentage of a single species may be of concern due to the potential of species targeted pests and disease such as the recently identified Ash dieback Chalara fraxinea (Forestry Commission 2012). Tree species diversity is important in order to lessen the potential impact, of an increased risk from pests and disease, due to climate change. If variation in species is low, then the potential risk to tree populations is increased.

The majority of the remaining (named) species are small to medium sized trees traditionally used for planting in the urban environment. The more beneficial remaining species include Oak, Beech, Sycamore, Chestnut and London plane which, if combined, amount to 8.2% of the City tree population. Excluding category ‘Other’ almost 20% of the Council tree stock are, or have the potential to be, large urban trees, able to contribute most to the detrimental effects of climate change in the urban environment.

8 Conclusions for Policy Inception

In order to help plan for the goal of increasing canopy cover in Cambridge, a growth model was used to identify the approximate canopy cover that would occur under a number of different tree planting scenarios. The purpose of the model is to help predict the number of trees that are likely to be needed to be planted across the City of Cambridge in order to achieve the increases identified in each scenario. In turn, this information will provide the Council with a more tangible understanding of what is needed to achieve their goal, and where to direct policies in the future.

8.1 Targets for Canopy Cover

Modelling has been carried out to predict canopy growth over future years for a quantity of trees planted each year over 5 years (Table 12). The figures are based on a newly planted tree having a canopy of 0.5 metre radius with no growth in year 1 or 2 due to establishment stresses. Subsequent shoot extension growth is estimated to increase by **0.155 metre** annually (Bradshaw *et al.*, 1995, p22) resulting in trees planted in year 1 having an average canopy radius of **5.02 metres** and **79.17m^2** area after 30 years of growth. Table 12 predicts an increase in canopy cover for 1 tree planted every year, over 5 years, resulting in a canopy cover of **252.40m^2** in 30 years time. All results take into account a tree loss of 25% owing to stresses and other factors.

Table 12. Canopy area prediction

	Scenario 1 (1 Tree per year) Canopy Area (m^2)	Scenario 2 (10 Trees per year) Canopy Area (m^2)	Scenario 3 (100 Trees per year) Canopy Area (m^2)	Scenario 4 (250 Trees per year) Canopy Area (m^2)	Scenario 5 (500 Trees per year) Canopy Area (m^2)	Scenario 6 (1000 Trees per year) Canopy Area (m^2)
Year 1 – 1st Tree Planted	0.79	7.85	78.54	196.35	392.70	785.40
Year 2 - 2nd Tree Planted	1.57	15.71	157.08	392.70	785.40	1570.80
Year 3 – 3rd Tree Planted	2.92	29.19	291.86	729.65	1459.31	2918.62
Year 4 – 4th Tree Planted	4.98	49.80	497.98	1244.95	2489.91	4979.82
Year 5 – 5th Tree Planted	7.91	79.05	790.53	1976.34	3952.67	7905.35
Year 10	37.55	375.48	3754.83	9387.08	18774.16	37548.32
Year 15	83.99	839.91	8399.09	20997.72	41995.44	83990.87
Year 30	336.53	3365.34	33653.37	84133.42	168266.84	336533.69
25% Loss	252.40	2524.00	25240.03	63100.07	126200.13	252400.27

Using the figures in Table 12 we can predict the number of trees that would need to be planted each year, over 5 years, to attain canopy cover targets for each land use within Wards. Canopy cover targets are those required to attain the City average canopy cover for each land use and for each Ward. The calculations for canopy target figures are included in Appendix 1 and 2. These figures show further detail regarding canopy deficit for land ownership, within land use type, for each ward.

A total of four scenarios were created for consideration:

- Scenario 1 - Canopy cover increase by Ward, Land-use & Ownership.

  This scenario targets planting specifically by Ward, land use and ownership giving a percentage increase of 2.26%.

- Scenario 2 - Canopy cover increase by Ward & Land-use.

  This scenario targets planting specifically by Ward and land use, giving more flexibility in the ownership factor, resulting in an increase of 2.01%.

