Climate Change Adaptation in London through Resilient Ecosystem Services Management

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By

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Abstract

As urban populations continue to grow around the world, cities and their residents become increasingly vulnerable to climate change risks. Detrimental impacts on natural ecosystems have been observed in the built environment, as well as poorer quality of life. As urban areas are characterised by complex adaptive systems, the concept of ecosystem services represents an important tool for the management of urban socio-environmental quality and can be applied to climate change adaptation and mitigation strategies.

This thesis investigates London's potential resilience to climate changes through ecosystem services management. In particular, the socioecological capacity of the All London Green Grid for contributing to climate change resilience via patterns of green spaces, and carbon storage and sequestration through urban street trees, will be the central focus in the research. This capacity was assessed firstly by conducting an evaluation of the landscape metrics of Greater London's green spaces to determine the extent and quality of green infrastructure, and how this varies according to relevant socioeconomic variables. This was achieved using GIS and the spatial analysis programme FRAGSTATS. This broad-scale evaluation was then supported by greater in-depth field measurements, focusing specifically on street trees, within selected eleven Business Improvement Districts (BIDs), which are an important vehicle for the local management of the ALGG and thereby climate resilience. This local-scale assessment also incorporated greater evaluation of ecosystem service provision by vegetation, and in particular street trees and their capacity for carbon storage and sequestration. Finally, governance of green spaces within BIDs and broader understanding of resilience and climate change was assessed with qualitative research methods, including semi-structured interviews of different agents and agencies involved in the ALGG network. This included investigation of decision-makers' perspectives on vulnerabilities and the prospects for further developing London green spaces, to determine the feasibility of different management options.

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List of Abbreviations

AFOLU	Agriculture, Forestry and Other Land
ALGG	All London Green Grid
BID	Business Improvement District
CALFED	California water management project
CAS	Complex Adaptive System
CCS	Carbon capture and storage
CDR	Carbon dioxide removal
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
CSS	Carbon storage and sequestration
DBH	Diameter at breast height
EIAs	Environmental Impact Assessments
ES	Ecosystem Service
Eurostat	European Office for Statistics
GHG	Greenhouse Gas
GiGL	Greenspace Information for Greater London
GIS	Geographic Information System
GLA	Greater London Authority

GtC	Giga tonne Carbon
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
LNP	Local Nature Partnerships
LULUCF	Land Use, Land-Use Change and Forestry
N_2O	Nitrous oxide
NPFF	National Planning Policy Framework
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Ecologic Co-operation and Development
PgC	Pentagram of Carbon
ppb	Parts per billion
ppm	Parts per million
SEAs	Strategic Environmental Assessments
SIC	Soil Inorganic Carbon
SOC	Soil Organic Carbon
TfL	Transport for London
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organisation

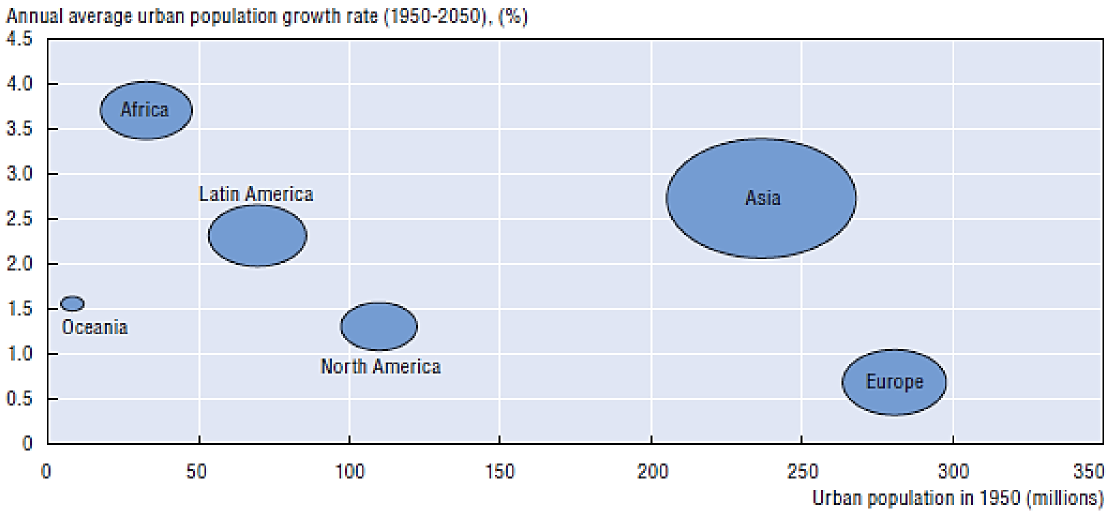
Table of Contents

List of Figures

List of Tables

1. Introduction

54 percent (3.9 billion in 2014) of the world's population resides in urban areas, and it is estimated that 66% (6.3 billion) will be urban dwellers by 2050, with around 90 per cent of the population increase in Asia and Africa (UN, 2015) (Figure 1.1). High population densities and diverse economic activities in urban areas create social issues as well as a range of environmental impacts including air pollution, soil contamination, loss of biodiversity, and health problems (Alberti *et al.*, 2003; Dobbs *et al.*, 2011; Grimm *et al.*, 2008). Many of these impacts are linked to urban climate conditions, which are dynamic and likely to change over coming decades as global climate envelopes shift their distribution and characteristics.



Notes: Urban areas are defined according to the *UN Population Database* which takes into account each country's own definition of urban. Bubble size depicts population size in 2010.

Source: Adapted from OECD (2010, p.40)

Figure 1.1 Predicted urban population growth (1950-2050) by continent

Despite the relatively long history of urban development and transformation from classical antiquity, environmental or socio-ecological impacts during urbanisation have only come to the forefront of research in recent decades (Alberti *et al.*, 2003; Pickett *et al.*, 2001). In sociology, research on urban social problems such as the marginalised in urban areas, labour rights, and social movements for equality, have developed relatively rapidly. On the other hand, research on urban ecosystems has not shown such rapid progress in environment and ecological theories and applications (Francis and Chadwick, 2013), particularly within a sustainability framework.

In spite of an increase in environmental consciousness in the nineteenth century, it was only in the 1970s that environmental issues entered mainstream political discourse (Holdgate, 1996). Since the UN Human Settlement Programme in 1978, urban areas have drawn more attention in terms of ecological theories and practices (Francis and Chadwick, 2013). Yet the release of *Our Common Future* or *The Brundtland Report* in 1987 gave more impetus to research on urban ecology in the context of sustainability. The report played a role in boosting efforts to achieve sustainable development incorporating economic growth, social equity, and environmental improvements.

The concept of the 'eco-city' is a notable example of the integration of urban ecology into urban development within a sustainability framework (Roseland, 2001). It has become dominant in sustainability policy (Caprotti, 2014). As one example for creating an 'eco-city', the International Council for Local Environmental Initiatives (ICLEI) Local Governments for Sustainability, founded in 1990, facilitates coordination between local governments, and national and regional government organisations to achieve sustainable development. This international association provides useful information and training opportunities on adapting to climate change as well as consulting with municipalities and its partners. The C40 Cities Climate Leadership Group (C40), founded in 2005, provides another instance of developing ecology in and of an ‘eco-city’. This international network enables its member cities to commit to reducing climate change impacts and risks by exchanging effective programmes and policies. Active dialogue between cities has made substantial advances in reducing greenhouse gases (GHGs).

The most appropriate way of achieving such change is yet to be determined and is complicated. Research is needed to explore how urban socio-ecological sustainability may be achieved in a changing environment. This thesis explores this in the context of London.

1.1. Urbanisation and urban ecosystems

Even though the definition of ‘urban’ differs between countries, it is most commonly defined on the basis of ‘growth rate, ethnicity, socio-economic structure, degree of patchiness, and energy use (more than 100,000 kcal m^2y^{-1})’ (Gaston, 2010; McIntyre, 2011, p.9), along with ‘measures of population density, administrative boundaries and/or spatial dominance of the built environment’ (Francis *et al.*, 2012, p.183; Gaston, 2010). When describing urban areas, the terms *city, town, metropolis,* and *settlement* are alternatively used, along with some subcategories such as *suburban, peri-urban, ex-urban, urban core, urban fringe, satellite* and *periphery* (Francis and Chadwick, 2013), which together comprise urban ecosystems. As a city experiences urbanisation, the classification of subcategories is useful for investigating and reducing impacts on urban ecosystems on a local basis.

But what is the exact definition of urbanisation? Urbanisation is a relatively broad term that is difficult to define precisely. However it can be viewed as ‘the process by which a rural area becomes an urban one, or the degree to which an area is urbanised’ (Gaston, 2010, p.10); ‘a demographic trend and a component of global land transformation’ (Pickett *et al.*, 2011, p.331);

and ‘a process of contiguous de-territorialisation and re-territorialisation through metabolic circulatory flows, organized through social and physical conduits or networks of metabolic vehicle’ (Swyngedovw, 2006, p.22). The formation and growth of urban areas generally depends on the expansion of human migration from rural areas to urban areas, and urban population increases from differences between birth and mortality rates (Gaston, 2010). Yet the main driver for such movement comes from economic variables (Francis and Chadwick, 2013), and the speed of urbanisation mainly depends on the level and pace of economic growth. For instance, people tend to move from rural areas to urban areas in pursuit of more opportunities for better living and working conditions as well as higher income (Lee and Maheswaran, 2011; Phillips, 2011). As a higher density of population and more active economic activities occur in urban areas, the city becomes a megacity, in which the total population exceeds ten million people; Algiers, Jakarta, Lahore, London, Manila, Seoul, Tokyo, Shanghai, and New York are examples of this kind of metropolitan area. The transformation towards megacities has been accompanied by more urban infrastructure such as business buildings, more complex transport infrastructure, cultural and educational facilities, and stronger administrative facilities. In such metropolitan cities, understanding their urban ecology is crucial for estimating the interrelations between the built and natural environment, as well as the consequences.

The term ‘ecology’ (*Oecologie*) was conceptualised by the German zoologist Haeckel in 1869. The original definition of ecology in Volume II, Chapter 11 ‘Oecologie und Chorologie’ in *Generelle Morphologie* (General Morphology, 1866) is as follows:

> *By ecology, we mean the whole science of the relations of the organism to the environment including, in the broad sense, all the “conditions of existence.” These are partly organic, partly inorganic in nature; both, as we have shown, are of the greatest significance for the form of organisms, for they force them to become adapted. Among the inorganic conditions of existence to which every organism must adapt itself belong, first of all, the physical and chemical properties of its habitat, the climate*

> *(light, warmth, atmospheric conditions of humidity and electricity), the inorganic nutrients, nature of the water and of the soil, etc.*

Yet as a scientific endeavour it started to draw a particular attention from the 1960s along with concerns about threats from human-oriented civilisation and technological development. It is now applied in diverse disciplines including literature, politics, environment, science, etc. Ecology is more simply defined as the interactions and relationships between organisms and the environment (Francis and Chadwick, 2013; Gaston, 2010).

Urban ecology therefore refers to the interrelations between the built and natural environment, and their component organisms, in urban areas. The concept has moved initially from 'human influences on spatial patterns and processes within cities' towards 'incorporating urban areas more holistically and within "ecosystem concepts"' (Francis and Chadwick, 2013, p.3). Urban ecology can be viewed differently by science and planning disciplines (Pickett *et al.*, 2011). It can be regarded as 'studies of the distribution and abundance of organisms in and around cities, and on the biogeochemical budgets of urban areas' from the former perspective (Pickett *et al.*, 2011, p.333). Such approaches are useful for understanding urban ecosystems by focusing on the urban physical environment, urban soils, and flora and fauna in cities (Pickett *et al.*, 2001). On the other hand, it can be defined as 'design of the environmental amenities of cities for people, and on reducing environmental impacts of urban regions' from the planning perspective (Pickett *et al.*, 2011, p.333). Altogether, an appreciation of urban ecology and urban ecosystems allows scientists, planners and decision makers to comprehend 'how the social, economic and ecological aspects of cities interact', so that 'the feedbacks and dynamics of the ecological linkages must be assessed' (Pickett *et al.*, 2001, p.139).

An appreciation of urban ecology and urban ecosystems can be gained through theoretical frameworks such as that of the complex adaptive system. The concept of complex adaptive systems (CAS) can help social scientists and planners to follow complicated interactions between urban and natural ecosystems and their consequences. It comes from complexity theory, which has been expanded from the physical sciences to the social sciences as a tool allowing feedback and learning (Innes and Booher, 1999; Levin, 2003). As complex adaptive systems are large entities wherein multiple components are dynamically and continuously interconnected (Eidelson, 1997), they can encompass wide and diverse ranges of social and natural patterns within civil society. In addition, the system maintenance basically requires an external stimulus and the capacity to self-organise and to adapt to radical changes (Emison, 1996; Innes and Booher, 1999; Levin, 2003). Such features can be applicable to urban ecosystems as well.

The 'ecosystem' is a crucial forum in which 'a physical environment and organisms in a specified area are functionally linked' (Pickett *et al.*, 1997, p.186). It is not easy for natural scientists to predict a natural system's patterns and processes. Yet the system has the capacity to self-regulate organisms interacting with other variables and with the environment (Berkes *et al.*, 2003, p.3). Its adaptive capacity also allows an ecosystem to maintain the status-quo (engineering resilience) or further develop so as to become more resilient to abrupt changes (ecological resilience) (Holling, 1996). As an ecosystem has such characteristics including instability, self-regulation and adaptive capacity, it can be comprehended as a complex adaptive system (Alberti *et al.*, 2003; Francis and Chadwick, 2013, p.51; Levin, 1998).

Urban areas can be appreciated as complex adaptive systems, as urban landscapes are socio-ecological systems of complicated and interconnected links between humans and natural systems. Urban ecosystems are considered as areas in which a high density of human population exists surrounded by a mixture of built and semi-natural environments (Pickett *et al.*, 2011; Pickett *et al.*, 2001). According to Dobbs *et al.* (2011); Douglas *et al.* (2011, p.3); Escobedo *et* *al*. (2011), they are also defined as the built-up areas containing 'the habitat of urban people, their pets, their garden plants, the adapted animals and organisms (birds, moulds, etc.) and the pests (rats, weeds, parasites, etc.).' All of these interpretations emphasise high human population densities, a complex mixture of artificial and more natural habitats containing a wide range of different organisms, and complex interactions between ecosystem components. As complex adaptive systems, urban ecosystems also show the capacity to self-organise and to adapt to external stresses (e.g. heat waves, droughts and floods), which can be dependent on institutional capacity (e.g. regulation) or economic status.

An appreciation of urban areas as complex adaptive systems allows urban planners and decision-makers to effectively manage individual ecosystems in specific urban areas. The process of urbanisation brings economic and social benefits to urban ecosystems, but its direct and indirect negative impacts on urban ecosystem services are readily apparent. Traffic congestion, altered landscape structure (e.g. unplanned urban sprawl and growth of slums), climatic conditions, hydrological cycle, carbon cycle and biodiversity are examples (Niemelä *et al.*, 2010; Whitford *et al.*, 2001). In addition, it is still difficult to predict or quantify the impacts of natural components (e.g. climate variables) on ecological (e.g. change in biodiversity) and human variables (e.g. socio-economic patterns) or the system in total.

As climatic variations are particularly difficult to predict, measurement of impacts on soil quality, carbon cycle and changes in biodiversity has shown slow progress. Furthermore, complexity in prediction may come from 'time lags' between the coupling of humans and nature, and the onset of ecological and socio-economic consequences (e.g. the relationship between investment in soil improvement and changes in income levels in Kenya) (Liu *et al.*, 2007). Ultimately, it can be inferred that urbanisation in urban ecosystems results to some extent in the loss of self-organising abilities, imbalance, and reduced adaptive capacities to external threats. It is significant that urban ecosystems should be interpreted through the lens of complex adaptive systems, so as to establish clear directions for effective environmental management.

1.2. Research Problem and Objectives

When most mega-cities face similar climate change impacts and risks (e.g. warm spells, heavy precipitation, tropical cyclone, drought and high sea level), their strategies and practice are diverse, depending on geographical location or the level of adaptive capacity. Most mega-cities have their own urban planning and strategies for handling climate change impacts. Even though those cities have built knowledge and infrastructure in the face of climate change impacts to some extent, other unexpected changes in climatic conditions and its impacts on the urban area require new approaches or management practices. Under such situations, the existence of networks enabling cities to exchange their best practices, programmes and policies for handling such impacts is crucial, as well as a holistic approach considering climate change mitigation and adaptation, and consideration of how urban ecosystem can be resilient. And in terms of active dialogue considering such approaches, London is a useful city to consider as there are diverse and active partnerships ongoing at local, public, private, academic, national and international levels (e.g. London Climate Change Partnership or Space4Clinate).

In other words, as a representative among mega-cities, this thesis focuses on London, as a city that (1) has substantial potential for increasing vulnerability to climate change, (2) has a strategy for building climate resilience through an increase of both cover and connectivity of green infrastructure in order to address a suite of environmental issues, including climate resilience, and (3) has different patterns of street blocks and management practices due to diverse public and private land ownership and management leading to different neighbourhood conditions and environments. The third reason has been long discussed in Greater London as an approach for better public welfare (GLA, 2011). The All London Green Grid (ALGG) project, encouraged by the Greater London Authority (GLA), has aims to tackle those issues as it is ultimately an urban greening and regeneration project. In other words, the ALGG initiative progressed in London is meaningful as it can bring diverse ecosystem service benefits while building resilience to climatic risks. For this reason, London was selected as a representative for showing how urban socio-ecological sustainability has been accomplished. The process and outcomes from the initiative would give implications for other cities to try to envisage diverse strategies for bringing socio-ecological sustainability in the face of climate change impacts.

Within this context, green spaces in Greater London, and street trees and green infrastructure management in London Business Improvement Districts (BIDs) will be investigated, for the following reasons: (1) BIDS are important units of management of the ALGG, but there is a potential conflict between the provision of green spaces in the BIDs for environmental vs. socio-economic purposes; (2) BIDs are discrete spatial areas for detailed quantification of small areas of green space, for which varying levels of information are available; and (3) BIDs are areas where different management interpretations of the ALGG can be investigated for businesses, local councils, and the GLA. BIDs are unique in their role as a nexus of commercial interests and urban politics for the improvement of defined geographical areas (Hoyt, 2003).

The overall aim of the thesis is to determine London’s potential resilience to climate change through ecosystem services management. In particular, the socioecological capacity of the All London Green Grid for contributing to climate change resilience via green space patterns and carbon storage and sequestration through urban trees will be the central focus. This stem from a socio-ecological perspective and include not just the development of an understanding of how much carbon urban trees may store and sequester, but also how this process is understood by those responsible for the management of green infrastructure in London.

These aims will be addressed using a mixed methods approach: measuring spatial patterns of green infrastructure and the effectiveness of urban trees in terms of carbon storage and sequestration in BIDs will be assessed quantitatively, while multi-stakeholder (businesses, local authorities, the Greater London Authority, and other ALGG-related organisations) perspectives on decision-making processes related to climate change or environmental management will be assessed using qualitative methods, such as semi-structured interviews. Some of the interview content will be used as background information, particularly related to interpretation for public urban tree management. The literature generally uses the term ‘green space’, but ‘open space’ in London is often used by various stakeholders. For this reason, the terms ‘open space’ and ‘green space’ will be used interchangeably in this thesis.

The specific objectives of this thesis are as follows:

1) To examine and understand the current patterns of open space distribution and open space composition in Greater London through spatial mapping (GIS) and spatial analysis (using the FRAGSTATS programme) and determine associations and potential drivers of open spaces with socioeconomic variables, as well as implementation for open space management and governance.
    - The characteristics of open spaces in Greater London should be clarified so as to identify their current landscape metrics. This will provide a ‘current state’ measure of open spaces in London that will be used to (1) inform an understanding of where open spaces are located, how they are distributed, their size distributions, and what types of open space exist; (2) allow a comparison of the open spaces in the whole Greater London, Inner and Outer London in general; (3) determine the correlations

with a relevant suite of socioeconomic variables; and (4) provide context for subsequent discussions of open space management and governance.

2) To determine the number, diversity and location of street trees, as well as their contribution to carbon storage and sequestration as a basis for (1) figuring out contributors to carbon storage and sequestration estimates; (2) quantifying carbon storage and sequestration estimates in central Business Improvement Districts as well as its monetary value; and (3) making management and governance observations and recommendations for building urban resilience.
   - This objective will be addressed by using field tree data to explore how different types and numbers of urban trees may vary, what kinds of trees are the most and least effective for carbon storage and sequestration, and which BID areas show the highest and lowest values. Field tree measurement (i.e. species identification, measurement of tree DBH and heights, and tree condition) is a powerful technique for directly and precisely investigating carbon content, which will be determined using the i-Tree programme, a state-of-the-art, peer-reviewed software suite from the USDA Forest Service utilising appropriate species-specific algorithms to relate tree dimensions to carbon stored and sequestered. This information on carbon sequestration and storage will provide stakeholders with useful information when progressing urban greening in BIDs as a part of the implementation of the ALGG.
3) To determine (1) stakeholder perception of the extent to which the All London Green Grid has impacts on resilience to climate change; (2) what kinds of impacts and influences participants have on the development of the ALGG project along with climate change resilience policy; (3) knowledge of stakeholder perspectives on the likelihood and value of the ALGG project development, particularly in relation to

overcoming governance barriers; and (4) how stakeholders have created governance during the progress of the ALGG initiative.

- The wide participation of diverse stakeholders is crucial for open space management within the climate change resilience framework, as resilience to climate change impacts is not limited to environmental aspects but includes social and economic perspectives. Stakeholders in relation to open space management have their own goals, such as recreation, aesthetics, air quality control and climate regulation. For this reason, investigation of the motivations for open space management and preferences of open space type is a prerequisite for determining how they have contributed to building urban resilience within the ALGG governance. The thesis will also investigate whether they also consider the function of carbon sequestration a priority. The primary mechanism for this will be semi-structured interviews with key stakeholders from businesses, local authorities, Forestry Commission and the Greater London Authority.

1.3. Structure of the Thesis

This research explores the extent of the contribution of ecosystem service management to climate change adaptation and mitigation literature. As interdisciplinary research into the impacts of green infrastructure on urban resilience to climate changes, it also contributes to carbon storage and sequestration from urban trees literature, research on urban ecology within adaptive complex system theory, and research on social-ecological frameworks in climate change adaptation discourses This thesis covers Greater London at a large spatial scale for looking into the bigger picture of the capital’s socioeconomic situation and urban resilience, and Business Improvement Districts at a small spatial scale and special spatial units with best practices such as trials to combat socioeconomic inequality and environment issues for improving urban resilience. Business Improvement Discitis are also under the scheme of urban greening projects as a part of the All London Green Grid initiative. In this sense, some best practices and policies within the BIDS allow policy makers and urban planners in deprived or vulnerable areas to ameliorate climatic risks and other impacts in London or other cities by adopting such practices for spatial improvement. Consequently, the research methodology will be applicable to other cities which face similar climate change risks and socioeconomic situations.

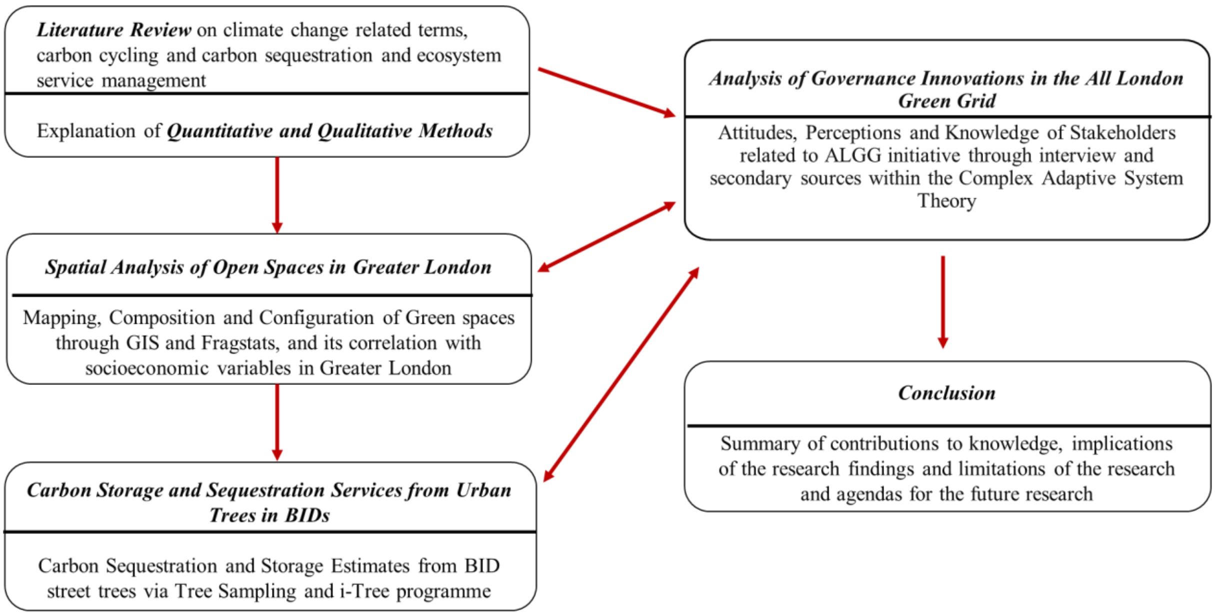


Figure 1.2 Structure and flow chart for thesis

Chapter 1, the introduction, has given detailed explanations as to why this thesis targets urban ecosystems and the current trend of urbanisation. In addition, this chapter identifies the main research objectives.

Chapter 2 is mainly literature reviews on three themes: climate change impacts and carbon cycling; responses to climate change in urban ecosystems such as ecosystem service management; and carbon sequestration in urban green spaces and urban trees. This chapter presents essential background material before developing this research further.

Chapter 3 gives an overview of two quantitative and one qualitative research methods. Even though each empirical chapter has its research methodology presented separately, this chapter covers site description including a literature review of Business Improvement Districts (BIDs), background of the London Plan and the All London Green Grid Project as resilience strategies, strengths and weaknesses of mixed-research methods, a brief literature review on Geographic Information System (GIS), and functions and effectiveness of GIS, followed by spatial analysis of open spaces. In addition, the necessity of tree sampling for carbon measurements will be elaborated as a quantitative research method. After that, the reason that semi-structured interviews were selected from among other qualitative research methods will be explained, as well as a brief elaboration of potential interviewees.

Chapter 4, *Spatial Analysis of Open Spaces in Greater London*, provides a wider spatial context for elaborating patterns and functions of open spaces in Greater London. Spatial analysis of green spaces in Greater London through the ArcGIS and FRAGSTATS programmes provides a snapshot of the current configuration and composition of the green spaces, which has never been measured before. Patterns are statistically analysed alongside with socioeconomic variables, so as to clarify correlations between the variables. This establishes a baseline for recommendations on green space management and governance.

Chapter 5, *Carbon Storage and Sequestration Services from Urban Trees in BIDs*, focuses on quantification of regulating ecosystem services in Business Improvement Districts in which economic activities are more concentrated in Greater London. Along with surveyed tree composition and density, carbon storage and sequestration estimates and its monetary value from urban trees within the boundary of central eleven BIDs will be determined through the i-

Tree programme. The outcomes will be useful for urban planners to manage urban street trees and deliver practices.

Chapter 6, *Analysis of Governance Innovations in the All London Green Grid* is about governance development and patterns in which diverse stakeholders are involved in open space management and delivery projects related to the All London Green Grid initiative. The theoretical framework for understanding such governance, contents of interview questionnaires, analysis of interview contents and secondary data sources, and discussions on urban green regeneration will be covered. All the interview questions are related to responses to climate change impacts, barriers for proceeding green infrastructure projects, as well as effectiveness and consideration of carbon storage and sequestration in their projects and strategies. Interview analysis will be conducted with the application of complex adaptive system (CAS) theory, so as to fully comprehend each stakeholder's role in a complex urban socio-ecological system.

Chapter 7, the conclusion part presents a summary of contributions to knowledge, implications of the research findings for future planning and management, and a brief discussion of the links between the quantitative and qualitative methods, and their effectiveness, including achievements, limitations and recommendations.

2. Literature Review

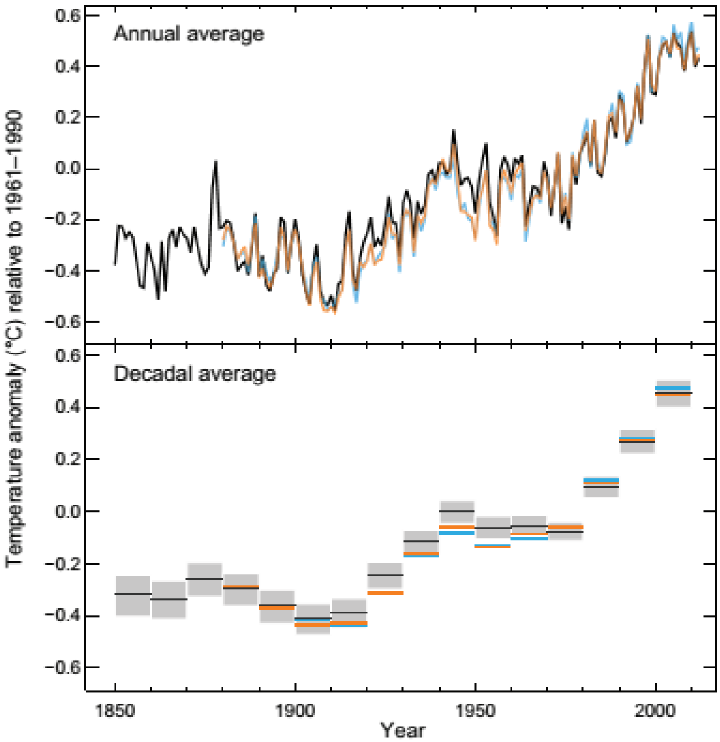
2.1. Climate change impacts and carbon cycling

2.1.1. Observation of global climate change

The causes of, consequences of, and responses to anthropogenic climate change are major environmental questions for the Anthropocene (Crutzen and Steffen, 2003; Houghton, 2009; Steffen *et al.*, 2011). As each stakeholder has different views and responses (or strategies), much debate on the subject has raged and climate change has been viewed as a ‘wicked problem’ in a social context. This is because the issue has been characterised by a lack of definitive formulation, endless searches for neutral solutions, unexpected and subsequent consequences, and discrepancies (Rittel and Webber, 1973). This kind of wicked problem requires a scientific and objective approach so as to draw out integrated solutions.

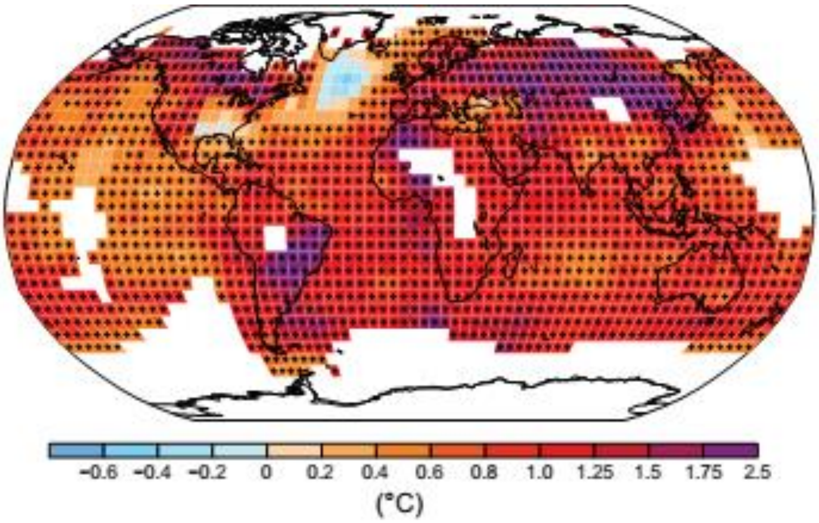
Abundant and objective scientific data is required in order to allow policy-makers or planners to make appropriate decisions. In an effort to lessen uncertainty, scientists have tried to reach a consensus that climate change is the consequence of natural and anthropogenic patterns and processes influencing the Earth’s energy budget and energy fluxes (IPCC, 2013). Every year, national and international progress in mitigating and adapting to climate change risks and related disasters are assessed at the UN Climate Change Conference, alongside specific debates on limiting global target temperature increases.

Since the 2009 Copenhagen Accord, parties have maintained that the global temperature increase by 2100 should be below 2^{o}C (UNFCCC, 2010). In recent negotiations in Doha and Durban, efforts have been strengthened to limit it to 2 or 1.5^{o}C over pre-industrial levels (UNFCCC, 2012; 2013). The Paris Agreement, agreed in 2015 but entered into force in 2016, became significant as it became legally binding, as signatory countries must make efforts to limit global temperature rises to below 2ºC and less than 1.5ºC if possible (https://cop23.com.fj/about-cop-23/about-cop23/), even though there are still discussions ongoing about how to achieve this. The conference officially provides international targets that are desirable and feasible to its member parties. During the process, accurate and objective information and data (e.g. Intergovernmental Panel on Climate Change (IPCC) reports) from the 'science of climate change' and 'the future scale of human activities' (Houghton, 2009, p.15) contribute to the decisions made, as they have the potential to lower uncertainties on causes and consequences of climatic change. In addition, if scientific procedures are applied into the process of strategy formulation related to anthropogenic climate change, planners would conduct more systematic, transparent, accountable and reproducible analysis (Stirling, 2007).



Source: Adapted from IPCC (2013)

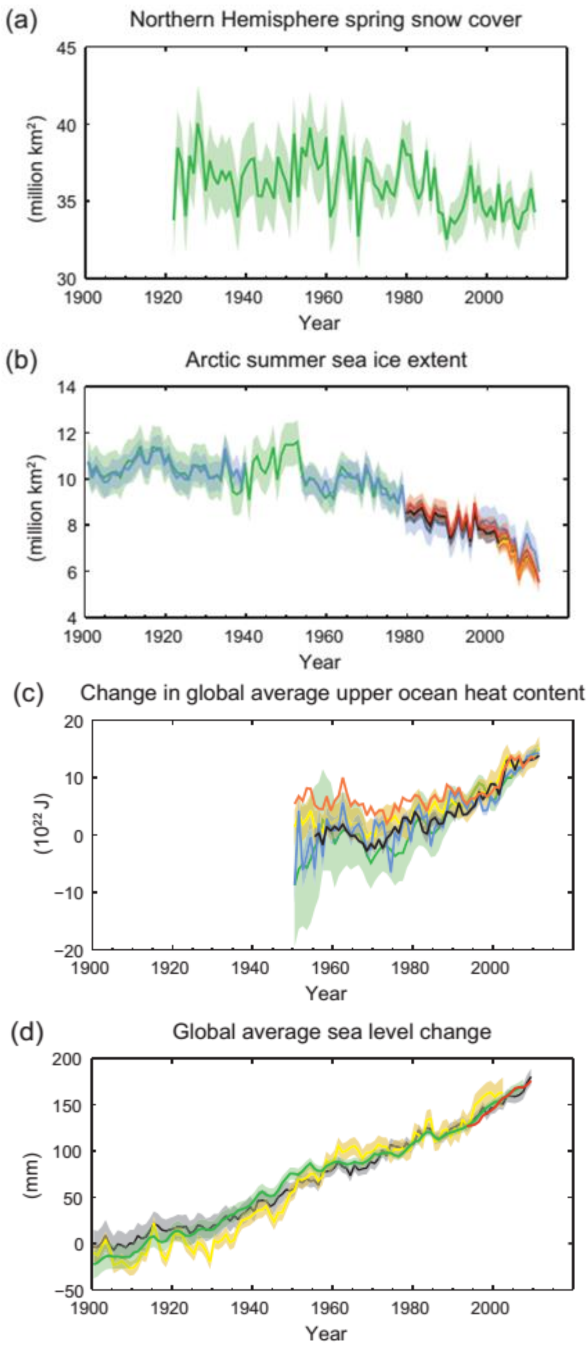
Figure 2.1 Observed globally average combined land and ocean surface temperature anomalies (related to the mean of 1961-1990) from three data sets (1850-2012)



Source: Adapted from IPCC (2013)

Figure 2.2 Map of the observed surface temperature change using linear regression from one dataset (1901-2001)

Climate change observation is a crucial means for obtaining sound evidence for climate change science. Among diverse scientific reports on climate change, the IPCC report provides natural and social scientists, planners and decision-makers with comprehensive and objective information and data. The recent fifth IPCC report physically categorises observed changes in climate systems in temperature, energy budget and heat content, water cycle and ice sheets in the Greenland and Antarctic regions, sea levels, extremes and carbon and other biogeochemical cycles. In particular, as a renowned indicator of climate change (IPCC, 2013), the general changes in the global surface temperature allow climate scientists to estimate the extent of climatic changes in the future. As shown in Figures 2.1 and 2.2, land and ocean surface temperatures recorded an increase of 0.85°C (0.65 to 1.06) on average during the period from 1880 to 2012, and a rise between the 1850 to 1900 period and the 2003 to 2012 period indicated 0.78°C (0.72 to 0.85) on average (IPCC, 2013).



Source: Adapted from IPCC (2013)

Figure 2.3 Multiple observed indicators of a changing global climate (1870s-2010s)

Such multilevel indicators provide historical trends in climate change impacts. Since 1900, the snow cover during the spring season in the northern hemisphere, and the sea ice cover during the summer have shown decreasing trends, whereas there have been globally increasing tendencies in the upper ocean heat content and in the global sea level on average. Specifically, as shown in Figure 2.3, the average rate of ice loss from glaciers (excluding glaciers on the periphery of the cryosphere) was highly likely to record 226 (91 to 361) Gt yr^{-1} during the 1971 to 2009 period, and recorded 275 (140 to 410) Gt yr^{-1} from 1993 to 2009 (IPCC, 2013). This leads to an increasing risk of sea level rise over time. More specifically, the mean rate of sea level rise had a high possibility of being 1.7 (1.5 to 1.9) mm yr^{-1} over the period 1901 to 2010, 2.0 (1.7 to 2.3) mm yr^{-1} over the period 1971 to 2010, and 3.2 (2.8 to 3.6) mm yr^{-1} between 1993 and 2010 (IPCC, 2013). During the warming of the upper ocean (0-700 m), its upper 75m had warmed by 0.11°C (0.09 to 0.13) per decade during the period 1971-2010, as well as the accelerated ocean acidification taking up 30% of CO_2 emissions (IPCC, 2013). Based on above data, the warming is occurring globally, beyond the northern hemisphere. Among the greenhouse gases creating these changes, carbon has been at the centre of climate change policy and carbon management notions, as the balance of the gas has most influence on the Earth's ecosystems.

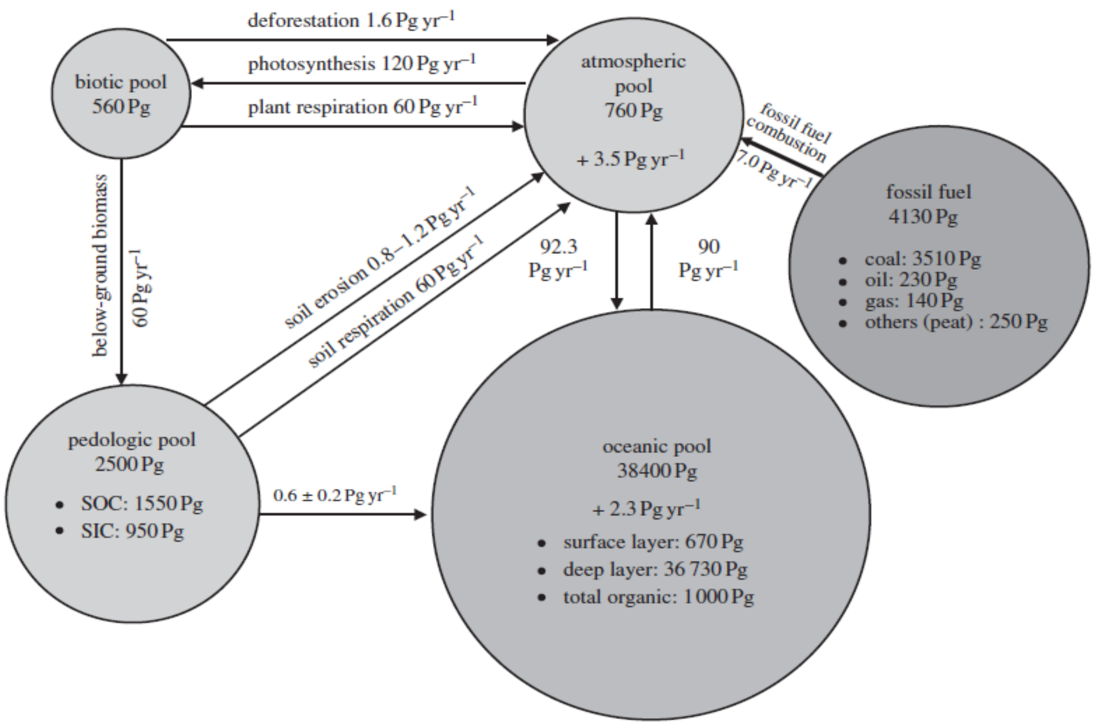
2.1.2. The global carbon cycle and climate change

Carbon is circulated among carbon reservoirs such as the atmosphere, the ocean, and terrestrial ecosystems within the Earth's system. This process is called the carbon cycle. In the global carbon cycle, approximately 210 $GtCyr^{-1}$ is transported through major reservoirs, wherein terrestrial and atmospheric pools constitute 60% in terms of carbon circulation (Renforth *et al.*, 2009). Carbon circulation between geological reservoirs and the atmosphere occurs via photosynthesis, respiration, decomposition, and combustion (Smithson *et al.*, 2008). However, anthropogenic activities such as land use change and fossil fuel uses have triggered more releases of CO_2 emissions than expected have led to the imbalance in the global carbon cycle along with adverse ecological consequences, such as air pollution, soil contamination, loss of biodiversity, and health problems (Alberti *et al.*, 2003; Dobbs *et al.*, 2011; Grimm *et al.*, 2008). The carbon cycle is therefore directly and indirectly affected by the growth in global GHG emissions from the energy supply sector (an increase of 145%), transport (120%), industry (65%), land use change and forestry (40%) (IPCC, 2007). Since 1750, emissions of greenhouse gases such as CO_2, CH_4, and N_2O have been increasing, reaching 391 ppm, 1803 ppb and 324 ppb respectively in 2011 (IPCC, 2013). In 2010, GHG emissions were released in the following proportions: 35% in the energy supply sector, 24% in AFOLU (Agriculture, Forestry and Other Land Use), 21% in industry, 14% in transport and 6.4 % in buildings (IPCC, 2014a).

CO_2 itself does not have a serious negative impact on the Earth's climate system, but the sharp increase in CO_2 concentrations brings abrupt rises in temperature and the amount of water vapour in the atmosphere due to its function as a blanket over the Earth's surface (Houghton, 2009, p.13). Unlike other greenhouse gases (e.g. CH_4, and N_2O), CO_2 has an infinite lifetime, and the scale of atmospheric impact can readily be larger after passing through the ocean and terrestrial reservoirs (Smithson *et al.*, 2008). CH_4 and N_2O (consisting of 18% and 9% in GHG emissions respectively) come mainly from agricultural activities, whereas CO_2 (approximately 72%) is mainly emitted through energy-related activities such as energy consumption and production, and transport, etc. Even though excess gas will be eliminated by natural processes to some extent, long-lived anthropogenic greenhouse has substantial negative effects on ecosystems, and human society (America's Climate Choices, 2010; Compton *et al.*, 2011; IPCC, 2014b; Marland *et al.*, 2003; Vitousek, 1994).

In addition, the removal rate of the gas cannot be detached from the storage capacity of CO_2 in terrestrial (particularly plants and soils) and oceanic carbon pools (Watson *et al.*, 1992). Even though the storage capacity has not been precisely measured due to the difficulty of measuring each carbon pool, it is possible to confirm that each pool is reaching their limits of naturally removing the gas due to increasing human activities. Since the pre-industrial period, CO_2 concentrations have risen by 40% from fossil fuel consumption and land use changes (IPCC, 2013). As for annual global CO_2 emissions, fuel combustion and cement production emitted 8.3 (7.6 to 9.0) $GtCyr^{-1}$ from 2002 to 2011, and 9.5 (8.7 to 10.3) $GtCyr^{-1}$ in 2011 (54% above the 1990 level), whereas the consequences from land use changes were 0.9 (0.1 to 1.7) $GtCyr^{-1}$ during the same period (IPCC, 2013). Such a rising trend, mainly from fuel combustion and cement production, and land use changes, has influenced the fluxes of the global carbon pools, even though there are some natural differences in fluxes among carbon pools over time.

Appreciating the whole carbon cycle provides more information for climate change-related policies, as well as estimating future trajectories in carbon reservoirs (Churkina, 2008). Lal (2008a) indicates how global carbon pools (biotic, atmospheric, pedologic and oceanic pools) and fossil fuels interact, including perturbation by anthropogenic activities (Figure 2.4). Even though the Figure is somewhat outdated, on the basis of data on carbon pools and fluxes among main reservoirs from various scholars and IPCC, it gives an outline of the interactions among pedologic (2.5×10^3 Pg), atmospheric (760 Pg with increasing at 3.5 Pg C per year), and biotic carbon pools (560 Pg). The global fluxes in pools are difficult to measure or estimate because the amount of carbon changes constantly (e.g. the different level of ocean acidification in each area).



Source: Adapted from Lal (2008a, p.816)

Figure 2.4 Fluxes between the Global Carbon Pools

The oceanic pool (about 39 $\times 10^3$ Pg increasing at 2.3 Pg C per year), which is the largest one, should be continuously tracked so as to gain more exact information on changes in fluxes of the global carbon pool. There has been considerable research on carbon storage and changes in carbon fluxes. In terms of oceanic carbon changes, the correlation between CO_2 and pH level is applied to observation of changes in the natural ecosystem. For instance, accumulated CO_2 emissions through aquatic systems (e.g. rivers or streams) result in ocean acidification, which can be confirmed with its lower pH level. Yet the feedback of the ocean's carbon cycle to climate change is not yet certain, due to its interlinked and nonlinear processes (Riebesell *et al.*, 2009).

Terrestrial carbon pools indicate more signs and magnitudes of terrestrial carbon cycle feedback of the anthropogenic phenomenon than the oceanic pool. Geologic pools mainly consist of coal (3510Pg), oil (230Pg), gas (140Pg) and others (250Pg), but the increasing depletion of fossil fuels in the pool at the rate of 7.0 Pg per year influences the atmospheric pool (Lal, 2008a). In addition, different management of terrestrial carbon pools (pedologic and biotic pools) is considered as a variable that influences the atmospheric carbon pool (Lal, 2010). As shown in Figure 2.4, the pedologic pool consists of soil organic carbon (1550 Pg) and soil inorganic carbon (950 Pg).

Soil organic carbon enhances soil quality, as it has a direct connection with the amount of organic matter within soil. Soil inorganic carbon is made up of elemental carbon and carbonate materials like calcite, dolomite, and gypsum, and is crucial in arid and semi-arid soils (Lal, 2004a; 2008a). Soil (in)organic carbon cannot be excluded when explaining carbon soil sequestration, as it determines the rate and capacity of sequestration in soils.

Table 2.1 The Global CO_2 Budget

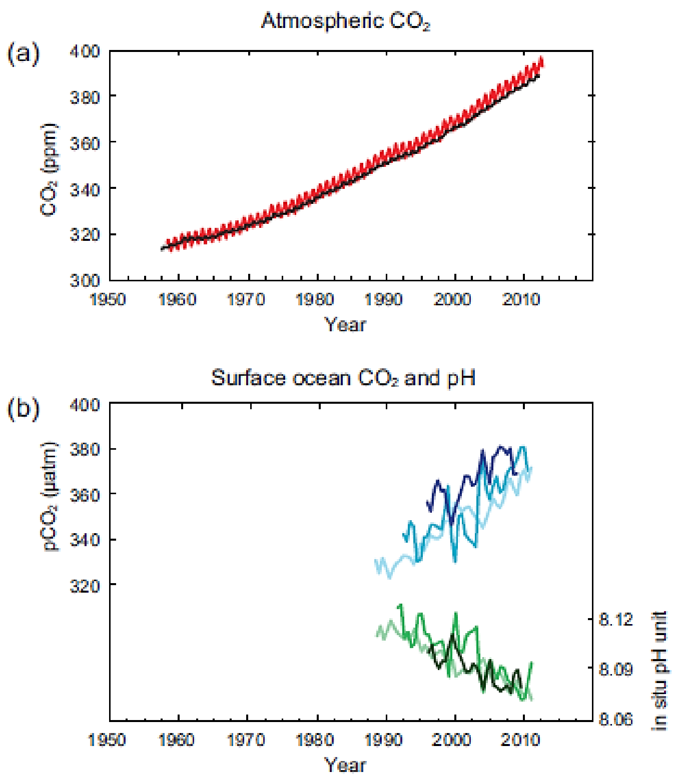
	1750–2011 Cumulative PgC	**1980–1989 PgC yr^{-1}**	**1990–1999 PgC yr^{-1}**	**2000–2009 PgC yr^{-1}**	**2002–2011 PgC yr^{-1}**
Atmospheric increase	240 ± 10	3.4 ± 0.2	3.1 ± 0.2	4.0 ± 0.2	4.3 ± 0.2
Fossil fuel combustion and cement production	375 ± 30	5.5 ± 0.4	6.4 ± 0.5	7.8 ± 0.6	8.3 ± 0.7
Ocean-to-atmosphere flux	–155 ± 30	–2.0 ± 0.7	–2.2 ± 0.7	–2.3 ± 0.7	–2.4 ± 0.7

Land-to-atmosphere flux	30 ± 45	–0.1 ± 0.8	–1.1 ± 0.9	–1.5 ± 0.9	–1.6 ± 1.0
Partitioned as follows					
Net land use changed	180 ± 80	1.4 ± 0.8	1.5 ± 0.8	1.1 ± 0.8	0.9 ± 0.8
Residual land sink	–160 ± 90	–1.5 ± 1.1	–2.6 ± 1.2	–2.6 ± 1.2	–2.5 ± 1.3

Source: Adapted from IPCC (2013, p.486)

In a recent effort to estimate more exact carbon fluxes and CO_2 budget, the 2013 IPCC report gave more detailed information on the fluxes in or between carbon pools. According to the IPCC (2013), 240 (230 to 250) PgC of anthropogenic CO_2 emissions has been stored in the atmosphere, 155 (125 to 185) PgC has been accumulated in the ocean and 160 (70 to 250) PgC has been taken up in terrestrial ecosystems (1750 to 2011). The global CO_2 budget and the balance of carbon fluxes among the global carbon pools, shows the largest total cumulative emissions recorded (375 ± 30 PgC) from fossil fuel combustion and cement production, including a contribution of 8 PgC from the production of cement, and 180 ± 80 PgC from net land use changes over the period 1750 to 2011 (Table 2.1). In other words, the rate of accumulating emissions in the atmosphere fostered by fossil fuel combustion, cement production, and land use changes has shown a more rapid increase compared to accumulation rates in the ocean and terrestrial biospheres.

Land use change leading to a decrease in the areal extent of diverse habitats and the quality of natural ecosystems has reduced soil quality, influencing the soil organic pool, and ultimately the global cycle as well (Lal, 2001). In order to balance the global cycle, the exact measurement of carbon in each reservoir is required. Continuous observation of its pool system is also necessary in order to sense the change through several indicators covering atmospheric CO_2 and surface ocean CO_2 and pH (Figure 2.5). The oceanic reservoir comprises the largest amount of carbon, whereas the atmosphere stores the smallest amount of carbon. Yet the atmosphere is the crucial pool due to its role as a conduit among reservoirs, and its potential for carbon storage has been studied in details since 1958 (Post *et al.*, 1990).



Source: IPCC (2013)

Figure 2.5 Multiple observed indicators of a changing global carbon cycle

(a) Atmospheric concentrations of carbon dioxide from Mauna Loa and the South Pole since 1958; (b) Partial pressure of dissolved CO_2 at the ocean surface (blue curves) and in situ pH (green curves), a measure of the acidity of ocean water. The measurements are from three stations in the Atlantic and the Pacific Oceans.

Research on terrestrial ecosystems still lags behind compared to the two other reservoirs. Even though it is certain that the natural terrestrial ecosystems, including urban green spaces, function as carbon sinks (Schlesinger, 2000), there is still uncertainty about the extent to which ecosystems can absorb and store carbon (Post *et al.*, 1990). Yet understanding the global carbon cycle and budget would allow urban planners to design urban green spaces for more effective carbon sequestration through soils and vegetation.

2.1.3. Urban ecosystems as carbon sinks

Due to higher population, concentrated economic activities and consequent climate impacts and risks, studies on urban areas should attract more attention in pursuit of successful climate change mitigation and adaptation practices. During the process of urbanisation, terrestrial formations have become carbon sources rather than sinks due to long-term sensitivity to climate change impacts (Melillo *et al.*, 2002). It has been generally accepted that urban and suburban areas are regarded as net carbon sources while ex-urban and rural landscapes are seen as carbon sinks (Zhao *et al.*, 2011). Yet if ecosystem services in urban areas function properly, and proper low carbon technologies are deployed, cities are highly likely to play a role as carbon sinks, depending on land management. Even though there is still a lack of comprehensive studies on urban ecosystems (e.g. ecosystem services and goods) (Dobbs *et al.*, 2011), reformation of urban ecological systems as carbon sinks is ongoing through diverse urban regeneration projects (e.g. Ottawa’s Urban Green Space Network, Scotland’s Urban Networks for People and Biodiversity Project, and London’s Green Grid Project).

For example, soil carbon sequestration practices for improved land management provide urban areas with great possibilities to become carbon sinks along with substantial economic incentives, such as low investment costs and immediate implementation (Jo, 2002; Post *et al.*, 2004). Driven by urbanisation, degraded soils have resulted in the depletion of soil organic carbon (SOC) (Pouyat *et al.*, 2006), which has changed urban ecosystems into carbon sources. On the contrary, it means that proper accumulation of soil organic carbon though soil carbon sequestration practices (e.g. zero/reduced tillage in cropland, revegetation with higher carbon return rates to soils, and development of urban green spaces, or improvement of degraded lands) can enhance soil quality (Renforth *et al.*, 2009; Smith, 2004b).

Increasing urban green spaces has been known to be a cost-effective form of land management due to (for example) the higher rate of carbon storage in urban soils and vegetation (Beesley, 2012; Pouyat *et al.*, 2002). Jo (2002) indicates that urban green spaces can lower atmospheric CO_2 levels by the following measures: (1) carbon sequestration from urban trees and shrubs via photosynthesis; (2) reduction of fossil fuel consumptions through decreasing demand for cooling (via shading and evapotranspiration) and heating (via wind speed reduction); (3) storage of organic carbon from litter fall. Terrestrial carbon sequestration via photosynthesis or humification, however, has limits in sink capacity (50~100 Pg) even though its environmental effects are immediate, positive, low cost and low risk (Lal, 2008a). Therefore, the exact measurement for carbon uptake and storage in urban soils, and proper planting of vegetation, should be followed along with land management and planning processes by each region.

Nevertheless, there are few studies on urban soil carbon sequestration, as most research on soil carbon sequestration has been done in the agriculture sector. In addition, research on urban organic carbon pools has been mainly focused on trees rather than other vegetation (Pataki *et al.*, 2006), as trees contain more evidence of carbon sequestration and storage, e.g. carbon storage (about 700 Mt) estimates and a gross net sequestration rate (22.8 $MtCyr^{-1}$) in the US's urban trees from Nowak and Crane (2002). Even though there are some difficulties in gaining data on urban soil carbon and proper vegetation, urban soil carbon sequestration practices play a partial role in mitigating CO_2 emissions. In particular, these projects can bring more synergy effects such as resilience to climate change impacts if other climate change mitigation and adaptation practices (e.g. development of renewable technologies, low carbon transport or building and development of drought-resistant crops or vegetation) are followed.

2.2. Responses to climate change in urban ecosystems

2.2.1. Discourses on responses to climate change impacts

When it comes to discourses on methods for coping with disasters and risks caused by climate change, social scientists and policy-makers generally meet the challenges by separating related strategies and methods into adaptation and mitigation. Since the Kyoto Protocol, diverse international responses covering financial support for climate change adaptation, and a technology transfer framework from developed to developing countries, have been provided through annual climate change negotiations. Over time, the outcomes from several negotiations have brought shifts from an international commitment at a broad and general level to a more specific one at national and regional levels, as well as changes from the solely mitigation-focused responses to more balanced approaches to both mitigation and adaptation. The international commitment initially started from the legally-binding emission reductions of GHG emissions in developed countries, but has become more detailed and location-specific over time.

In the Bali Action Plan, the long-term cooperative mechanism was highlighted in five categories: shared vision, mitigation, adaptation, technology and financing. In the Cancun Agreements, more comprehensive efforts were developed, providing developing countries with more support (e.g. finance, technology and capacity building) for coping with climate change impacts. The specific contents to be handled are updated in each category on the basis of national and international data, including each country's adaptation and mitigation actions. In the 2013 UN Climate Change Conference in Warsaw, the mandatory commitments to monitor, report and verify national actions were articulated so as to provide more sound information for the next climate change agreement. The outcome from the 2015 COP 21 in Paris was the Paris Agreement, aiming to keep a global temperature rise below 2ºC above pre-industrial levels, and to make efforts to limit the increase to 1.5ºC. In the 2016 COP 22 in Marrakech, water-related issues (e.g. scarcity and sanitation) in developing countries, and reduction of green emissions through low carbon energy sources were the focal topics.

Adaptation has been regarded as a vague concept, as its effects take time to become clear compared to mitigation (IPCC, 2014b). Mitigation approaches are easier to quantify economically and allow projections in diverse scenarios, which has brought clearer direction for investment. Due to complexities and ambiguity in estimating climate change impacts, methods are sometimes employed without clear direction. It seems premature to judge, but recent climate change research shows a tendency toward using both terms in order to explain complexities in urban ecological approaches to climate change.

Climate change mitigation is mainly technology-driven or -oriented. It has four mechanisms: (1) action on non-energy emissions (e.g. avoidance of deforestation); (2) reduction of demand for emission-intensive goods and services; (3) improvement of energy efficiency; and (4) switching to technologies that produce fewer emissions and lower the carbon intensity of production (Stern, 2007). In short, climate change impacts are substantially reduced through research, development and diffusion of low carbon technology such as renewable resources, nuclear power and carbon capture and storage. The technology plays a role in radical reduction of GHGs in climate change mitigation policy. Yet there are some obstacles such as costs and availability of technology development and deployment. For instance, there are some environmental justice- and governance-related issues, including availability of sites, suitable climatic conditions, concentrated emission sources, and volatile oil and carbon prices (Stern, 2007) as well as NIMBY (an abbreviation for the phrase "Not In My Back Yard") syndrome (e.g. residential opposition to installation of wind power plants or nuclear power plants, or building pipelines for geological carbon storage after abiotic carbon sequestration near the community due to unexpected environmental concerns). Moreover, mitigation methods require time and financial resources for R&D and 'technology learning', which is regarded as one of major obstacles for securing more low carbon technology investment.

On the other hand, adaptation is more related to fundamental changes in public behaviour or perception as well as development of policies and regulations for enhancing adaptive capacity, or implementation of operational adaptation decisions (Adger *et al.*, 2005; Tompkins *et al.*, 2010). An adaptive capacity refers to the capacity of the socio-economic system to deal with inevitable environmental surprises as well as enhancing its environment-related conditions (Gallopín, 2006). Effective adaptation planning is in the centre of enhancing adaptive capacities of the marginalised, and this was articulated in the 2012 UN Climate Change Conference in Doha as well. Adaptive capacity is closely related to reduction of vulnerability and increase in resilience. The enhancement of the capacity is more important than investigation of local vulnerability to climate change in a specific site (Wreford *et al.*, 2010). This term has been explored in greater depth recently in the socio-ecological resilience literature as it is a crucial factor for a society to become less or more resilient to unexpected external threats.

Adaptation approaches are mainly divided into *risk management*, *vulnerability reduction* and *resilience approaches*. Considering their site-specific characteristics (Berkes and Jolly, 2002), diverse adaptation approaches should be utilised on the basis of conditions and features of the system of interest, sensitivities and vulnerabilities (Smith *et al.*, 2000). In addition, adaptation approaches generally focus more on equity issues, which means who can be winners or losers after applying different adaptation policies. When it comes to the history of climate change adaptation, risk management as a risk-based adaptation approach has been widely used due to its evident political and economic benefits when confronting and forecasting known environmental hazards or events. Yet other approaches should be updated, as they have substantial possibilities for handling urban adaptation, which is still under-researched due to the past national climate change policies focusing more on agricultural sectors rather than urban adaptation, and the initial concentration on mitigation instead of adaptation at a city level partly driven by international support (IPCC, 2014b).

Vulnerability approaches can be viewed as a moral responsibility to address a lack of social justice in order to help the public avoid harm, lower social inequality and enhance the adaptive capacities of the vulnerable (Eakin *et al.*, 2009). On the other hand, resilience approaches seek system integrity and advancement of system components to 'avoid an abrupt 'flip' of a coupled social-ecological system into a less desired state' in pursuit of minimising the probability of unexpected changes (Eakin *et al.*, 2009). The vulnerability approach creates losers and winners, whereas the resilience approach seeks a win-win strategy. Nonetheless, such features are affected by the power structures and distribution within a social system handling resource management and creating vulnerabilities (Adger *et al.*, 2005). Good governance is also crucial for successful adaptation policy. Vulnerability, resilience and adaptive capacity are inter-related in a non-linear but systemic way (Gallopín, 2006), responding to and shaping ecosystem dynamics and changes (Berkes *et al.*, 2003).

2.2.2. Resilience in urban ecosystems

Resilience is defined as the magnitude or amount of disturbance a system can absorb before it radically changes state, as well as the capacity to self-organise and adapt to emerging circumstances (Adger, 2006; Berkes *et al.*, 2003; Folke, 2006; Francis and Chadwick, 2013). According to Folke (2006, p.258), resilience is an advanced concept indicating 'the dynamic development of complex adaptive systems with interactions across temporal and spatial scales'. Urban ecosystems are regarded as complex adaptive systems as there are complicated interactions between humans and the natural (and artificial) environment. Even though there are different phases and paces when adapting to climate change impacts, most urbanised areas are equipped with basic adaptive capacity to some extent, given the social and cultural infrastructure. Yet adaptive capacity can be enhanced or reduced in accordance with adaptation policies. As there is still a lack of urban adaptation strategies and methods on various temporal and spatial scales, a balanced mix of diverse resilience tools such as ecosystem management, building adaptive capacity and self-organising capacity should be adopted in building climate change adaptation policy. In addition, a social–ecological systems resilience lens though which to view integrated ecosystem management would provide indicators and methods for climate change adaptation (Adger, 2000; Boyd and Osbahr, 2010; Folke *et al.*, 2005).

Most creatures can build adaptive capacity after experiencing sudden and unexpected changes through learning-by-doing (Cundill G. *et al.*, 2012; Grantham Hedley S. *et al.*, 2010; Holling, 1978; Tschakert and Dietrich, 2010). Adaptive capacities depend on learning experiences and time. Yet as climate change negatively impacts on people's lives at large spatial and temporal scales, the built adaptive capacities and infrastructure shows limited ability to cope with the adverse impacts. For instance, frequent, abrupt and heavy rainfalls in winter 2013 created serious flooding, along with serious damage to households and communities in the UK. The

UK's flood risk management and practices case clearly showed the consequences of a lack of adaptive capacities and adaptation practices such as flooding warning systems, infrastructure for prevention and exact and swift rescue operations. Such a sense of crisis is not enough to bring about more active adaptation actions due to several barriers: (1) public value of vulnerable resources; (2) difficulty in making a collective decision; (3) lack of information about adaptation decisions; and (4) uncertainty as to who is in charge of the action (Tompkins *et al.*, 2010, p.628).

As one way to overcome such barriers, classification of spatial and sectoral scales is required to face unpredicted risks and building resilience in urban areas. Spatial scales (e.g. regional, local, national, and international) play a pivotal role in understanding non-linear and complex social-ecological systems. Categorisation of adaptation practices in sectors is useful for investigating which part is vulnerable and requires more research. For instance, the UK's adaptation practices can be found in several sectors such as construction (20%), non-sector specific (18%), water supply (18%), flood risk management (16%), biodiversity and conservation (11%), agriculture/forestry (10%) and transport (7%) (Tompkins *et al.*, 2010). Interestingly, fewer activities in biodiversity and conservation, and agriculture/forestry have been confirmed despite their relative importance for providing balanced urban ecological systems. The relatively low percentage perhaps comes from slower lead times, as it takes time to observe remarkable changes in fauna and flora. However, as urban dwellers benefit from ecosystem services provided by semi-natural ecosystems within the built environment, it is important to understand how diverse ecosystem services function, what they provide and how they contribute to urban resilience to climate change risks.

2.2.3. *Vulnerabilities in urban ecosystems*

Vulnerability is 'a scale of the relative likelihood of different socio-economic groups and geographic regions experiencing negative consequences' (Ribot *et al.*, 2009, p.29) and the 'state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt' (Adger, 2006, p.268). As cited in the 5th IPCC report, it can be viewed as sensitivity or susceptibility to be affected, or lack of adaptive or coping capacity (IPCC, 2014b). According to Gallopín (2006), vulnerability can be interpreted in diverse ways, but this notion is crucial for 'identifying the relationship between vulnerability, resilience and adaptive capacity' (p.294). Vulnerability is closely related to exposure, sensitivity and adaptive capacity in terms of socio-economic perspectives.

It then follows that a successful climate change adaptation strategy should start from a classification (Table 2.2) of vulnerability in urban ecosystems. Such a strategy should encompass social patterns and tangible consequences in complex systems, although this could lead to some difficulties in quantifying vulnerability (Adger, 2006). Even though urban climate change has direct or indirect impacts on natural and urban ecosystems as well as human health in a complex way, the relationship between urban climatic impacts and urban vulnerabilities is generally accepted. For instance, there are warm spells and heat waves making urban ecosystems vulnerable to urban heat and air pollution, heavy rainfall leading to the likelihood of floods, droughts leading to water shortages and rising food prices, and increasing sea levels putting coastal cities such as New York, Miami, New Orleans, Mumbai, Nagoya and Osaka at risk (Campbell-Lendrum and Corvalán, 2007; Depietri *et al.*, 2012; IPCC, 2014c; Rosenzweig *et al.*, 2006; Tan *et al.*, 2010).

Table 2.2 Climatic impacts and vulnerabilities in urban ecosystems

<table>
<tr><th>Climatic Impacts</th><th>Impact on natural ecosystems</th><th>Impact on urban areas</th><th>Impact on health and household coping</th></tr>
<tr><td>Warm spells and heat waves</td><td>Reduced crop yields in warmer regions; wildfire risk; wider range for disease vectors</td><td>Urban heat islands effect; concentration of vulnerable people; increased air pollution</td><td>Increased risk of heat-related mortality and morbidity; more vector-borne disease; increased respiratory disease; food shortages</td></tr>
<tr><td>Heavy precipitation events</td><td>Damage to crops; soil erosion; water-logging; water quality problems</td><td rowspan="2">Increase in floods and landslides; disruption to livelihoods and urban economies; damage to homes, possessions, businesses and to transport and infrastructure; often risks to social networks from large displacements of population</td><td rowspan="2">Deaths, injuries, increased food and both water-borne and water washed diseases; more malaria; decreased mobility; dislocations; food shortages; mental health risks from displacement</td></tr>
<tr><td>Intense tropical cyclone</td><td>Damage to crops, trees and coral reefs; disruption to water supplies</td></tr>
<tr><td>Drought</td><td>Land degradation; lower crop yields; livestock deaths; wildfire risks and water stress up</td><td>Water shortages; distress migration into urban centres; hydroelectric constraints; lower rural demand for goods/services; higher food prices</td><td>Increased food and water shortages; increase in malnutrition and waterborne diseases; mental health risks; respiratory problems from wildfires</td></tr>
<tr><td>High Sea Level</td><td>Salinization of water sources</td><td>Loss of property and businesses; damage to tourism; damage to buildings from rising water table</td><td>Coastal flooding; risk of death and injuries up; loss of livelihoods; health problems from salinated water</td></tr>
</table>

Source: Adapted from Bartlett (2008, p.13) and Bulkeley (2013a, p.41)

Criteria for determining the vulnerability of urban areas include geographic location (e.g. coastal locations exposed to flooding), and ‘interaction between urban processes, daily lives and climatic risks’ (Bulkeley, 2013a, p.28). For instance, New Orleans shows how urbanisation, ecological sustainability and climate change are linked (IPCC, 2014b). This city, situated on a low-lying site in the face of rising sea levels, became chaotic after Hurricane Katrina devastated its social network and energy facilities, leading to an exacerbated environmental disaster. It took a long time for the city to return to a more stable condition, as financial resources were insufficient. As climate systems are difficult to predict, these areas will remain vulnerable to flooding unless there is more advanced development of a flood warning system and secure financial resources invested in climate-related projects (e.g. New York's municipal green bonds or the $350 million and 100-year certificated green bond issuance in the District of Columbia Water and Sewer Authority). Accurate data on climate risks and vulnerabilities (IPCC, 2014b) should be followed as well, so as to lower urban vulnerabilities and plan urban adaptation strategies at a location-specific level.

Vulnerability arising from the interaction between urbanisation and climate change impacts can be interpreted as social vulnerability (e.g. urban heat islands, which disproportionately affects the urban poor when exposed to extreme weather). This kind of vulnerability, as individual vulnerability, is closely related to poverty, influenced by income distribution and access to economic resources, and resource dependency resulting in social and economic constraints (Adger, 1999). On the other hand, inequality from deteriorating institutional and market structures can be regarded as collective vulnerability (Adger, 1999). This sort of collective vulnerability can hinder balanced urbanisation and economic growth as it does not guarantee social security to urban dwellers. Besides such vulnerabilities, the degradation of aquatic (e.g. salinization of water sources) and terrestrial environments (e.g. soil degradation leading to food insecurity) can lower adaptive capacity.

Lower adaptive capacity in urban ecosystems partly depends on urban microclimate change such as changes in temperature and precipitation, evaporation, humidity, soil moisture and organic levels, vegetation growth speeds, air quality, and water table and aquifer levels (IPCC, 2014b). To aid the recovery of ecosystem functions modified by climate change impacts, the concept of ecosystem services is a tool for enhancing urban resilience, and for examining consequences and impacts on resilience.

2.2.4. Ecosystem services as a resilience tool

A definition of ecosystem services is meaningful to allow systematic and holistic evidence of environmental values for human wellbeing to be compiled (Escobedo *et al.*, 2011; Fisher and Turner, 2008). Ecosystem services are defined as values that 'people derive from functioning ecosystems, the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being' (Boyd and Banzhaf, 2007; Costanza *et al.*, 2011, p.1; Escobedo *et al.*, 2011; Fisher *et al.*, 2009; Millennium Ecosystem Assessment, 2005; Wallace, 2007). Even though there are attempts to categorise ecosystem services on the basis of human values (Wallace, 2007), this thesis follows the classification recommended by the 2005 Millennium Ecosystem Assessment (Table 2.3): *provisioning services, regulating services, cultural services, and supporting services*.

Table 2.3 Classification of Ecosystem Services

Service Categories	Definition	Products from Ecosystems	Human Impact
Provisioning Services	'Ecosystem services that combine with built, human, and social capital' 'Material benefits'	Food, fibre (wood, jute, cotton, wool), fuel, genetic resources (genes and generic information used for animal and plant biotechnology), biochemical, natural medicines and pharmaceuticals, ornamental resources (animal and plant products), fresh water	Direct and short-term
Regulating Services	'Ecosystem services that regulate different aspects of the integrated system' 'Essential preconditions for other ecosystem service'	Air quality regulation, climate regulation, water regulation, erosion regulation, water purification and waste treatment, disease and pest regulation, pollination, natural hazard regulation	Direct and short-term
Cultural Services	'Ecosystem services that combine with built, human, and social capital to produce recreation, aesthetic, scientific, cultural identity, or other cultural benefits' 'Immaterial benefits'	Cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism	Direct and short-term
Supporting Services	'Ecosystem services that maintain basic ecosystem processes and functions'	Soil formation, photosynthesis, primary production, nutrient cycling, water cycling	Indirect and long-term

Source:Costanza *et al.* (2011, p.2); Millennium Ecosystem Assessment (2005); Niemelä *et al.* (2010)

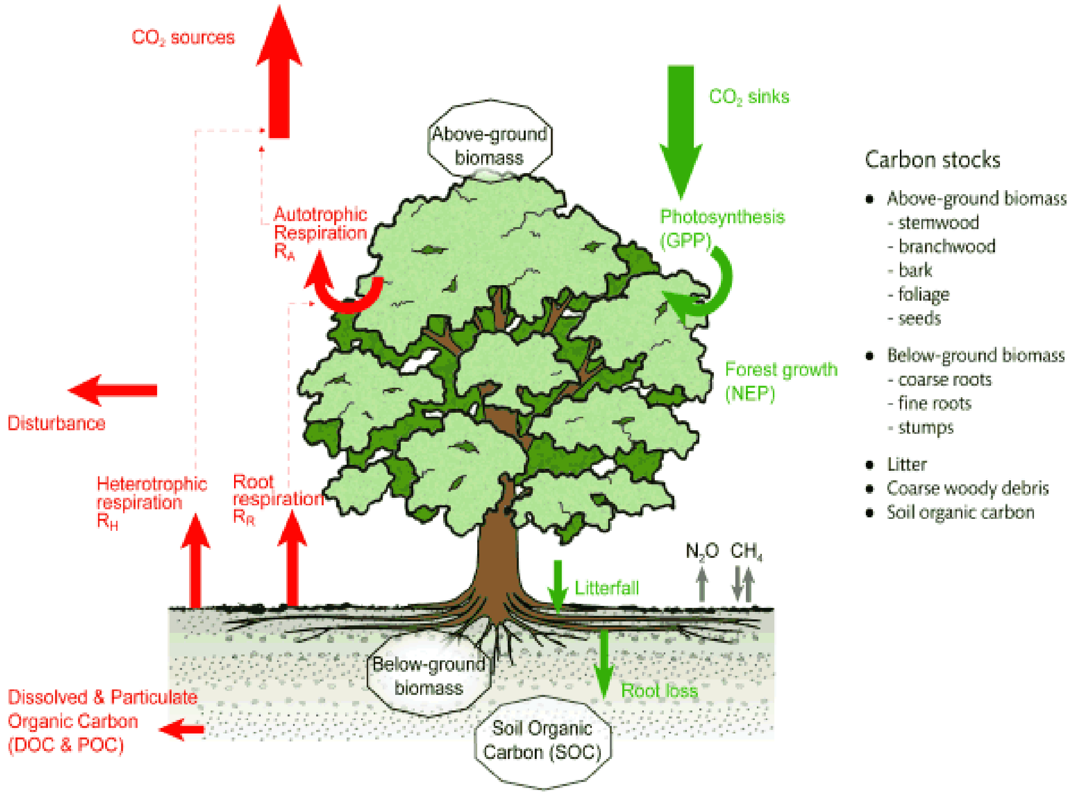
Ecosystem services contribute to the 'functioning of ecosystems and human survival at a range of scales, from local to global' (Francis, 2009). They are also useful for the conservation of biodiversity and natural resources (Wallace, 2007). In other words, benefits from ecosystem services can come from the interplay between natural capital and manufacture, human and social capital (Costanza *et al.*, 2011). Recreational ecosystem services (e.g. 'outdoor recreation, nature observation, education, photography, picking wild berries and mushrooms, hunting, boating, swimming and fishing'; see Niemelä *et al.* (2010), p.3230) in urban forests or parks can be an example of such interplay. Interestingly, services do not function in isolation, but show high connectivity. For instance, carbon sequestration can be regarded as a regulating ecosystem service, as it helps to regulate hydrological cycles and organic soil carbon cycles in urban green spaces. From a long-term perspective, it can be interpreted as a supporting ecosystem service as it occurs in the course of photosynthesis and impacts on soil formation, the carbon cycle and the nutrient cycle. Carbon sequestration, particularly carbon sequestration from urban street trees, will be handled later in this thesis as a crucial form of ecosystem service resulting in the enhancement of adaptive capacity in urban ecosystems.

Some issues, such as the generation of inadequate information on benefits from urban ecosystem services, and the development of appropriate methodology or methods, remain challenges. Evaluation of ecosystem services should incorporate suitable methods for their quantification and valuation (Jim and Chen, 2009) as well as adequate data. A lack of such data and methods have led to poor land-use planning and management (Niemelä *et al.*, 2010). In addition, products from ecosystem services have diverse features as some come directly from nature, and others are a mix of social and natural variables. For instance, recreational and commercial outcomes are hard to regard as simply ‘ecological’ as they are affected by other inputs such as labour or capital (Boyd and Banzhaf, 2007). For this reason, ecosystem or environmental valuations are still regarded as challenges for economists and ecologists (Niemelä *et al.*, 2010). Ecosystem services have experienced failures in measuring units of account as they are public goods (Boyd and Banzhaf, 2007), despite the fact that measurement of such non-market services helps to form risk perceptions, behaviour, and political support for conservation initiatives (Rudd *et al.*, 2011, p.481). In addition, economic and ecological valuation can be useful to measure trade-offs in a socio-ecological system in which human welfare can be improved in a sustainable way (Farber *et al.*, 2002).

2.3. Carbon sequestration in urban green spaces

2.3.1. Physical basis of carbon sequestration

As a 'carbon dioxide removal (CDR)' method, carbon sequestration (not carbon capture and storage (CCS)) has been expected to lower CO_2 emissions in the carbon cycle while improving the storage capacity of carbon in reservoirs such as land, ocean, and geological formations (IPCC, 2013). Carbon is sequestered and stored in terrestrial biospheres driven by forest regeneration, climatic effects, and the soil itself (Figure 2.6). The fluxes of CO_2 from soils are closely related to the growth of plants, which provide organic residues to decomposers (Schlesinger and Andrews, 2000). Much study of soil carbon sequestration has focused on influences on soil organic carbon and atmospheric carbon emissions in agriculture (e.g. crop growth and framing practices) (Follett, 2001). In other words, such anthropogenic management of carbon cycle still has uncertainties in the potential for enhancement of soil productivity, as specific methods largely depend on land needs and socio-cultural features (IPCC, 2013).



Source: Forestry Commission

Figure 2.6. The process of carbon sequestration and storage via photosynthesis

Once there are land use changes, accumulation of carbon in soils is lost (Smith, 2004b). In other words, as temperature increases occur along with rises in plant maintenance and soil respiration rates, and CO_2 levels in the atmosphere (which has a direct effect on photosynthesis) increase as a result of climate warming, terrestrial carbon storage declines as well (Cox *et al.*, 2000). In particular, time is required to recover the balance of soil organic carbon levels in soils. Nevertheless, the rate of soil sequestration can be accelerated by an increase in rates of organic matter inputs, and separation of carbon into selected carbon pools with longevity (Post *et al.*, 2004). Table 2.4 indicates several means for improving soil carbon sequestration in each pool, including forestry, cropland, grazing land, revegetation areas, and other potential sinks.

Table 2.4. Soil carbon sequestration measures

Forestry	Increase in soil carbon stocks via afforestation, reforestation, improved forest management or revegetation
Cropland	Zero/reduced tillage Conservation Reserve Programme Convert to permanent crops and deep-rooting crops Improve efficiency of animal manure use and crop residue use Agricultural use of sewage sludge Application of compost to land Rotational changes, fertilizer use, irrigation, organic farming Convert cropland to grassland Management to reduce wind and water erosion
Grazing land	Improve efficiency of animal manure use and crop residue use Improve livestock management to reduce soil disturbance and to maximize manure C returns Agricultural use of sewage sludge Improved management to reduce wind and water erosion
Revegetation	Increasing soil carbon stocks by planting vegetation with higher carbon returns to soil, or with litter more resistant to decomposition
Other potential sinks	Protection and creation of wetlands Protection and creation of urban green spaces Improvement of degraded lands Protection of sediments and aquatic systems

Source: Adapted from Smith (2004b, p.214)

2.3.2. *Carbon sequestration in urban green spaces*

Urban green spaces are defined as 'any open vegetated area' within the built environment (Francis and Chadwick, 2013, p.73). They include street trees, public parks, gardens, lawns, allotments, urban forests, cultivated land, brownfield and wasteland, wetlands, lakes/seas and streams (Bolund and Hunhammar, 1999; Francis and Chadwick, 2013). They are arenas for the preservation of flora and fauna and increase biodiversity in urban ecosystems (Bolund and Hunhammar, 1999). Urban green spaces are found in all cities but are particularly common in Europe, taking up 2 per cent to 46 per cent of urban areas (14 per cent in the UK) (Francis and Chadwick, 2013).

Table 2.5. Ecosystem Services from urban green spaces

Problems in urban areas	Service Categories	Outcomes from urban green spaces
Air pollution from transportation, and cooling and heating from buildings	Regulating services	Air filtering driven by vegetation filtering pollution and particulates from the air
Urban heat island effects	Regulating services	Micro-climate regulation
Noise from traffic, and its side effects such as worse human health and subsequent costs	Regulating services	Noise reduction
The higher flood likelihoods and degraded water quality via modified water flows driven by building infrastructure	Regulating and supporting services	Rainwater drainage
Less room for rest and meditation	Cultural services	Enhancing the quality of life, and psychological stability through aesthetic and cultural values

Source: Bolund and Hunhammar (1999)

Even though there are diverse benefits from ecosystem services related to urban green spaces (Table 2.5), this thesis is focused on regulating ecosystem services from urban green spaces (e.g. carbon storage and sequestration) as well as cultural ecosystem services (e.g. therapeutic aspects). Air quality regulation, microclimate regulation and water regulation are included in regulating ecosystem services. Urban forests contribute to eliminating air pollutants (e.g. sulphur dioxide, nitrogen oxides, ozone, carbon monoxide and particulates), which is crucial for megacities that experience rapid urbanisation and industrialisation (Jim and Chen, 2009). Tree shading- and evapotranspiration-cooling effects are typical examples in the literature of the influence of urban forests on local microclimates (Dwyer and Miller, 1999). In terms of water regulation services, street and park trees can reduce runoff, which minimises erosion and stream sediments as well as higher biological indicator scores in urban areas with tree canopies (Mahon and Miller, 2003).

In addition, urban green spaces provide carbon sinks, and carbon sequestration functions as a regulating service in public parks, green areas, and tree plantings (Niemelä *et al.*, 2010). For instance, 79 per cent of carbon can be stored in the organic material of a tree, particularly in the trunk and stems; and 18 per cent in the root system (ICLEI, 2006). Urban vegetation is a crucial component in providing supporting services (e.g. photosynthesis) in urban ecosystems, but it only sequestrates small amounts of the carbon dioxide concentrations of a city (Niemelä *et al.*, 2010) if there are single vegetation species planted (particularly with low capacity for sequestration), or disconnections between open spaces. As well as higher connectivity for higher chances to store and sequester from vegetation, there should be proper choices of tree species as well as better management and maintenance by keeping their mortality lower (Strohbach *et al.*, 2012), along with more creation of green spaces (particularly shrubs and trees rather than herbaceous plants or grasses). Even though CO_2 emissions are also released during maintenance and decomposition of trees, the emissions from planting open spaces can be offset by higher rates of sequestration. In the process of photosynthesis, however, carbon dioxide and oxygen are balanced from carbon sequestration and oxygen generation (Jim and Chen, 2009). Then validity and effectiveness of carbon sequestration in urban areas should be examined on the basis of sizes and classifications of urban green space area and components, as well as changes in demographic and economic activities (e.g. CO_2 emission per capita) for estimating its associations with urban green infrastructure.

Soils are essential components of all ecosystems and represent sinks for nutrients and environmental contaminants (Marcotullio, 2011; Pickett *et al.*, 2011; Pickett *et al.*, 2001). Soils have been regarded as a carbon sink, and should be reported as a carbon pool under the "Land Use, Land-Use Change and Forestry" (LULUCF) activities, which is indicated in articles 3.3 and 3.4 of the Kyoto Protocol (UNFCCC, 1998). Soils are considered as 'a major C sink' due to its storage capacity of CO_2 in organic matters (Lal, 2008a). Soils feature sensitive in ecosystems, and soil quality is affected by 'soil type, compaction, temperature, moisture, pH and location' (Francis and Chadwick, 2013, p.62). In terms of carbon pools, soils retain more organic carbon in terrestrial ecosystems, which are three to four times more than vegetation supporting organic matter, and the atmospheric pool (Lal, 2004b; Post *et al.*, 1982; Rasse *et al.*, 2005).

Urban soils are differently classified from natural soils as they are modified by human activities in 'a collection of patches, or mosaics of ecological communities' (Marcotullio, 2011). This kind of soil is cultivated and perhaps contaminated from 'anthropogenic sources (e.g. construction debris, solid waste, and reconfigured natural soils)' (Francis and Chadwick, 2013, p.61). Modified soils generally retain between 50 and 75 per cent of the original soil organic carbon pool, which comes from oxidation, mineralisation, leaching and erosion (Lal, 2008a, p.821).

Urban soils have become more vulnerable due to urbanisation and climate change. For instance, as droughts last longer than expected, urban soils have unstable soil structure and lower moisture in autumn and saturated soil in the winter and spring seasons. In the process soils lose soil organic carbon determining soil fertility or soil quality (Ontl and Schulte, 2012; Panagos *et* *al.*, 2013; Reeves, 1997). In addition, urbanisation results in soil erosion and soil degradation with losing soil organic carbon. As urbanisation generally requires frequent land use, there are direct and indirect effects. ‘Physical disturbances, burial of soil by fill material, coverage by impervious surfaces, and addition of chemicals and water’ are representative direct effects, whereas indirect effects include ‘changes in the abiotic and biotic environment, the urban heat island, soil hydrophobicity, atmospheric deposition of pollutants’ and invasion of alien species (Pickett *et al.*, 2001, p.132).

2.3.3. Validity of carbon sequestration

A diverse commercialisation of low carbon technologies such as renewable energy (e.g. wind, solar, and bioenergy or biomass), nuclear energy and carbon capture and storage (CCS) has not yet been available for mitigating climate change impacts. Consequently, actions for achieving stabilisation levels of CO_2 concentrations (450-650 ppm) in order to keep below the 2ºC agreement, are difficult to realise. According to IPCC (2007), reduction of emissions, enhancement of pollution removals and avoidance of emissions are required for climate change mitigation. Carbon sequestration, in particular, can play a ‘minor but central role’ in developing and deploying cutting edge energy technologies such as renewable energy technology with lower costs and risks, and immediate emission mitigation portfolios (Smith, 2004a). Traditional research on carbon sequestration is mostly found in ‘abiotic sequestration’ which is the technological advancement of capturing and storing carbon underground while avoiding leakage problems. The technology has hidden economic, social, and political costs as with other energy technologies. In addition, studies within the last decade have found that public awareness of CCS and carbon sequestration in the UK, US, Sweden and Japan remains low (Table 2.6). However, as more use of fossil fuels is driven by volatile energy prices, the carbon treatment issue has been seriously handled in international conferences. CCS projects are actively progressed in several countries such as the UK, China and Korea.

Table 2.6. Responses to: "Have you heard of or read about any of the following in the past year?" (Japanese respondents were also asked if they "know to some extent" these technologies)

Technology	**UK**	**US**	**Sweden**	**Japan (heard or read)**	**Japan (know to some extent)**
Wind energy	69%	50%	83%	44%	52%
More efficient appliances	40%	49%	68%	45%	38%
Nuclear energy	39%	54%	87%	41%	54%
Hydrogen cars	26%	48%	46%	45%	33%
Bioenergy /biomass	10%	10%	54%	34%	18%
CCS	**5%**	**4%**	**15%**	**22%**	**9%**
Carbon sequestration	**2%**	**3%**	**8%**	**38%**	**52%**

Source: Adapted from Reiner *et al.* (2006, p.3)

This thesis considers carbon sequestration as a tool for ecological recovery ('biotic sequestration') in terrestrial ecosystems but focuses particularly on the role of vegetation. Terrestrial sequestration for carbon management is described in Table 2.7. Terrestrial C sequestration is defined as 'transfer of atmospheric CO_2 into biotic and pedologic C pools' (Lal, 2008a, p.820). Soil carbon sequestration refers to 'removal of atmospheric CO_2 by plants and storage of fixed carbon as soil organic matter' (Lal, 2004b, p.9). The concept of soil carbon sequestration has started to gain more attention in the framework of urban ecology since the 2005 Millennium Ecosystem Assessment report, and there is a relative lack of literature on the topic. Effectiveness of carbon sequestration requires data and estimates at the local level, which allows stakeholders in specific areas to reduce CO_2 concentrations within land management strategies (e.g. green spaces in rural areas, urban green spaces, tropical forests, etc.).