- Scenario 3 - Canopy cover increase by Ward & Ownership.

This scenario targets planting specifically by Ward and ownership resulting in a 1.66% increase.

- Scenario 4 - Canopy cover increase by Ward Only.

  This scenario targets planting specifically by Ward only resulting in a 1.16% increase.

ADAS would recommend that Scenario 2 is the most achievable. The omission of the ownership factor allows tree planting requirements in each ward to be increased by, for example, the City Council, when there are found to be limiting factors within the private and highways owned land for a specific land use type.

Tables 13a and 13b summarise the results for Scenario 2 – detailed information can be found in Appendix 1 and 2 for all scenarios.

Table 13a. Scenario 2 – Canopy cover increase by ward and land use

Scenario 2 Canopy cover increase by Ward & Land-use			
Ward	**Total Trees Planted**	**Trees planted per year over 5 years**	**Canopy Cover Increase (m^2)**
Abbey	4174	835	210709.07
Arbury	600	120	30272.50
Castle	447	89	22584.00
Cherry Hinton	2432	486	122778.51
Coleridge	1625	325	82019.46
East Chesterton	1111	222	56077.60
Kings Hedges	1096	219	55350.04
Market	402	80	20294.90
Newnham	11	2	548.59
Petersfield	123	25	6217.09
Queen Ediths	2481	496	125246.24
Romsey	868	174	43809.77
Trumpington	356	71	17973.14
West Chesterton	484	97	24425.83
Totals	**16210**	**3242**	**818307**

Table 13b. Scenario 2 – Current and projected canopy characteristics

Current and projected canopy characteristics	Total
Current Canopy Cover (m^2)	6961906.77
Future Canopy Cover (m^2)	7780213.50
% increase in Canopy Cover	11.75%
Current Canopy Cover as % of land area	17.08%
Future Canopy Cover as % of land area	19.08%
Actual % increase in Canopy Cover	2.01%

As discussed in section 7.1, research by Gill et al. (2007) identified that increasing canopy cover by 10% in locations with limited vegetation could decrease urban temperatures by up to 2.5 degrees based on urban temperature predictions up to 2080. This research relates specifically to urban areas with limited canopy cover, yet as the study area (Cambridge City) comprises numerous non-urban land use classes, targets should be set accordingly to take this factor into account. A percentage increase of 2% could be achieved by increasing canopy cover within wards to the City average. An aspirational percentage increase of 5% should be considered as a secondary target for the City. Similar targets have been proposed by the Forestry commission “In principle, the Forestry Commission's minimum policy objective is that development ought, through Green Infrastructure provision, to lead to an increase in tree canopy cover by 5%” (Forestry Commission, 2010). To achieve this secondary target, over 8000 trees would need to be planted each year over a 5 year period.

8.2 Methods for Achieving Targets

Models exist for analysing increases in urban canopy cover. Luley and Bond (2002) offer the following model:

CT=CB+CN+CG-CM

Where:

CT = Total Urban Tree Cover in the modelling domain over time (realisation of Urban Tree Cover goal);

CB = the existing Urban Tree Cover;

CN = Urban Tree Cover increase from new trees (planting);

CG = the growth of existing Urban Tree Cover; and,

CM = Urban Tree Cover mortality or loss due to natural and man-induced causes.

In the present study CT has been recommended as a 2% increase in Cambridge City's Canopy Cover (increase to 19.1%) after 30 years. Current analysis shows the value of CB to be 17.2% and our figures recommend that CN requires over 16,000 trees to be planted over 5 years to realise this increase. For the purposes of this study we shall assume a steady state between CG and CM. However, both CG and CM can be influenced in order to increase City canopy cover. The growth of existing canopy cover can be optimised and tree mortality reduced by adopting, enforcing and promoting current best practice, codes of practice and statutory controls in the care, maintenance and protection of trees in addition to the design and creation of tree-friendly places (Tree & Design Action Group 2012).