Table 2.7. Carbon management in terrestrial ecosystems

<table>
<tr><th colspan="2">Management of terrestrial carbon pool</th><th colspan="2">Sequestration of Carbon in terrestrial pool</th></tr>
<tr><td>reducing emissions</td><td>eliminating ploughing

conserving water and decreasing irrigation need using integrated pest management to minimize the use of pesticides

biological nitrogen fixation to reduce fertilizer use</td><td>sequestering emissions as SOC</td><td>increasing humification efficiency

improving soil aggregation

deep incorporation of SOC through establishing deep-rooted plants, promoting bioturbation and transfer of DOC into the ground water</td></tr>
<tr><td>offsetting emissions</td><td>establishing biofuel plantations

biodigestion to produce CH_4 gas

bio-diesel and bioethanol production</td><td rowspan="2">sequestering emissions as SIC</td><td rowspan="2">forming secondary carbonates through biogenic processes

leaching of biocarbonates into the ground water</td></tr>
<tr><td>enhancing use efficiency</td><td>precision farming

fertilizer placement and formulations

drip, sub-irrigation or furrow irrigation</td></tr>
</table>

Source: Adapted from Lal (2008a, p.820)

Research on carbon sequestration has been typically found in ‘forest management, cropland management, grazing land management and re-vegetation’ (cited in Article 3.4 of the Kyoto Protocol, known as ‘land use, land-use change and forestry’ (LULUCF)) (Smith, 2004a). It can be interpreted that literature on carbon sequestration has been more focused on large scale forest or farming practices in semi-arid or degraded lands, rather than correlations between soil and vegetation, and soil itself in urban ecosystems. In developing countries, carbon sequestration from degraded agricultural soils can be regarded as a win-win strategy (Tschakert, 2004) in terms of food security and mitigation of GHG concentrations. However soil carbon sequestration projects sometimes face some issues such as land ownership, transaction costs, and lack of awareness towards climate change risks (Jindal, 2006a). For instance, organic farming practices, particularly in developing countries (e.g. Senegal or Kenya), sometimes require land use change decisions from farmers or land owners. The net profits (e.g. carbon sequestration effect, prevention of soil degradation, and sustainable food security) from organic farming takes more than one year. Then public perception towards conservation and restoration of degraded land should be raised via teaching and training in local communities, in order to gain positive ecological outcomes such as reduction in soil erosion and soil degradation and increase in biodiversity.

The effectiveness of carbon sequestration has been researched mainly in the agricultural sector, so as to improve soil quality and yield productivity. Even though there is great potential for investigating the effectiveness of carbon sequestration in urban areas (e.g. likely improvement of soil fertility and lower carbon emissions in households with private gardens, or small or large scales of green spaces), there is still limited research on its effectiveness in the urban landscape. It mainly comes from urban dynamics and a complex mixture of carbon sources.

Urban greening projects or utilisation of brownfields focus more on instant and direct effects such as increasing human comfort (e.g. urban heat island mitigation, or improvement of air quality), or aesthetic features (e.g. urban brownfields redevelopment), rather than time-consuming and indirect effects such as CO_2 emission reduction itself. The relationship between urban vegetation and temperature through evaporation has shown strong evidence in terms of urban heat mitigation, whereas the relationship between urban vegetation and urban CO2 emissions has been less researched so far (Bergeron and Strachan, 2011).

On scientific and political bases, carbon is disputable because its impacts on urban ecosystems, and further on natural ecosystems, still have weak evidence that may make it hard to justify as a main policy. For this reason, policy makers have shown unclear policy directions on carbon management, even though there is evidence on carbon sequestration effectiveness through trees, and large scale urban parks (Liu and Li, 2012; Nowak and Crane, 2002). Such unclear policy direction influences public perception on carbon sequestration related policies. In addition, as diverse stakeholders engage more in decision-making processes of such environmental regulation, more forums or seminars inducing more participation from the public should be followed so as to reflect their opinions into future policies.

As IPCC scientists indicated, soil carbon sequestration has the possibility to reduce 90 per cent of GHG emissions in the agricultural sector (Cantab, 2009). In addition, soil organic carbon sequestration means that carbon is put into the surface layer of 0.5-1m depth through the natural processes of humification (Lal, 2008a) without causing harm to ecosystems. It also pursues sustainable development, biodiversity conservation, ecological restoration and improvement of soil quality (Jindal, 2006b). As urban soil carbon sequestration programmes depend on recommended management practices and land use changes to some extent, it has been studied more particularly in North America and Northern Europe. As cost and environmental effectiveness determine success of policies and programmes, soil carbon sequestration programmes cannot be free from monitoring and evaluation costs (Richards *et al.*, 2006). The limits of geologic capacities to store carbon cannot guarantee its long-term effectiveness. The interplay between vegetation and soil can play a role in regulating CO_2 emissions in urbanised areas in the face of climate change threats to some extent.

3. Research Methods

3.1. Background to Site Selection

This thesis focuses on not only large-scale open spaces in Greater London, but also small-scale green spaces in Business Improvement Districts. For this reason, the process of selecting more specific BIDs is required as the first step, so as to validate the effectiveness of green spaces (i.e. trees on streets and in small areas of green space) in highly developed BIDs. BIDs are business-led local organisations or partnerships in geographically-defined areas that collect a levy from businesses, and represent their business interests while providing services and additional improvements in the pursuit of public and private benefits (Department for Communities and Local Government, 2013). This model emerged from the need to handle economic and social problems of urban areas, particularly in inner urban areas in the mid-1960s (Lloyd *et al.*, 2003). As a model for urban revitalization or regeneration, the BID model has rapidly spread from North America (mainly in the 1980s, but initially appeared in Toronto in the 1960s) to other countries due to flexibility in governance (e.g. sensitivity to the local situation, multiple stakeholders, and a wide spread of commercial interests, etc.) (Hoyt, 2003). The market-based model (e.g. tax incentives, rates relief and capital allowances for investment for local development within defined zones (Lloyd *et al.*, 2003, p.298) has gained attention after recognising the limits of the command-and-control approach (e.g. government intervention within a rigid and centralized institutional hierarchy while minimizing flexible local governance (Lloyd *et al.*, 2003)) when handling urban problems at a local scale (Hoyt, 2003).

Since the 1990s, the BID concept has been implemented in the UK, and there has been growing recognition of its potential economic, social and environmental benefits to local communities. It became legally approved as part of the *Local Government 2003* and the *2004 UK Business Improvement Regulations*. The levy charged on all business rate payers along with non-domestic rates bill is used to develop any projects and services which will benefit businesses in the defined areas, but 'the only requirement is that it should be something that is in addition to services provided by local authorities'. (Department for Communities and Local Government, 2013, pp.4-5). A BID is basically within the boundary of its corresponding local authority, but business operations across local authorities' boundaries became possible after the government's introduction of Cross Boundary Business Improvement Districts in April 2013 (Source: https://www.gov.uk/guidance/business-improvement-districts). A BID can be set up by the local authority, a business rate payer or a company which has plans to develop BID areas, or has an interest in its land, and a BID proposer should develop proposals indicating the services to be provided, the BID's size and scope, who is responsible for the levy, the estimated amount of levy and the way of levy calculation, and business plans, and then submit them to the local authority (Source: https://www.gov.uk/guidance/business-improvement-districts). In addition, businesses vote in a ballot which determines the progress of the proposal and is managed by the local authority. A BID is managed by a BID itself, and the maximum period of its levy can be charged for 5 years with possibility of renewal through a new ballot (Source: https://www.gov.uk/guidance/business-improvement-districts).

The BID model is pivotal when developing London's Economic Development Strategy and the London Plan. There are now 37 BIDs in London, but the number and geographical extent of these organisations are on the rise. According to the 2013 Department for Communities and Local Government report, Business Improvement Districts can be grouped into three categories: City Centre BIDs, High Street and Town Centre BIDs, and Industrial Estate BIDs. The City Centre BIDs are mostly located in Central London with more commercial and retail features.

The High Street and Town Centre BIDs are situated in low-to-medium demographic areas, mostly in Outer London, and the rest in Inner London with more focus on retail. The Industrial Estate BIDs are all found in Outer London with relatively smaller capacity than the above two kinds of BIDs, but have more potential for providing diverse business services as well as non-levy income (Department for Communities and Local Government, 2013).

City Centre BIDs will be targeted in this thesis due to their high economic activity and population, as well as CO_2 emissions. This consists of 11 BIDs: Better Bankside, Team London Bridge, Fitzrovia, Inmidtown, Waterloo Quarter Business Alliance, Vauxhall One, Baker Street BID, Victoria BID, Paddington BID, New West End Company, and Heart of London Business Alliance. The BIDs belong to four boroughs: Southwark, Camden, Lambeth and City of Westminster (Table 3.1 and Figure 3.1). The identification of each borough for each BID is crucial as the local authority plays a pivotal role in operations of BIDs (e.g. management of ballot process, management of billing, collection of the levy, and hold of the levy in a ringfenced revenue account for the BID body and planning consultation (Source: https://www.gov.uk/guidance/business-improvement-districts). Most existing BIDs have high possibilities to further extend their geographical boundaries so as to provide greater improvements in local communities. The current geographical information and maps are provided later, so as to clearly indicate to what extent the defined areas have open spaces as well as potential benefits from their designation as BIDs.

Table 3.1 Targeted London Borough and London BIDs

London Borough	City Centre Business Improvement Districts
Southwark	**Better Bankside** (North to the River Thames, west to the end of Southwark Street (not including any of Blackfriars Road), south to Southwark Street and east to Borough High Street)
	Team London Bridge
Camden	**Fitzrovia** (1 mile (1.6km) north of Trafalgar Square, partly in the London Borough of Camden)
	Inmidtown
Lambeth	**Waterloo Quarter Business Alliance**
	Vauxhall One
City of Westminster	**Baker Street BID**
	Fitzrovia (1 mile (1.6km) north of Trafalgar Square, partly in the City of Westminster)
	Victoria BID
	Paddington BID (The west, south, and east of Paddington Station)
	New West End Company
	Heart of London Business Alliance (Leicester Square to Piccadilly Circus)

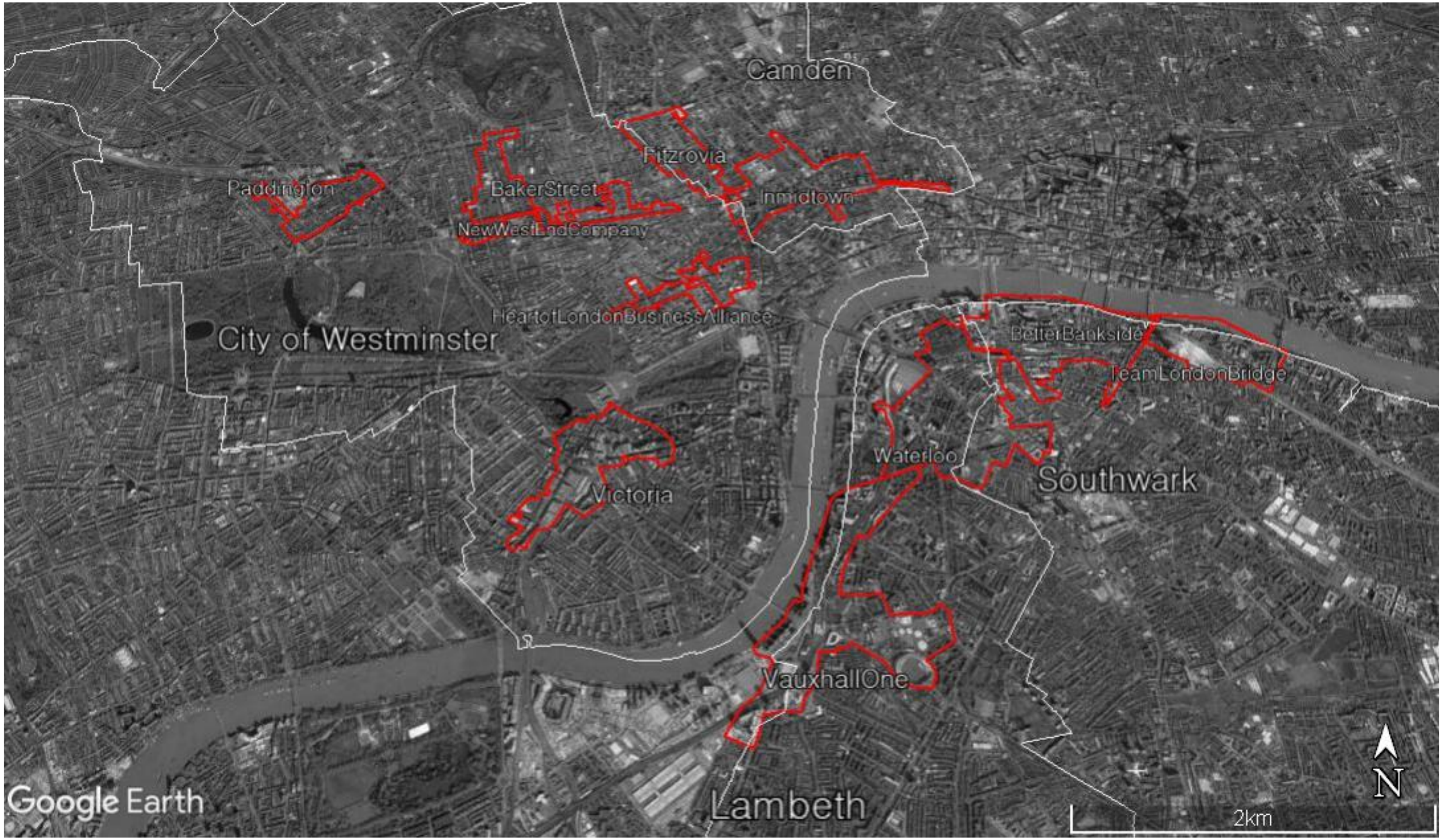


Figure 3.1 Map of Boroughs and Business Improvement Districts

Most boroughs in Inner London mostly show high population density, job density and carbon emissions with low density of green spaces. However, Southwark, Camden, Lambeth and the City of Westminster are also investigated after considering factors such as population density, job density, percentage of green spaces, total carbon emissions, and the presence of defined BIDs. According to the 2014 London Borough Profile from London Data store, the City of Westminster Borough, in which most BIDs are City Centre BIDs, showed the highest record in terms of GLA population estimate, population density, job density (followed by City of London), number of active businesses, percentage of green spaces (which may be outdated to some extent), and total carbon emissions.

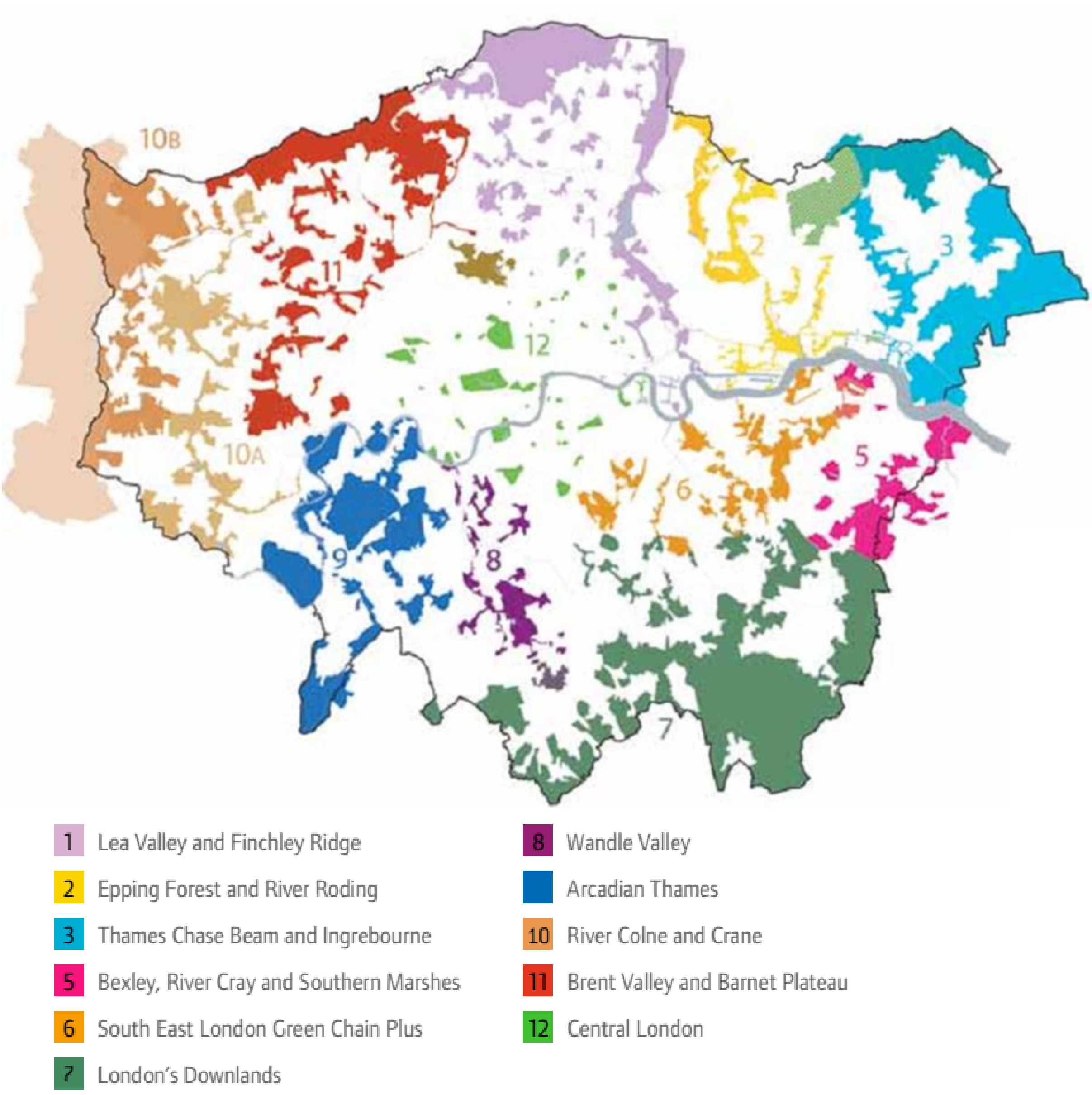
As for open spaces investigated, public open spaces were selected for three reasons: continuous management practices required from local authorities, ownership issue in private green spaces and easier access to the specific spaces for tree sampling. Compared to private spaces, public open spaces require careful management decisions and practices (e.g. tree species selection or tree planting location) as those spaces can become easily vulnerable as they are widely used and have the potential to be damaged. Along with the ownership and accessibility issue when doing the field work, private spaces were not considered; they are also excluded from the London Plan, and so are considered beyond the remit of this research. Specifically, parks and gardens, natural and semi-natural urban greenspaces, green corridors (e.g. trees in cycling routes or roads), allotments, cemeteries and churchyards, and civic spaces and others will be included. The criteria for classifying public open spaces, on the basis of their size, facilities and local importance, are clearly indicated in the London Plan (Appendix 5). According to the criteria, selected open spaces in Greater London are clearly identified in Chapter 4, and such open space management related to the All London Green Grid is handled in Chapter 6. Carbon storage and sequestration estimates are conducted in Chapter 5.

3.2. Background of London Plan and the All London Green Grid Project as Resilience Strategies

One of the world's largest emitters of carbon dioxide, the UK has developed a wide range of strategies related to climate change impacts. London is also responsible for around 10 per cent of the country's emissions. In London, climate change-related strategies and policies (adaptation and mitigation) have been handled under the London Plan, which is a comprehensive strategic plan for London covering economic, environmental, transport and social aspects in the Greater London over the next 20-25 years (GLA, 2016b). It has six objectives, four in direct relation to green infrastructure. Since the initial release of the London Plan in 2004, there have been several updates and alterations in 2008, 2011 and 2016, given that the population will continuously grow in the city as well as an anticipated increase in the diversification of economic, social and environmental issues. According to the population projections, London will have a population increasing from 8.2 million in 2011 to 9.2 million in 2021, 9.54 million in 2026, 9.84 million in 2013, and 10.11 million in 2036 (GLA, 2016b).

The previous 2011 version of the London Plan emphasises 'a clear spatial framework' containing political priorities, and public participation whilst reflecting 124 recommendations suggested by an independent panel, which publicly examined 7,177 comments from 944 entities and individuals. The 2011 London Plan was partly influenced by the Natural Environment White Paper focusing on the function of the natural environment for sustainable development, and a consultation of a National Planning Policy Framework (NPFF) (more on providing green infrastructure) in 2011. In this sense, the London Plan itself does not only limit economic development, but also social and environment issues within a Sustainable Development framework. The 2016 London Plan has consolidated alterations, setting out policies and explanatory supporting materials and taking the year 2036 as its formal end date (2031 in the 2011 version) given the more rapidly growing population than anticipated in the 2011 version. (GLA, 2016b).

The All London Green Grid is a part of the London Plan (see Policy 2.18 of the Plan, Appendix 1). The ALGG Supplementary Planning Guidance (SPG) replaced the 2008 East London Green Grid SPG. East London Green Grid SPG focused on the regeneration of East London for improving living quality of residents after the London 2012 Olympic Games. Its objective was also the creation of interlinked urban open spaces with diverse ecosystem service functions. The concept of Green Grid in this East London Green Grid SPG can be found in the 2006 East London Sub-Regional Development Framework and was further developed into the framework of the London Plan. It was further expanded after collaborations with such organisations as the London Development Agency, the East London boroughs, Thames Gateway London Partnership, Environment Agency, Natural England, Greater London Authority, etc. At that time, the East London Green Grid Areas covered six areas: Lea Valley, Epping Forest and River Roading, Thames Chase, Beam and Ingrebourne, London Riverside, Bexley River Cray and Southern Marshes, and Green Chain Plus. Yet the All London Green Grid has been expanded into twelve areas including the area covered in the East London Green Grid (see Figure 3.2).



Source: Map derived from GiGL data, 2011

Figure 3.2 Map of All London Green Grid Project

In the ALGG project, spatial coverage has been expanded as well as its multiple functions. The project does not merely focus on connectivity of open spaces, and its functions, but attempts to integrate economic, social and environment plans and strategies (e.g. Neighbourhood Plans, Local Development Documents, Area Action Plans, Intensification area Planning Frameworks, Community Strategies, Open Space Strategies, Regeneration Framework Initiatives, Master Plans, Development Proposals, Projects and Local Transport Plans) (GLA, 2012).

The ALGG project seeks four purposes, which are similar to functions of ecosystem services: productivity (e.g. enhancement of natural biodiversity ecosystems and provision of food), response (adapting to climate change impacts), attraction (enhancing aesthetical characteristics), and connection (providing more walking and cycling routes for a healthy life and natural biodiversity ecosystems) (GLA, 2012). The detailed objectives and functions of ALGG can be found in Appendix 2. All London Green Grid project covers a full range of public and private open spaces from parks, allotments, commons, woodlands, recreation grounds, playing fields, city farms, cemeteries, children's play grounds, and the Blue Ribbon Network (GLA, 2012). The mapping of above green areas can be found in Figure 3.2.

As for positive responses to climate change impacts through the ALGG project, that is, in terms of resilience to climate change impacts, green space networks would provide a drainage system defending against floods and lowering local flood risks and cooling effects in the built environment while reducing urban heat island effects in the summer season. The case studies are well known, and have been researched (e.g. Fairlop Waters Country Park, the Borough of Redbridge: sustainable resourcing and cooperation, Wandle Valley, the Boroughs of Wandsowrth, Merton, Croydon, Sutton and Lambeth: working strategically, and Victoria Business Improvement District: auditing green infrastructure (CPRE London and Neighbourhoods Green, 2014)). Yet even though the literature on urban green spaces' impacts on socioeconomic variables, and carbon sequestration from urban forests has been gradually increasing, more finance needs to be secured for green infrastructure projects. This thesis would suggest building more green networks in Greater London considering environment and socioeconomic impacts.

3.3. Mixed Research Methods

This thesis adopts mixed research methods while putting equal emphasis on quantitative and qualitative approaches. The ultimate intention is to use each step to inform those that follow. The first quantitative process, classification of open spaces and quantification of their landscape metrics, informed both the second quantitative process, tree sampling for carbon measurement, and the qualitative process, which is the investigation of stakeholder perspectives of open spaces and their management, particularly in relation to climate resilience and carbon sequestration.

Specifically, green spaces were mapped through the ArcGIS software programme so as to indicate the pattern of land cover, and calculation of landscape metrics for estimating fragmentation and connectivity was conducted in Greater London as a whole, and for Inner and Outer London through spatial analysis programmes such as the FRAGSTATS programme. Outcomes from tree sampling in streets and open spaces in eleven selected BIDs indicated the current state of sequestered and stored carbon density and effectiveness on carbon sequestration. Semi-structured interviewing of several stakeholders as a qualitative research method was conducted in order to gain more validity as to what extent the All London Green Grid project has been, or could be, effective in terms of carbon management and urban resilience.

'Mixed-research methods' refers to mixing or combining quantitative and qualitative research techniques, approaches and concepts within a study framework thorough collection, analysis and interpretation for a better understanding of research problems (Ivankova *et al.*, 2006;

Johnson and Onwuegbuzie, 2004; Onwuegbuzie and Leech, 2006). This research movement has gained weight in social and behavioural sciences (Collins *et al.*, 2007) since the 1960s as the “third wave” or “third research movement” (Johnson and Onwuegbuzie, 2004). Such methods have not been widely used due to the respective philosophical and practical nature of each approach. Quantitative methods test hypotheses with observation (deduction), whereas qualitative ones develop hypotheses after observation (induction). This means there are substantial differences in research design, data collection, and analysis in each approach. In addition, as for forming research questions, quantitative research questions are more specific with a focus on description, comparison and relationship among variables, whereas qualitative research questions are more open-ended and evolving (Onwuegbuzie and Leech, 2006). Moreover, quantitative approaches allow researchers to more easily gain more practical and objective results (e.g. numerical data), and to assess the economic value of ecosystem services, which is driven by a specific policy (TEBB, 2011). As for qualitative analysis, it had been neglected as a research method due to its perceived lack of objectivity, and it still has limits in assessing ‘naturally occurring interaction’ and noting trends in actors’ activities in reality (Coffey and Atkinson, 1996, p.19). In spite of such weaknesses, researchers have taken qualitative approaches due to the ‘preferences and/or experience of the researchers’ and ‘the nature of research problem[s]’ (Strauss and Corbin, 1998, p.11), as these methods allow them to select ‘strategies and methods’ in the process of data acquisition and analysis of the collected data (Coffey and Atkinson, 1996, p.4). Such methods can be powerful in answering diverse research questions, and creating more complete data, if the above features are properly managed. As for the reasons for combining both kinds of research methods, as each of the methods is not enough for fully explaining the trends and detailed circumstances of a complex system such as urban green infrastructure and the ALGG, such attempts would provide opportunities for yielding sounder analysis after fully employing their respective strengths (Ivankova *et al.*, 2006).

This thesis uses the convergent parallel research design, which is the most widely-used approach to mixing methods. Its aim is to obtain quantitative and qualitative results after collection and analysis of each dataset, integrating the outcomes so as to understand the research problem at multiple levels within a system (Curry *et al.*, 2009). According to Curry *et al.* (2009), the following decisions should be made before building a mixed research methods design: 'determine the level of interaction between the quantitative and qualitative strands'; 'determine the priority of the quantitative and qualitative strands"; "determine the timing of the quantitative and qualitative strands'; and 'determine where and how to mix the quantitative and qualitative strands'.

3.4. GIS-based Mapping and Analysis for Open Spaces

Since the 1960s, Geographic Information Systems (GIS) have been widely used to indicate features and patterns of landscapes on the Earth's surface. This system has several strengths in terms of time-saving for map production and revisions, data storage, overlap of data layers, and easy evaluation for large-scale of areas (e.g. open spaces including parks, forests, gardens, corridors, etc.) (Dwyer and Miller, 1999). In addition, its role has been strengthened as a powerful tool for visualisation and communication, audit and inventory (or data collection), retrieval, conversion/changing, spatial analyses, prediction, modelling and decision making (Abbas *et al.*, 2010; Chen *et al.*, 2009; Deng *et al.*, 2011; Wadsworth and Treweek, 1999) in such various fields as business, economics, geography, politics, etc. In terms of visualisation, GIS is a tool for mapping the areas of interest in an effective way. More specifically, the importance of spatial relationships has gained attention, particularly in environmental and resource economics, due to its influence on socio-economic and natural processes (Bateman *et al.*, 2002). In this sense, mapping is a crucial process for researchers or policy-makers to recognise and analyse patterns and current states in a specific area (e.g. traffic patterns, resource management, the spatial ratio of open spaces, and patterns of CO_2 emissions in correlation with demographic changes, or business activities, etc.).

Even though there have been few attempts to estimate (economic) values of ecosystem services through visualisation and mapping (Chen *et al.*, 2009; Deng *et al.*, 2011), GIS has been the most powerful tool for spatial analysis for open spaces in urban areas (Comber *et al.*, 2008). As there has been a growing awareness of impacts from mapping, GIS has consolidated its status as an attractive means for analysing geospatial data (e.g. digital elevation model (DEM) or satellite imagery), biophysical data (e.g. land use/land cover categories, natural resource map), and socio-economic data (e.g. demographic maps or municipal boundary maps) (Chen *et al.*, 2009; Comber *et al.*, 2008; Deng *et al.*, 2011). The acquisition of such multi-source databases can be achieved through diverse data sources. As for geospatial data or biophysical data, as satellite systems further improve, imagery with high resolution (>10 metres) can be easily acquired through Google Earth, or remote sensing techniques. In addition, socio-economic data can be obtained through local governments, or councils.

Esri's ArcGIS, which is the most well-known geographic information system, has shown remarkable improvements in terms of user-friendliness while providing diverse open source layers, multi-layering functions, editing geospatial data, and creating maps, as well as embedded functions from diverse software extensions (e.g. Spatial Analysis, Network Analysis, and Geo-statistical Analyst) and third parties, and easier connection with Google Earth data.

Landscape metrics analysis was conducted through spatial data such as natural features of Greater London acquired from GiGL (Greenspace information for Greater London). Along with the obtained datasets, spatial metrics was calculated through FRAGSTATS, which is a spatial pattern analysis programme for calculating various landscape metrics indicating landscape configuration and composition. The software programme is excellent at calculating connectivity indices, and verifying the values coming from analysis through ArcGIS (Esbah, 2009).

3.5. Tree Sampling for Carbon Measurements

Sampling is defined as the process of choosing a segment from a whole entity for analysis or hypothesis testing. As the process influences the quality of researchers' inferences (Collins *et al.*, 2007), selection of samples should be carefully considered on the basis of the characteristics of the research. In mixed-method research, sampling design requires particular attention for integration, considering the differences in philosophy, research questions, and research design, and complexity in 'representation, legitimation, integration and politics' (Collins *et al.*, 2007). In general, quantitative research tends to use random sampling, whereas qualitative research is associated with non-random sampling (Onwuegbuzie and Leech, 2006). Yet there are common considerations when selecting samples for mixed-research methods. That is, the samples should: 'provide adequate data pertaining to the phenomenon of interest'; 'help the researcher to obtain data saturation, theoretical saturation, and/or informational redundancy'; and 'allow the researcher to make statistical and/or analytical generalizations' (Collins *et al.*, 2007, p.270).

As Gil *et al.* (2011) indicate, the Intergovernmental Panel on Climate Change (IPCC) also recommends measuring vegetation and soil in the field so as to estimate carbon stocks and fluxes. Plants such as trees and shrubs have a large potential for sequestering carbon from the atmosphere. In particular, trees and shrubs can store carbon twenty-one times more than other plants such as herbaceous plants and grasses (ICLEI, 2006). When estimating carbon accumulation, two methods are widely used: 'measuring the timber height of sample trees including broadleaved trees' and 'measuring the total height of sample trees including conifers' (Jenkins *et al.*, 2011, p.29). According to the Carbon Code (Jenkins *et al.*, 2011), there are five approaches for forest carbon management: model-based evaluation, full survey, plot-based survey, two-stage survey, and sample-based inventory. In this thesis, stratified sampling will be adopted when measuring trees in BIDs. Sampling will be standardised according to the size of selected patches of open spaces to increase methodological rigour and allow for confidence in statistical comparisons. Prior to the sampling practice, selection of trees will be conducted in the field and on Google Earth Pro. In addition, GPS readers will be used for recording location information (Johnson, 2005), as some trees' locations, particularly in squares or parks, are hard to record accurately. Carbon calculations based on tree measurements will be obtained through the i-Tree programme in which species or genera-specific algorithms are already stored.

3.6. Semi-Structured Interviews

When conducting qualitative interviews, there are three categories: unstructured; semi-structured; and structured. Structured interviews provide well-organised questions and such methods are sometimes useful for saving time and money, but there are limits in obtaining more information about a specific phenomenon or policy. Semi-structured interviews are open-ended, which allows researchers to ask more questions, as well as providing more freedom for respondents to express their opinions (Aberbach and Rockman, 2002; DiCicco-Bloom and

Crabtree, 2006). In addition, this kind of interview provides opportunities to recognize the norms and values of participants (Louise Barriball and While, 1994; Stephens, 2007). In other words, open-ended interviews should be conducted after considering three aspects: ‘the degree of prior research on the subject of concern’; ‘desire to maximize response validity’; and ‘receptivity of respondents’, as well as issues such as time consumption in conducting interviews, money issues, and limits in data analysis (Aberbach and Rockman, 2002, p.674).

Considering these various interview formats, the semi-structured interview is the most widely used, allowing interviewers to handle social and personal matters (in individual interview), and diverse experiences (in the group interview) (DiCicco-Bloom and Crabtree, 2006). Based on production and transfer of knowledge in relation to decision-making processes in terms of climate change adaptation policy, it was considered that semi-structured interviews were most appropriate for this thesis. Interviews were divided into three rounds on the basis of hierarchy ranging from representatives from BID organisations, councils and the Greater London Authority, who are closely related to the All London Green Grid project, as well as other involved organisations. Before conducting interviews, email or phone calls were used as a prerequisite, so as to set interview time, explain the research background and aims, and send interview questions in advance, allowing interviewees to prepare if they so wished.

The interviews were individual rather than group, as it is not easy to gather such people together. In addition, individual interviews provided a more conversational tone, which allowed more vivid and personal perspectives to be expressed. Furthermore, if anonymity was requested due to political sensitivity, individual interviews allowed this. As the All London Green Grid project is in progress under the guidance of the Greater London Authority, there were also opportunities to gain diverse opinions from more disparate stakeholders such as BID people, council officers, residents or other public or private companies in several seminars held in London City Hall.

The interviews focus on decision-makers' and practitioners' perspectives on the effectiveness of carbon sequestration as a climate change resilience tool, and the All London Green Grid project as well. In addition, decision-makers' perspectives on vulnerabilities and the prospects for further developing London green spaces were explored, so as to determine the feasibility of different management options. Interviews were recorded and transcribed with permission from respondents. If they wanted to be informed of any empirical outcomes after the fieldwork, a summary will be provided as well. Ethical approval was obtained for this research from the King's College London Research Ethics Committee: the reference number is MR/14/15-27.

4. Spatial Analysis of Open Spaces in Greater London

4.1. Introduction

Greater London (51.5000° N, 0.0833° W) covers 1,572 km^2 (607 square miles) and consists of 33 boroughs (14 of which together comprise Inner London). Based on data from Greenwich Park climate station in London from 1981 to 2010, Greater London's average annual temperature ranges from minimum 7.8 °C to maximum 15.3 °C, with mean annual rainfall of 557.4 mm (Met Office, 2015). It is a largely 'green' city (Forman, 2008), with estimates of green space at over 100,000 ha (approximately 63% of a total area of 160,000 ha), though not all is publicly accessible (only 16% of London's area, or 25,600 ha; Environment Agency (2010); Ginn and Francis (2014)). Estimates vary depending on source of data. Greenspace Information for Greater London (GiGL) suggest that 47% of Greater London is composed of green spaces, and 33% of London is covered with vegetated green spaces along with 14% which is estimated as vegetated private and domestic green spaces, in addition to 2.5% coverage by blue spaces (e.g. rivers, canals, and reservoirs) (GiGL, 2017). Open spaces in Greater London can be classified into twelve broad types of land use, based on Planning Policy Guidance 17: Planning for Open Space, Sport and Recreation (Table 4.1). 39% of the capital is defined by GiGL as open space, including public and private spaces but excluding private gardens. Public open spaces consist of 18% of the total open spaces in Greater London, and they can be classified as regional, metropolitan, district or local parks, and small and linear open spaces on the basis of The London Plan (Table 4.2) (see Appendix 3) (GiGL, 2017).

Figure 4.1 shows a map of open spaces in Greater London, which was created on the basis of spatial data acquired from GiGL in 2015. The map indicates current spatial distribution of open spaces in Greater London, which allows an initial visual overview of open spaces.

Table 4.1 Categorisation of Open Spaces in Greater London

Land Use	**Area (ha)**	**Percentage of total area of Greater London (%)**
Other Urban Fringe	12893	8.09%
Outdoor Sports Facilities	10718	6.72%
Parks and Gardens	9207	5.77%
Natural and Semi-natural Urban Greenspace	8859	5.56%
Amenities	6575	4.12%
Green Corridors	5671	3.56%
Other	3063	1.92%
Unknown	2601	1.63%
Cemeteries and Churchyards	1390	0.87%
Allotments, Community Gardens and City Farms	995	0.62%
Children and Teenagers	72	0.05%
Civic Spaces	74	0.05%
Total:	62118	38.96%

Source: GiGL (2017), http://www.gigl.org.uk/keyfigures/, Figures taken from GiGL open space dataset (May 2015)

Table 4.2 Categorisation of Public Open Spaces in Greater London

Public Open Space	**Area (ha)**	**Percentage of Greater London**
Metropolitan Parks	8065	5.06%
Regional Parks (excluding Wandle Valley and Colne Valley)	6755	4.24%
Local Parks and Open Spaces	5668	3.55%
District Parks	4413	2.77%
Linear Open Space	2689	1.69%
Small Open Spaces	804	0.50%
Pocket Parks	125	0.08%
Total:	**28519**	**17.88%**

Source: GiGL (2017), http://www.gigl.org.uk/keyfigures/, Public Open Space designations were sourced from published borough documents

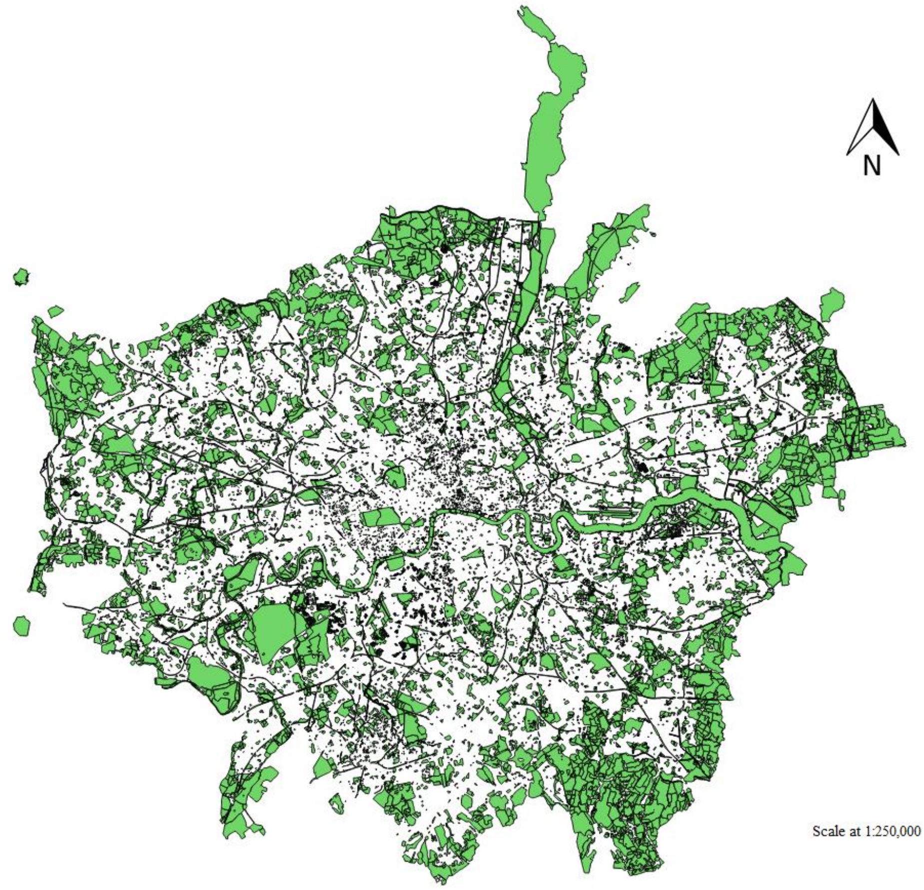


Figure 4.1 Map of Open Spaces in Greater London. (Data source: Greenspace Information for Greater London CIC (GiGL)

Figure 4.1 shows that Inner London has reduced coverage of open spaces compared to other parts of Greater London, and that the open spaces found there are more widely dispersed. Outer London shows a generally higher coverage of open spaces, comprised of larger and fewer patches. In addition, West London has greater amounts of open space than East London, even though more projects for creating open spaces have been actively ongoing in East London boroughs. Yet mere mapping cannot provide policy-makers or researchers with sufficiently detailed information for setting climate change adaptation strategies. It is increasingly recognised that such strategies need to be considered and coordinated at the landscape scale (e.g. Ginn and Francis (2014)), and as such specific analysis of landscape metrics is required so as to determine patch area distribution, distances between patches, patch density or patch richness, and the landscape as a whole.

This chapter focuses on landscape-scale spatial analysis for open spaces across Greater London, in particular comparisons between Inner and Outer London. Specifically speaking, spatial analysis will be conducted in East and West Inner London, and East and North-East, South, and West and North-West Outer London. The classification of Inner and Outer London legally is on the basis of the London Government Act 1963 (http://www.legislation.gov.uk/ukpga/1963/33). The City of London is not a 'borough' as it is governed by the City of London Corporation, but is regarded as an inner London 'council'. According to the statutory definition of Inner and Outer London, 'Inner London' covers Camden, Greenwich, Hackney, Hammersmith and Fulham, Islington, Kensington and Chelsea, Lambeth, Lewisham, Southwark, Tower Hamlets, Wandsworth, and Westminster. 'Outer London' refers to Barking and Dagenham, Barnet, Bexley, Brent, Bromley, Croydon, Ealing, Enfield, Haringey, Harrow, Havering, Hillingdon, Hounslow, Kingston-upon-Thames, Merton, Newham, Redbridge, Richmond-upon-Thames, Sutton, and Waltham Forest. Yet when it comes to statistical estimation in the Office for National Statistics and the Census, under the Nomenclature of Territorial Units for Statistics (NUTS), a hierarchical classification of administrative areas created by the European Office for Statistics (Eurostat), which gained legal status in spring 2000, was adopted in May 2003 and entered into force in July 2003 (http://ec.europa.eu/eurostat/web/nuts/history), the classification of Inner and Outer London is different. Essentially, in Inner London, Greenwich is excluded but Haringey and Newham are included (see Appendix 4). For this thesis, classification of location is on the basis of the NUTS for clarity.

Spatial analysis of open spaces in Greater London was conducted through ArcGIS and the FRAGSTATS software programme (McGarigal, 2014). Even though ArcGIS itself has diverse network, spatial analysis and statistical analysis functions, FRAGSTATS provides users with more immediate and detailed spatial analysis functions and results, as well as its more user-friendly features; it is also widely used within the discipline of landscape ecology, which is concerned with landscape structure and organisation (Hepcan, 2013; Li *et al.*, 2001; Tian *et al.*, 2014). Such broad-scale spatial analysis is meaningful as, although there are several studies of landscape metrics of open space (or green space) in cities (e.g. Asgarian *et al.* (2015); Kong *et al.* (2007); Maimaitiyiming *et al.* (2014); Rafiee *et al.* (2009); Tian *et al.* (2014)), no such information exists for London. Particularly for the concerns of this thesis, a landscape-scale understanding of open spaces is an important precursor to more specific analyses of open spaces in BIDs.

Spatial characteristics and configurations of open spaces present several implications for urban planners, as such patterns can have impacts on ecological function and process (Gustafson, 1998). Mainly driven by interactions of physical and social factors (e.g. urban planning or human population density), patterns of urban landscape developments (e.g. connectivity or fragmentation of patches) have substantial impacts on ecological changes and provision of ecosystem services (e.g. changes in species diversity and richness, water runoff and erosion) (Turner and Ruscher, 1988). Consequently, quantification of landscape patterns is needed so as to precisely estimate current configurations and spatial variability, and thereby infer influences on the ecology of the city. Quantification of spatial patterns and heterogeneity is not easy, however, and a lack of unified definition of spatial components and less distinct methods of numerically estimating landscape and ecological patterns presents several challenges across various stages of the quantification process (Gustafson, 1998).

Landscape analysis is reliant on the acquisition of high-quality imagery or other precise spatial data. This has been made easier by more accurate and accessible aerial photography, satellite imagery and topographic maps in recent years (Fichera *et al.*, 2012; Hester *et al.*, 2008; Khosravi *et al.*, 2014; Maimaitiyiming *et al.*, 2014; Mathieu *et al.*, 2007). This in turn has facilitated increasing study of urban spatial characteristics such as size, shape, dominance and diversity of urban patches (Aguilera *et al.*, 2011). According to Turner and Ruscher (1988, p.241), quantification of land use patterns can be divided into several modes such as 'mean number and size patches', 'fractal dimension of patches', 'amount of edge between land uses' and 'indices of diversity, dominance, and contagion.'

Estimation of spatial structure and configuration provides researchers and urban planners with information about arrangements of built- or non-built areas as well as potential spaces requiring more diverse management in cities to enhance ecosystem services. Such management interventions may include changes to the individual landscape patches (e.g. in terms of size, shape or quality), or increasing connectivity between patches at the landscape scale.

This chapter does not consider the relationship between current configurations of open spaces and provision of ecosystem services (although see Chapter 5 for discussion of regulating ecosystem services involving trees). Here, following an exploration of the landscape metrics of London's open spaces, the interrelationship between socioeconomic variables, and configurations and distributions of current open spaces in the Greater London will be investigated. This will provide urban planners and policy-makers with information about the extent to which current configurations of open spaces have connections with such socioeconomic variables.

4.2. Research Aims, Objectives and Hypotheses

The aims of this chapter are: (1) to quantify the spatial patterns of London's open spaces at the landscape scale; (2) to relate these patterns to socioeconomic variables in order to determine associations and potential drivers of open space patterns; and (3) to make management- and governance-related observations regarding London's open spaces at the landscape scale on the basis of accessibility and availability of urban green spaces and landscape configuration and composition pattern for urban resilience. This will be achieved through the following objectives:

(1) Obtain a suitable dataset on the spatial distribution of London's open spaces;
(2) Refine and process the dataset into GIS layers suitable for landscape-scale analysis;
(3) Analyse landscape patterns using the FRAGSTATS programme;
(4) Correlate spatial patterns with a relevant suite of socioeconomic variables;
(5) Discuss the results of the above objectives to determine key patterns and potential drivers of open space distribution, in particular between Inner and Outer London; and
(6) To make governance and management recommendations to further open space planning and management at the landscape scale.

On the basis of mapping of open spaces in Greater London leading to a rough assumption on landscape patterns, particularly between Inner and Outer London, and categorisation of open spaces in Greenspace Information for Greater London, and other literature on landscape metrics of green space in urban areas (Asgarian *et al.*, 2015; Kong *et al.*, 2007; Tian *et al.*, 2014) and association between socioeconomic status and green spaces (Heynen *et al.*, 2006; Hoffimann *et al.*, 2017; Tzoulas *et al.*, 2007; Wolch *et al.*, 2014), the research proceeds based on the following hypotheses:

H[1]: Landscape metrics of open spaces in London will indicate a fragmented configuration with limited connectivity, as found for green space in other global cities.

H[2]: Landscape metrics will vary according to type of open space, such that spatial differences will be determined.

H[3]: Differences in landscape metrics of open spaces will vary between Inner and Outer London, reflecting an urban-rural gradient and legacy of land use changes associated with urbanisation.

H[4]: Socio-economic variables will be found to correlate to open space metrics, as found in other cities.

4.3. Methodology

4.3.1. Methodological overview

Following data acquisition, evaluation of open spaces in Greater London will be conducted through progressing four processes: (1) data processing; (2) data conversion (both in ArcGIS); (3) calculation of converted data using FRAGSTATS; and (4) integrated analysis of spatial data and socioeconomic data. These are illustrated in Figure 4.2.

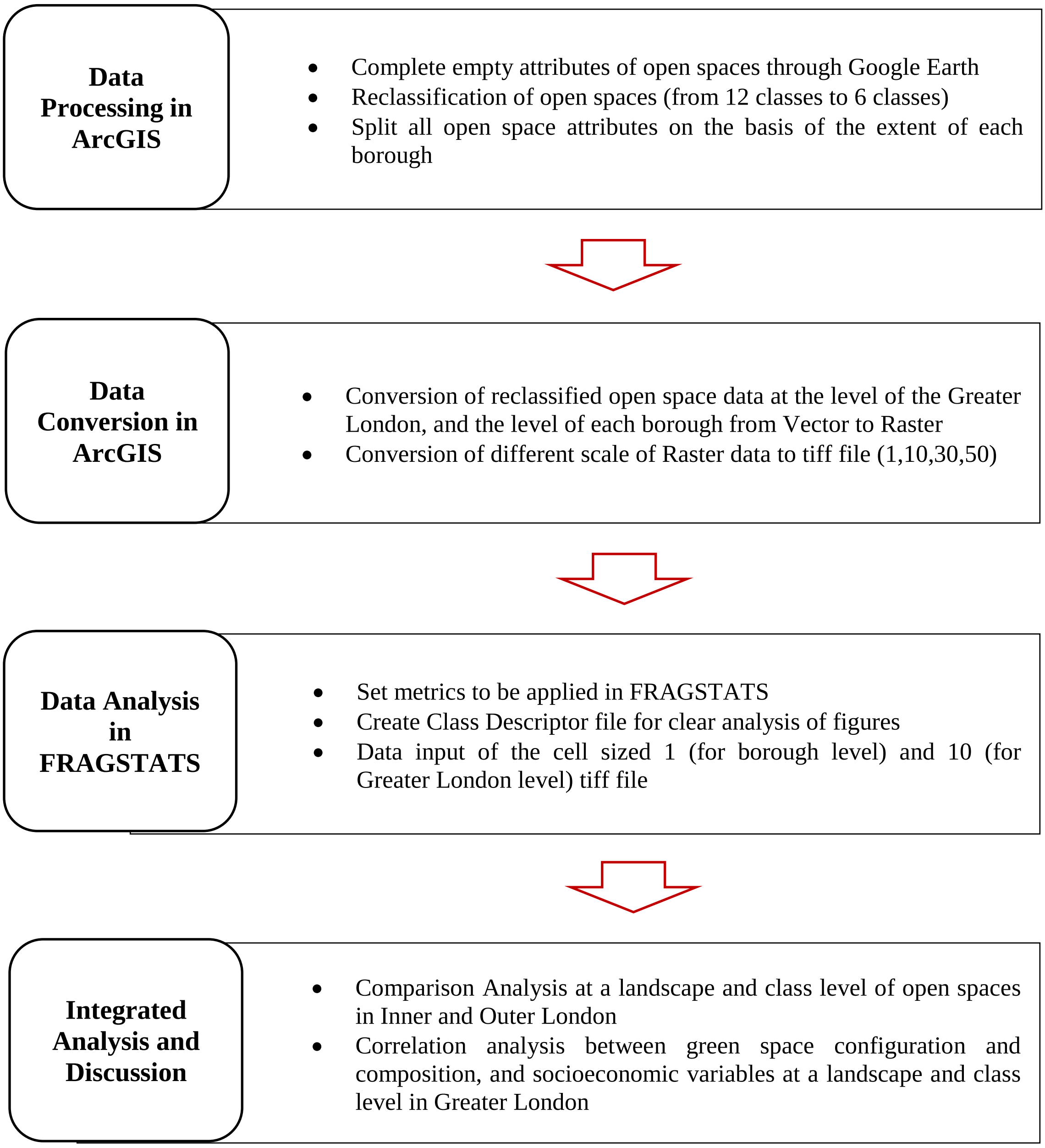


Figure 4.2 Methodological flow chart for Chapter 4

4.3.2. Data Acquisition

Open spaces data for Greater London were supplied by Greenspace Information for Greater London (GiGL) in May 2015. The acquisition of data was conducted after signing a data use license, in which the raw data, data products and services remain the copyright of GiGL. The licensed data can be renewed every year, but reports on how data was used should be submitted to GiGL after the data use. Its open space data is on the basis of 'a long-running survey of open spaces throughout the capital, updated with available data from the London Boroughs and information submitted by recorders, the general public and volunteers', while keeping continuously close relationships with London Boroughs for verifying and validating accurate data, which provides the evidence base behind the All London Green Grid (http://www.gigl.org.uk/open-spaces/). The GiGL open space ArcGIS files were considered to be best available for the purposes of spatial analysis. Alternatives included OpenStreetMap data, which is free, open source, and covers diverse points of interest, natural features, administrative boundaries, buildings, etc. The main disadvantage of OpenStreetMap is that the attributes are not coordinated, and so application of the FRAGSTATS programme to the data was not possible.

Socioeconomic data was obtained from the 'London Borough Profile' dataset at the London Datastore (https://data.london.gov.uk/dataset/london-borough-profiles) (released on 13th May 2016). In addition, data on total carbon emissions from Industry and Commercial, Domestic, Transport, LULUCF Net Emissions, and per capita emissions were gained from UK local authority and regional carbon dioxide emissions national statistics: 2005-2014 released from Department of Energy and Climate Change (https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-2014).

4.3.3. Data Processing in ArcGIS

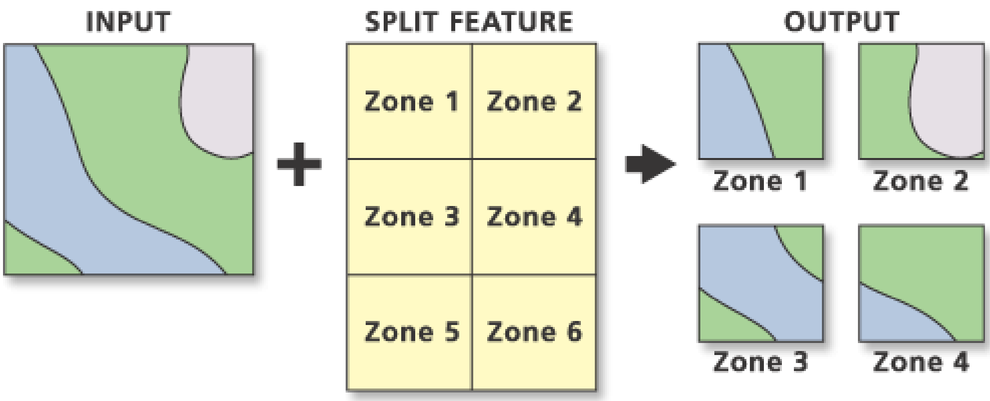
All data processing such as filling empty data attributes (such as open space name, size and category), and the separation of each borough from the Greater London data, was conducted using ArcGIS. Completion of empty attributes of open spaces came first. The attributes of 232 out of 12,256 open spaces were not classified according to Planning Policy Guidance 17 and remained empty. These 232 empty attributes were filled after finding their precise locations and features on Google Earth and other open space websites in London, on the basis of their official names (e.g. park or church names) and their given information from raw data. Following this process, the completed open spaces were classified into each open space category.

The next step was reclassification of open spaces. Under Planning Policy Guidance 17, open spaces are categorized into 12 types (Appendix 5), but for the purposes of the research presented here, open spaces were re-categorized into 6 types, as some categories of open spaces are so finely designated that accurate analysis was made difficult (Table 4.3). In sum, the five original open space categories of 'outdoor sport facilities', 'amenity', 'children and teenagers', 'allotments, community gardens and city farms', and 'civic spaces' were amalgamated into the category of 'Amenity'. The three categories of open spaces such as 'other urban fringe', 'other', and 'unknown' were reclassified as 'Other and Unknown.'

Table 4.3 Reclassification of Open Space Types

Reclassified Open Spaces	**Classification of open spaces under Planning Policy Guidance 17**
Amenity	Outdoor Sport Facilities Amenity Children and Teenagers Allotments, Community Gardens and City Farms Civic Spaces
Cemeteries and Churchyards	Cemeteries and Churchyards
Green Corridors	Green Corridors
Natural and Semi-natural Urban Greenspace	Natural and Semi-natural Urban Greenspace
Other and Unknown	Other Urban Fringe Other Unknown
Parks and Gardens	Parks and Gardens

Once the open spaces were reclassified, the attributes were split according to borough boundaries. The split function in ArcGIS 'creates new feature classes by overlaying two sets of features', meaning that is about breakdown of input features such as polygons, lines, and points into several output feature classes (See Figure 4.3, ArcGIS Desktop 9.3 Help, 2011).



Source: ArcGIS Desktop 9.3 Help
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Split_(Analysis)

Figure 4.3 Illustration of Data Split Process

As the attributes database contained information on which borough they are belonged to, the split function was used in ArcGIS. This process is required to obtain each borough's features of open spaces such as composition, configuration and connectivity, following data conversion from vector to raster, and consequently to a TIFF file at a cell size of 1 (as explained below).

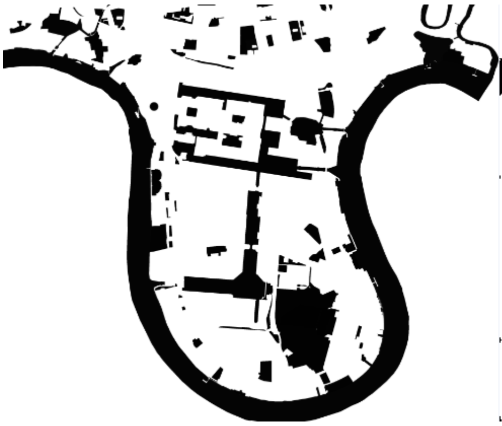
4.3.4. Data Conversion in ArcGIS

The calculation of landscape metrics for open spaces in Greater London was conducted through a spatial pattern analysis programme, FRAGSTATS 4.2. For input layer type, there are several file options (e.g. ASCII, Binary, ESRI grid, GeoTIFF grid, Imagine grid, etc.). The data type of ASCII was planned to be used as input data, in which row count, column count, background value (optional), cell size, and nodata values should be manually entered. Yet as there were several size mismatch errors when running the programme. For this reason, TIFF file format was used as an input data, as the TIFF file was automatically set in the input dataset without any size mismatch errors. The file was converted from shape file (feature) to raster, and to TIFF file through conversion functions of ArcGIS 10.2.2.

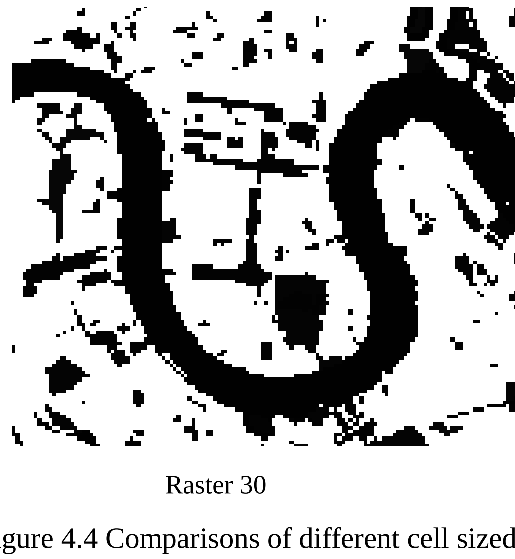
The conversion of open space data from vector to raster was conducted after reclassifying classes of open space categories. Determination of a proper cell size is crucial at the stage of GIS application planning, as details of features shown by a raster mostly depend on the cell (pixel) size, or spatial resolution of the raster (Esri, 2017). The rasterization procedure was performed at different scales, to determine to what extent a fine-scale conversion can provide more detailed and precise spatial information. The open space data was rasterized at 1, 10, 30, and 50 cell sizes. Following this process, the vector features of the Greater London were converted to a raster file at a cell size of 10. The split borough features were converted at a cell size of 1, so as to provide maximum detail at this finer scale of analysis.

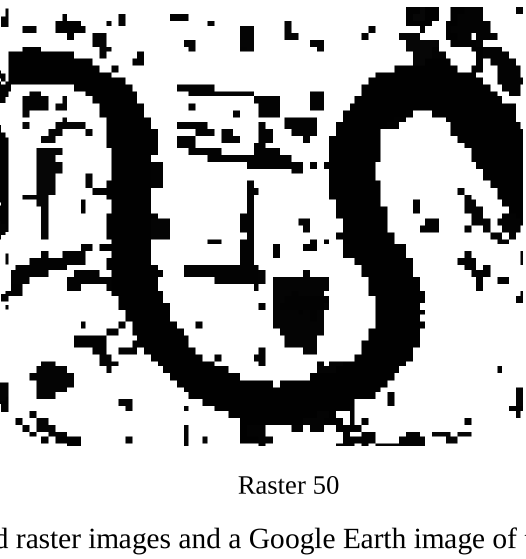
As seen in Figure 4.4, those rasterized images can be easily compared with aerial images from Google Earth to verify their accuracy at a simple level. Figure 4.4 shows the area of Isle of Dogs, which is located in the East End of London. The scale of 10, 30 and 50 was obtained from the whole landscape of Greater London, whereas the scale of 1 was gained after splitting into each borough from the whole landscape of Greater London. Fine measurement scale, or resolution allows more accurate and detailed information about study areas to be obtained, whereas coarser measurement scales would be useful for estimating deficiencies and necessity for particular purposes (Zhang *et al.*, 2014). According to Goodchild *et al.* (2007), spatial resolution will likely not be finer than 1 cm, and temporal resolution will likely not be finer than 1s in most cases. There is clearly greater accuracy in terms of number, size and shape of patches with increased fineness of scale, but the difference between 1 cell and 10 cell resolution is relatively minor. The 1 cell resolution is only achievable by separating out individual boroughs, and so it was decided that 10 cell resolution was most appropriate for the landscape scale analysis of Greater London.

Google Earth Image



Raster 1 Raster 10





Raster 30 Raster 50

Figure 4.4 Comparisons of different cell sized raster images and a Google Earth image of the Isle of Dogs. (Note that 1 cell resolution is only achieved by separating data according to borough; this is why no patches appear sound of the River Thames at 1 cell resolution, as this area is a separate borough.)

4.3.5. Data Analysis Process in FRAGSTATS

As for sampling strategy, there are seven sampling strategies in FRAGSTATS: No sampling; User-provided tiles; Uniform tiles; Moving window; User-provided points; Random points without overlap; and Random points with overlap (McGarigal, 2014). When calculating the targeted metrics, 'no sampling' design for 'specifying multiple input layers (i.e. a batch) in the Input Layers tab which is the conventional approach (McGarigal, 2014, p.62), and patch and landscape metrics were set in the 'analysis parameters' tab. As spatial metrics on a class and landscape level are the main focus of this chapter, patch level metrics were not included here. Table 4.5 shows the 18 metrics at a landscape level and 8 metrics at a class level that were calculated, as well as their formula, units, range, and description.

Table 4.4 Class Descriptor Details

ID	Name	Enabled	IsBackground
1	Green Corridors	true	false
2	Amenity	true	false
3	Other and Unknown	true	false
4	Parks and Gardens	true	false
5	Cemeteries and Churchyards	true	false
6	Natural and Semi-natural Urban Greenspace	true	false

Prior to the input of the original cell size 1 TIFF file, it was necessary to create a class descriptor file to allow easy recognition of each category of open space. The text format file should contain the ID number, the name of each class, and clarification of true or false in Enabled and IsBackground, while including all arguments separated by a comma. The details of the class descriptor file can be found in Table 4.4.

After uploading the descriptor file in the Common tables section, the TIFF file of each borough was uploaded in the Layers section, and Sampling Strategy was set to No Sampling for Class and Landscape Metrics. The Use 8 cell neighbourhood rule in the section of Analysis Parameter was applied. Before running the programme, targeted metrics were selected in Area-Edge Metrics, Aggregation Metrics, Shape Metrics in Class, and Landscape metrics respectively, which are meaningful for estimating connectivity and fragmentation.

Several metrics are commonly used to determine structural composition of landscapes and to quantify extent of connectivity and fragmentation (Aguilera *et al.*, 2011; De Clercq *et al.*, 2006; Lausch and Herzog, 2002; Tian *et al.*, 2014). These include total class area, class percent of landscape, number of patch, patch area distribution at the class level, and total landscape area and area-weighted mean patch area distribution at the landscape level in *Area-Edge Metrics*; number of patches, patch density at a class metrics, and contagion landscape shape index, number of patches, patch density and Euclidean nearest neighbour distance the landscape level in *Aggregation Metrics*, and perimeter-area fractal dimension and contiguity index distribution at the landscape level in *Shape Metrics* (McGarigal, 2014) (see Table 4.5). Yet some of these spatial metrics may be auto-correlated, which means selection of metrics should be carefully considered, and there should be integrated examination and interpretation of metrics.

'Aggregation' can be defined as the tendency of patch types to be clustered in large and aggregated distributions (Aguilera *et al.*, 2011; McGarigal, 2014). Metrics selected for measurement here include Number of patches (NP), Patch Density (PD), Landscape Shape Index (LSI), Contagion (CONTAG), and Euclidean Nearest Neighbour Distance (ENN) indicate aggregation and disaggregation of a landscape.

Open Spaces in Inner and Outer London at a landscape level were analysed on the basis of spatial measures of connectivity and fragmentation. The detailed investigation of such a spatial configuration can be determined after analysing and interpreting values from metrics of aggregation and disaggregation, and shape complexity. The features of connectivity and fragmentation were investigated in East and West Inner London, and East and North-East, South, and West and North-West Outer London.

Table 4.5 Class Metrics and Landscape Metrics in the group of Landscape Pattern based Metrics

Area-Edge Metrics				
Class Metrics	**Formula**	**Unit**	**Range**	**Description**
Total Class Area (CA)	$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10,000}\right)$ a_{ij} = area (m^2) of parch ij	Hectares	CA > 0, without limit	The sum of the areas (m^2) of all patch of the corresponding patch type, divided by 10,000
Percentage of Landscape (PLAND)	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ P_i = Proportion of the landscape occupied by patch type (Class) i a_{ij} = area (m^2) of parch ij A = total landscape are (m^2)	Percent	0 < PLAND ≤ 100	The sum of the area (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100
Patch Area Distribution_Mean (Area_MN)				
Landscape Metrics	**Formula**	**Unit**	**Range**	**Description**
Total Landscape Area (TA)	$TA = A\left(\frac{1}{10,000}\right)$ A = total landscape area (m^2)	Hectares	TA > 0, without limit	The total area (m^2) of the landscape, divided by 10,000 (to convert to hectares). Note, total landscape area (A) includes any internal background present.
Area-weighted mean Patch Area Distribution (Area_AM)	$AM = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}}\right)\right]$	Hectares	AREA_AM > 0, without limit	AM (area-weighted mean) equals the sum, across all patches in the landscape, of the corresponding patch metric value multiplied by the proportional abundance of the patch (i.e., patch area (m^2) divided by the sum of patch areas). Note, the proportional abundance

				of each patch is determined from the sum of patch areas rather than the total landscape area, because the latter may include internal background area not associated with any patch

Aggregation Metrics				
Class Metrics	**Formula**	**Unit**	**Range**	**Description**
Number of Patches (NP)	$NP = n_i$ n_i = number of patches in the landscape of patch type (class) i	None	NP $\geq$ 1, without limit	The number of patches of the corresponding patch type
Patch Density (PD)	$PD = \frac{n_i}{A}(10{,}000)(100)$ n_i = number of patches in the landscape of patch type (class) i A = total landscape area (m^2)	Number per 100 hectares	PD > 0, constrained by cell size	The number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100
Landscape Metrics	**Formula**	**Unit**	**Range**	**Description**
Contagion (CONTAG)	$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[P_i \cdot \frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right] \cdot \left[\ln\left(P_i \cdot \frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right](100)$ P_I = Proportion of the landscape occupied by patch type i g_{ik} = number of adjacencies between pixels of patch types I and k based on the double-count method m = number of patch types present in the landscape, including the landscape border if present	Percent	0 < CONTAG $\leq$ 100	Minus the sum of the proportional abundance of each patch type multiplied by the proportion of adjacencies between cells of that patch type and another patch type, multiplied by the logarithm of the same quantity, summed over each unique adjacency type and each patch type, divided by 2 times the logarithm of the number of patch types; multiplied by 100
Landscape Shape Index (LSI)	$LSI = \frac{.25\ E^*}{\sqrt{A}}$ E = total length (m) of edge in landscape; includes the entire landscape boundary and some or all background edge segments A = total landscape area (m^2)	None	LSI $\geq$ 1, without limit	A standardized measure of total edge or edge density that adjusts for the size of the landscape

Number of Patches (NP)	$NP = N$ N = total number of patches in the landscape	None	NP ≥ 1 without limit	The number of patches in the landscape
Patch Density (PD)	$PD = \frac{N}{A}(10{,}000)(100)$ N = total number of patches in the landscape A= total landscape area (m^2)	Number per 100 hectares	PD > 0, constrained by cell size	The number of patches in the landscape, divided by total landscape area (m^2), multiplied by 10,000 and 100
Euclidean Nearest Neighbour Distance_MN				

Shape Metrics				
Landscape Metrics	**Formula**	**Unit**	**Range**	**Description**
Perimeter-Area Fractal Dimension (PAFRAC)	$PAFRAC = \frac{2}{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}(\ln p_{ij} \cdot \ln a_{ij})\right] - \left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]} \Big/ \left[\left(N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^2\right) - \left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)^2\right]$ a_i = area (m^2) of patch ij P_{ij} = perimeter (m) of patch ij N = total number of patches in the landscape	None	$1 \leq PAFRAC \leq 2$	2 divided by the slope of regression line obtained by regressing the logarithm of patch area (m^2) against the logarithm of patch perimeter (m)
Contiguity Index Distribution (CONTIG)	$CONTIG = \frac{\left[\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}^{*}}\right] - 1}{v - 1}$ C_{ijr} = contiguity value for pixel r in patch ij v = sum of the values in a 3-by-3 cell template (13 in the case) a_{ij} = area of patch ij in terms of number of cells	None	$0 \leq CONTIG \leq 1$	The average contiguity value for the cells in a patch minus 1, divided by the sum of the template values (13 in this case) minus 1

Source: Adapted from McGarigal (2014)

4.3.6. Statistical analyses

When estimating spatial patterns of open spaces at a landscape and class level, analyses of variance were performed to determine statistically significant differences of each metric between Inner and Outer London, and every sub-region. The analysis was conducted with the Mann-Whitney U test, which is a nonparametric test for testing two independent samples, and the Kruskal-Wallis H test for testing more than two independent samples. For instance, when comparing patch numbers in Inner and Outer London, or in two sub-regions of Inner London, the Mann-Whitney U test was employed, whereas when comparing three sub-regions of Outer London, the Kruskal-Wallis H test was used.

Correlations were also calculated to determine possible relationships between socioeconomic variables for each borough and the area of different open space classifications, to determine if broad trends are observed for all types of open space, or just some. To determine if correlations exist between the landscape metrics calculated for each borough (n = 33) and socioeconomic variables, non-parametric Spearman correlation analyses were performed. All socioeconomic variables were obtained from 'London Borough Profile', London Datastore (https://data.london.gov.uk/dataset/london-borough-profiles). Socioeconomic indicators and their definition can be found in Table 4.6. In order to standardise for area, the landscape metrics of total patch area and number of patches were corrected by area of each borough. Other metrics utilised already incorporate a measure of area in their calculation (e.g. patch density) and so further standardisation in this fashion was not required.

Table 4.6 Socioeconomic Indicators and Definitions

Themes	Indicators	Definition
Borough population numbers and density	GLA Population Estimate 2016[1]	Population estimation in London, 2016
	Population density (per hectare) 2016[2]	Population estimation per hectare in London, 2016
Population age distribution	Average age 2016[3]	Age of the population on average in 2016
	Proportion of population aged 65 and over 2016[4]	Proportion of those are aged 65 and over in 2016
Level of education	Proportion of population of working age with degree or equivalent and above 2015[5]	Proportion of the working population aged between 16 and 64 who received more education in 2015
Immigration/Ethnicity	% of resident population born abroad 2014[6]	Percentage of residents born abroad in 2014
	% of pupils whose first language is not English 2015[7]	Percentage of students whose mother tongue is not English in 2015
Employment	Number of jobs by workplace 2014[8]	Numerical figures of jobs by workplace in 2014
	Jobs density 2014[9]	Number of jobs in an area divided by the population aged between 16 and 64 in the area in 2014
	Modelled household median income estimates, 2012/13[10]	Median average gross annual household income for London in 2012/13 (no account of average household size or composition within each area)
Housing	Median house price 2014[11]	The midway point of houses sold at market price in 2014

1 Source: GLA (datastore) http://data.london.gov.uk/demography/
2 Source: GLA (datastore) http://data.london.gov.uk/dataset/land-area-and-population-density-ward-and-borough
3 Source: GLA (datastore) http://data.london.gov.uk/dataset/ons-mid-year-population-estimates-custom-age-tables
4 Source: GLA (datastore) http://data.london.gov.uk/demography/
5 Source: Annual Population Survey http://data.london.gov.uk/labour-market-indicators/
6 Source: ONS http://data.london.gov.uk/dataset/population-country-birth-and-nationality-borough
7 Source: DfE http://data.london.gov.uk/dataset/percentage-pupils-first-language-borough
8 Source: Business Register Employment Survey http://data.london.gov.uk/dataset/workplace-employment-sex-and-status-borough
9 Source: Office for National Statistics http://data.london.gov.uk/dataset/workplace-employment-sex-and-status-borough
10 Source: GLA Estimates http://data.london.gov.uk/dataset/household-income-estimates-small-areas
11 Source: CLG http://data.london.gov.uk/dataset/average-house-prices-borough

Crime	Crime rates 2014/15[12]	Rates of occurred crimes per thousand population
Life expectancy[13]	Male life expectancy (2012-14)	Statistical measure of the average time Men in London is expected to live
	Female life expectancy (2012-14)	Statistical measure of the average time Women in London are expected to live
Quality of life indicators[14]	Life satisfaction score (2011-14)	Satisfaction level of Londoners' life (score 1-10)
	Worthwhileness score (2011-14)	Level of Londoners' worthwhileness (score 1-10)
	Happiness score (2011-14)	Level of Londoners' happiness (score 1- 10)
	Anxiety score (2011-14)	Level of Londoners' anxiety (score 1-10)

4.4. Analysis of Landscape Spatial Configuration

4.4.1. Overview

In this section presents the landscape-level discussion of open spaces in Greater London, and Inner and Outer London. The class-level discussion of open spaces will follow in Section 4.5 (details can be found in Appendix 6 and 7). In total, there were 21,007 patches of open space, totalling 62,105.72 ha on the basis of the 2015 GiGL database. Total open space in Greater London covered 1881.99ha, from 636.57 patches. The mean and standard deviations of each metric of open spaces in Greater London, Inner and Outer London can be found in Table 4.7.

Outer London had more open spaces (**TA**) than Inner London: Outer London had 2,841.21ha on average whereas Inner London had an average of 580.19ha. In addition, the standard deviation value of total area in Outer London (2,040.84ha) is also higher than in Inner London (303.73ha). It can be inferred that boroughs in Outer London had more diverse sizes of open spaces than in

12 Source: Metropolitan Police Service http://data.london.gov.uk/dataset/crime-rates-borough
13 Source: ONS http://data.london.gov.uk/dataset/life-expectancy-birth-and-age-65-borough
14 Source: APS http://data.london.gov.uk/dataset/subjective-personal-well-being-borough

Inner London. On the basis of values of area-weighted mean patch area distribution (**AREA_AM**), Outer London shows greater fragmentation (75.35ha) and more dispersion of patch area distribution (60.15ha) than in Inner London (37.20ha and 37.55ha respectively).

Even though Outer London (717.78) had more mean patches of open spaces (**NP**) than Inner London (526.35), Inner London (134.18) shows a higher mean patch density (**PD**) than Outer London (33). As for the standard deviation of patch number and patch density, Inner London shows higher values than Outer London, 503.19 and 149.35 respectively. This means that even though Inner London had fewer patches of open spaces than Outer London, boroughs in Inner London had a more dispersed range of patch numbers and substantially more open spaces per area than boroughs in Outer London.

Greater London recorded 60.63% on average of aggregation rate (**CONTAG**). On the basis of higher mean (61.97%) and standard deviation (5.75) of patch disaggregation in Inner London, boroughs in Inner London had a lower number but a wider range of disaggregated patches than in Outer London (59.65% and 3.39 respectively). As for patch isolation, Inner London had a higher tendency of more isolation between patches, given that the mean **ENN_AM** was 145.15m and Outer London 125.74m. In addition, Inner London boroughs also had a wide range of ENN_AM as its standard deviation is 86.42m compared to Outer London 36.14m.

As for patch contiguity or connectedness, the contiguity index (**CONTIG_MN**) in Inner London (0.82) showed a higher value than in Outer London (0.74), meaning that boroughs in Inner London had more connected patch patterns than in Outer London. Yet boroughs in Outer London (standard deviation of 0.09) had a more diverse range of contiguity index than in Inner London (standard deviation of 0.06).

As for irregular landscapes, Outer London (28.07) shows a higher mean landscape shape index (**LSI**) value than Inner London (26.07), meaning boroughs in the former region show more irregular landscapes than in the latter area. Yet the LSI standard deviation value is higher in Inner London (9.66) than Outer London (4.92), indicating that Inner London boroughs had wider ranges of irregularity.

Mean and standard deviation of Perimeter area ratio index (**PAFRAC**), a shape complexity index, in Inner London (1.15 and 0.04 respectively) are higher than in Outer London (1.13 and 0.02 respectively). It suggests that Inner London has more complicated landscape shapes, as well as a wider range of shape complexity values than in Outer London.

Table 4.7 Mean and Standard Deviation Values at a Landscape Level in Greater London

	Greater London		**Inner London**		**Outer London**	
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**
TA[15]	1881.99	1915.21	580.19	303.73	**2841.21**	**2040.84**
AREA_AM[16]	59.17	54.54	37.20	37.55	**75.35**	**60.15**
NP[17]	636.57	396.56	526.35	**503.19**	**717.78**	283.37
PD[18]	75.93	108.82	**134.18**	**149.35**	33.00	18.95
CONTAG[19]	60.63	4.61	**61.97**	**5.75**	59.65	3.39
ENN_AM[20]	133.97	62.16	**145.14**	**86.42**	125.74	36.14
CONTIG_MN[21]	.77	.09	**.82**	.06	.74	**.09**
LSI[22]	27.22	7.25	26.07	**9.66**	**28.07**	4.92
PAFRAC[23]	1.14	.03	**1.15**	**.04**	1.13	.02

[15] Total Landscape Area (Area-Edge Metrics)
[16] Area-Weighted Mean Patch Area Distribution (Area-Edge Metrics)
[17] Number of Patches (Aggregation Metrics)
[18] Patch Density (Aggregation Metrics)
[19] Contagion (Aggregation Metrics)
[20] Area-Weighted Mean Euclidean Nearest Neighbour Distance (Aggregation Metrics)
[21] Contiguity Index Distribution (Shape Metrics)
[22] Landscape Shape Index (Aggregation Metrics)
[23] Perimeter-Area Fractal Dimension (Shape Metrics)

4.4.2. Number of Patches (NP)

Number of patches (NP) is simply a measure of the number of patches (in this case, open spaces) within a defined area. It is related to fragmentation or the extent of subdivision of the corresponding patch types, with the inference that in areas with higher numbers of patches, those patches will be smaller and more isolated, and therefore have low connectivity (Hepcan, 2013). Even though number of patches is a good measure for estimating fragmentation, patch number itself does not provide much information on spatial distribution. In other words, this metric alone is not enough for interpreting fragmentation and connectivity. It should be interpreted alongside total patch area, and mean patch area distribution.

There is a significant difference in the number of patches in Inner and Outer London ($U=58.5$, $p=0.005$). Outer London contained more patches than Inner London (see Figure 4.5); 13,638 (65%) and 7,369 (35%) respectively. Yet there is no significant difference in number of patches among sub-regions in Inner ($U=18$, $p=0.49$) and Outer London ($\chi^2=1.42$, $p=0.49$) respectively. The Borough of Wandsworth had by far the highest number of patches (2166), with the second-highest being Greenwich (1451). The lowest number of patches was found in Hammersmith & Fulham (138) (Figure 4.6).

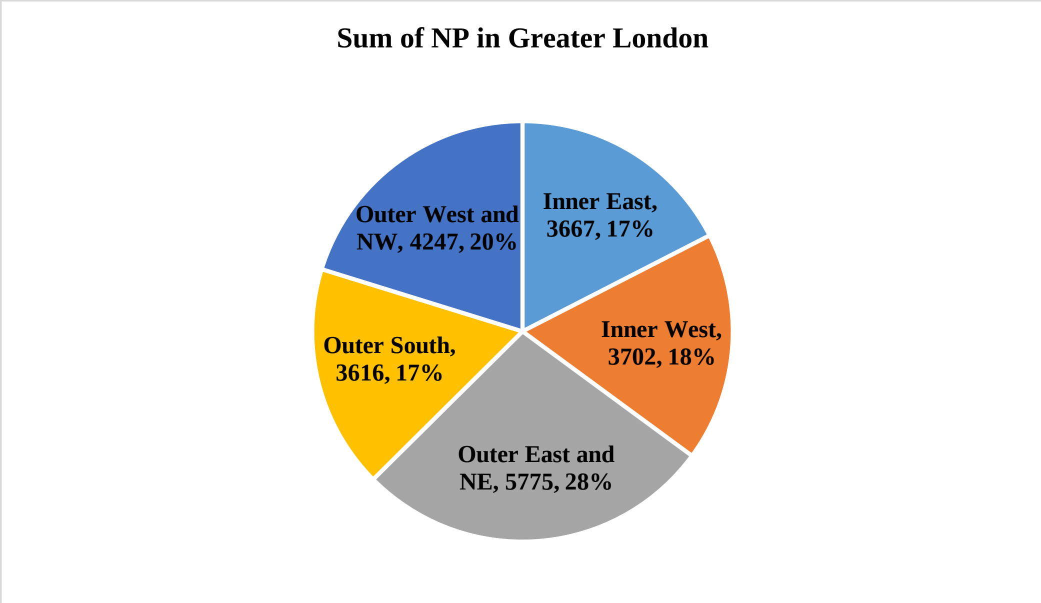
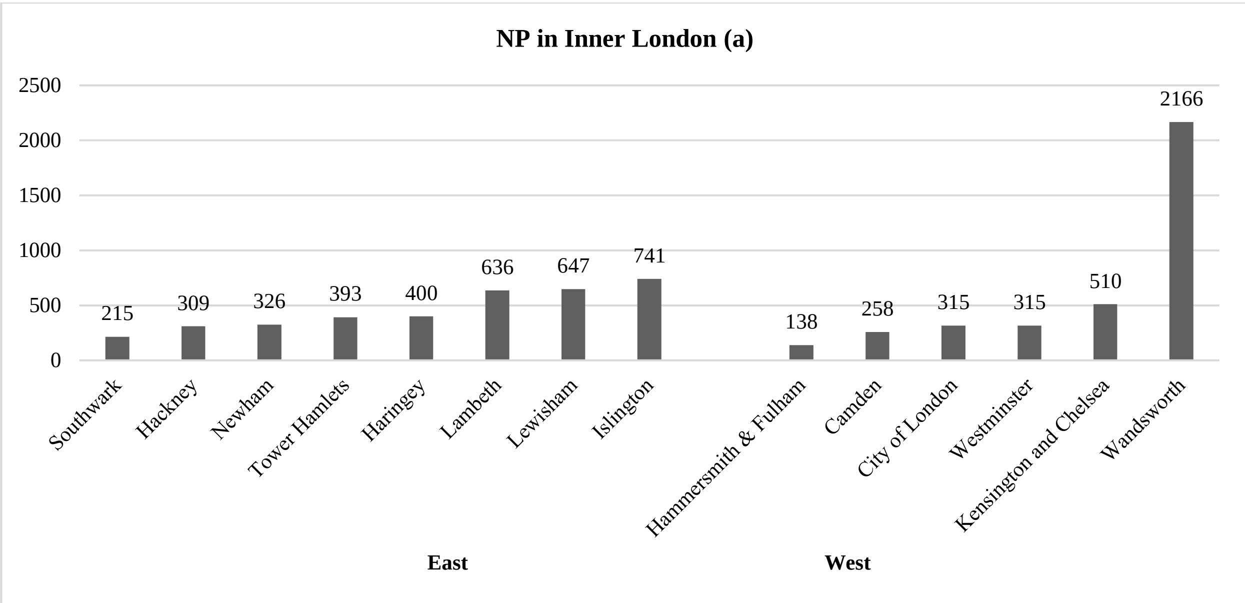


Figure 4.5 Number of patches and proportion of total patches in Inner and Outer London and further subdivisions.



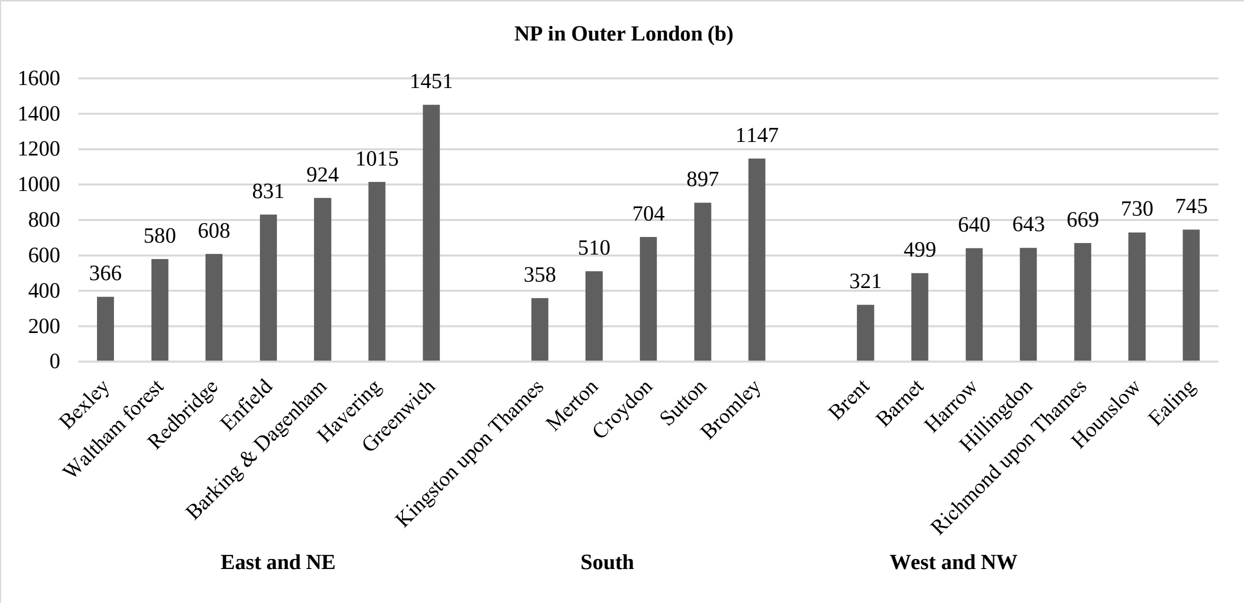


Figure 4.6 Number of Patches in Inner (a) and Outer (b) London

4.4.3. Patch Density (PD)

As a measure of spatial heterogeneity, patch density (PD) is another meaningful metric for exploring the distribution of patches (McGarigal, 2014). Low patch density generally indicates low fragmentation, (fewer patches, close together) whereas high patch density shows high fragmentation (more patches, far apart). Overall patch densities in West Inner London were the highest, at 1076.3, followed by Inner East (802.3). These are both far higher than subdivisions of Outer London (Figure 4.7). There is a significant difference in patch density in Inner and Outer London ($U=38$, $p <0.001$). Yet there is no significant difference in patch density among sub-regions in Inner ($U=19$, $p=0.573$) and Outer London ($\chi^2=0.28$, $p=0.869$) respectively. The highest patch density was found in City of London (537), with the second-highest being Islington (366). Low patch densities were mostly found in Outer London, with the lowest patch density being Hillingdon, followed by Bromley (13.3) and Bexley (14.6). Remarkably, several boroughs show similar patch density with different ranges, and such clusters were more frequently found in Outer London (Figure 4.8):

(1) 10 < PD < 30: Hillingdon, Bromley, Bexley, Havering, Barnet, Richmond-upon-Thames, Enfield, Croydon, Kingston-upon-Thames and Redbridge in Outer London;

(2) 30 < PD < 50: Brent, Hounslow, Merton, Harrow, Waltham Forest and Ealing in Outer London;

(3) 30 < PD < 50: Newham, Southwark, Hammersmith and Fulham, Camden, Haringey, and Westminster in Inner London (Figure 4.8).