It is therefore recommended that four elements are considered in order to increase canopy cover within Cambridge City; these being:

1. Strategic
2. New Planting
3. Protection of existing and future tree canopy cover
4. Maintenance of the existing canopy cover

Each strategy, or a number of methods to achieve strategic goals within different elements, should be targeted towards specific audiences within the population of Cambridge City. Examples of specific target audiences include large land owners, Cambridge City electorate, Highways, tree industry professionals and Cambridge City Council among others.

8.2.1 Strategic Approach

Local authorities are increasingly required to take an over-arching strategic approach covering all aspects of their tree stock. It is recommended that a 'Tree Strategy' for Cambridge City is adopted. Trees should also be included in wider policy in order to provide clarity and visibility to a wider audience. Examples of where trees could be included as an influencing factor of policy include local plan, design code, health, sustainability, conservation area and climate change policy. Cambridge City has a significant amount of land owned privately; the larger land owners within this audience should be targeted to encourage the wider use of tree strategy to manage their significant tree population.

8.2.2 New Planting

This study has specified canopy targets to increase canopy cover to the city average by land use for each Ward. Further detail on land ownership is available in Appendix 1 which identifies that fact that the majority of canopy deficit is on privately owned land. A 'New Planting' strategy should target the public in order to engage the community and promote private tree planting. The City Council is in an advantageous position in targeting private residents with information. Methods, under this strategy, could be distributed and made know to the vast majority of the City with relative ease. The Council is also in a position to negotiate beneficial deals with suppliers due to the potential audience they can reach and, potentially, the current relationship they may have with such suppliers. A proposed method that could make use of these advantages is the negotiation of reduced tree cost, from current suppliers, to private buyers and the subsequent promotion of such a scheme via currently used distribution channels.

The channels used to disseminate information, by the Council, should be exploited further to educate the City electorate. Such information could be the explanation of Cambridge City goals for increases in urban tree cover and the reasons behind such goals. Information should be pushed to encourage tree planting, the identification of healthy trees when purchased, good tree establishment practise and an interest in trees generally; the creation of a 'Tree Warden' scheme is highly recommended although may require increased City Council resource to manage volunteers efficiently and professionally.

Controversially perhaps, is the recommendation of financial reward to private residents showing proof of new tree planting. A reduction in Council fees to private residents for planting and maintaining new tree planting must be given consideration. Section 7.1 above expands on the future benefits trees will provide to the City as a whole, which in most circumstances, could be given a monetary value. Models and methodology exist that can place a monetary value on the ecological and health benefits of trees; it is not impossible to imagine that, with the aid of technology, a private resident could provide a yearly assessment of their new planting; the outcome being a nominal value to be used in models to offset a small proportion of Council fees. Further to this, the information in this report could determine scale of fees by land use i.e. planting in open space land use would demand much lower (if any at all) reductions compared to City centre planting. Such a system could also reduce costs significantly for the City Council; every one tree planted under such a scheme is one less tree to be planted by the Council to meet the planting targets contained within this study.

8.2.3 Protection of Existing and Future Tree Canopy Cover

Cambridge City's tree stock is afforded protection if located in conservation areas or where Tree Preservation Orders (TPOs) are assigned to them individually or by area. Appendix 3 includes a plan for each ward showing the extent of any conservation area, area TPO and individual TPOs. The plans also identify the location of individual trees within specific height categories. It is recommended that this data is used to carry out a TPO review which should target specific height classes to ensure future tree stock is protected. Priorities for the review should be set by the City Council's Arboricultural department; specific recommendations for priority targets are made in section 7.2.4. Further to this, land ownership should also be considered when determining review priority. It is suggested that land owned by City Council or Highways would be lower priority as they are afforded a degree of protection from the relevant land owner.

As a condition of planning permission, targets for tree planting and subsequent canopy cover should at least maintain the city canopy cover average for land use type. Figures within this study could determine the number of trees required for a development dependant on its size. In circumstances where canopy targets cannot be met on new developments, planning conditions should ensure off-site provision. Off-site provision should be at the Council's discretion, targeting areas of low canopy density and reducing the potential burden of tree planting targets recommended in this study.