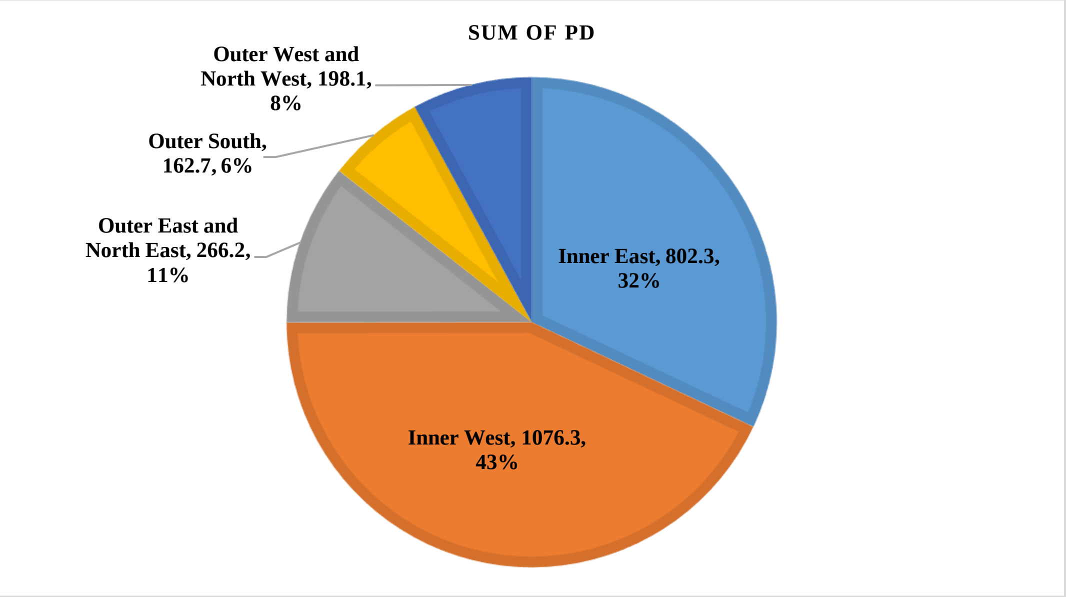
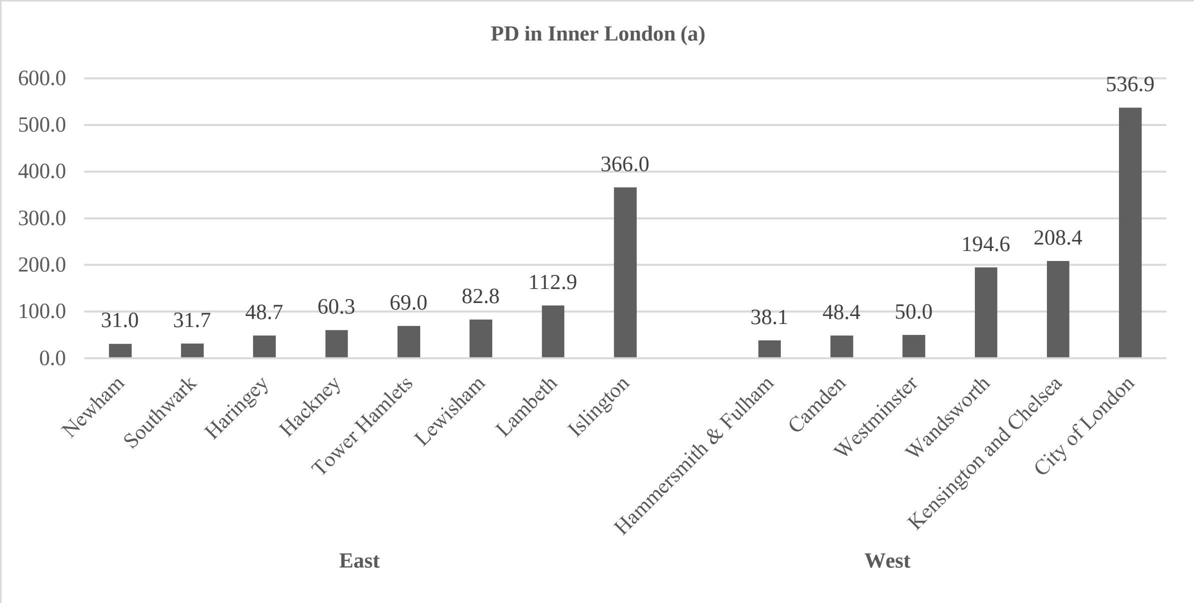


Figure 4.7 Proportion of Patch Density in Inner and Outer London



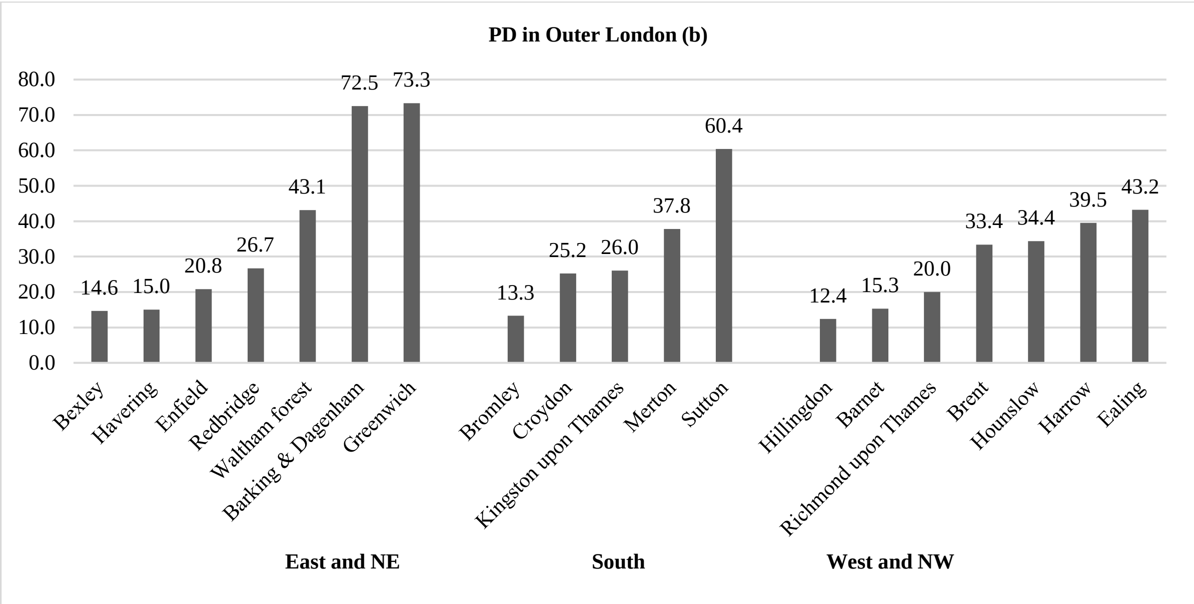


Figure 4.8 Patch Density in Inner (a) and Outer (b) London

4.4.4. Landscape Shape Index (LSI)

Landscape shape index (LSI) is another indicator for recognizing aggregation status. This index is a straightforward measure of landscape complexity, and is only meaningful relative to the size of the landscape (McGarigal, 2014). It is a more powerful indicator than perimeter-area ratio (PARA) and perimeter-area fractal dimension (PAFRAC) (McGarigal, 2014; Tian *et al.*, 2014). In short, a high value of LSI indicates an irregular landscape or the increase in length of edge within the landscape.

There is no significant difference in landscape shape index in Inner and Outer London (U=92, p=0.142). There is also no significant difference in landscape shape index among sub-regions in Inner (U=14, p=0.228) and Outer London (χ^2=1.23, p=0.539) respectively. In general, as seen in Figure 4.9, different regions in Inner and Outer London show similar landscape shape, while showing Outer London (83.7) has a more irregular landscape shape than Inner London (51.6) which would come from the number of patches between two London areas. Yet in the whole London, Outer West and NW, Outer East and NE, Outer South, and Inner East London have similar regular shape with the value of around 27.9, which is slightly more irregular than Inner West London with the average LSI of 23.7.

The highest and lowest LSI were found in Inner London; Hammersmith and Fulham (15.2) and Wandsworth (44.8) respectively. The remarkable points are several boroughs show similar irregularities. In Inner London, Hammersmith and Fulham (15.2), Westminster (16.9), Camden (17.1), and Southwark (18.4) had similar low similar LSI values, whereas Islington (43.5) and Wandsworth (44.8) had similar high LSI values. In Outer London, Redbridge (19.6), Kington upon Thames (20.8) in South, and Richmond-upon-Thames (22.8) had similar low LSI values, whereas Ealing (33.8), Bromley (35.9) and Greenwich (38.4) showed similar high LSI values. (Figure 4.10).

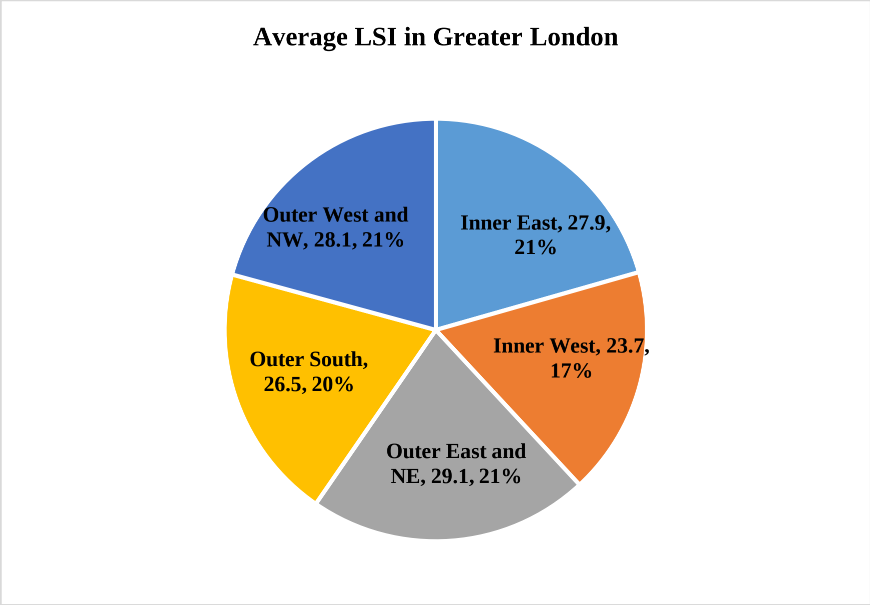
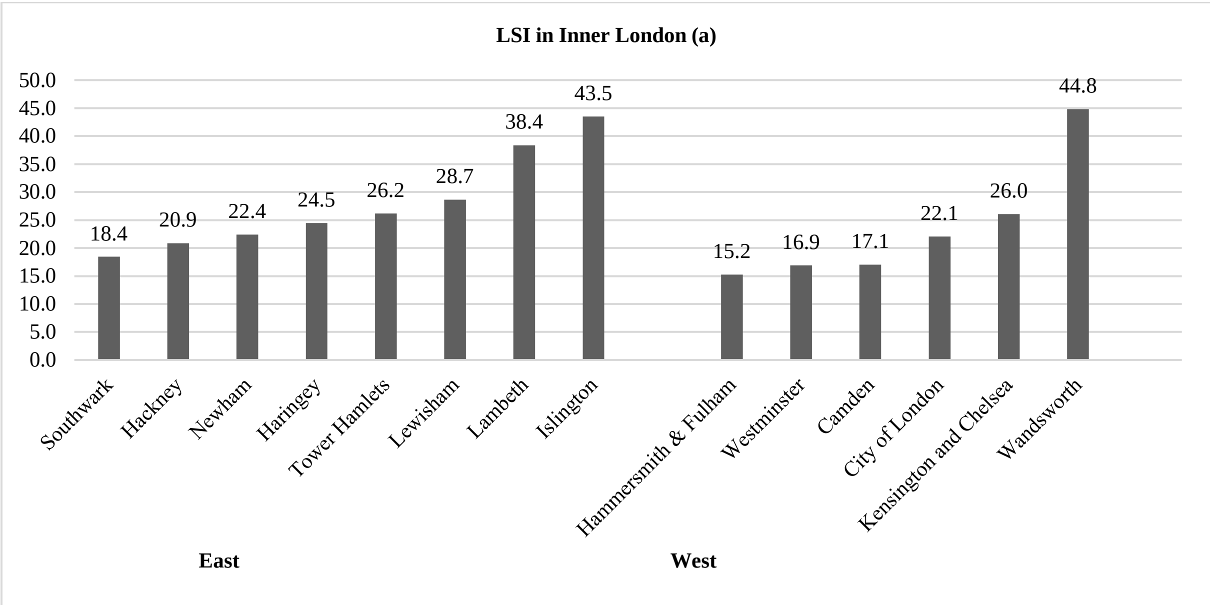


Figure 4.9 Proportion of Average LSI in Inner and Outer London



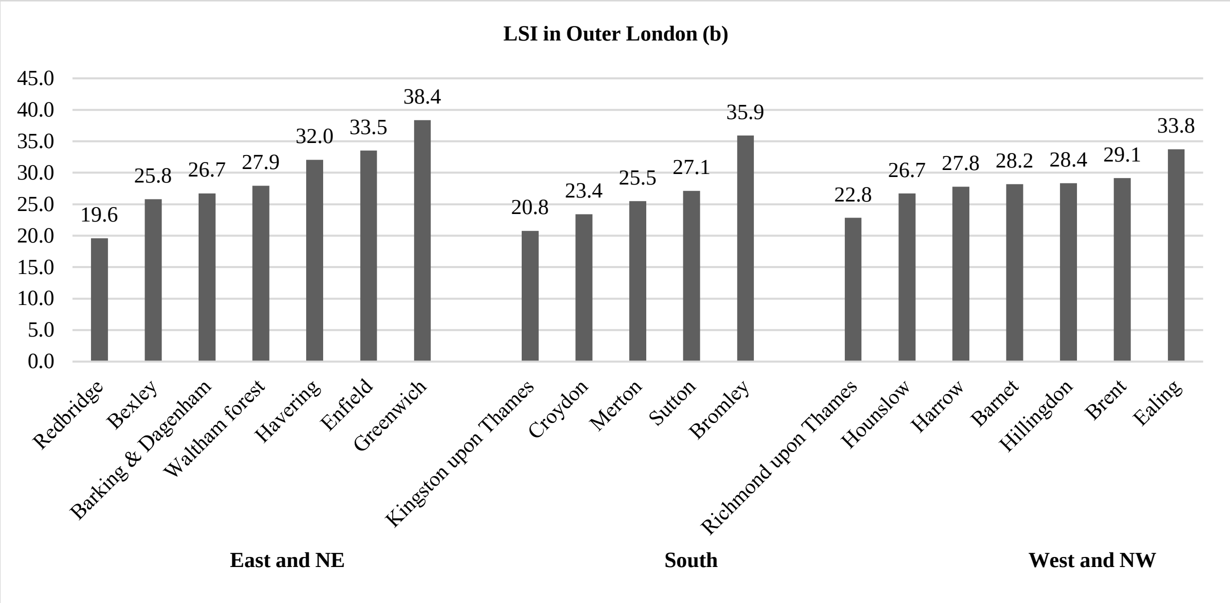


Figure 4.10 Landscape Shape Index in Inner (a) and Outer (b) London

4.4.5. Contagion (CONTAG)

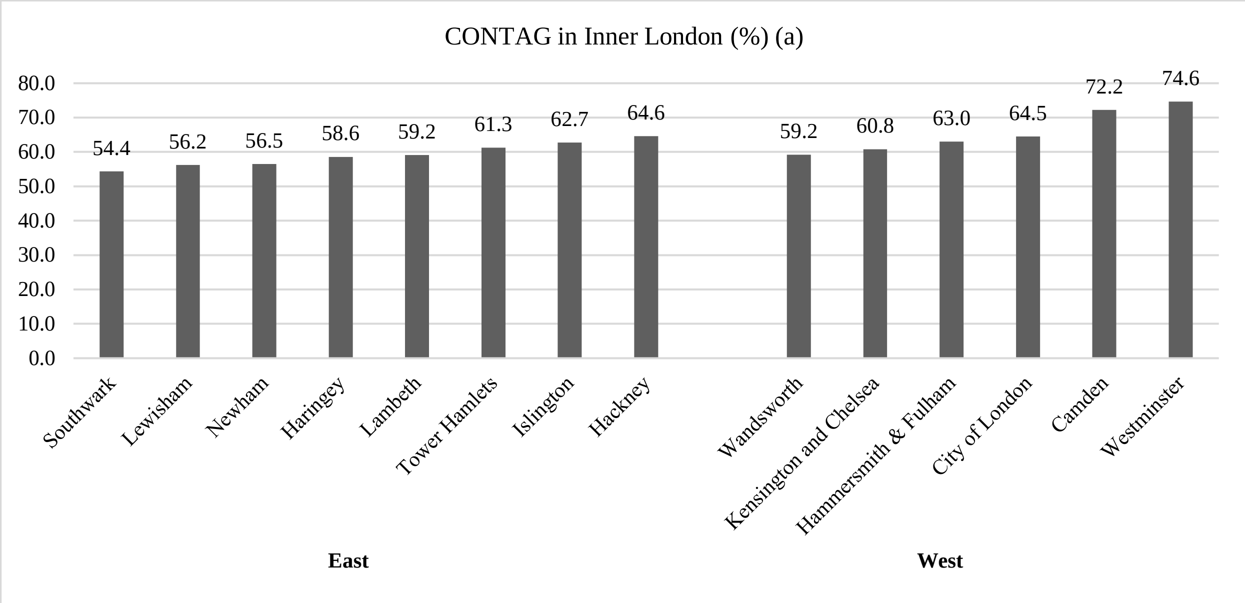
Contagion (CONTAG) is a complicated indicator to simply interpret values. It measures the intermixing of units of different patch types (interspersion) and the spatial distribution of path types such as aggregation or 'clumpiness' at the landscape level (dispersion) (McGarigal, 2014). This metric was firstly introduced by R.V. O'Neill *et al.* (1988) as a measure for quantifying fragmentation or aggregation of patches in a landscape in ecosystem analysis on habitat fragmentation, vegetation succession, and animal movements (Frohn, 1997; R.V. O'Neill *et al.*, 1988). As this metric is derived on the basis of the number of pixels, spatial resolution, class diversity and raster orientation (Frohn, 1997), it should be carefully interpreted. As for the patch interspersion, well-interspersed patches show low values in Contagion metrics. Yet when there is a constant interspersion in a landscape with larger aggregated patch types, contiguous patches have larger values in Contagion than in a landscape with small fragmented patch types.

Nevertheless, the direct interpretation of Contagion is that lower contagion index refers to more disaggregated patch types, and vice versa.

There is no significant difference in Contagion index between Inner and Outer London (U= 106, p=0.339). Yet there is a significant difference in Contagion index among boroughs in Inner London (U=8, p=0.043), and in Outer London (χ^2=6.020, p=0.049) respectively. The borough of Westminster had the highest Contagion of 74.6% and Barking and Dagenham recorded the lowest Contagion of 53.1%. In general, some boroughs show a similar Contagion trend, mainly consisting of two groups (i.e. 50 < CONTAG < 60, 60 < CONTAG < 70) (Figure 4.11):

(1) 50 < CONTAG < 60: Southwark, Lewisham, Newham, Haringey, Lambeth and Wandsworth in Inner London, and Barking and Dagenham, Bexley, Greenwich, Brent, Redbridge, Hounslow, Hillingdon, Enfield and Enfield in Outer London;

(2) 60 < CONTAG < 70: Kensington and Chelsea, Tower Hamlets, Islington, Hammersmith and Fulham, City of London and Hackney in Inner London, and Merton, Sutton, Kingston-upon-Thames, Richmond-upon-Thames, Havering, Croydon, and Bromley in Outer London.



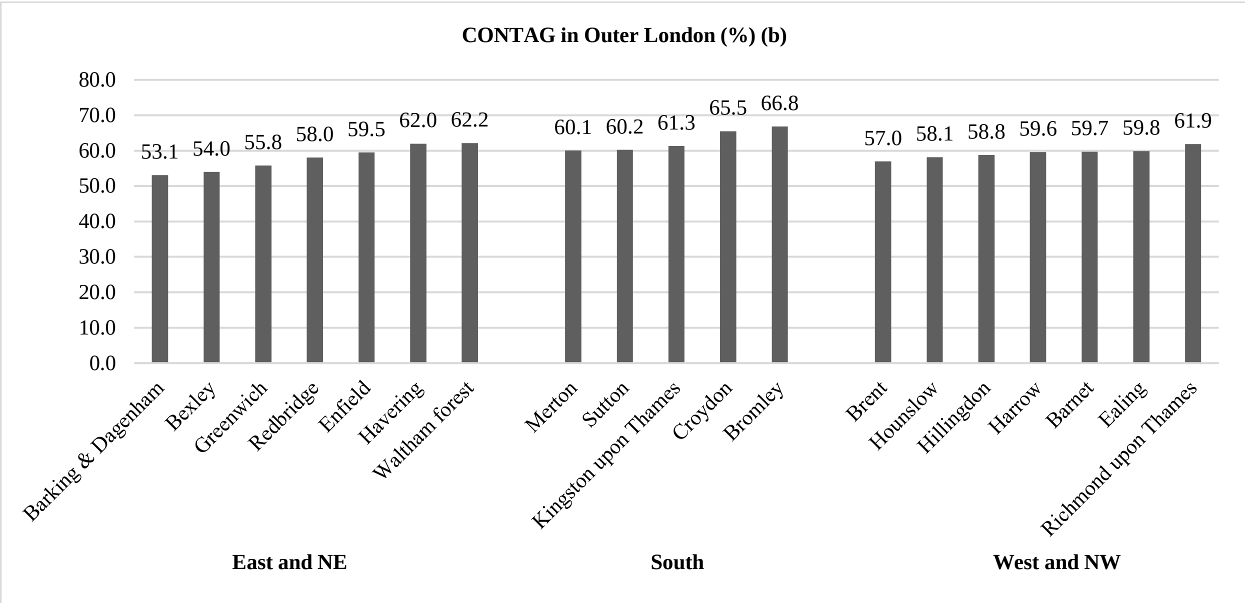
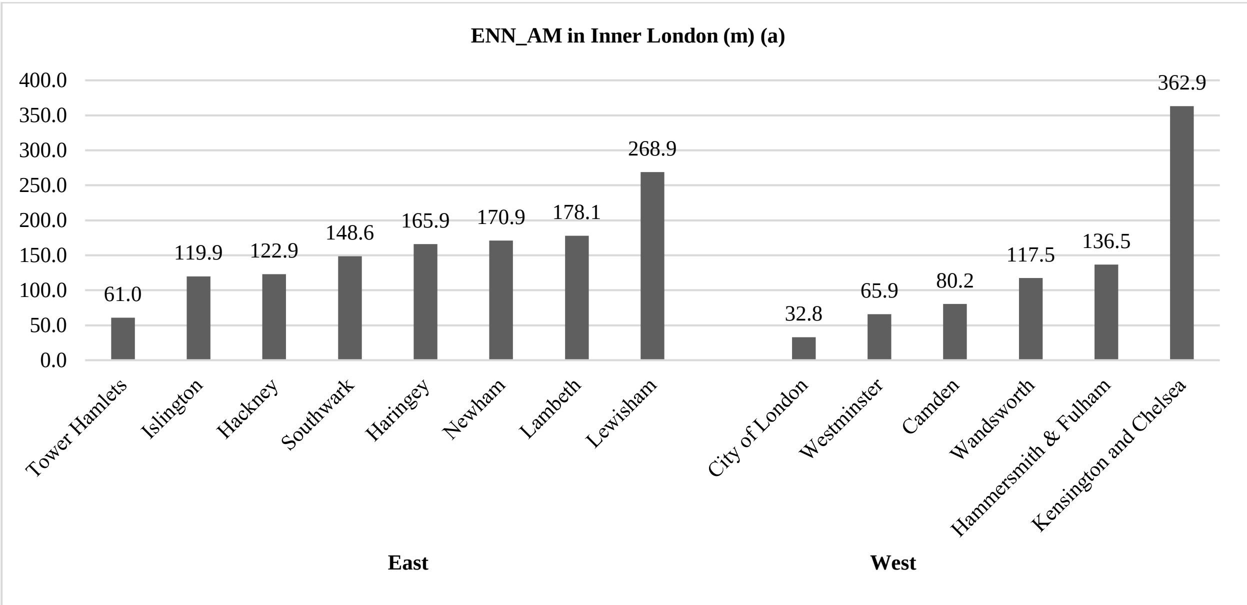


Figure 4.11 Contagion Index in Inner (a) and Outer (b) London

4.4.6. Euclidean Nearest Neighbour Distance (ENN)

Euclidean Nearest Neighbour Distance (ENN) measures patch isolation and proximity. This index can be defined as the simplest means for measuring the shortest straight-line distance between nearest neighbours by considering the distance from cell centre to cell centre of patches. When ENN decreases, the distance also shows a downward trend, which infers there is less patch isolation or dispersion. With the increasing ENN, there is more patch isolation and dispersion. When investigating ENN, Mean Euclidean Nearest Neighbour Distance (ENN_MN) considers all patches as equal. Given patch size impacts on measurement of distance, area-weighted mean Euclidean Nearest Neighbour Distance (ENN_AM) was selected for estimating isolation or proximity between patches in Inner and Outer London.

In general, Inner London shows a tendency of more isolation between patches, given that the mean ENN_AM of Inner London was 145.15m and Outer London 125.7m. There is no significant difference in ENN_AM index between Inner and Outer London (U=124, p=0.760). There is also no significant difference among boroughs in Inner (U=14, p=0.228) and Outer London (χ^2=1.415, p=0.4930) respectively. In Inner London, the City of London showed the most proximate tendency with the shortest ENN_AM of 32.8m, whereas Kensington & Chelsea indicated the most isolated pattern with the longest ENN_AM of 362.9m. In the whole of Outer London, Bromley indicates the least isolated pattern with the lowest ENN_AM (66.0m) but Barking & Dagenham in East and North-East shows the least proximate tendency between patches with the highest ENN_AM (200.2m) (Figure 4.12).



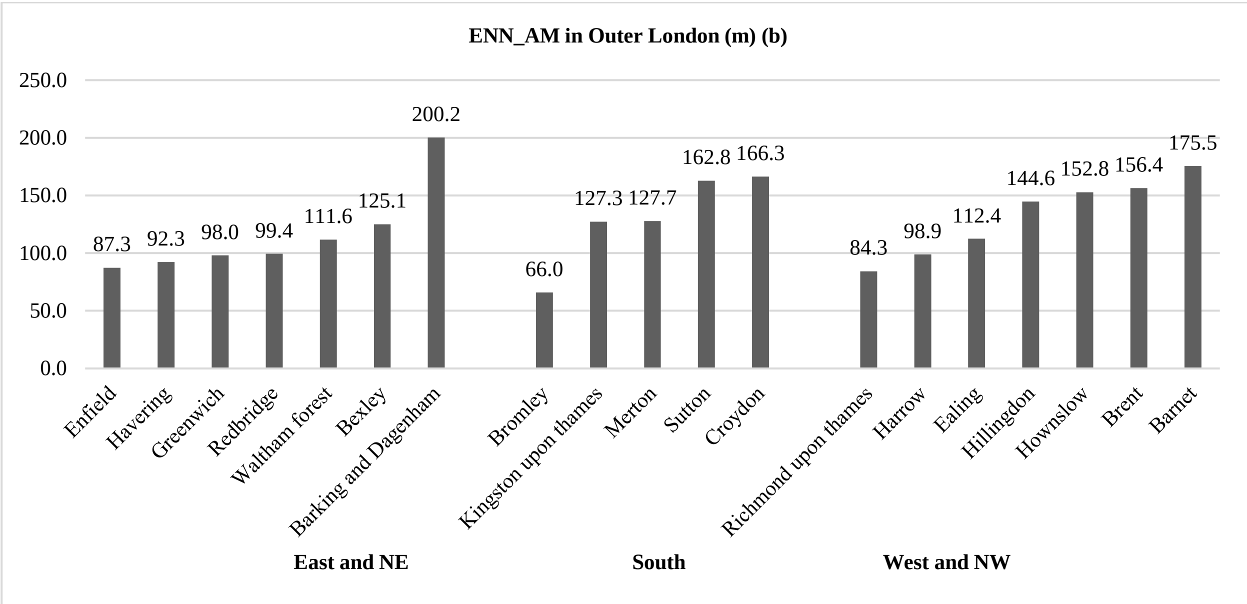


Figure 4.12 ENN_AM Index in Inner (a) and Outer (b) London

4.4.7. Contiguity Index (CONTIG)

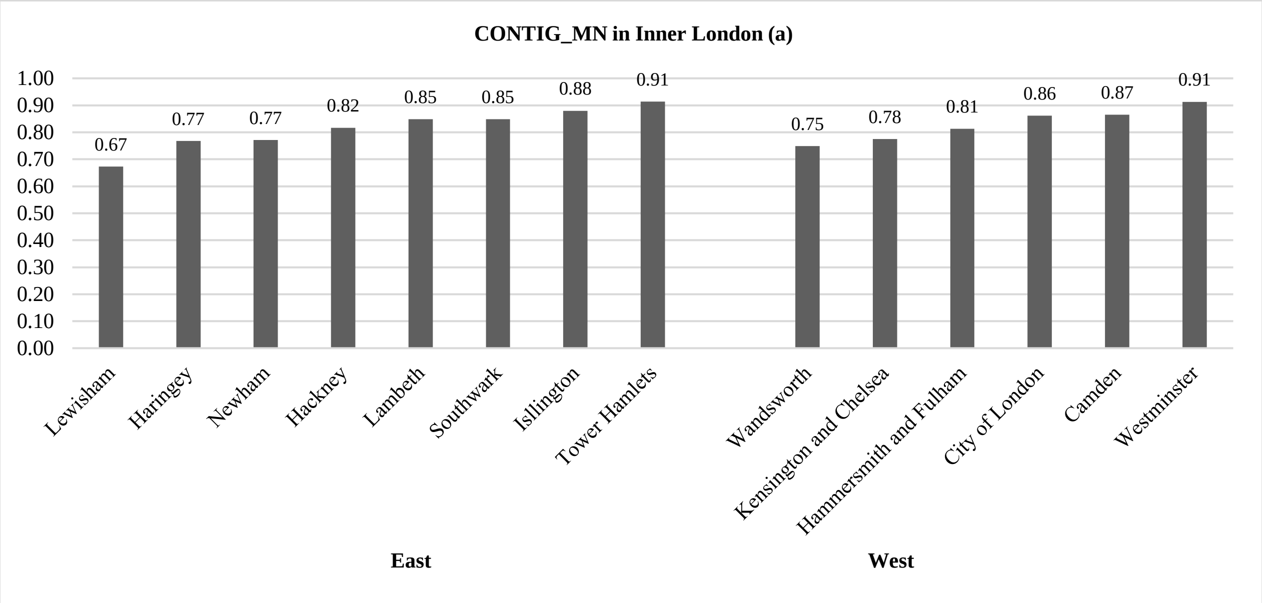
The Contiguity metric is used for estimating spatial connectedness or contiguity of cells within a grid-cell patch, which creates information on patch boundary configuration as well as patch shape. The index is between 0 and 1, and when patch contiguity or connectedness increases, it increases to a maximum of 1. There is a significant difference in Contiguity index between Inner and Outer London (U=70, p=0.021). Yet there is no significant difference in Contiguity index among sub-regions in Inner (U=22, p=0.852) and Outer London (χ^2=1.722, p=0.423) respectively.

The Boroughs of Tower Hamlets and Westminster had the highest Contiguity index (0.91), and the lowest Contiguity index was found in Croydon (0.57). In general, boroughs fell into three main groups (i.e. 0.6 < CONTIG < 0.7, 0.7 < CONTIG < 0.8, 0.8 < CONTIG < 0.9) (Figure 4.13):

(1) 0.6 < CONTIG < 0.7: Barking & Dagenham, Redbridge, Kingston-upon-Thames, Hillingdon, Lewisham, Merton, and Hounslow;

(2) 0.7 < CONTIG < 0.8: Richmond-upon-Thames, Ealing, Wandsworth, Greenwich, Haringey, Newham, Kensington and Chelsea, Enfield, Sutton, Waltham Forest, and Bromley;

(3) 0.8 < CONTIG < 0.9: Hammersmith and Fulham, Havering, Hackney, Bexley, Lambeth, Southwark, Barnet, City of London, Camden, Harrow, Islington, and Brent.



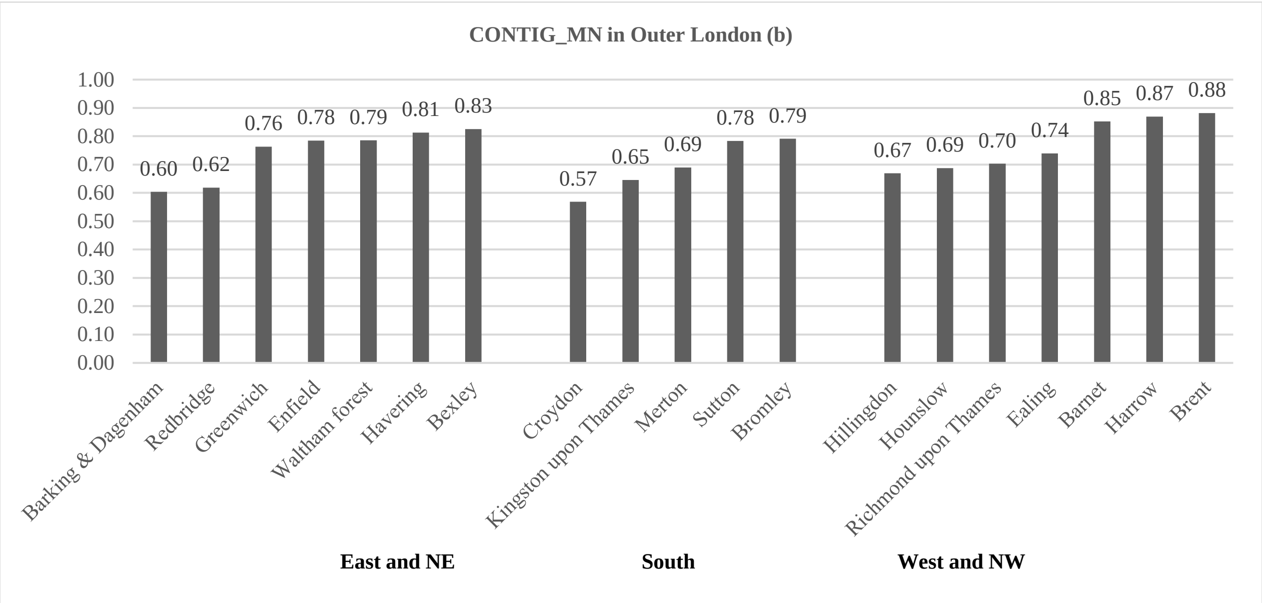


Figure 4.13 CONTIG_MN Index in Inner (a) and Outer (b) London

4.4.8. Perimeter area ratio index (PAFRAC)

When it comes to shape complexity, Perimeter area ratio index (PAFRAC) is a good indicator for recognizing and comparing among areas. When its value closes to 1, it means the shape of area is closer to squares. But when it approaches 2, the shape is more complicated and highly convoluted.

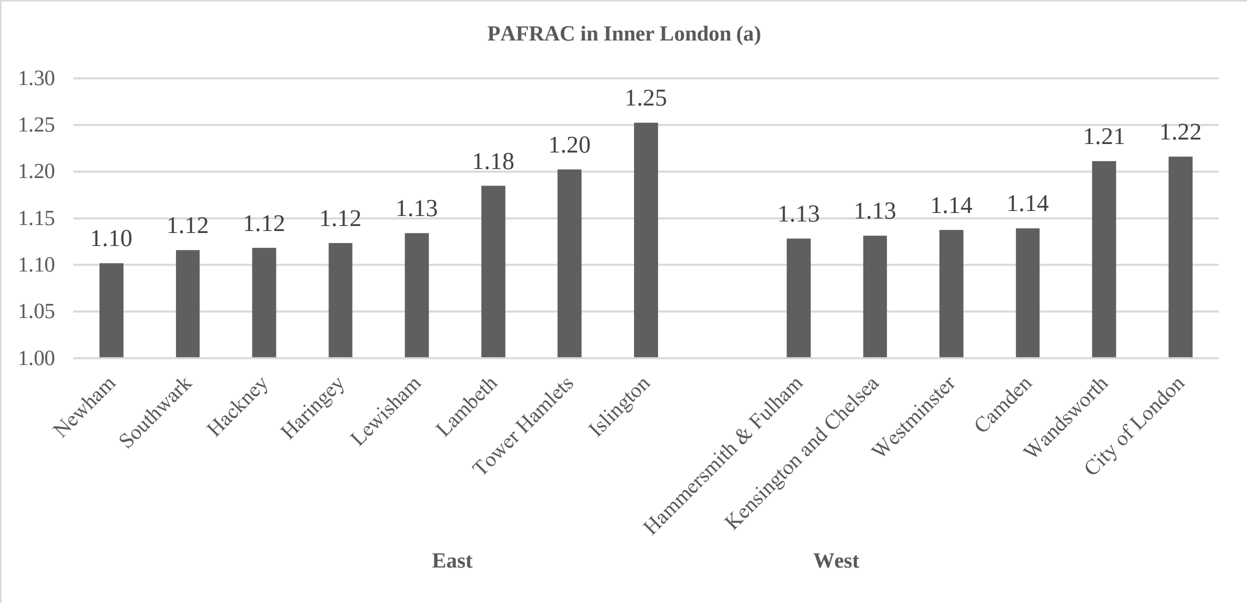
There is no significant difference in perimeter area ratio index (PAFRAC) between Inner and Outer London (U=110.5, p=0.418). There is also no significant difference among boroughs in Inner (U=16, p=0.345) and in Outer London (χ^2=5.385, p=0.068) respectively. The Boroughs of Newham and Croydon showed the least complicated and the simplest shape of open spaces with the lowest PAFRAC value of 1.10, whereas the Borough of Islington had the most complicated shape with the highest PAFRAC value of 1.25. In general, Greater London had substantially simple shapes of open spaces as shown in Figure 4.14. Several boroughs showed similar simplicity or complexity, which were found in four groups (i.e. 1.10 < PAFRAC < 1.13, 1.13 < PAFRAC < 1.16, 1.16 < PAFRAC < 1.19, 1.19 < PAFRAC < 1.22) (Figure 4.14):

(1) 1.10 < PAFRAC < 1.13: Newham, Croydon, Bromley, Kingston-upon-Thames, Barnet, Ealing, Hounslow, Hillingdon, Southwark, Hackney, Haringey;

(2) 1.13 < PAFRAC < 1.16: Lewisham, Hammersmith & Fulham, Kensington and Chelsea, Redbridge, Bexley, Sutton, Richmond-upon-Thames, Westminster, Camden, Havering, Merton and Harrow;

(3) 1.16 < PAFRAC < 1.19: Waltham Forest, Greenwich, Enfield and Lambeth;

(4) 1.19 < PAFRAC < 1.22: Tower Hamlets, Barking & Dagenham, Brent and Wandsworth.



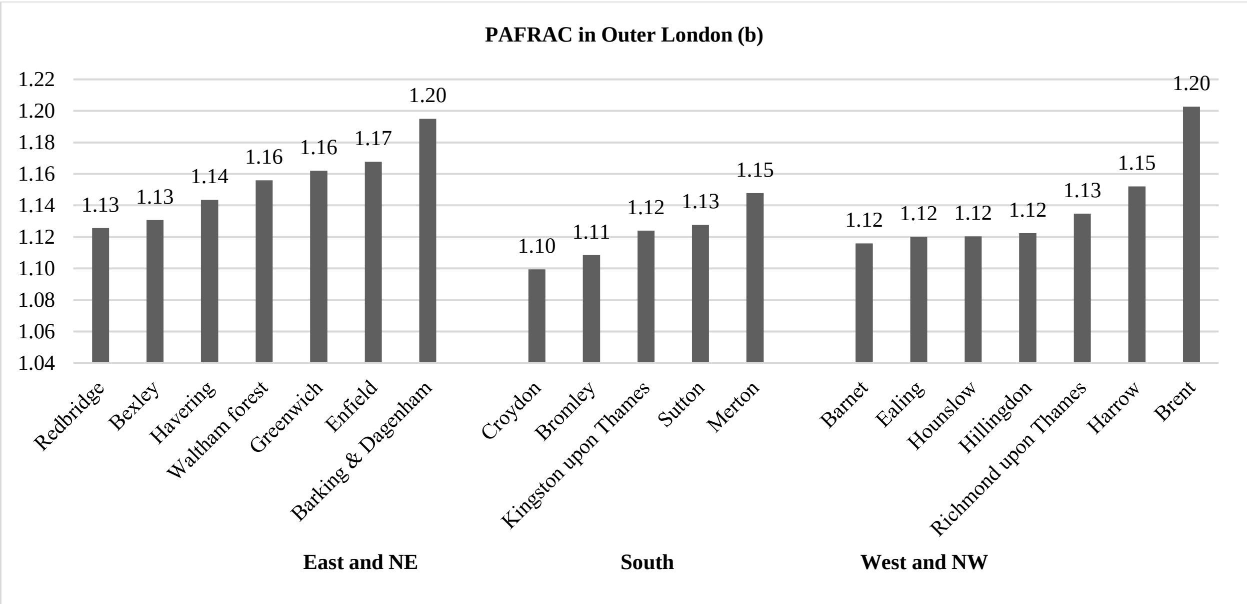


Figure 4.14 PAFRAC Index in Inner (a) and Outer (b) London

4.4.9. Area-weighted mean Patch Area Distribution (AREA_AM)

The mean surface of patches allows calculation of the characteristics of aerial distribution among patches (McGarigal, 2014). It functions as indicating the average size of patches in or across a particular landscape as well as suggesting the level of aggregation (Aguilera *et al.*, 2011; Hepcan, 2013). In addition, it can be seen that mean patch size is closely related to number of patches, which means that when the total patch numbers reduce, mean AREA increases. It can be inferred that when the index of mean Area increases, the corresponding landscape has a tendency of fragmented pattern. At a landscape level, in other words, a particular patch type with smaller mean patch size than other patch type can be interpreted as fragmented. Mean patch size can be calculated from the patch area, divided by 10,000 (for conversion to hectares), and again divided by number of patches. It means this index cannot inform the presence of patch numbers. Yet as this research more focuses on the landscape-centric perspective, area-weighted mean patch size will be employed.

There is a significant difference in area-weighted mean patch area distribution between Inner and Outer London ($U=60$, $p=0.007$). Yet there is no significant difference among boroughs in Inner ($U=19$, $p=0.573$) and Outer London ($\chi^2=2.030$, $p=0.362$) respectively. In general, Outer London tends to have more fragmented open spaces than Inner London. The Borough of Islington had the least fragmented patch pattern with the lowest AREA_AM value of 2.02ha, with the second lowest being City of London (2.13ha). The Borough of Richmond-upon-Thames showed the most fragmented patch pattern with the AREA_AM value of 291.9ha, followed by the Borough of Bromley (124.3ha). Some boroughs show a similar fragmentation pattern, mainly consisting of five groups (i.e. $20 > AREA$, $20 < AREA < 40$, $40 < AREA < 60$, $60 < AREA < 80$, $80 < AREA$):

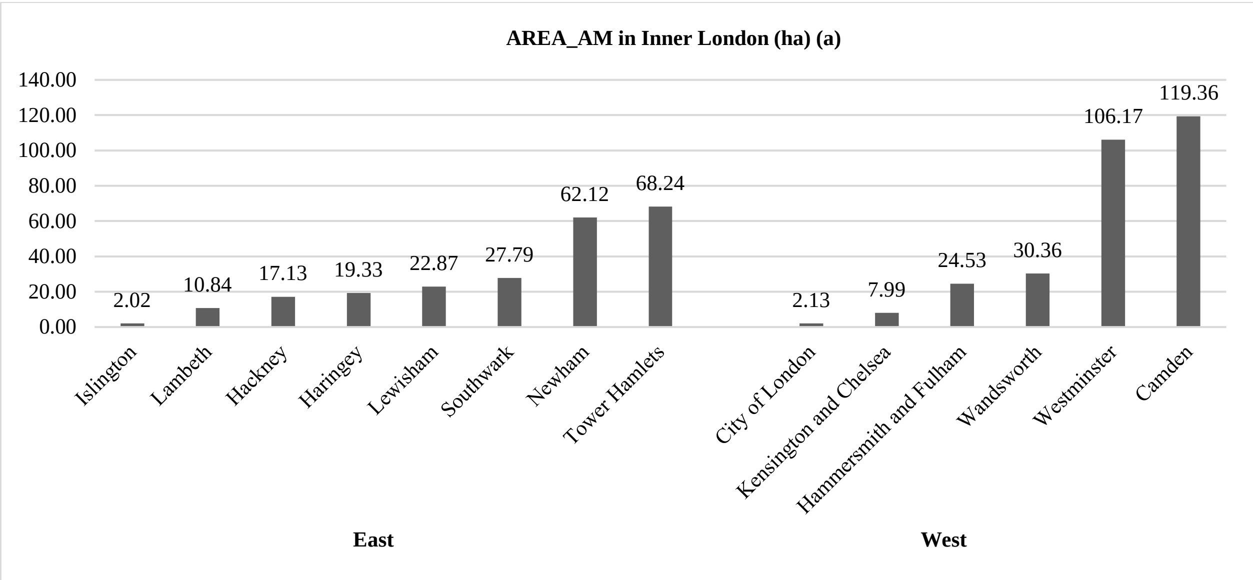
(1) 20 >AREA: Islington, City of London, Kensington and Chelsea, Lambeth, Hackney and Haringey;

(2) 20 < AREA < 40: Brent, Lewisham, Ealing, Hammersmith and Fulham, Southwark, Wandsworth, Waltham forest and Harrow;

(3) 40 < AREA < 60: Merton, Hounslow, Kingston-upon-Thames, Sutton, Barking and Dagenham and Barnet;

(4) 60 < AREA < 80: Newham, Tower Hamlets, Greenwich and Croydon;

(5) 80 < AREA: Redbridge, Hillingdon, Bexley, Havering, Westminster, Enfield, Camden, Bromley, and Richmond-upon-Thames.



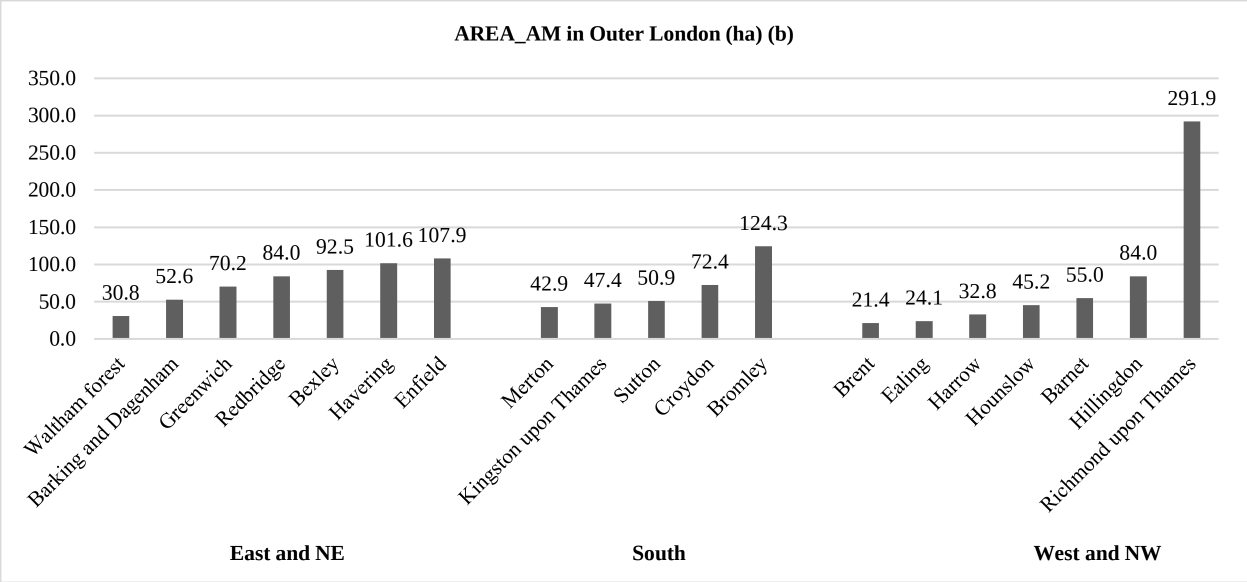


Figure 4.15 AREA_AM Index in Inner (a) and Outer (b) London

4.5. Analysis of Class Spatial Composition

4.5.1. Spatial Composition of Classes in Greater London

In this section, landscape composition in Greater London was investigated at a class level. The open spaces were divided into six classes: (1) amenity, (2) cemeteries and churchyards, (3) green corridors, (4) natural and semi-natural urban green space, (5) other and unknown, and (6) parks and gardens. The selected analytical metrics were 'Class Area' and 'Percentage of Landscape' in Area Metrics, and 'Number of Patch' and 'Patch Density' in Aggregation Metrics. First, a class-based analysis of Greater London was performed to give an overview of which class was most or least dominant across the city. Following this, two different suites of analysis were conducted: class proportion, and borough status per class in Inner and Outer London as well as the sub-regions of East and West Inner London and East and North-East, South, and West and North-West Outer London.

Table 4.8 Class Level of Greater London

TYPE	Area Metrics		Per capita Class Area	Aggregation	
	CA (ha)	PLAND (%)		NP	PD
Amenity	19370.62	28.66	0.002236 ha (22.36 m^2)	7257	10.73
Other and Unknown	16505.8	24.42	0.001905 ha (19.05m^2)	983	1.45
Parks and Gardens	12811.98	18.95	0.001479 ha (14.79m^2)	1661	2.45
Natural and Semi-natural Urban Greenspace	11354.29	16.8	0.001311 ha (13.11 m^2)	788	1.16
Green Corridors	6130.37	9.07	0.000708 ha (7.08 m^2)	3619	5.35
Cemeteries and Churchyards	1406.66	2.08	0.000162 ha (1.62 m^2)	439	0.64

In Greater London, amenity open spaces showed the highest coverage (19,370.62 ha, around 29%), followed by the 'other and unknown' class (11,6505.8 ha, 24%), parks and gardens (12,811.98 ha, 19%), natural and semi-natural urban green space (11354.29 ha, 16%), green corridors (6130.37 ha, 9%), and cemeteries and churchyards (1406.66, 2%). Based on London's 2015 population (8,663,300), this equates to 22.36 m^2 has per capita of amenity open spaces, 1.62 m^2 of cemeteries and churchyards, 7.08 m^2 of green corridors, 13.11 m^2 of natural and semi-natural urban greenspace, 19.05m^2 of other and unknown, and 14.79m^2 of parks and gardens. For number of patches and patch density, amenity shows the highest values (7,527/10.73), followed by green corridors (3,619/5.35), parks and gardens (1,661/2.45), other and unknown (983/1.45), natural and semi-natural urban greenspace (788/1.16) and cemeteries and churchyards (439/0.64).

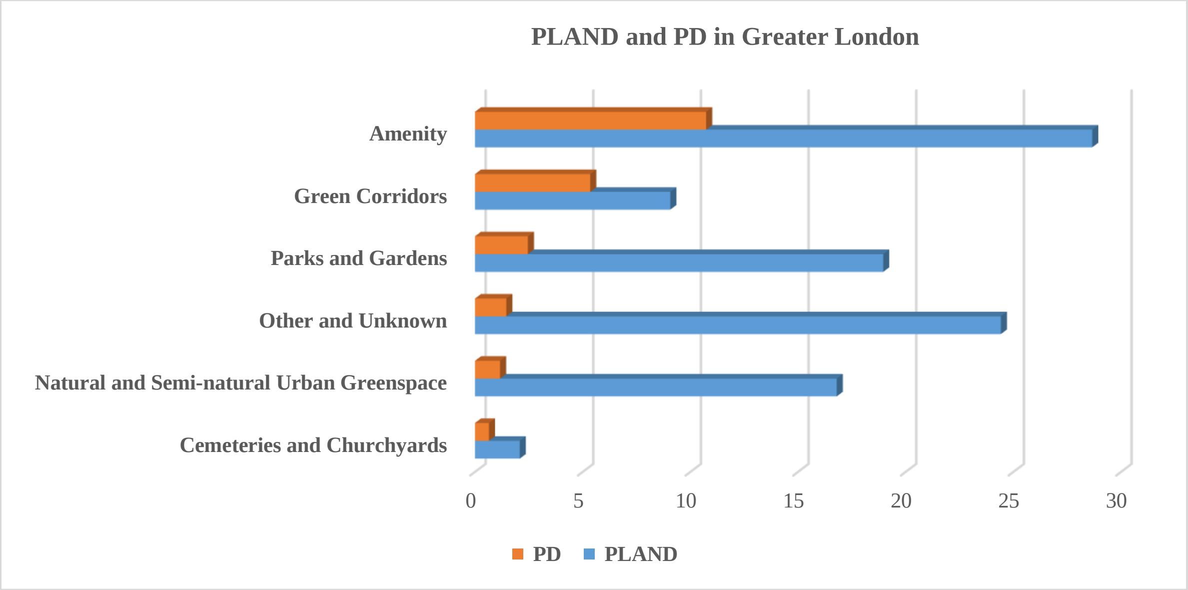


Figure 4.16 PLAND and PD of Classes in Greater London

4.5.2. Class Total Area and Percentage of Class Area in Inner and Outer London

Total Class Area (CA) allows a determination of which boroughs have the smallest and largest coverage of each corresponding class, whereas Percentage of Class Area (PLAND) allows estimation of proportional abundance of the classes in each sub-region and borough. In this section the metrics Total Class Area will be only employed when comparing each borough. There are significant differences in total areas of amenity (U=26, $p < 0.001$), cemeteries and churchyards (U=49, p=0.002), green corridors (U=60, p=0.007), natural and semi-natural urban green spaces (U=28, $p < 0.001$), other and unknown (U=58, p= 0.005), and parks and gardens (U=30, $p < 0.001$) in Inner and Outer London.

There are no significant differences in total areas of amenity (U=19. p=0.573/ χ^2=1.436, p=0.488), green corridors (U=16, p=0.345/ χ^2=2.064, p=0.356), natural and semi-natural urban green space (U=9, p=0.059/ χ^2=0.359, p=0.836), other and unknown (U=16, p=0.345/ χ^2=2.077, p=0.354), and parks and gardens (U=16, p=0.345/ χ^2=0.458, p=0.795) among sub-regions in Inner and Outer London respectively. Even though there was no significant difference in total area of cemeteries and churchyards in Inner London (U=18, p=0.491), there was a significant difference in Outer London (χ^2=7.622, p=0.022). Small extents of class area were generally found in Inner London, but large extents of class area were mostly found in Outer London, except for green corridor, for which the lowest and highest extent were all found in Outer London.

The Borough of City of London had the lowest total amenity area (4.29ha), whereas the Borough of Havering had the highest total amenity area (3580.85ha). The mean of total amenity was 551.64ha (± 696.47) area in Greater London, 159.80ha (± 140.84) in Inner London, and

840.36ha (± 800.38) in Outer London. The Borough of Islington had the lowest total cemeteries and churchyard area (3.85ha), whereas the Borough of Enfield recorded the highest total cemeteries and churchyard area (1466.08ha). On average, total cemeteries and churchyards area was 177.43ha (± 288.41) in Greater London, 65.37ha (± 98.60) in Inner London, and 260ha (± 351.99) in Outer London.

The Borough of Brent had the lowest total green corridor extent (18.10ha), whereas the highest area was found in the Bromley Borough (1885.61ha). The mean of total green corridor was recorded as 387.12ha (± 458.22) in Greater London, 132.74ha (± 97.42) in Inner London, and 574.56ha (± 528.20) in Outer London.

The lowest total natural and semi-natural urban greenspace was found in the Westminster Borough (0.00001ha), and the Borough of Havering recorded the highest value of 570.87ha. On average, total natural and semi-natural urban greenspace was 100.58ha (± 131.60) in Greater London, 26.49ha (± 38.68) in Inner London, and 155.18ha (± 149.31) in Outer London. The smallest total other and unknown extent was found in the Borough of Westminster (4.41ha), whereas the largest one was found in the Borough of Bromley (4866.72ha). The average total other and unknown space recorded at 368.39ha (± 873.45) in Greater London, 94.35ha (± 89.60) in Inner London, and 570.32ha (± 1117.61) in Outer London.

The lowest total area value of parks and gardens was 0.47ha which was found in City of London, whereas its highest value was 1343.86ha, which was the Borough of Hillingdon. The average total area of parks and gardens was 296.82ha (± 321.97) in Greater London, 101.43ha (± 109.19) in Inner London, and 440.79ha (± 352.30) in Outer London.

Table 4.9 Class Total Area in Inner London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Camden	4.68	19.32	**363.86**	15.82	25.27	103.74
City of London	**4.29**	7.69	**23.75**	0.22	22.25	**0.47**
Hackney	52.12	18.06	225.71	1.94	27.93	186.86
Hammersmith and Fulham	33.17	4.50	40.01	7.90	166.36	110.52
Haringey	310.95	84.54	220.24	23.38	160.90	22.17
Islington	48.43	**3.85**	101.62	5.90	28.19	14.48
Kensington and Chelsea	118.76	37.01	38.92	10.01	37.61	2.44
Lambeth	154.82	18.88	213.06	66.27	7.64	102.71
Lewisham	208.41	52.94	125.46	102.39	**272.59**	19.98
Newham	213.18	116.21	166.83	16.25	132.22	**406.87**
Southwark	60.23	141.54	32.60	**114.49**	235.34	93.13
Tower Hamlets	208.41	21.18	67.97	4.92	55.33	211.41
Wandsworth	374.99	**373.48**	143.11	1.39	144.91	75.35
Westminster	**444.81**	16.00	95.23	**0.00**	**4.41**	69.94

Table 4.10 Class Total Area in Outer London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	199.71	248.70	216.85	275.00	**26.25**	308.29
Barnet	1591.54	135.13	231.78	308.94	730.33	267.36
Bexley	552.51	360.83	604.51	**25.67**	485.54	470.66
Brent	208.50	137.17	**18.10**	41.77	227.84	328.77
Bromley	234.25	42.57	**1885.61**	279.52	**4866.73**	1315.82
Croydon	1062.03	176.51	1254.27	33.16	66.70	195.69
Ealing	826.32	159.78	67.80	49.90	311.57	308.49
Enfield	349.50	**1466.08**	1373.62	172.35	544.74	79.88
Greenwich	743.10	163.42	299.40	53.14	419.71	299.76
Harrow	698.66	289.81	97.01	26.78	108.13	399.36
Havering	**3580.85**	848.43	1168.36	**570.87**	54.45	534.57
Hillingdon	1285.97	32.50	343.18	373.01	1821.00	**1343.86**
Hounslow	307.00	121.53	775.16	34.00	251.49	632.90
Kingston upon Thames	569.07	**18.70**	473.73	140.50	113.02	**60.73**
Merton	609.63	80.15	31.44	154.95	97.19	376.98
Redbridge	803.19	34.38	493.04	215.77	122.28	606.35
Richmond upon Thames	1645.13	152.95	881.27	67.71	325.35	277.70
Sutton	611.43	25.03	92.25	89.60	202.50	464.10
Waltham Forest	**88.52**	446.25	609.21	35.75	61.22	103.82

4.5.3. Number of Patches and Patch Density in Inner and Outer London

At a class metrics level, number of patches simply shows 'the extent of subdivision or fragmentation of the patch type' with more relation to ecological processes, whereas patch density indicates 'aspects of landscape pattern' to a limited extent, allowing comparison among various sized landscapes (McGarigal, 2014, pp.149-150). Even though these metrics cannot convey information about patch sizes and spatial distribution of patches, they are crucial for determining which borough had the most and least patches and patch density. Unlike Total Area and Percentage of Class Area, patch numbers and patch density should be estimated separately as the two metrics entail different information.

There are no significant differences in patch number of amenity (U=81, p=0.060), green corridor (U=112, p=0.461) and other and unknown class (U=95.5, p=0.174) in Inner and Outer London. Yet there are significant differences in patch number in cemeteries and churchyards (U=64.5, p=0.011), natural and semi-natural urban green space (U=58, p=0.005), and parks and gardens (U=62.5, p=0.009) in Inner and Outer London. Among sub-regions in Inner and Outer London, there are no significant differences in patch numbers of amenity (U=23.5, p=0.950/ χ^2=23.5, p=0.950), cemeteries and churchyards (U=22, p-0.852/ χ^2=22, p=0.852), green corridors (U=15, p=0.282/ χ^2=15, p=0.282), natural and semi-natural urban green spaces (U=20, p=0.662/ χ^2=20, p=0.662), other and unknown (U=22.5, p=0.852/ χ^2=22.5, p=0.852), and parks and gardens (U=16.5, p=0.345/ χ^2=16.5, p=0.345).

The lowest patch number was mostly found in Inner London boroughs except for amenity and green corridors. In the amenity class, the lowest and highest values were found in Inner London. The class of green corridor had the highest patch number value in Inner London than in Outer London. The Borough of Camden had the lowest amenity patch numbers (9), whereas the

Borough of Wandsworth had the highest amenity patch numbers (1954). The mean of amenity patch number was 226.79 (± 354.78) in Greater London, 234.64 (± 504.15) in Inner London, and 221 (± 200.28) in Outer London.

The Borough of Hammersmith and Fulham recorded the lowest cemetery and churchyard patch numbers (3), whereas the Borough of Greenwich recorded the highest patch number (147). On average, cemeteries and churchyard patch number was 35.91 (± 36.04) in Greater London, 17.93 (± 14.68) in Inner London, and 49.16 (± 41.43) in Outer London. The lowest patch number value of green corridor was found in the Borough of Brent (17), and the Borough of Islington recorded the highest value of 555. On average, green corridor patch number was 197.52 (± 167.66) in Greater London, 159.29 (± 152.08) in Inner London and 225.68 (± 176.90) in Outer London.

The lowest patch number of natural and semi-natural urban greenspace was found in two boroughs; City of London (1) and Westminster (1). The highest patch number recorded at 121 in the Borough of Sutton. The average patch number of natural and semi-natural urban greenspace recorded at 34.45 (± 34.23) in Greater London, 21.07 (± 28.48) in Inner London, and 44.32 (± 35.42) in Outer London. The Borough of Camden had the lowest patch number of other and unknown class (4), whereas the Greenwich Borough had the highest patch number (239). The mean of the class was 70.88 (± 61.75) in Greater London, 54.79 (± 52.24) in Inner London, and 82.74 (± 66.76) in Outer London.

The lowest patch number value of parks and gardens was found in Kensington and Chelsea (3), and the highest value was found in the Borough of Havering (294). The average patch number of parks and gardens was 71.03 (± 66.40) in Greater London, 38.64 (± 28.85) in Inner London, and 94.89 (± 76.29) in Outer London.

Table 4.11 Patch Number of Each Class in Inner London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Camden	**9**	31	123	24	**4**	67
City of London	71	33	31	**1**	**174**	5
Hackney	36	10	166	2	14	81
Hammersmith and Fulham	10	**3**	**29**	9	30	57
Haringey	224	11	63	4	76	22
Islington	60	11	**555**	3	71	41
Kensington and Chelsea	175	8	158	10	156	**3**
Lambeth	71	9	428	75	12	41
Lewisham	361	12	113	**84**	62	15
Newham	83	9	78	8	52	**96**
Southwark	14	43	34	55	53	16
Tower Hamlets	108	19	184	6	23	53
Wandsworth	**1954**	**48**	107	13	28	16
Westminster	109	4	161	**1**	12	28

Table 4.12 Patch Number of Each Class in Inner and Outer London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	42	105	**555**	96	**5**	121
Barnet	243	16	107	34	49	50
Bexley	155	43	63	30	51	24
Brent	93	10	**17**	**7**	65	129
Bromley	187	25	437	69	182	247
Croydon	102	43	320	25	30	184
Ealing	277	115	61	25	126	141
Enfield	155	67	403	25	167	**14**
Greenwich	**927**	**147**	80	8	**239**	50
Harrow	376	21	162	16	26	39
Havering	154	62	435	44	26	**294**
Hillingdon	326	9	64	97	76	71
Hounslow	**35**	107	432	20	58	78
Kingston upon Thames	137	**5**	47	50	47	72
Merton	173	28	39	35	190	45
Redbridge	334	31	78	104	43	18
Richmond upon Thames	72	50	330	23	108	86
Sutton	325	10	328	**121**	54	59
Waltham Forest	86	40	330	13	30	81

There are no significant differences in patch density of amenity (U=83, p=0.710, cemeteries and churchyards (U=98, p=0.212), natural and semi-natural urban greenspaces (U=110, p=0.418), and parks and gardens (U=86, p=0.091) in Inner and Outer London. Yet there are significant differences in patch density in green corridors (U=51, p=0.002) and other and unknown (U=74, p=0.032) in Inner and Outer London. Among sub-regions in Inner and Outer London, there are no significant differences in patch density of amenity (U=19, p=0.573/ χ^2=0.079, p=0.961), cemeteries and churchyards (U=22, p=0.852/ χ^2=3.826, p=0.148), green corridors (U=22, p=0.852/ χ^2=1.334, p=0.513), natural and semi-natural urban green spaces (U=24, p=1/ χ^2=1.469, p=0.480), other and unknown (U=23, p=0.95/ χ^2=0.774, p=0.679), and parks and gardens (U=19, p=0.573/ χ^2=1.310, p=0.519). The lowest patch density was mostly found in Outer London boroughs except for natural and semi-natural urban greenspaces. In the natural and semi-natural urban greenspace class, the lowest and highest values were all found in Inner London.

The Borough of Hounslow had the lowest amenity patch density (1.65), whereas the Borough of Wandsworth had the highest amenity patch density (175.52). The mean of amenity patch density was 22.48 (± 36.60) in Greater London, 38.67 (± 51.39) in Inner London, and 10.55 (± 10.95) in Outer London. The Borough of Hillingdon recorded the lowest patch density (0.17), whereas City of London recorded the highest cemetery and churchyard patch density (56.25). On average, cemeteries and churchyard patch density was 4.21 (± 9.61) in Greater London, 6.68 (± 14.40) in Inner London, and 2.39 (± 2.52) in Outer London.

The lowest patch density value of green corridor was found in the Borough of Hillingdon (1.23), and the Borough of Islington recorded the highest value of 274.11. On average, green corridor patch density was 24.93 (± 48.45) in Greater London, 45.21 (± 69.63) in Inner London and 9.98 (±10.77) in Outer London.

The lowest patch density of natural and semi-natural urban greenspace was found in Westminster (0.16), whereas the highest patch density recorded at 13.31 in the Borough of Lambeth. The average patch density of natural and semi-natural urban greenspace recorded at 2.73 (± 3.27) in Greater London, 3.6 (± 4.19) in Inner London, and 2.09 (± 2.30) in Outer London.

The Borough of Havering had the lowest patch density of other and unknown class (0.38), whereas City of London had the highest patch density (296.57). On average, its patch density recorded at 15.75 (± 51.82) in Greater London, 31.98 (± 78.09) in Inner London, and 3.80 (± 3.77) in Outer London.

The lowest patch density value of parks and gardens was found in Enfield (0.35), and the highest value was found in the Borough of Islington (20.25). The average patch density of parks and gardens was 5.83 (± 5.05) in Greater London, 8.05 (± 6.16) in Inner London, and 4.19 (± 3.35) in Outer London.

Table 4.13 Patch Density of Each Class in Inner London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Camden	**1.69**	5.82	23.09	4.51	**0.75**	12.58
City of London	121.02	**56.25**	52.84	1.70	**296.58**	8.52
Hackney	7.02	1.95	32.38	0.39	2.73	15.80
Hammersmith and Fulham	2.76	0.83	8.00	2.48	8.28	15.73
Haringey	27.24	1.34	7.66	0.49	9.24	2.68
Islington	29.63	5.43	**274.11**	1.48	35.07	**20.25**
Kensington and Chelsea	71.50	3.27	64.55	4.09	63.74	**1.23**
Lambeth	12.60	1.60	75.97	**13.31**	2.13	7.28
Lewisham	46.18	1.54	14.45	10.74	7.93	1.92
Newham	7.89	0.86	7.42	0.76	4.95	9.13
Southwark	2.07	6.35	**5.02**	8.12	7.82	2.36
Tower Hamlets	18.97	3.34	32.32	1.05	4.04	9.31
Wandsworth	**175.52**	4.31	9.61	1.17	2.52	1.44
Westminster	17.29	**0.63**	25.54	**0.16**	1.90	4.44

Table 4.14 Patch Density of Each Class in Inner London

Area name	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	3.29	**8.24**	**43.54**	7.53	0.39	9.49
Barnet	7.44	0.49	3.28	1.04	1.50	1.53
Bexley	6.20	1.72	2.52	1.20	2.04	0.96
Brent	9.67	1.04	1.77	0.73	6.76	**13.41**
Bromley	2.17	0.29	5.07	0.80	2.11	2.86
Croydon	3.66	1.54	11.48	0.90	1.08	6.60
Ealing	16.07	6.67	3.54	1.45	7.31	8.18
Enfield	3.89	1.68	10.11	0.63	4.19	**0.35**
Greenwich	**46.85**	7.43	4.04	**0.40**	12.08	2.53
Harrow	23.21	1.30	10.00	0.99	1.61	2.41
Havering	2.28	0.92	6.44	0.65	**0.38**	4.35
Hillingdon	6.27	**0.17**	**1.23**	1.87	1.46	1.37
Hounslow	**1.65**	5.04	20.36	0.94	2.73	3.68
Kingston upon Thames	9.96	0.36	3.42	3.63	3.42	5.23
Merton	12.81	2.07	2.89	2.59	**14.07**	3.33
Redbridge	14.68	1.36	3.43	4.57	1.89	0.79
Richmond upon Thames	2.15	1.49	9.85	0.69	3.22	2.57
Sutton	21.89	0.67	22.09	**8.15**	3.64	3.97
Waltham Forest	6.40	2.97	24.54	0.97	2.23	6.02

4.6. Correlation analyses of open spaces with socioeconomic variables

4.6.1. Correlations in socioeconomic variables and landscape metrics in Greater London

Correlation coefficients and significant relationships identified between borough landscape metrics and socioeconomic variables across Greater London are highlighted in Table 4.15. In relation to the suites of socioeconomic variables:

(1) **Population**: population density was significantly negatively correlated to total open space area (corrected by borough area) and mean patch area distribution, along with significantly positive correlations with number of patches and patch density. This indicates that that those boroughs with denser populations generally have less overall open space, and high numbers of smaller, densely distributed open spaces.

(2) **Population age distribution**: variables such as average age, proportion aged 65 and over were positively correlated to total and mean open spaces, and contagion, but negatively related to patch density. This suggests that older populations are generally found in those boroughs that have more open spaces with fewer, more connected patches.

(3) **Education**: the proportion of working population with bachelor degrees or higher was negatively linked to open space area, and positively linked to patch density. This indicates that educated workers often reside in boroughs with limited area of open spaces, but with higher numbers of small patches.

(4) **Immigration/ethnicity**: these variables were negatively linked to total area of open spaces, suggesting that boroughs with higher proportions of immigrants or non-white ethnicity also had less overall area of open spaces.

(5) **Employment**: these variables indicate significant negative correlations between employment and both area and number of open spaces, though with a positive relationship to contagion.

(6) **Housing**: median house price was significantly negatively correlated to area and number of open spaces, though there was a positive correlation with patch density and contagion. This suggests that those boroughs with the most expensive houses had less open space, though the open spaces that were present were often close together.

(7) **Crime**: crime rates were negatively correlated to area and number of open spaces, though showed a positive relationship to patch density. This suggests that fewer crimes are committed in areas with abundant open spaces, but that having lots of small open spaces close together may increase crime.

(8) **Life expectancy**: there was a greater effect for males. Positive correlations with total area and contagion, negative for patch density. This suggests that those boroughs that have greater life expectancy are also those that have more open space in bigger patches.

(9) **Quality of life**: these are all positively related to area of open spaces, with the exception of anxiety, which is negative. This may mean that people are happier near open space, or that those boroughs with more open space generally have happier people (older, richer). Patch density is negatively related to quality of life (with the exception of anxiety which is positive), suggesting that the higher fragmentation, the lower quality of life in boroughs.

Overall, this suggests that those boroughs with denser, younger, more highly-educated and multicultural populations tend to be those with less open space, and in which open spaces are smaller and more densely spaced. Those boroughs with older populations are more likely to be those with more open space, and wherein the open space is in larger, less densely-spaced patches. This probably reflects density of the urban landscape, with older residents living in larger, less dense housing adjacent to large open spaces (e.g. parks, woodland, and golf courses) and younger and multicultural residents living in denser housing adjacent to small, fragmented patches of open space. In London, most expensive houses are in highly urbanised areas with less open space and are probably luxury flats. This trend contradicts some studies in other cities (e.g. the denser the urban forest, the higher house prices are). This will be discussed further below.

Table 4.15 Correlation between open space configuration and socioeconomic factors

	GLA Population Estimate 2016	Population density (per hectare) 2016	Average Age, 2016	Proportion of population aged 65 and over, 2016	% of resident population born abroad (2014)	Proportion of working age with degree or equivalent and above (%) 2015	Modelled Household median income estimates 2012/13	Number of jobs by workplace (2014)	Jobs Density, 2014	Crime rates per thousand population 2014/15	Median House Price, 2014	Average Band D Council Tax charge (£), 2015/16	% of area that is Greenspace, 2005	% of pupils whose first language is not English (2015)	Male life expectancy, (2012-14)	Female life expectancy, (2012-14)	Life satisfaction score 2011-14 (out of 10)	Worthwhileness score 2011-14 (out of 10)	Happiness score 2011-14 (out of 10)	Anxiety score 2011-14 (out of 10)
Total Open Space Area / Area of Boroughs	0.146	-.754**	.359*	.411*	-.542**	-.519**	-0.236	-.445**	-.358*	-.700**	-.564**	.559**	.911**	-.435*	0.321	0.079	.409*	.545**	.401*	-0.287
Mean Patch Area Distribution	0.317	-.652**	.362*	.394*	-0.330	-.392*	-0.212	-0.193	-0.169	-.545**	-.439*	.567**	.736**	-0.334	.373*	.350*	.455**	.447**	.394*	-.357*
Number of Patch/Area of Boroughs	-.389*	.445**	-0.235	-0.328	0.136	0.287	0.203	0.028	0.087	0.327	0.311	-.407*	-.493**	0.196	-0.286	-.388*	-.392*	-0.312	-0.321	0.340
Patch Density	-0.317	.652**	-.362*	-.394*	0.330	.392*	0.212	0.193	0.169	.545**	.439*	-.567**	-.736**	0.334	-.373*	-.350*	-.455**	-.447**	-.394*	.357*
Contagion	-0.299	0.041	.392*	0.125	-0.028	0.340	.539**	.352*	.508**	0.157	.477**	-0.061	0.014	-0.060	.359*	0.287	-0.055	-0.203	-0.247	0.205
Mean Shape Index Distribution	0.059	-0.244	0.121	.368*	-0.087	-0.096	-0.181	-.347*	-0.223	-.398*	-0.179	.438*	0.274	-0.104	0.165	0.269	0.192	0.033	0.076	-.406*

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

4.6.2. Correlations in socioeconomic variables and different open space classifications

Correlation coefficients and significant relationships identified between area of different open space classes and socioeconomic variables across Greater London are highlighted in Table 4.16. In relation to the suites of socioeconomic variables:

(1) **Population**: positive correlations were found between total population and area of cemeteries and other and unknown open spaces, but negative correlations were observed between population density and all types of green space, indicating that the most densely populated boroughs had limited open spaces; presumably because high residential density precludes the availability of open space.

(2) **Population age distribution**: older populations were associated with greater area of amenity and natural and semi-natural open spaces.

(3) **Education**: negative correlations were found with almost all types of open space, meaning that the tendency for highly-educated people to be found in those boroughs with limited area of open space applies to all types.

(4) **Immigration/ethnicity**: negative correlations were found for most types of open space, indicating that the trend for higher proportions of immigrants or those with non-white ethnicity to be found in those boroughs with limited open space applies to most of the open space types. The only exception was parks and gardens.

(5) **Employment**: negative correlations were found for cemeteries, green corridors and natural and semi-natural open spaces. This may reflect most workers living in boroughs with less disturbed/managed open spaces, and perhaps the tendency for wealthier retired people to occupy areas with higher areas of these types of open space.

(6) **Housing**: housing was negatively correlated with almost all types of open space, again perhaps reflecting luxury apartments and houses in relatively denser Inner London.

(7) **Crime**: negatively correlated to all types of open space, with the exception of green corridors, so there is no tendency for the relationship of crime with area open space to vary with type.

(8) **Life expectancy**: male life expectancy was only linked to amenity area, no influence on female life expectancy. Either boroughs with richer populations have more amenities, or access to amenities improves male life expectancy.

(9) **Quality of life**: amenity, green corridors and natural open spaces particularly positively associated with satisfaction, interestingly not for cemeteries or parks and gardens. Cemeteries were linked to less anxiety, however.

Overall, this suggests that most of the patterns for open spaces in general apply to all types of open space, though in some cases certain types might be more important – for example amenity and life expectancy, happiness with more natural open spaces and amenity access.

Table 4.16 Correlation between open space composition and socioeconomic factors

	GLA Population Estimate 2016	Population density (per hectare) 2016	Average Age, 2016	Proportion of population aged 65 and over, 2016	% of resident population born abroad (2014)	Proportion of working age with degree or equivalent and above (%) 2015	Modelled Household median income estimates 2012/13	Number of jobs by workplace (2014)	Jobs Density, 2014	Crime rates per thousand population 2014/15	Median House Price, 2014	Average Band D Council Tax charge (£), 2015/16	% of area that is Greenspace, 2005	% of pupils whose first language is not English (2015)	Male life expectancy, (2012-14)	Female life expectancy, (2012-14)	Life satisfaction score 2011-14 (out of 10)	Worthwhileness score 2011-14 (out of 10)	Happiness score 2011-14 (out of 10)	Anxiety score 2011-14 (out of 10)
Amenity	0.26	-.614**	.421*	.499**	-.365*	-.351*	-0.068	-0.324	-0.314	-.715**	-.422*	.611**	.773**	-0.312	.477**	0.184	.417*	.485**	.441*	-0.228
Cemeteries and Churchyards	.391*	-.410*	0.053	0.278	-0.265	-.476**	-.484**	-.457**	-.627**	-.488**	-.525**	.401*	.437*	-0.177	-0.004	-0.037	0.18	0.306	0.283	-.402*
Green Corridors	0.226	-.521**	0.187	0.199	-.574**	-.419*	-0.292	-0.317	-.348*	-0.338	-.457**	.512**	.683**	-.387*	0.168	0.016	0.067	.363*	0.234	-0.175
Natural and Semi-natural Urban Greenspace	0.265	-.606**	0.168	.453**	-.464**	-.423*	-0.306	-.395*	-.344*	-.548**	-.553**	.531**	.656**	-.486**	0.172	0.008	.381*	.589**	.416*	-0.335
Other and Unknown	.421*	-.495**	0.143	0.119	-.354*	-0.221	-0.217	-0.212	-0.28	-.527**	-0.334	0.312	.450**	-.388*	0.195	0.121	.545**	.581**	.615**	-0.297
Parks and Gardens	0.241	-.509**	0.164	0.322	-0.089	-.604**	-.374*	-0.311	-0.294	-.495**	-.621**	.366*	.565**	-0.099	0.083	-0.044	0.292	0.257	0.206	-0.204

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

4.7. Discussion

4.7.1. Accessibility and Availability of Urban Greenspace

A widely-connected network of good quality green space is a crucial component for building a more resilient city. The provision of good quality and quantity of green space has gained more attention from urban planners as more evidence has emerged regarding the economic, environmental and social benefits its ecosystem services provide. A focus on green space is increasingly important due to: (1) growing concern about degraded urban green spaces, partly due to their low priority status on any political agenda; (2) the complexity of and difficulty in placing urban green infrastructure in compact cities, which requires more intensive development in Europe: (3) more focus on brownfield development than greenfield, along with a high possibility of sacrificing existing green space for urban intensive development; and (4) growing evidence for the environmental, social and economic benefits from urban green spaces (Kabisch *et al.*, 2016; Swanwick *et al.*, 2003).

Even though there is increasing attention on the importance of maintaining and delivering green spaces led by private actors (e.g. private gardens or community-led gardens), public green space is still a good indicator to compare green space status and characteristics among cities as it has an important role in contributing to quality of life for the public (e.g. psychological comfort and satisfaction, and physical fitness) (Morar *et al.*, 2014; Nasution and Zahrah, 2012). As seen in Figure 4.17, Dubai, Istanbul, Mumbai and Shanghai have less than 3% of public green spaces, whereas Moscow has the largest public green space with 54%. Some cities such as Hong Kong (40%), Stockholm (40%), Shenzhen (45%), Vienna (45.5%), Sydney (46%) and Singapore (47%) record higher public green spaces than others. London also shows a high public green space proportion (33%).

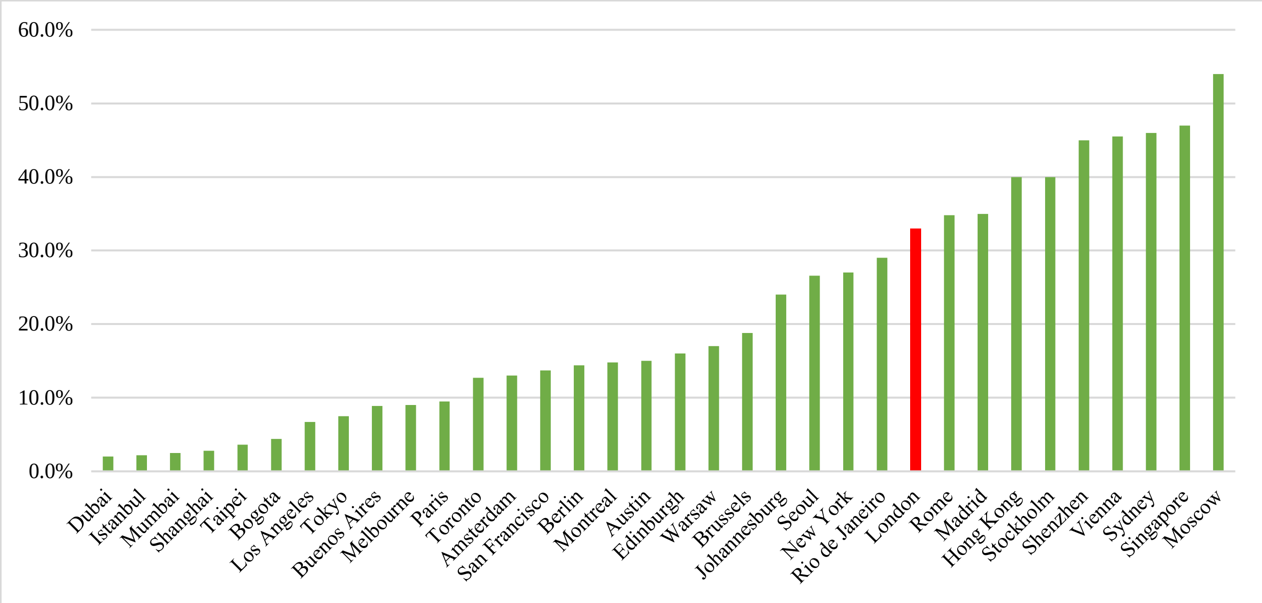


Figure 4.17 Public Green Space Proportion of World Cities (parks and gardens)

(Source: Author's work, based on data from World Cities Culture Forum (see Appendix 8))

Besides a general trend of greenspace proportion, greenspace accessibility and availability indicators are employed to suggest proximity and access to greenspace, as well as urban greening rates, and ultimately quality of life (e.g. Maria *et al.* (2016)'s European technical report and World Health Organisation (2010). Per capita green space is used as a quantitative indicator for assessing urban greening rates (Badiu *et al.*, 2016) among districts, boroughs, cities and countries. A decrease or increase in per capita green space can relate to increasing or decreasing distance to larger urban greenspaces via fragmentation (Barton and Pretty, 2010; Khalil, 2014), resulting in deprivation of greenspace benefits to residents. Though distance to green space is important, this discussion focuses more on amount per capita to allow greater comparisons. Greenspace per capita in Greater London, Inner and Outer London will be shown so as to determine which area has the most or least per capita open space, as well as comparisons with other cities. Even though green space per resident varies among cities, the

WHO suggested that a city should have at least $9m^2$ of urban green space per capita, suggesting an ideal target of $50m^2$ per capita (Morar *et al.*, 2014; World Health Organisation, 2010). Every city has its own specific target value of per capita green space (Kabisch *et al.*, 2016), allowing inhabitants greater and easier access to green spaces (e.g. 6-7m^2/inhabitant in Berlin (see Table 4.17)). Natural England (2010, p.12) suggests more detailed recommendations indicating distances and sizes to promote access to greenspace, highlighting in particular easier and safer access to green infrastructure:

(1) of at least 2 hectares in size, no more than 300 metres (5 minutes' walk) from home;
(2) at least one accessible 20 hectare site within two kilometres of home;
(3) one accessible 100 hectare site within 5 kilometres of home; and
(4) one accessible 500 hectare site within 10 kilometres of home; plus
(5) a minimum of 1 hectare of statutory Local Nature Reserves per 1000 population

Table 4.17 Berlin Open and Green Space

Type of open space	**Near-residential open space**	**Near-development open space**	
Minimum size	0.5 ha	10 ha (neighbourhood park)	50 ha (borough park)
Guideline	6 sqm/inh.	7 sqm/inh.	7 sqm/inh.
Intake area	500 m	1,000 m	1,500 m

Source: Senate Department for Urban Development and Housing
http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eda605_01.htm

As Fuller and Gaston (2009) indicate, urban greenspace provision highly depends on city area rather than the number of residents, leading to the trend of compact cities showing low per capita greenspace, even though there has been a more robust greenspace network through an active interaction between residents and nature (e.g. street plantings or management of private gardens). Yet there has been a decreasing trend of urban greenspace per capita in most cities over time (see Appendix 9), even though there are green network promotion initiatives in many cities. Figure 4.18 shows per capita greenspace status of selected cities in the OECD countries in 2014. Athens had the smallest greenspace for an inhabitant, at 0.97m^2, whereas Warsaw provided the largest greenspace per resident, at 1022.32 m^2; followed by Ljubljana (922.61 m^2). Athens, Tokyo and Seoul could not reach the WHO's minimum greenspace per capita (9m^2), as those cities would need more diversified urban greenspace planning strategies (e.g. functionalisation of the informal greenspace or interconnection of green corridors with public transportation (Morar *et al.*, 2014)). London (35.16m^2) showed a relatively low value, similar to New York (39.39m^2). Such cities (e.g. Madrid, London, New York and Sydney) still need to provide city-dwellers with more space where possible at finer scales, so as to achieve the WHO's ideal target of 50m^2.