It is recommended that category 'C' TPOs are considered for all new development within Cambridge City. Section 4 of the Form of the Tree Preservation Order, which falls under the Town and Country Planning (Tree Preservation) (England) Regulations 2012 states:

> *In relation to any tree identified in the first column of the Schedule by the letter "C", being a tree to be planted pursuant to a condition imposed under paragraph (a) of section 197 (planning permission to include appropriate provision for preservation and planting of trees), this Order takes effect as from the time when the tree is planted*

All new development must conform to BS:5837:2012 *Trees in relation to Design, Demolition and Construction – Recommendations*. Pre-planning submissions and subsequent requirements must ensure the recommendations are met. In all circumstances, relevant conditions must be robust: written, approved and monitored by the appropriate department, which may increase the need for City Council resource.

With regard to subsidence claims, the evidence base for both the removal and retention of a tree or trees must be adequate and conform with industry best practise. The London Tree Officer Association (LTOA) have agreed a protocol to ensure claim evidence is consistent (LTOA, 2008). It is recommended that Cambridge City Council adopt a similar protocol.

Many trees are damaged by Utilities companies. The City Council should ensure that current best practise is followed and conforms to specifications produced by the National Joint Utilities Group (NJUG, vol 4).

The increased threat to trees from pest and disease due to climate change should be of concern. Strategies to reduce this threat should be considered such as sourcing of tree stock propagated from seed in the UK. This would minimise the threat of pest and disease importing by the nursery trade.

8.2.4 Maintenance of Existing Tree Canopy Cover

Urban tree longevity can be improved by increased use of industry best practice standards relating to the management of trees. The recommendations within the relevant British standard (BSI, 2010) should be adhered to and a realistic budget should be set to allow the Council to manage their urban tree population in this way. Poor management can lead to shortened useful life and potential risk of harm from tree failure. Guidelines (NTSG, 2012) have recently been produced by The National Tree Safety Group outlining the minimum requirements to satisfy a tree owner's duty of care. Scheduled tree removals on Council or Highways owned land should, where feasible, be replanted to maintain planting position. The majority of tree removals in the urban environment are visible to Tree Surgeons and/or Arboriculturists; it is recommended that they be approached to promote tree replacement.

8.2.5 Proposed Strategies

Table 14 proposes a number of strategies which could be implemented by Cambridge City to enhance, protect, maintain and strategically manage their tree stock in order to achieve increased canopy cover, with an overarching goal of reducing the effects of future climate change within the urban environment.

Table 14. Proposed Strategies

Strategy	Goals	Proposed Method
Strategic	▪ Adopted strategic approach to all aspects of tree management ▪ Adopted goals for increase canopy cover ▪ Encourage wider use of tree strategies	▪ Create and implement a tree strategy ▪ Embed trees in wider policy targets ▪ Encourage large land owners to implement tree strategies
New Planting	▪ Increase canopy cover	▪ Establish Cambridge City tree budget for new tree planting ▪ Engage with Cambridge City Electorate to promote understanding of Cambridge City goals and perceived benefits ▪ Ensure the procurement of healthy trees ▪ Establish/enhance/maintain tree warden scheme ▪ Establish partnerships; share information with large land owners and encourage tree planting ▪ Negotiate discounted tree price for Cambridge City Electorate ▪ Financial reward for private tree planting ▪ Investigate the viability of technologically aided assessments of privately funded new tree planting and maintenance to offset Council fees
Protection	▪ Protect existing canopy cover	▪ TPO review ▪ Wider use of category ‘C’ TPO ▪ Promote good design incorporating tree friendly places ▪ Promote best practice to Highways and external utility providers ▪ Adopt evidence base protocol for subsidence

		claims ▪ Promote wider use of new planting from UK grown tree stock
Maintenance	▪ Maintain existing and future tree canopy cover	▪ Establish Cambridge City tree budget for tree maintenance ▪ Establish trees as an asset and manage accordingly ▪ Promote and enforce best practice tree maintenance ▪ Limit unnecessary tree removal through promotion of NTSG guidance ▪ Promote replacement planting following tree removals

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