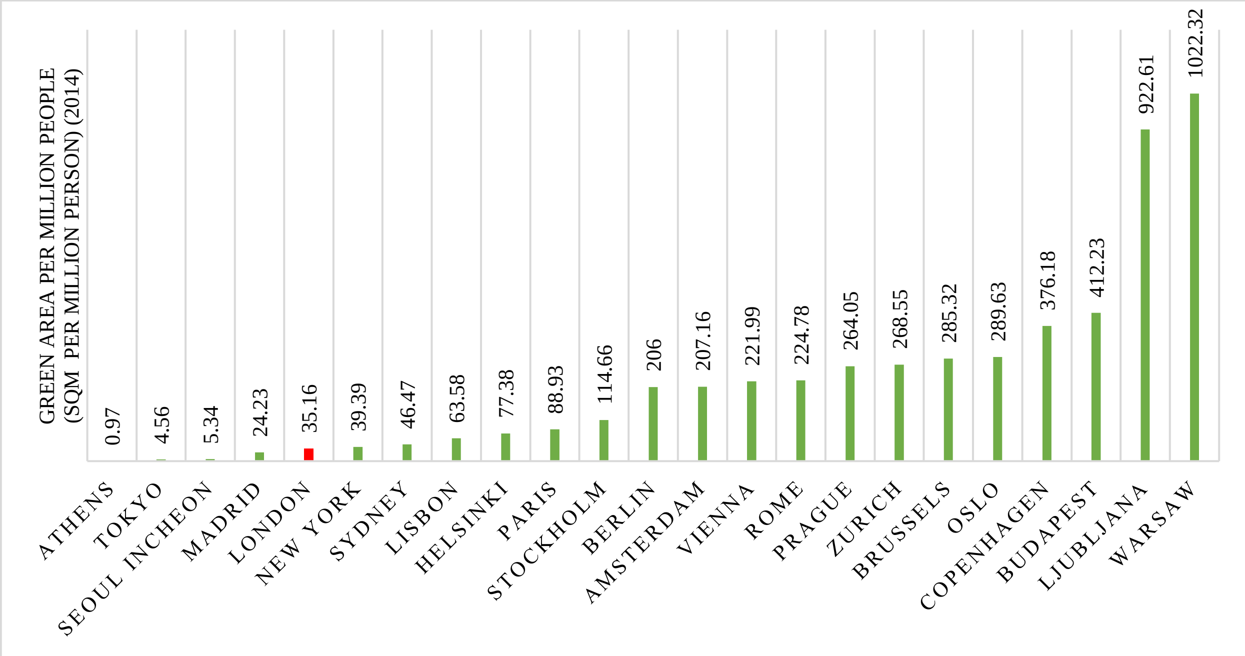


Figure 4.18 Green area per capita in selected OECD member cities in the year 2014

(Source: data from Organisation for Ecologic Co-operation and Development (2016) OECD.Stat. online database)

On the basis of data from GiGL in 2015, and the 2016 population data from the London Borough Profile, London Datastore, greenspace per capita was calculated. As seen in Figure 4.19, and the below manual calculation, values are different. Measurement values will naturally show some differences due to variations in definition of urban greenspace in different datasets, and setting a different threshold for greenspace detection (e.g. per capita greenspace in Prague: 74.56m^2 in ESM (2016) 10m, 64.46m^2 in local dataset, and 36.48m^2 in Urban Atlas 2012 (Maria *et al.*, 2016)). Within the GiGL dataset, the inclusion of the River Thames as open space, for example, may explain some of the variation found. In this section, measurement methodology will not be handled but will focus more on differences between Inner and Outer London, in particular highlighting the greenspace per capita status in Inner London.

Based on the analysis of GiGL data conducted here, greenspace provision in Greater London was substantially high, 0.0073ha (73m^2) per capita, on the basis of Natural England's criteria (20m^2 per inhabitant) and the WHO's minimum and ideal criteria (9m^2 and 50m^2 per capita). Yet as Inner and Outer London show different landscape and socioeconomic traits, estimation of accessibility and availability of greenspaces should be conducted separately. In general, Outer London recorded much higher green space per resident of 0.010ha (100m^2) than Inner London's 0.0024ha (24m^2), due to large extents of open spaces covering a higher population number in its larger land area than in Inner London. As shown in Figure 4.19 and Appendix 10, boroughs in Inner London mostly failed to meet Natural England's minimum target, even though most of them showed slightly higher values than the minimum urban green space per capita suggested by the WHO. Except for four (Hackney (20m^2), Islington (49m^2), City of London (170m^2), and Kensington and Chelsea (41m^2)), none of boroughs had enough greenspace per resident, ranging from 9m^2 to 19m^2. Outer London boroughs mostly provide greenspace per capita ranging from 30m^2 to 276m^2 above the Natural England's minimum target. The Borough of Brent had the lowest greenspace for a resident (30m^2), followed by Waltham Forest (50m^2) and Ealing (50m^2), whereas the Borough of Havering had the highest greenspace for an inhabitant (276m^2), followed by Bromley (268m^2).

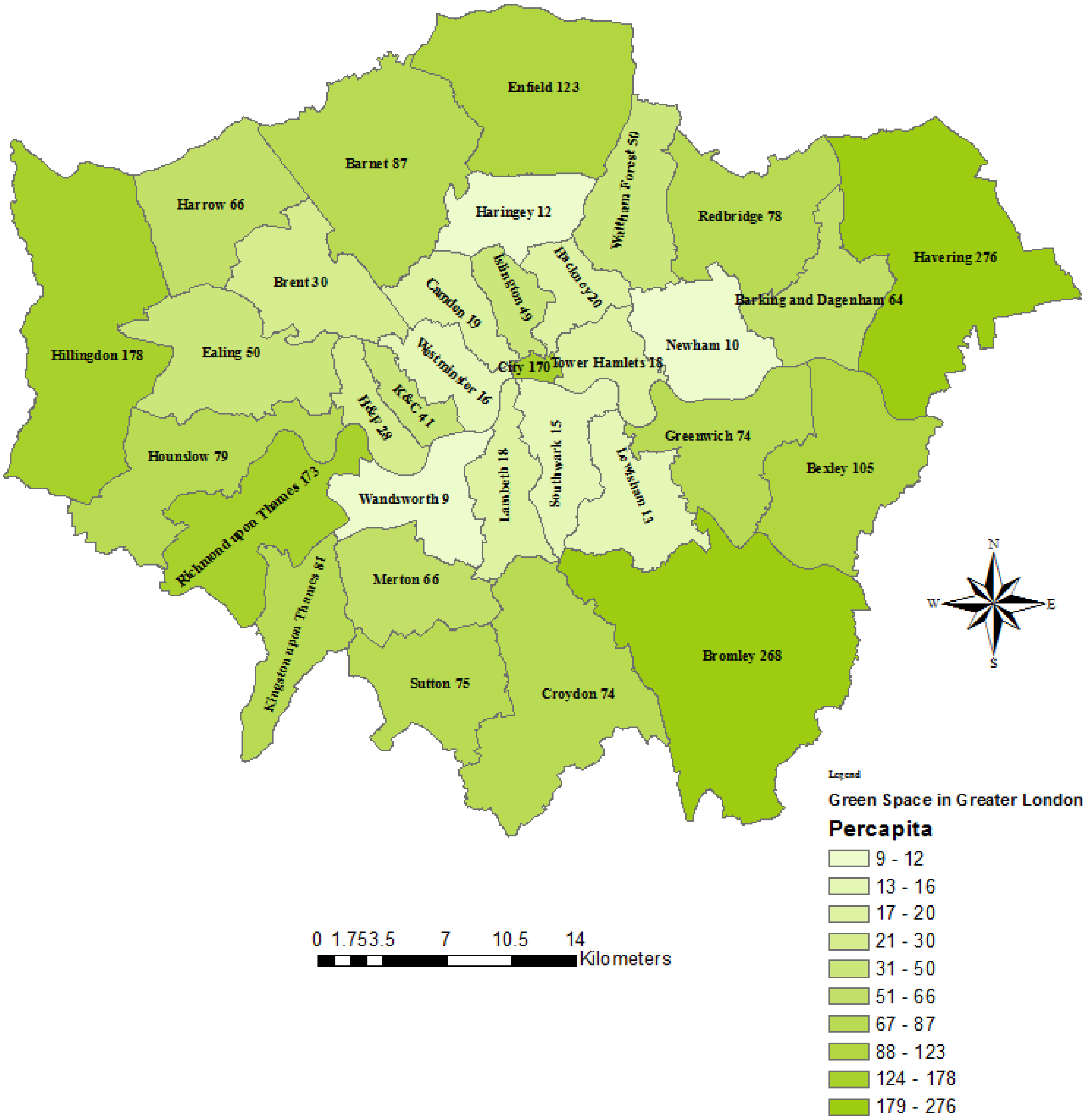


Figure 4.19 Green Space per Capita in Greater London Boroughs (m^2)

(Copyright: Author, Source: Green space per capita was calculated on the basis of such two data as spatial data of green space area in boroughs (2014) obtained from GiGL, and demographic data of GLA population estimate/projection (2016) obtained from GLA Datastore http://data.london.gov.uk/demography/. The mapping was conducted through ArcGIS 10.3.1 (see Appendix 10))

4.7.2. Greenspace Landscape Configuration for Urban Resilience

Indicators such as per capita greenspace present availability and supply rates of greenspace in cities, as well as a vague estimation of life quality from greenspace. Yet quantification of landscape configuration also provides urban planners with spatial arrangements for improving accessibility to greenspaces; in particular measures of fragmentation and connectivity, which are important concepts for providing ecosystem services (Ahern, 2013). In this chapter, quantification of spatial patterns of open spaces in Greater London was conducted through three landscape metrics of open spaces such as Area metrics, Aggregation metrics and Shape metrics, so as to suggest a fragmented configuration with some in particular areas showing connectivity. Differences in open space landscape metrics can be found between Inner and Outer London, which can be broadly regarded as an urban-rural gradient. In other words, Inner London had a smaller and more fragmented landscape configuration than Outer London based on Area and Aggregation metrics, but the former had substantial ample green spaces for residents, on the basis of Shape metrics and per capita green space. As there are relatively limited metrics data for different cities, most of the discussion here is based around comparisons within London.

Outer London had larger green spaces, and a less fragmented landscape pattern than Inner London, given that there were higher total areas (2841.21 ha), lower patch density (33), and lower ENN_AM (125.74 m) than Inner London (580.19ha, 145.14 m and 134.18 respectively). The green space pattern in highly urban areas generally shows smaller and more fragmented configuration, which can be found in lower total area, and higher patch density (Tian *et al.*, 2014), and higher ENN_AM. Yet as each borough, particularly Inner London, has different landscape configurations, and diverse spatial usage, it is not easy to apply general interpretations of fragmentation and connectivity. For instance, the City of London showed the smallest area (58.67 ha) and the highest patch density (536.9) with the lowest ENN_AM

(32.8m), but Kensington and Chelsea had 244.76 ha (the third-smallest area), and 208.4 of patch density (the third-largest patch density) with the highest ENN_AM (362.9 m). This implies that both boroughs relatively have small and fragmented configuration of open space, but the area of each borough should be considered. The City of London has the least spatial extent among the boroughs in Greater London, indicating that the distance between open spaces naturally got smaller. As for the least fragmented landscape configuration, Bromley and Hillingdon in Outer London recorded 8,624.5 ha (the largest) and 5,199.52 ha (the third-largest) respectively, along with patch density of 13.3 (the second-smallest) and 12.4 (the smallest) respectively. Bromley had 66 m ENN_AM, and Hillingdon had 144.6 m ENN_AM, which is hard to interpret in terms of fragmentation. In this sense, application of total area and patch density would be more useful for explaining fragmentation at the borough scale.

Green spaces in rural areas, in which there are large extents of vegetated areas and less human activity, show a complicated shape (Turner, 1989), whereas landscapes influenced by human activities usually have a simpler shape than rural areas (R. V. O'Neill *et al.*, 1988). Consequently, given higher values of Contiguity index and perimeter area ratio index in Inner than Outer London (i.e. more connected but complicated landscape pattern), green spaces in Inner London have strong possibilities of attracting people and providing ecosystem service benefits, as people are living in closer proximity to such spaces. Overall, the Borough of Tower Hamlets (0.91 of CONTIG, 1.20 of PAFRAC) and Islington (0.88 of CONTIG, 1.25 of PAFRAC) in Inner London showed more connected and complicated landscape pattern, and Croydon (0.57 of CONTIG, 1.10 of PAFRAC) in Outer London showed a less connected and complicated pattern.

Besides ecosystem services provision (e.g. temperature regulation, carbon sequestration, biodiversity conservation and storm water run-off), higher accessibility and availability to greenspaces has shown socioeconomically correlated benefits: quality of life (e.g. reduced stress and more relaxation (Cackowski and Nasar, 2003; Martin *et al.*, 2004; Tsunetsugu *et al.*, 2013)), house prices (Kong *et al.*, 2007) in accordance with proximity to greenspace (Morancho, 2003), and on social integration or inclusion of the older and younger generations, and of multi-ethnic groups (Castonguay and Jutras, 2009; Seeland *et al.*, 2009; Swanwick *et al.*, 2003). Greater London boroughs with high population density, and younger, highly-educated and multicultural population had fewer but smaller and denser open spaces, which also suggest a decrease in life quality and increase in crime rates and house prices. According to the study on psychological and physiological effects of short-term visits to urban nature environments in Helsinki, led by Tyrväinen *et al.* (2014), a built-up urban environment with few single urban trees results in a negative influence on feelings of retro-activeness, vitality and positive mood, even though people could feel relaxation from physical activities (e.g. viewing and low-speed walking). On the contrary large urban parks (more than 5ha) and well-managed urban woodlands had 'positive well-being effects on urban inhabitants, and particularly for healthy middle-aged women' (Tyrväinen *et al.*, 2014, p.8). In short, Inner London mostly had such boroughs in that socioeconomic situation, implying that residents in Inner London are more vulnerable to socioeconomic (e.g. policy changes or economic downturn), and natural (e.g. river floods or heat wave) disturbances in the urban environment which eventually impact on urban ecosystem services in a vicious cycle. In such boroughs, rather than aiming to supply larger areas of greenspace, it may be best to provide inhabitants with numerous greenspaces (Morancho, 2003) closer to home, for example converting abandoned areas into green infrastructure in communities, or interconnection of green corridors with the public transport networks. Although such improvements may not be suitable alternatives for large parks, they are a more realistic way of increasing area and proximity to green space.

4.7.3. Land Use of Greenspaces for Urban Resilience

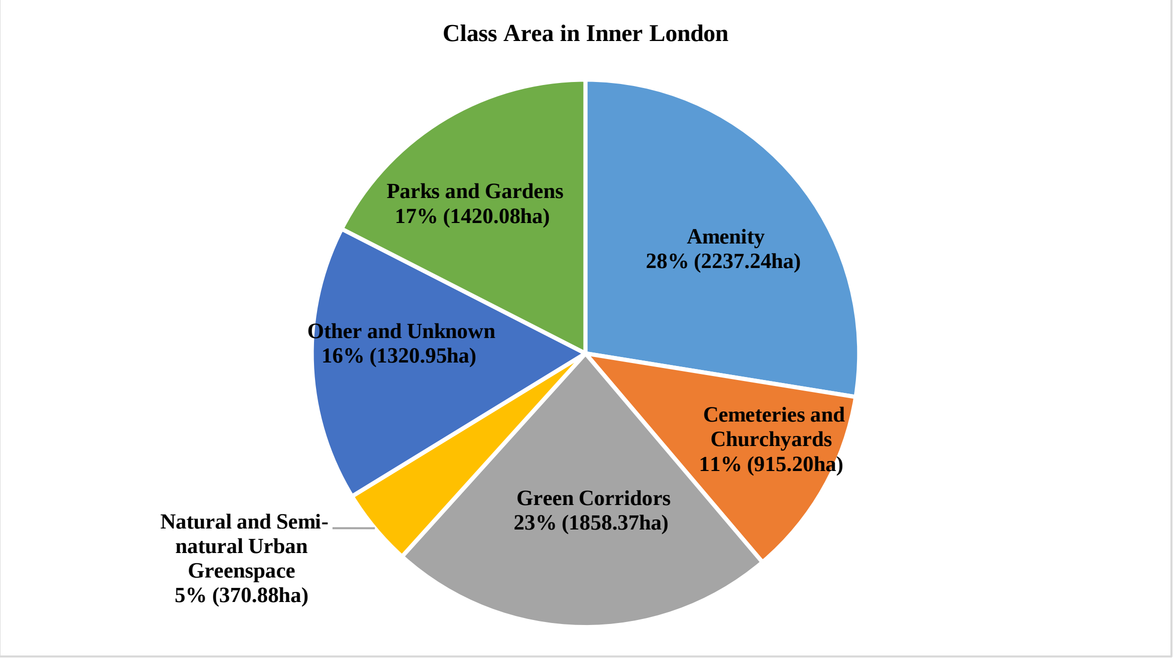
Compared to landscape-level analysis, the class-level analysis employed relatively small numbers of metrics: the two area metrics of class total area (CA) and percentage (PLAND), and the two aggregation metrics of number of patch and patch density. The class-level metrics do not give any information on fragmentation and connectivity, but rather suggest the current composition of urban greenspace land use. It further helps to provide urban planners with information about deficit of specific classes for which residents may show preference, or the need for a specific land use (e.g. educational or recreational functions) (Badiu *et al.*, 2016). The class-level analysis would allow them to find the most highly-valued open spaces which provide people with more enhanced quality of urban life (e.g. various settings in which to pursue multiple outdoor activities, improve social inclusion and cultural diversity (Burgess *et al.*, 1988; Castonguay and Jutras, 2009).

Through the correlation analysis of open space classes and socioeconomic factors (i.e. population, age, education, immigration and ethnicity, employment, housing crime, life expectancy and quality of life), the influence of open space categories on ecological and social resilience can be identified, as the resilience 'may be linked through the dependence on ecosystems of communities and their economic activities' (Adger, 2000, p.347). Those socioeconomic variables are used as an indicator for estimating social vulnerability or adaptive capacity, as well as a 'predictor of vegetation composition at the residential neighbourhood scale' due to such indicators depending on the residents' ability or willingness to change their neighbouring environments (Martin *et al.*, 2004, p.356).

As seen in Table 4.8 in Section 4.5.1, the most abundant class was amenity (19,370.62 ha, 29%, 22.36m^2 per capita space), and the least abundant class was cemeteries and churchyards

(1,406.66 ha, 2%, 1.62m^2 per capita space) in Greater London. Yet such composition showed a slight difference in Inner and Outer London respectively. In Figure 4.20, amenity remained the most abundant class (28% in Inner and 30% in Outer London respectively), whereas the least abundant class was natural and semi-natural urban green space (5% in Inner and Outer London respectively). Green corridors (23%) was the second abundant class in Inner London, but Outer London showed the same proportion of 20% in two classes: green corridors, and other and unknown. Parks and garden, and other and unknown classes showed a similar composition in Inner London.

Amenity can be regarded as more valuable greenspace class in terms of its environmental and socioeconomic impacts on urban inhabitants, than other classes. Amenity is the highest proportion in Inner and Outer London, meaning that this class of open space has a strong influence on people’s daily lives, even though its values are easily underestimated by urban planners due to its non-traded market price (Kong *et al.*, 2007). In other words, amenity greenspaces provide residents or communities with spaces for improving their quality of life, so that it has a strong relation with the quality of communities, physical activities, satisfaction and health of residents (Morar *et al.*, 2014). Yet a more economic approach has been taken as a method for attracting more investment in amenity (e.g. hedonic pricing method to calculate economic values of ecosystem and environmental services which have a direct impact on market prices). According to studies of the effects of community gardens, one of the amenity categories, in New York a study led by Voicu and Been (2008) found that such gardens had positive effects on the values which were driven by the poorest in a community, raising neighbouring property values by as much as 9.4% 5 years after the garden opening, and increasing tax revenues of about $500,000 over a 20-year period. Thus, it would be meaningful to look into the correlation between some specific amenity categories and socioeconomic variables at a borough scale in Inner London, as each borough and some districts in each borough face different environmental, economic and social configurations.



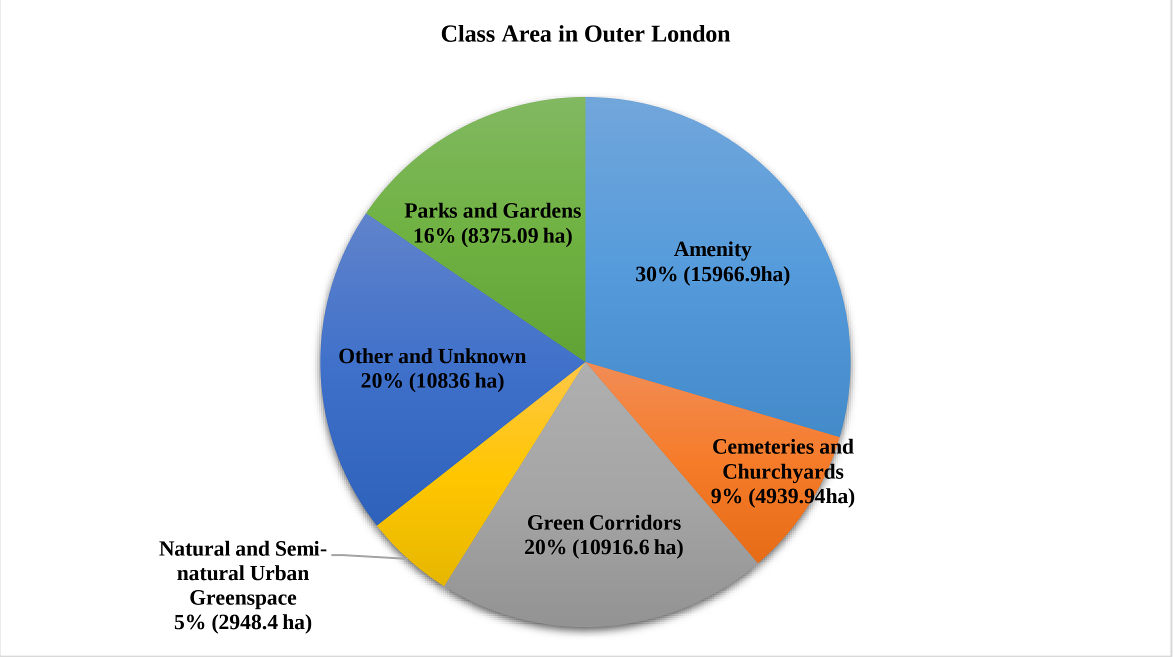


Figure 4.20 Land Use Composition on the basis of class extents in Inner and Outer London

Urban parks (larger than 5ha) and large urban woodlands (i.e. natural and semi-natural greenspace) bring out positive well-being effects and stress-reducing effects on residents, as well as feelings of vitality and creativity, particularly after spending more time in those vegetated areas (Tyrväinen *et al.*, 2014). In addition, parks with more diverse functions such as recreation have a relationship with the value increase of proximate properties (Crompton, 2001). Yet the size of parks may have different functions as 'green magnets' that attract visitors from diverse socioeconomic groups and distances (Gobster, 1998); and provision of ecological services from short distances from small parks within residential neighbourhoods (Martin *et al.*, 2004). In the Greater London Authority Economics' working paper led by Smith (2010), each hectare of park space within 1km from houses contributes to an increase in house prices of 0.08%, and a regional or metropolitan park (e.g. Richmond or Hyde Park) within 600 metres increases house values by between 1.9% and 2.9%. Such trends have been found in most cities such as Ontario, Paris, Seoul and Vienna, and there is a tendency that housing prices go up when the distance to greenbelts is shorter along with a lack of amenity supply (Source: http://theconversation.com/home-prices-tell-us-the-value-the-public-puts-on-green-spaces-71872). Given the negative correlation between greenspace and housing price in Greater London, housing prices were high in boroughs with less greenspace, meaning there are pricy flats with less greenspace and lower access to greenspaces, particularly in Inner London. In other words, there was a huge number of flats and houses that are expensive, but whose residents lack of accessible greenspaces in Inner London. Such a phenomenon would come from the small city area of Inner London, or different drivers for controlling housing prices: the high influx of the population over time; mortgage lending; and 'physical environment housing qualities (e.g. house size and age, with larger older housing being much more desirable), and distance from Central London' (Smith, 2010, p.34). This outcome suggests that local authorities in Inner London should find more abandoned green spaces for supplying the amenity services for better life quality of low- and middle-income households. Such socioeconomic inequality can be a long-lasting issue in most cities, and in particular there is a substantial increase in socioeconomic inequality and economic segregation in London, Amsterdam, Stockholm, Oslo, Vienna, Madrid, Milan, Athens, Budapest, Prague, Riga, Vilnius, and Tallinn (Tammaru *et al.*, 2016), which are capital cities that also accommodate diverse nationals. London has diverse socioeconomic inequality cases in which different patterns of street blocks and management decisions and practices are found due to diverse public and private land ownership and management leading to different neighbourhood environments.

As for cemeteries and churchyards, this class has a quite unique and different status in cities. In Zurich, this kind of greenspace is used as a place for relaxation and mindfulness, whereas it is considered as a conflict trigger in Romania (e.g. perception of aesthetic impact, and feeling of negativity from viewing or living within sight of a cemetery) (Tudor *et al.*, 2013). Given the negative correlation of the class and socioeconomic variables in Greater London, its role in building resilience is quite small except for a decrease in anxiety. It can be interpreted that this class is quite well managed, soothing and relaxing inhabitants, particularly in a compact area. Delivery and management of diverse vegetation within the class area would be beneficial for inhabitants to provide places to relax during the day.

The correlation between open space classes and social variables is more evident than property value changes. Lower crime, better quality of life, and a longer male life expectancy showed substantial positive correlations with all types of open spaces except for green corridors. Therefore, urban planners should design specific greenspace classes in specific locations in accordance with residents' needs and preferences. In addition, as Martin *et al.* (2004) indicate, there is a strong correlation between richness of residential vegetation and socioeconomic status in Phoenix, Arizona, US; the less rich assemblages of vegetation, the lower socioeconomic status in neighbourhoods, and vice versa. In the sense, proper installation of diverse and rich vegetation in each open space category would also contribute to an enhanced socioeconomic status in some deprived districts in Greater London.

4.8. Conclusion

Urban landscape configuration and composition are the outcomes of interactions between human activities and natural processes. The assessment of landscape patterns can be interpreted as estimation of natural changes influenced by government policy, local plans, and other anthropologic activities. Under Natural England's guidance on Landscape character assessment, identifying and describing landscape types (https://www.gov.uk/government/publications/landscape-character-assessments-identify-and-describe-landscape-types), the assessment of landscape character can be useful for informing 'policy development; local, neighbourhood, community or parish plans, and place-making; green infrastructure plans and strategies; waterways strategies; design briefs; project design and master planning; landscape impact and visual impact assessments; sensitivity and capacity studies; landscape designations including National Park and Area of Outstanding Natural Beauty designation etc.' (Tudor, 2014, p.10). The assessment brings the following advantages: 'establishment of a robust evidence base linked to place; provision of baseline evidence at the appropriate scale to inform a range of decision; presentation of a holistic approach to the whole geographic area; formation of an agreed spatial framework of landscape character areas or types to which different policy options and decision can be applied; integration of socio-cultural and natural considerations and provision an understating of how a place is experienced, perceived and valued by people; and identification of the key features that crease sense of place and the unique character of an area' (Tudor, 2014, pp.10-11) Such aims and benefits of the assessment are mostly in line with the definition of *landscape* from the European Landscape Convention of the Council of Europe specifically states following;

> '... has an important public interest role in the cultural, ecological, environmental and social fields, and constitutes a resource favourable to economic activity and whose protection, management and planning can contribute to job creation;
>
> ... contributes to the formation of local cultures and that is a basic component of the European natural and cultural heritage, contributing to human wellbeing…;
>
> ... is an important part of the quality of life for people everywhere: in urban areas and in the countryside, in degraded areas as well as in areas of high quality, in areas recognised as being of outstanding beauty as well as everyday areas;
>
> ... is a key element of individual and social well-being and that its protection, management and planning entail rights and responsibilities for everyone.'
>
> Preamble of the European Landscape Convention (Council of Europe, 2000, p.1)

On the basis of this definition, this chapter has been devoted to estimating the influences of urban green space landscape in terms of quantitative and qualitative perspectives. It has used an extensive Greater London open space dataset acquired from GiGL. Quantification of spatial patterns at the landscape scale via FRAGSTATS, a spatial analysis programme, was conducted for assessing composition and configuration of open spaces in Greater London, Inner and Outer London, after data handling in ArcGIS. Correlation analysis on spatial patterns and socioeconomic variables was also conducted in SPSS to determine impacts and potential drivers of open spaces. The implications for open space management, and governance observations were indicated on the basis of accessibility and availability of urban green space in Greater

London and other cities, as well as in greenspace configuration and composition for urban resilience.

The first (i.e. landscape metrics of open space in London indicating a fragmented configuration with limited connectivity) and third (i.e. differences between Inner and Outer London) hypotheses were shown through the landscape scale spatial analysis. In sum, smaller and more fragmented landscape configuration, but substantial enough greenspace for residents were found in Inner London than Outer London, in which there was a less fragmented landscape pattern with larger green spaces. Based on the correlation analysis which proves the fourth hypothesis (i.e. association between socio-economic status and open spaces), there was a tendency that London boroughs with high population density, and younger, highly-educated and multicultural populations had fewer but smaller and denser green spaces, which also can be associated with lower quality of life, high crime rates and high house prices. As for landscape composition for proving the second hypothesis (i.e. spatial differences according to open space types), amenity was the most abundant class, whereas cemeteries and churchyard class was the least abundant class in Greater London, even though there is a slight difference in composition in Inner and Outer London. Yet amenity was found as the most valuable greenspace class than other classes, in terms of environmental and socioeconomic impacts on urban dwellers.

Even though this chapter explores the relationship between current configuration and composition of open spaces with socioeconomic variables rather than provision of ecosystem services, regulating ecosystem services from trees will be elaborated in the next chapter. Yet this chapter will be meaningful for urban planners to find ways to build or strengthen urban resilience.

5. Carbon Storage and Sequestration Services from Urban Trees in BIDs

5.1. Introduction

Quantification of multiple ecosystem services from green spaces allows urban planners or policy-makers to justify investment in more green space projects. Natural capital has, until recently, been regarded as non-traded and of non-economic value, which has made it difficult for urban planners to make decisions on further investment in green infrastructure. Quantification of ecosystem services is a necessary process for promoting urban green infrastructure-related projects, particularly given recent advances in understanding the important role that urban forests may have in carbon storage and sequestration (Liu and Li, 2012), as well as other regulating services including reducing air pollution run-off retention, noise reduction and cooling of the local microclimate. These benefits have a positive influence on the quality of urban life, influencing not just the broader, regional-scale climate conditions, but also improving things like the health of residents. The quantification of the regulating services has been conducted in diverse ways, mostly employing equations of estimating a regulating ecosystem services' supply rates depending on types of green spaces (e.g. grass, shrubs, trees, forests, gardens, etc.) (Derkzen *et al.*, 2015).

According to Bolund and Hunhammar (1999), trees with bigger canopies have better air filtering capacity and microclimate regulating function (e.g. cooling). Among all kinds of urban green infrastructure components, trees are regarded as the most effective regulating ecosystem services provider, particularly for carbon storage and sequestration in urban areas (Liu and Li, 2012; Nowak and Crane, 2002; Nowak *et al.*, 2013). They are considered '[sinks] for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass' (Nowak and Crane, 2002, p.381). Carbon storage is defined by Rogers *et al.* (2015, p.36) as ‘the carbon currently held in trees tissue (roots, stem and branches)’, whereas carbon sequestration is ‘the estimated amount of carbon removed annually by trees.’ Definitions do vary between authors, however, with for example Chaparro and Terradas (2009, p.15) considering carbon storage to be ‘the annual rate of CO_2 storage during a growing season.’ Here, carbon storage is considered to be ‘the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation’, and carbon sequestration ‘the removal of carbon dioxide from the air by plants.’ In this research, net carbon sequestration was not included as the i-Tree programme only provided gross carbon sequestration (tonne/year). Carbon sequestration from plants, which is a form of biotic sequestration, depends on ‘managed intervention of higher plants and micro-organisms in removing CO_2 from the atmosphere’, eventually reducing or offsetting emissions (Lal, 2008b, p.819). In other words, as such above-ground biomass consists of the most crucial part in the carbon pool (i.e. the aboveground biomass, below-ground biomass, litter, woody debris and soil organic matter) of the terrestrial ecosystem (Vashum and Jayakumar, 2012), estimation of above-ground carbon stocks in cities provides urban planners with useful information on resource management (Davies *et al.*, 2011).

For measurement of carbon storage and sequestration in this research, the i-Tree programme was employed. i-Tree is ‘a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and rural forestry analysis and benefits assessment tools, quantifying the structure of trees and forests, and the environmental services that trees provide’ (https://www.itreetools.org/, 2017). The i-Tree Eco model provides estimations of diverse ecosystem services, including air pollution removal, public health impacts, carbon storage and gross carbon sequestration as well as net carbon sequestration, energy effects, avoided runoff, VOC emissions, and potential pest impacts (see Appendix 11), as well as urban forest structure and compensatory value of the urban forest, and the estimated economic value of ecosystem services. Yet depending on project configuration, data options, and project country location, not all ecosystem services can be covered (https://www.itreetools.org/eco/overview.php, 2017). It was initially developed specifically for the US, but an international version has been recently released, available in Canada, Australia, and the UK. This means that for these locations, fundamental basic data such as location and species information, meteorological (weather, precipitation, etc.), and air (pollution concentration and boundary layer height) is automatically given, and the automated processing is as for the US.

i-Tree Eco has been used for valuing several urban forests in the UK (e.g. Torbay and Glasgow), and a recent report focused on Greater London. In December 2015, as an outcome of the i-Tree assessment, the report 'Valuing London's Urban Forest' in partnership with Forestry Commission, Greater London Authority, London Tree Officers Association, Trees for Cities, Tree Council, Natural England and Treeconomics was released with publication funds from Unilever in the House of Lords, which covers the benefits of trees such as air pollution reduction, carbon storage and sequestration, amenity value, and stormwater benefits, as well as providing information on the structure and composition of London's urban forest. Of a total of 724 random plots (200 in Inner and 524 in Outer London), 476 plots were examined by over 200 volunteers and the remainder were surveyed by professional teams from Treeconomics, the London Tree Officers Association, Forestry Commission and Forest Research. The report (Rogers *et al.*, 2015), showed that in Greater London 2,367,000 tonnes of carbon was stored (around 15 t/ ha, £142 million value) and 65,534 tonnes of carbon per year was sequestrated (around 2.4 t/yr/ha, £3.9 million value, 2014).

This chapter does not cover carbon storage and sequestration estimation from all kinds of green infrastructure, but focuses on trees in streets and small patches of green space in eleven central BIDs, to complement some of the analysis in Chapter 4. As trees in many areas are public, tree management is mostly done by the corresponding boroughs, rather than businesses or industry from the BIDs themselves. Yet tree planting and management is not solely decided by the council itself but requires cooperation and opinion from stakeholders in the districts. Central BID areas were selected as they are the most business active areas, and as those areas are managed by a BID body itself responsible for development and implementation of their business plan so as to deliver more services (e.g. extra safety or security, cleansing and other environmental measures) to local businesses, mostly in partnership with the local authorities (GLA, 2016a). In this sense, it would be useful to quantify ecosystem services from the public trees in those areas, i.e. supply estimates of carbon storage and sequestration, to encourage support for urban tree planting and maintenance. Quantification of tree carbon storage and sequestration capacity depends on accurate measurements of tree species, diameter at breast height (DBH), and height. It is increasingly common for trees to be measured from remote sensing data due to its quick and extensive data acquisition, but some trees located in parks or between buildings are hard to measure accurately from imagery. This research utilised a diversity of methods for collecting, handling and analysing data (see Methodology section). Following an estimation of composition of the BID tree communities, tree DBH and height was measured for a population of trees, to determine regulating ecosystem service capacities through application of the i-Tree programme. In particular, the current status of carbon storage and sequestration supply estimates in each BID, and their monetary value, was explored. The implications of the findings for future management were also considered.

5.2. Research Aims, Objectives and Hypotheses

The aims of this chapter are: (1) to figure out contributing factors to carbon storage and sequestration estimates from trees in streets and in public green spaces; (2) to quantify regulating ecosystem services in central BIDs as well as its monetary value; and (3) to make management and governance observations and recommendations regarding the corresponding BID tree management and delivery practices, based on the results of aims (1) and (2). This will be achieved as follows:

1) Conduct stratified sampling of tree communities in 11 BIDs across commercial/industrial, residential, institutional, transportation, and public green spaces such as parks, squares and gardens (referred to as 'strata') to obtain measures of key tree parameters and to validate remote sensing methods.
2) Map the surveyed tree locations and each BID boundary in Google Earth Pro for defining plot area for each strata so as to calculate the total carbon storage and sequestration amounts for each BID.
3) Obtain outcomes such as tree composition, carbon storage and sequestration amounts, and its monetary value from study areas using the i-Tree programme.
4) Discuss the results of the above objectives to determine key determinants of differences of the regulating ecosystem service capacities among BIDs, and further among the corresponding four London boroughs.
5) To make governance and management recommendations to further tree planning and management at the regional scale.

The research proceeds based on the following hypotheses:

H^1: Differences in tree composition and density within BIDs will lead to differential ecosystem service provision, including carbon storage and sequestration.

H^2: Difference in per capita CO_2 emission in the corresponding four boroughs would partially come from difference in carbon storage and sequestration estimates influenced by different DBH, number and species of trees in the BIDs.

H^3: The value of carbon storage and sequestration will vary among BIDs, which will allow urban planners to determine tree management and delivery practices.

5.3. Methodology

5.3.1. Methodological Overview

Estimation of carbon storage and sequestration from urban trees requires skilled staff, money and time when measured in the field. Even though field measurements have more difficulties than desk studies (e.g. remote sensing-based methods such as terrestrial and airborne Light Detection and Ranging (LiDAR)), which is useful for quickly obtaining data at over larger spatial extent, it has been commonly used for acquiring necessary tree-related data (McPherson *et al.*, 1994; Nowak and Crane, 2002; Zhao and Sander, 2015). For this research, the tree data acquisition process and data analysis will be conducted through four processes: (1) field visits and preliminary sampling; (2) tree data collection and tree species identification in the field and using remote sensing- (3) data processing in i-Tree programme for carbon storage and sequestration calculations; and (4) exploration and discussion of these results. This sequence is illustrated in Figure 5.1.

5.3.2. Study Area

Sampling locations across eleven BIDs in central Inner London were selected based on stratified sampling techniques: street trees were surveyed along commercial/industrial, transportation, and residential land use, and in small patches of green space such as squares, small gardens or parks, and churchyards. According to UK local authority and regional carbon dioxide emissions national statistics, from 2015, per capita emissions in Inner London (10.94 t in 2015) were far higher than in Outer London (3.54 t in 2015). Figure 5.2 shows that City of London showed the highest per capita emissions (860.08 t), followed by Westminster (8.77 t), whereas Haringey and Lewisham showed the lowest per capita emissions (2.75 t) followed by Hackney (2.76 t). The surveyed BIDs mostly are in Westminster (5), and in Lambeth (2), Southwark (2) and Camden (2). The Borough of Lambeth recorded the lowest per capita emission of 3.2 t in 2015, followed by Southwark (3.87 t), and Camden (4.75 t). As for total CO_2 emissions, Westminster emitted the highest CO_2 emissions (2124 kt CO_2) among the corresponding boroughs, and in the whole group of boroughs in Inner London, Southwark (1196.51 kt CO_2), Camden (1145.97 kt CO_2), and Lambeth (1039.25 kt CO_2). Considering such trends, it would be useful to estimate regulating ecosystem service capacities from street trees, as well as each BID’s tree management and delivery practices, given that there is a real need to further mitigate emissions in these areas.

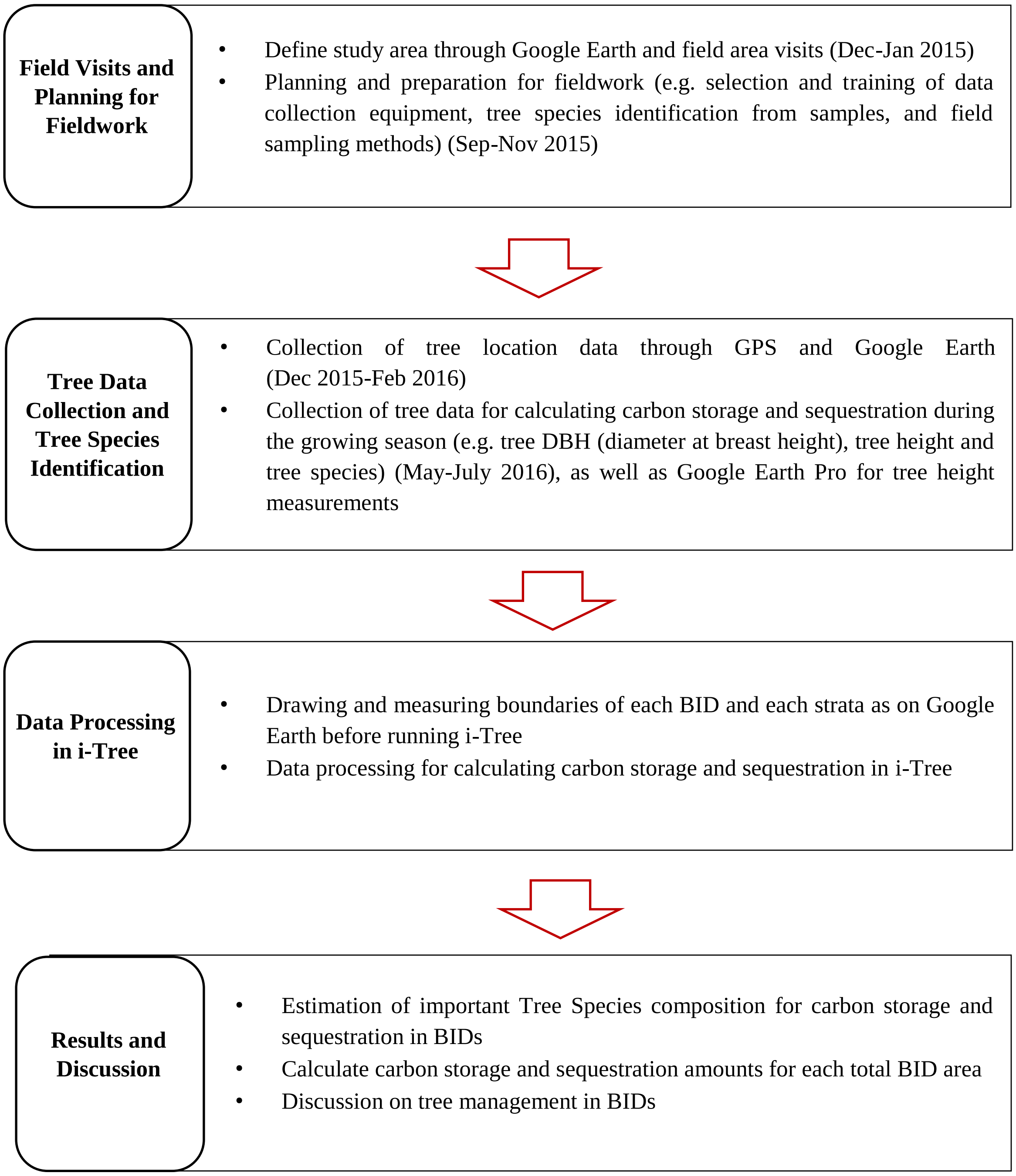
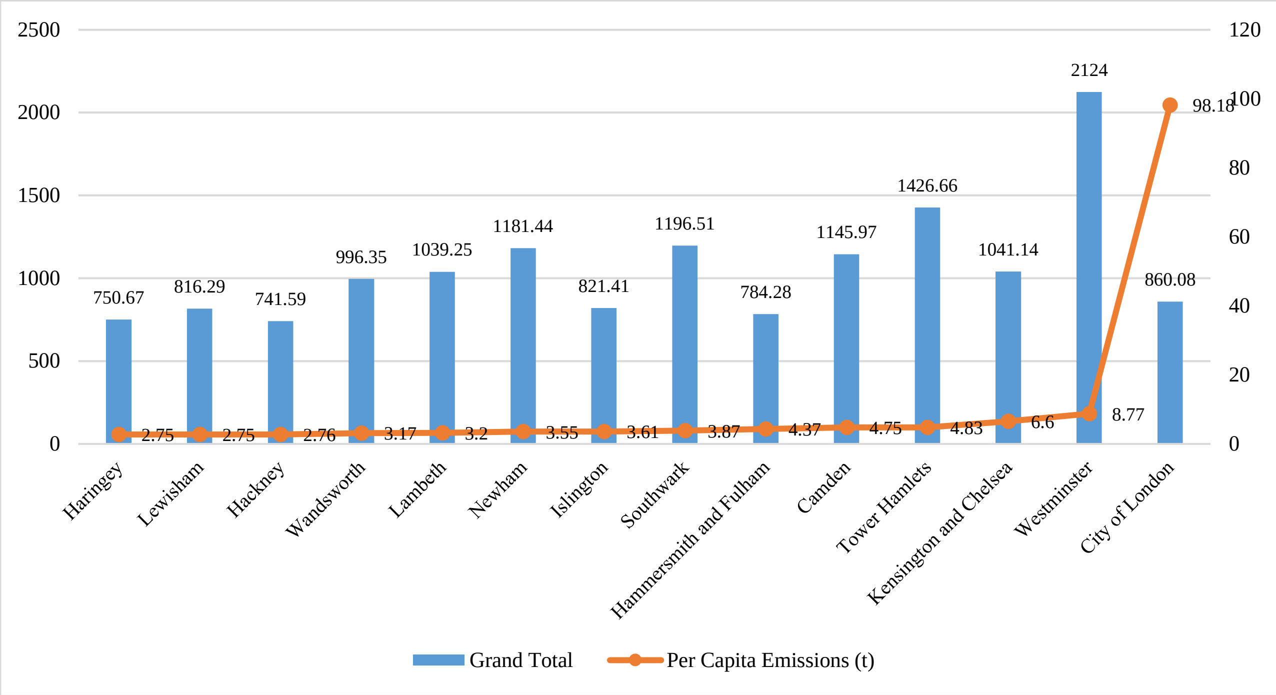


Figure 5.1 Methodological flow chart for Chapter 5



Source: Department for Business (2017), UK local authority and regional carbon dioxide emissions national statistics https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics (more details in Appendix 12)

Figure 5.2 Total CO_2 emissions (kt CO_2) and per capita emissions (t) in Inner London boroughs (2015)

Figure 5.3 is a map of surveyed areas and trees along with eleven business improvement districts boundaries in central London. The mapping shows which trees were measured in selected locations within each BID. The map was created on Google Earth Pro after overlaying tree data points which were collected using a Trimble Juno 3B GPS, with some missing location data corrected on Google Earth. The BID boundary polygons were added on the basis of geospatial information from each BID on Google Earth Pro.

5.3.3. Stratified Sampling Method

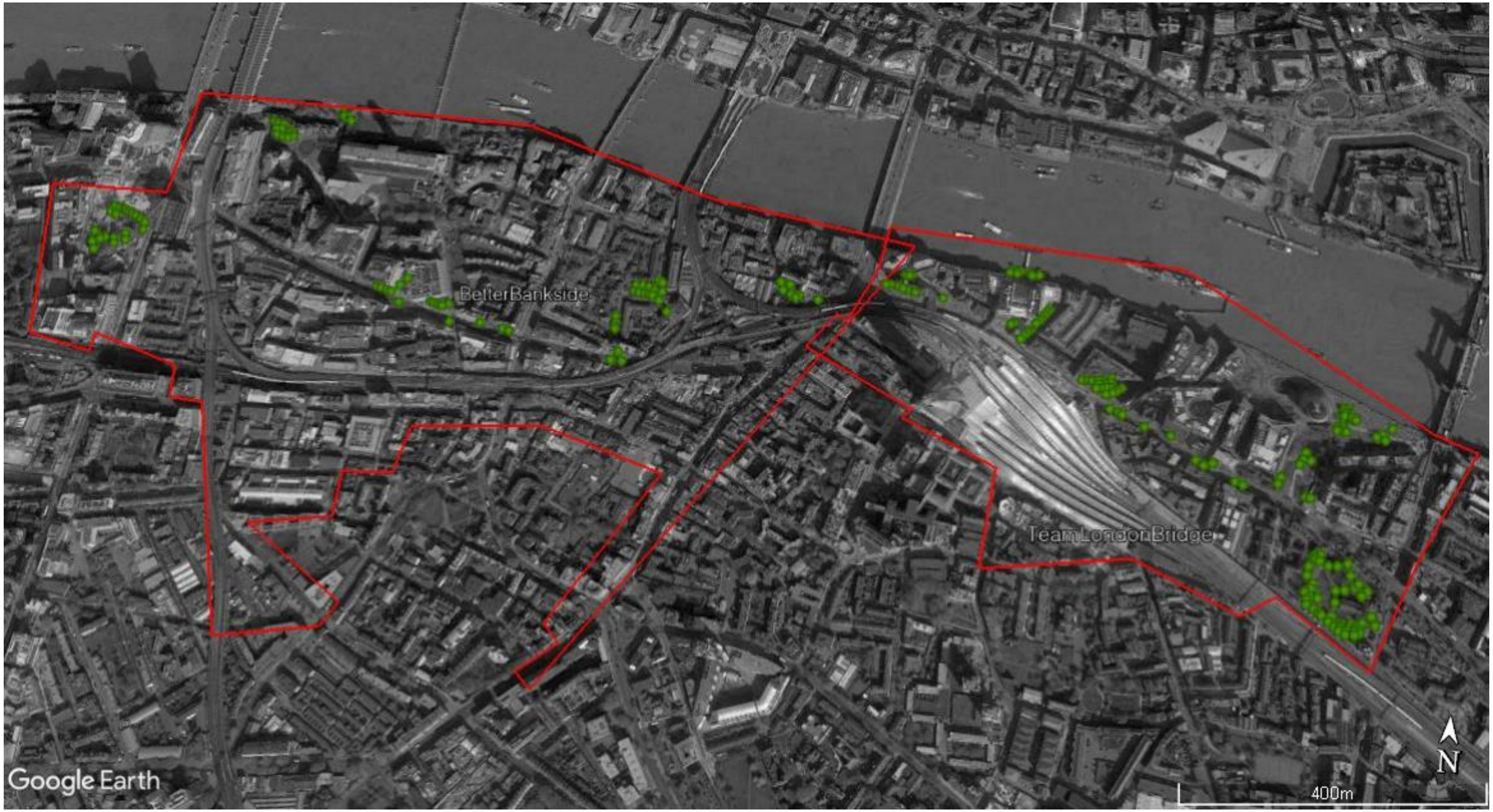
The decision of stratifying the tree data inventory based on urban land use type was made before collection of field data. Stratification of location is an effective way to estimate a tree (or above-ground vegetation) population in targeted areas (Ian D. Yesilonis and Pouyat, 2012; McPherson, 2014; Strohbach and Haase, 2012). Strata were designated based on land use classifications utilised in the i-Tree programme in which there are 13 default land use classes. At first, each stratum was classified as streets and small patches of green space (e.g. park or square) except for some BID areas without any public green spaces. The street strata were then reclassified as commercial/industrial, residential, institutional, and transportation which are already defined as land uses indicated in i-Tree programme (see Table 5.1).

Table 5.1 Reclassified street strata

Land Use	**Description**
Commercial/industrial	Land being used for commercial activities, including retail, services, and professional business. Also includes standard industrial land uses, such as manufacturing or processing, and outdoor storage/staging areas as well as parking spaces in downtown areas that are not connected with an institutional or residential use.
Institutional	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings, etc.
Park	Includes parks in undeveloped (unmaintained) areas as well as developed areas.
Residential	Freestanding structures serving one to four families
Transportation	Includes limited access roadways and related greenspaces (such as roads with on and off ramps, sometimes fenced), as well as railroad stations, tracks and yards, shipyards, airports, etc.

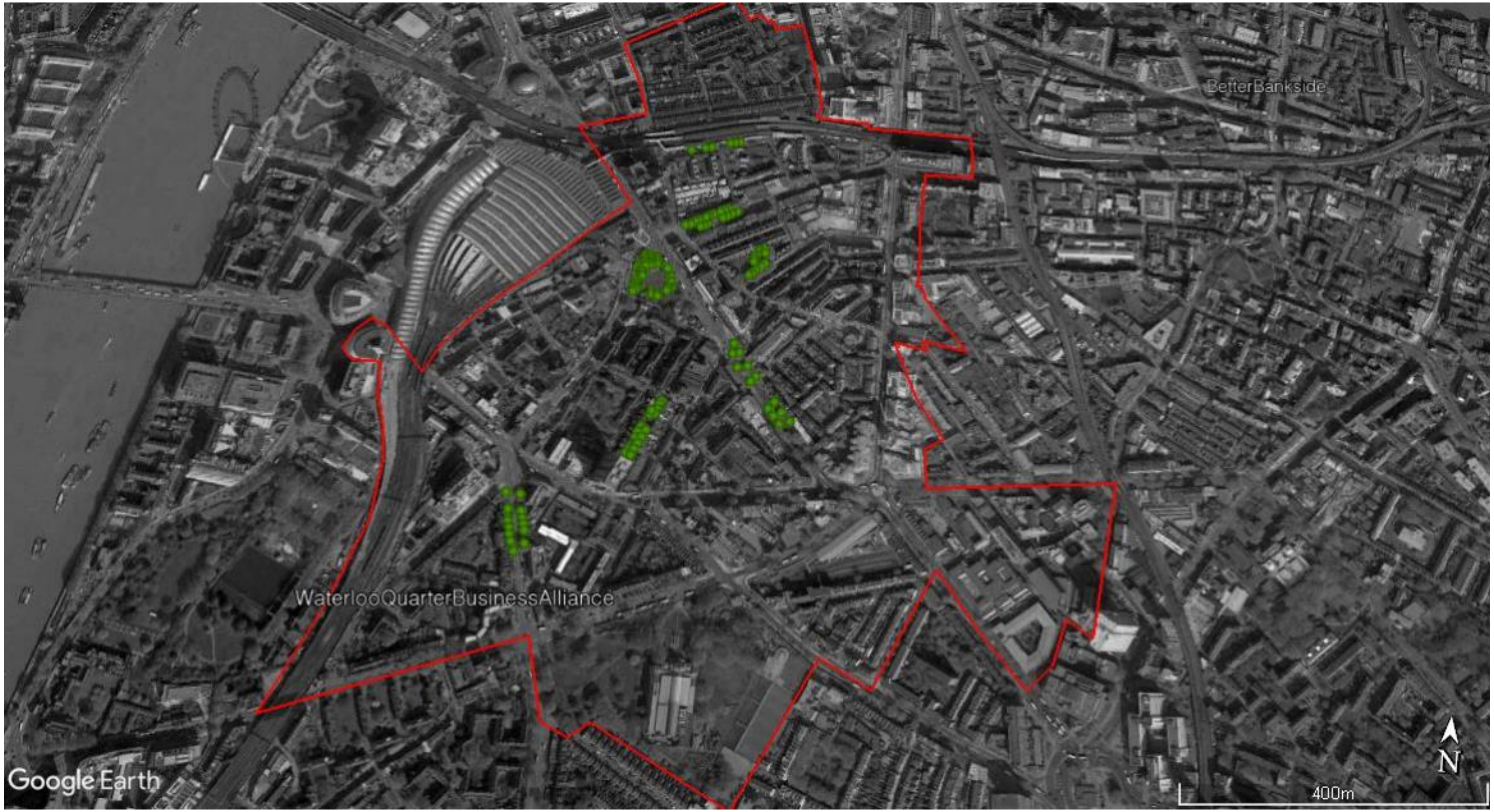
Source: Define Data Fields in Project Configuration in i-Tree Eco V6 Programme

In total, 831 trees were measured in 64 plots consisting of 57.32 ha. The size of each plot was not standardised due to different patterns and composition of trees in diverse economic areas. For instance, commercial and industrial plots were assigned areas between 0.7 and 2.5 ha, residential plots between 0.5 and 2 ha, transportation plots between 1 and 1.5 ha, and institutional between 0.22 and 2 ha depending on spatial conditions in which some BIDS have a large number of trees whereas others do not. For instance, in Victoria BID or New West End BID it is hard to find trees on streets in commercial areas; and so the area was assigned as 2.1 ha, whereas commercial areas in other BIDs with plenty of trees were assigned as around 1 ha. Squares and parks are fixed in area as the entire patch was measured, so that plot area values were diverse, except for the case of a substantially large park (0.1 ha per plot). The specific study areas and total study areas in each BID can be found in Table 5.2.

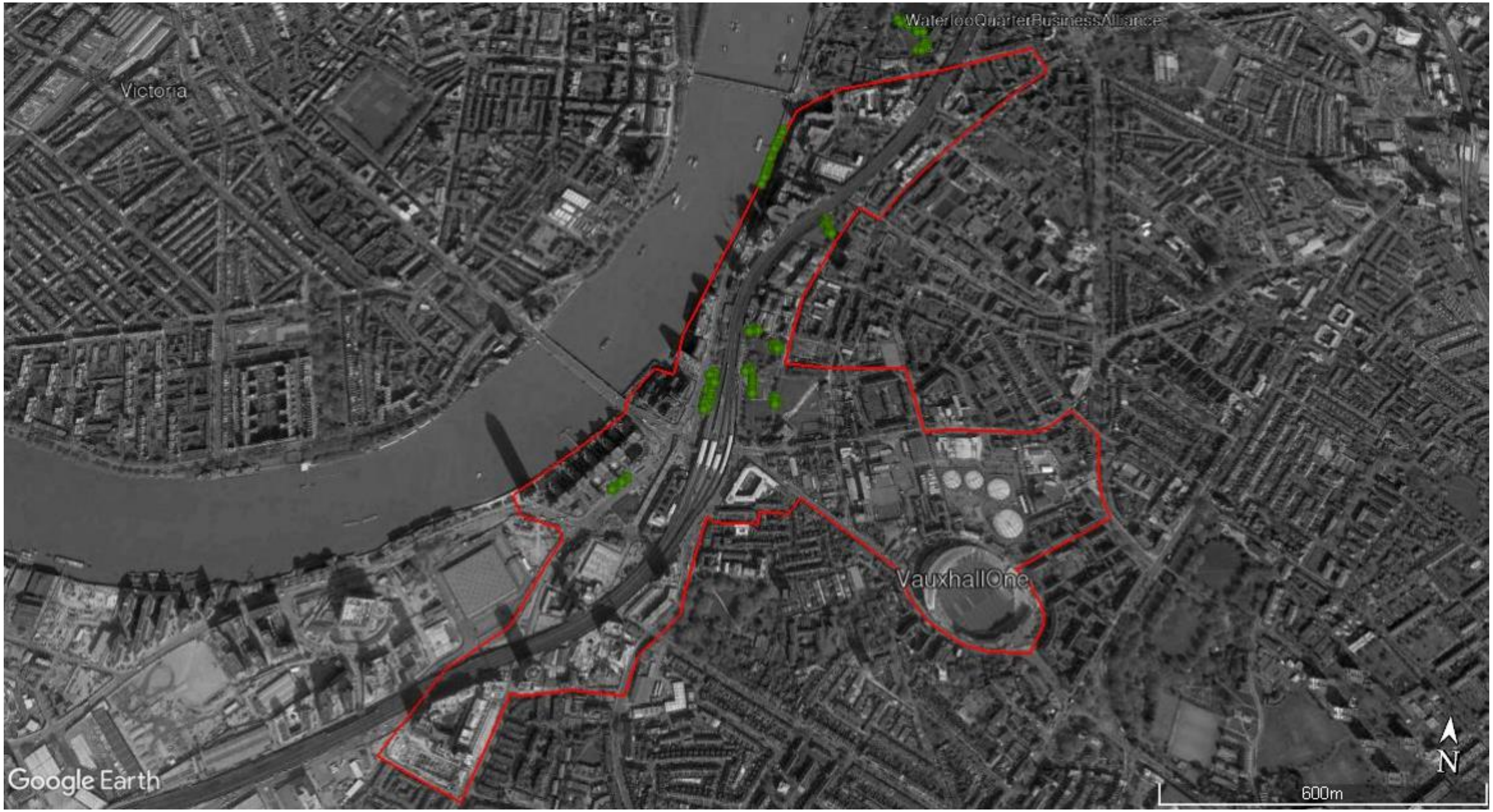


a) Team London Bridge and Better Bankside BIDs

b) Fitzrovia and Inmidtown BIDs



c) Waterloo Quarter Business Alliance BID



d) Vauxhall One BID

e) Paddington and Baker Street BIDs

f) Victoria BID

g) New West End Company BID

h) Heart of London Business Alliance BID

Figure 5.3 Maps of Surveyed areas and Trees in 11 Central BIDs. BID boundaries are delineated in red, while surveyed trees are marked with green points

5.3.4. Acquisition of Tree Location Data through GPS and Google Earth

Tree locations were initially recorded using a Trimble Juno 3B GPS device (923 points data). The Juno series devices use an integrated Global Navigation Satellite System (GNSS) receiver, which tracks only GPS satellites. Accurate GPS data signals can be obtained from more than seven satellites, otherwise GPS accuracy decreases. Besides satellite numbers for receiving more reliable location signals, there are other signal obstructions such as buildings, trees and people. Some signal obstructers prevented the precise recording of each tree's location, particularly between buildings, so some trees had their locations corrected via Google Earth after transferring GPS tree data.

Table 5.2 BID study area and tree numbers

Borough	City Centre Business Improvement Districts	Specific Study Areas	Tree Numbers and BID Study Area (ha)
Southwark	**Better Bankside (66.3 ha)**	• Southwark Cathedral Churchyard • Christ Church Southwark Churchyard • 5 different streets	• 16 trees (Google Earth) • 78 trees (Manually) • 94 trees, 5 ha (Total)
	Team London Bridge (36 ha)	• St. Johns Churchyard • Potters Fields Park • 5 different streets	• 20 trees (Google Earth) • 116 trees (Manually) • 136 trees, 6.51 ha (Total)
Camden	**Fitzrovia (35.3 ha)**	• Whitfield Gardens • 5 different streets	• 20 trees (Google Earth) • 39 tress (Manually) • 59 trees, 6.5 ha (Total)
	Inmidtown (56.7 ha)	• Red Lion Square • Bloomsbury Square • 5 different streets	• 52 trees (Google Earth) • 71 trees (Manually) • 123 trees, 6.58 ha (Total)
Lambeth	**Waterloo Quarter Business Alliance (79.4 ha)**	• Waterloo Millennium Green • Ufford Street Recreation Ground • 5 different streets	• 65 trees (Google Earth) • 62 trees (Manually) • 127 trees, 4.18 ha (Total)

	Vauxhall One (77.2 ha)	• Pedlars Park • Vauxhall Pleasure Garden • 3 different streets	• 35 trees (Google Earth) • 42 trees (Manually) • 77 trees, 6.4 ha (Total)
City of Westminster	**Baker Street (25.6 ha)**	• 5 different streets	• 17 trees (Google Earth) • 22 trees (Manually) • 39 trees, 5 ha (Total)
	Victoria (42.2 ha)	• Grosvenor Gardens • 2 different streets	• 33 trees, 5.45 ha (Total, Manually)
	Paddington (25.9 ha)	• Sussex Garden • Talbot Square • Norfolk Square • 4 different streets	• 78 trees, 5.84 ha (Total, Manually)
	New West End Company (22.2 ha)	• 5 different streets	• 22 trees (Google Earth) • 3 trees (Manually) • 25 trees, 2.65 ha (Total)
	Heart of London Business Alliance (23.2 ha)	• St. James Churchyard • Leicester Square Garden • 3 different streets	• 40 trees, 3.21 ha (Total, Manually)
• BID Total Area (490 ha) • BID Study Area (57.32 ha)		• 64 Plots in total • Height measurement via Google Earth Pro (247), and via Abney Level and Rangefinder or measurement tape (584) • Total trees (831)	

5.3.5. Tree Measurement and Identification

Measurement of tree heights, diameter breast heights (DBHs), and tree species were conducted during the growing season from May to July 2016; when measuring tree heights in Google Earth Pro, the photographed views were taken in Sep 2016 and obtained in March 2017. Tree DBHs were measured with a diameter tape or a girthing tape. DBH refers to the tree diameter measured at 1.3m (in continental Europe, the UK and Canada) from ground level. The heights of trees were measured using a rangefinder and a measuring tape for measuring the distance between an observer and the targeted tree, and an Abney level for obtaining the angle. The rangefinder is useful when an observer is working alone, in particular for measuring the height of tall trees. Measurements were usually taken in the early morning or early evenings, as the rangefinder requires a shot laser to be clearly visible on the trunk of the measured tree. In addition, as street trees are usually located in busy and crowded areas, such time slots allowed measurement of tree DBH and heights with less disturbance from pedestrians. An Abney level is a small surveying device composed of a sighting tube and a spirit level linked to a protractor, which measures angles of slope or inclination. From this, the height of a tree can be calculated;

The height of tree (Y) = Distance A*Tan (Angle) + the height of the observer

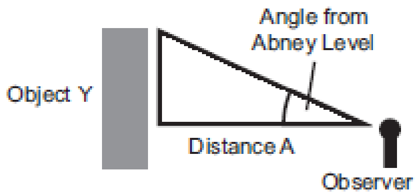


Figure 5.4 Measurement of Tree Height (Source: York Survey Supply, How to use an Abney level: operating instructions)

Another tree height measurement was obtained from Google Street View, which provides panoramic views photographed from diverse angles. This method can be regarded as photogrammetry. According to St-Onge *et al.* (2004), tree height measurement is possible through photogrammetric methods using parallaxes, but there is a high possibility of inaccuracy when measuring trees in dense forests as different tree heights come from different viewpoint positions along with their corresponding ground elevation. St-Onge *et al.* (2004) employed a stereo model and a digital terrain model (DTM) produced by an airborne-scanning system using light detection and ranging (LIDAR), to solve the problems. Yet this method is useful for street trees as there are relatively few obstructions, relative to more natural ecosystems such as woodlands. The barrier for such methods comes from time gaps. Trees were measured between May and July 2016 in field, but acquisition of the same period’s photography in Google Earth can be obtained after six months to one year. The height measurement in Google Street View was performed as follows; choose the targeted location of the tree's trunk; add a Placemark at the location; adjust the height of the Placemark until the top of the tree's crown is reached (https://rephaim23.wordpress.com/2015/10/03/measuring-tree-height-in-google-earth-3d-canopy-and-street-view/).

The number of trees measured in the field and through Google Earth Street View can be found in Table 5.2. The total tree number was 831 in which heights of 247 trees (30% of the total) were measured via Google Earth Pro and those of 584 trees (70% of the total) were measured in the field via Abney Level and Rangefinder or measurement tape. In order to check that the methods were broadly comparable, paired Wilcoxon Signed-Ranks tests were performed on heights measured both in the field and in Google Earth Pro for 23 street trees in Baker Street (Appendix 13). The test result was not significant ($z = -0.623$, $p = 0.534$), indicating no significant differences in height measurements of the trees, and so tree measurements from Google Earth were considered to be reliable enough to input into i-Tree.

The identification process of tree species was conducted in several ways. Leaves, bark and fruit during the growing season are crucial indicators for estimating specific tree species. Such identification was conducted in situ through an app (e.g. Tree Id (Sunbird Images ®, Authorised to Represent: Dr. Peter Mullen & Dr. Georg Pohland) and tree guide books (e.g. Collins Complete Guide to British Trees, and Collins Field Guide Trees of Britain (Paul Sterry 2007) and Northern Europe (Alan Mitchell 1974, Reprinted 1994)) including specific descriptions on bark, branches, leaves, reproductive parts, status and distribution, and tree distribution maps and photographs. In the office a field herbarium collection of tree leaves and pictures of tree leaves and barks were used to confirm identification and when having difficulties in identifying some tree species through the app and tree guide books.

5.3.6. Data Processing in i-Tree Programme

When starting the i-Tree Eco v6 programme, projects are either ‘complete inventory’ or ‘plot sample inventory’ types. In a complete inventory project, all the trees in selected study areas are included in the dataset, whereas all tree data collection in established sample plots in a study area are used in a plot-based sample project. The former is usually used for analysis of small areas such as residential or commercial locations, whereas the latter can be applied to research projects over broad-scale areas such as a city, woodland or large university campus. This research selected a complete inventory project to quantify approximate carbon storage, and carbon sequestration amounts for the total BID area were obtained by multiplying up from sampled areas.

Other information included in the programme set up included (in the Location tab): study area (ha); location and population (e.g. City of Westminster, or Camden (depending on the BID location) London, UK); units (i.e. metric), weather station details (i.e. the year: 2015, weather station: NORTHOLT, Elevation: 37.80 (metres), Position (lat, lon): 51.55, -0.41, Annual Precipitation: 299.46 (millimetres), Collection Completeness: Fair). The weather data was downloaded and processed from National Centre for Environmental Information (NOAA)’s National Climatic Data Centre (NCDC).

In the Data Collection Options tab, units were selected, and tree details were entered based on surveys. When calculating carbon storage and gross carbon sequestration, species (for biomass equation identification), DBH (for tree biomass calculation), total height (for biomass calculation), field land use (for assigning biomass adjustment factor), crown health and crown light exposure (for growth rates adjustment – only applied to gross carbon sequestration) are required. All required data were entered, as well as each individual tree’s geographic coordinates, with the exception of crown light exposure.

After carefully checking and reviewing the information, classification of strata was conducted in the Project & Strata Area function in the Project Configuration tab to define the strata, and allow an automatic area calculation per strata after tree data entry. Then assignment of strata was conducted for data entry in the Tree function in the Data tab. All required data were reorganized in the Excel file obtained from the i-Tree homepage (https://www.itreetools.org/resources/archives.php), before transferring the file into the programme. The monetary value outcomes were obtained after adjusting benefit prices such as electricity in £ (GBP) /kWh (0.15), heating in £ (GBP)/therm (1.45), carbon in £ (GBP)/tonne (60), and avoided runoff in £ (GBP)/m^3 (1.516), and the currency exchange rate (1US$=£1) which was provided by openexchangerate.org. Such benefit prices were assigned as the default values, which are those available when the software was installed (the measurement units were metrics), whereas the exchange rate was assigned when the programme was run.

5.3.7. Calculation and Statistical Analysis

The most common tree species, and tree species contributing the most to carbon storage and sequestration, were identified after running i-Tree. For carbon storage and sequestration for the total BID area, values for each sampled area were divided by area to obtain a value per unit area in each strata, and then the sampled areas were multiplied up to the total BID area, according to the approximate proportions of each strata found in a given BID. This method was also applied to calculation of monetary value estimates.

In terms of statistical analysis of tree DBH and heights, and carbon storage and gross carbon sequestration, descriptive statistical analyses were conducted so as to determine their status, to compare among BIDs. In addition, correlations were also calculated to determine possible relationships between per capita emissions in the corresponding borough, and carbon storage and sequestration in each BID. To determine if there are correlations between per capita emissions for the corresponding borough (four in total), and carbon storage and sequestration for each BID (n = 11), non-parametric Spearman correlation analysis was performed. Per capita emissions for each borough were obtained from UK local authority and regional carbon dioxide emissions national statistics (https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics) (see Appendix 12). Per capita emissions from Boroughs of Camden, Southwark, Lambeth, and City of Westminster in 2015 were applied to each corresponding BID when conducting the correlation analysis. In addition, mean tree DBHs and heights were included, so as to determine its correlation with carbon storage and sequestration, and further per capita emission.

5.4. Results

5.4.1. Composition of Tree Species for Carbon Storage and Sequestration in BIDs

The amount of stored CO_2 in trees can be calculated from the tree biomass, which is influenced by the crown cover, tree density, and trunk diameter, whereas carbon sequestration capacity depends on species composition and tree maturity (Chaparro and Terradas, 2009). In other words, composition of tree species, tree density and diameter are factors that decide carbon storage and sequestration capacity of trees. According to the i-Tree report on London's Urban Forest (Rogers *et al.*, 2015), the most important trees in terms of carbon sequestration in Inner London are the London plane (*Platanus* × *acerifolia*), sycamore (*Acer pseudoplatanus*) and oak (*Quercus* spp.). In total, 831 trees were surveyed and 69 species identified in selected study areas in 11 BIDs. Tree DBHs ranged from 11cm to 542cm (mean=127.12cm, SE=3.55, median=97cm, SD=102.37). Tree heights ranged from 3 m to 43m (mean=14.46m, SE=0.28, median = 13m, SD=7.97). The most common trees were the London plane (*Platanus* ×

acerifolia) in nine BIDs, and in the remaining two BIDs Callery pear (*Pyrus calleryana*) tree species were the most dominant in Baker street BID (51% of the total trees in this BID) and New West End BID (84% of the total trees in this BID) (see Table 5.3).

As for total carbon stored in surveyed trees in BIDs, trees in Inmidtown BID stored the most carbon (514.1tonnes/£30.8thousand/123 trees), whereas trees in New West End BID stored the least carbon (16.91 tonnes/£1.01 thousand/25 trees). Among all BIDs, trees in New West End BID were surveyed the least, but such tree species composition (only three species: Callery pear (*Pyrus calleryana*), Norway maple (*Acer platanoides*) and Sweetgum (*Liquidambar styraciflua*)) also contributed to the outcome. Inmidtown BID was the second-most tree surveyed area but 22 species of trees were identified: hedge maple (*Acer campestre*), box elder (*Acer negundo*), Tree of heaven (*Ailanthus altissima*), European white birch (*Betula pendula*), european hornbeam (*Carpinus betulus*), Sweet chestnut (*Castanea sativa*), common hawthorn (*Crataegus monogyna*), dove tree (*Davidia involucrate*), ash spp (*Fraxinus spp*), English holly (*Ilex aquifolium*), London plane (*Platanus × acerifolia*), plum spp (*Prunus spp*), cherry plum (*Prunus cerasifera*), higan cherry (*Prunus pendula*), oak spp (*Quercus spp*), black locust (*Robinia pseudoacacia*), whitebeam (*Sorbus aria*), English yew (*Taxus baccata*), bald cypress (*Taxodium distichum*), littleleaf linden (*Tilia cordata*), common lime (*Tilia × europaea*), and wych elm (*Ulmus glabra*).

When it comes to carbon sequestered in surveyed trees in BIDs, London Bridge BID recorded the most carbon sequestered (4.21 tonnes/year (£253/year)/136 trees), whereas New West End BID had the least carbon sequestered (405.2 kilograms/year (£24.3/year)/25 trees). Trees in London Bridge BID were surveyed the most among BIDs, and had 20 diverse tree species: silver maple (*Acer saccharinum*), horse chestnut (*Aesculus hippocastanum*), Tree of heaven (*Ailanthus altissima*), Italian alder (*Alnus cordata*), red ash (*Fraxinus pennsylvanica*), grey alder

(*Alnus incana*), Indian paper birch (*Betula utilis*), evergreen oak spp (*Quercus ilex*), European beech (*Fagus sylvatica*), ash spp (*Fraxinus spp*), caucasian ash (*Fraxinus angustifolia*), black mulberry (*Morus nigra*), London plane (*Platanus* × *acerifolia*), oriental planetree (*Platanus orientalis*), sweet cherry (*Prunus avium*), Scarlet oak (*Quercus coccinea*), black locust (Robinia pseudoacacia), whitebeam (*Sorbus aria*), littleleaf linden (*Tilia cordata*), and bigleaf linden (*Tilia platyphyllos*).

As for species storing most carbon, London plane was the most dominant, found in nine BIDs, Italian alder (*Alnus cordata*) (54%) was the most dominant species in Baker Street BID, and callery pear (*Pyrus calleryana*) (90%) was the most numerous species in New West End BID. In terms of the most carbon sequestering tree species, London plane (*Platanus* × *acerifolia*) was the most found species in seven BIDs. The remaining four BIDs showed different tree composition. In London Bridge BID, sweet cherry (25%) and Scarlet oak (23%) showed similar composition when sequestering carbon, whereas Baker Street BID had callery pear (*Pyrus calleryana*) as the most carbon sequestered species, followed by Italian alder (34%). New West End BID had callery pear (*Pyrus calleryana*) as the most dominant species for carbon sequestration, whereas Waterloo BID had European bird cherry (*Prunus padus*) (20%) and London plane (*Platanus* × *acerifolia*) (18%), as the most dominant species in this area.

Further discussion on contributing factors of carbon storage and sequestration capacity from urban trees in BIDs will be handled in the discussion at the end of this chapter. In the next section, estimation of carbon storage and sequestration in each BID will be clarified in terms of the quantity of stored carbon amount and its monetary value (tonnes and £), gross carbon sequestration estimates (tonnes and £/yr), and carbon storage and gross carbon sequestration per hectare estimates.

Table 5.3 Tree details in eleven studied BIDs

Business Improvement District	Most common tree species percent population (% of the total trees)	Number of Surveyed Tree Species	Total carbon stored and sequestered in surveyed trees in BIDs	Species storing most carbon (% of the total carbon stored)	Most carbon sequestrated trees (% of the total sequestered carbon)	Tree DBH Range (cm)	Tree Height Range (m)
London Bridge BID	London plane (22%), Sweet cherry (18%), and Scarlet oak (13%)	20	Carbon storage: 398.6 tonnes (£23.9k) Carbon sequestration: 4.21 tonnes/year (£253/year)	London plane (30%), Sweet cherry (19%), Scarlet oak (16%)	Sweet cherry (25%), Scarlet oak (23%), London plane (18%)	Range: 11-431 Mean: 105.75 (SE: 6.55) Std. Deviation: 76.39, Median: 90.5	Range: 4-39 Mean: 14.08 (SE = 0.56) Std. Deviation: 6.53, Median: 13
South Bank BID	London plane (30%), Oriental plane tree (17%), Indian paper birch and Littleleaf linden (10% respectively)	22	Carbon storage: 282.4 tonnes (£16.9k) Carbon sequestration: 531.6 kilograms/year (£31.9/year)	London plane (51%), Oriental plane tree (10%), Bigleaf linden (8%)	London plane (48%), Oriental plane tree (12%), Hedge maple (8%)	Range: 19-408 Mean: 125.89 (SE: 10.55) Std. Deviation: 102.28, Median: 100	Range: 3-40 Mean: 16.34 (SE = 0.96) Std. Deviation: 9.35, Median: 14
Victoria BID	London plane (97%)	2	Carbon storage: 154.3 tonnes (£9.26k) Carbon sequestration: 491.2 kilograms/year (£29.5/year)	London plane (99%)	London plane (96%)	Range: 17-423 Mean: 189.85 (SE: 19.76) Std. Deviation: 113.54, Median: 176	Range: 3-25 Mean: 15.33 (SE= 1.07) Std. Deviation: 6.13, Median: 17
Baker Street BID	Callery pear (51%), Italian alder (28%), London plane (8%)	7	Carbon storage: 82.68 tonnes (£4.96k) Carbon sequestration: 848.6 kilograms/year (£50.9/year)	Italian alder (54%), Callery pear (26%), London plane (17%)	Callery pear (48%), Italian alder (34%), London plane (11%)	Range: 16-254 Mean: 77.56 (SE: 7.9) Std. Deviation: 49.39, Median: 72	Range: 4-24 Mean: 11.54 (SE=0.89) Std. Deviation: 5.56, Median: 11
Heart of London BID	London plane (67%), Callery pear (10%), ash spp (8%)	9	Carbon storage: 149.7 tonnes (£8.98k) Carbon sequestration: 608.4 kilograms/year (£36.5/year)	London plane (94%), ash spp (3%), Callery pear (1%)	London plane (66%), ash spp (11%), Callery pear (10%)	Range: 23-427 Mean: 180.37 (SE: 19.08) Std. Deviation: 120.68, Median: 200	Range: 4-31 Mean: 18.42 (SE: 1.39) Std. Deviation: 8.80, Median: 19.5

Inmidtown BID	London plane (63%), European white birch (8%), Tree of heaven (7%)	22	Carbon storage: 514.1 tonnes (£30.8k) Carbon sequestration: 1.822 tonnes/year (£109/year)	London plane (75%), Tree of heaven (8%)	London plane (60%), Tree of heaven (8%)	Range: 12-511 Mean: 168.36 (SE: 10.57) Std. Deviation: 117.2, Median: 159	Range: 4-43 Mean: 17.02 (SE: 0.72) Std. Deviation: 8, Median: 17
Fitzrovia BID	London plane (61%), Hedge maple (20%), Callery pear (12%)	5	Carbon storage: 207.7 tonnes (£12.5k) Carbon sequestration: 743.5 kilograms/year (£44.6/year)	London plane (86%), Italian alder (6%), Black locust (5%)	London plane (68%), Hedge maple (15%), Callery pear (9%)	Range: 14-465 Mean: 137.44 (SE: 13.64) Std. Deviation: 104.83, Median: 129	Range: 4-30 Mean: 15 (SE: 0.95) Std. Deviation: 7.29, Median: 16
New West End BID	Callery pear (84%), Sweetgum (8%), Norway maple (8%)	3	Carbon storage: 16.91 tonnes (£1.01k) Carbon sequestration: 405.2 kilograms/year (£24.3/year)	Callery pear (90%), Norway maple (9%)	Callery pear (90%), Norway maple (7%)	Range: 15-74 Mean: 50.16 (SE: 2.77) Std. Deviation: 13.87, Median: 53	Range: 4-10 Mean: 8.24 (SE: 0.28) Std. Deviation: 1.42, Median: 8
Paddington BID	London plane (34.6%), Italian alder (11.5%), plum spp (10.3%)	14	Carbon storage: 299.3 tonnes (£18k) Carbon sequestration: 1.499 tonnes/year (£90/year)	London plane (54%), Italian alder (15%), Oriental plane tree (9%)	London plane (18%), Italian alder (14%), Swedish whitebeam (12%), Oriental plane tree (12%)	Range: 17-542 Mean: 182.58 (SE: 15.84) Std. Deviation: 139.92, Median: 126	Range: 4-41 Mean: 18.79 (SE: 1.29) Std. Deviation: 11.38, Median: 14.5
Vauxhall BID	London plane (46%), Horse chestnut (15%), Bigleaf linden and Smoothleaf elm (9% respectively)	10	Carbon storage: 229.9 tonnes (£13.8k) Carbon sequestration: 2.054 tonnes/year (£123/year)	London plane (53%), Horse chestnut (20%), Bigleaf linden (10%)	London plane (41%), Horse chestnut (21%), Bigleaf linden (11%)	Range: 21-273 Mean: 99.99 (SE: 5.19) Std. Deviation: 45.86, Median: 90.5	Range: 4-27 Mean: 10.68 (SE: 0.45) Std. Deviation: 3.98, Median: 10
Waterloo BID	London plane (24%), European bird cherry (13%), Callery pear (11%)	18	Carbon storage: 267.5 tonnes (£16k) Carbon sequestration: 2.616 tonnes/year (£157/year)	London plane (45%), European bird cherry (16%)	European bird cherry (20%), London plane (18%)	Range: 18-234 Mean: 86.06 (SE: 6.18) Std. Deviation: 69.68, Median: 65	Range: 4-29 Mean: 11.04 (SE: 0.51) Std. Deviation: 5.72, Median: 10

5.4.2. Carbon Storage and Sequestration Estimation in BIDs

According to Rogers *et al.* (2015), 499,000 tonnes of carbon (15.64 tonnes per hectare) was stored in trees in Inner London with an estimated value of £29.9 million, and 15,900 tonnes of carbon (0.5 tonnes per hectare) was sequestered in 2014, with an estimated value of £955,000. In this section, carbon storage and sequestration estimates will be presented, as well as their monetary value. According to Nowak *et al.* (2008), the modelled carbon values come from forest-derived equation estimates. When analysing the monetary value in the programme, carbon storage and gross carbon sequestration value was calculated based on the price of £60 per tonne, which is the default benefit price in i-Tree programme, and the default values are those available at the time of software installation (source: Notes from i-Tree programme software). In the entire eleven BIDs, 8,037.40 tonnes of carbon were stored in trees with an approximate value of £482,231.81 (16.40 tonnes and £984.15 per hectare), and 46.73 tonnes of carbon were sequestered with an estimated value of £2,795.40 (0.1 tonnes and £5.7 per hectare) in 2016.

As seen in Table 5.4 and 5.5, as for carbon storage, New West End BID showed the lowest carbon storage value (141.58 tonnes and £8,498.58), followed by Baker Street BID (211.71 tonnes and £12699.67). In the other hand, Inmidtown BID indicated the highest carbon storage value (2,214.57 tonnes and £132,888.3), followed by South Bank (1,248.21 tonnes and £74901.76). When it comes to gross carbon sequestration per annum in 2016, Fitzrovia had the lowest carbon sequestration supply capacity from trees (1.34 tonnes and £80.76), followed by Heart of London at 1.47 tonnes and £87.96). Yet Waterloo had the highest carbon sequestration value (9.95 tonnes and £596.18) followed by Inmidtown BID (7.88 tonnes and £471.05). London Bridge (7.76 tonnes and £465.64) had a similar value to Inmidtown BID.

When comparing tree carbon storage per hectare estimates for each BID, with the carbon storage per hectare estimates for the whole Inner London, the BIDs of London Bridge (20.41), South Bank (18.83), Inmidtown (39.06), and Paddington (17.08) showed higher carbon storage supply than the Inner London mean (15.64). Yet as for carbon sequestration per hectare, all BIDs showed far lower carbon sequestration supply (range from 0.04 to 0.22) than the Inner London mean (0.5). As for carbon storage per hectare, Inmidtown BID showed the highest carbon storage per hectare value (39.06 tonnes and £2,343.71), followed by London Bridge (20.41 tonnes and £1,224.57). On the other hand, New West End indicated the lowest carbon storage per hectare value (6.38 tonnes and £382.82), followed by Baker Street (8.27 tonnes and £496.08) and Vauxhall (8.98 tonnes and £538.89). When it comes to gross carbon sequestration per hectare in 2016, London Bridge had the highest value (0.22 tonnes and £12.93), followed by New West End (0.15 tonnes and £9.17), Inmidtown BID (0.14 tonnes and £8.31) and Waterloo (0.13 tonnes and £7.51). On the other hand, Southbank showed the lowest (0.04 tonnes and £2.13), along with similar trends found in the BIDs of Fitzrovia (0.04 tonnes and £2.29) and Victoria (0.04 tonnes and £2.70).

Table 5.4 Minimum, Maximum, Mean and Standard Deviation Values of Carbon Storage and Sequestration Estimates in Eleven BIDs

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Carbon Storage (t)	141.58	2214.57	730.6718	594.3804
Carbon Storage (£)	8498.58	132888.3	43839.25	35665.66
Gross Carbon Sequestration (t)	1.34	9.95	4.2482	3.09976
Gross Carbon Sequestration (£)	80.76	596.18	254.1273	185.8083
Carbon Storage per hectare (t)	6.38	39.06	15.6518	8.96148
Carbon Storage per hectare (£)	382.82	2343.71	939.0764	537.7207
Gross Carbon Sequestration per hectare (t)	0.04	0.22	0.0982	0.05689
Gross Carbon Sequestration per hectare (£)	2.13	12.93	5.8064	3.35813

Table 5.5 Carbon storage and sequestration estimates (tonne and £ & per hectare)

Business Improvement District Name	BID Total Area (ha)	BID Study Area (ha)	Average Carbon Storage (t)	Average Carbon storage (£)	Average gross carbon sequestration (t)	Average gross Carbon sequestration (£)	[24]Carbon Storage (t)	[25] Carbon storage (£)	[26] Gross carbon sequestration (t/yr)	[27] Gross Carbon sequestration (£/yr)	[28] Carbon Storage per hectare (t/ha)	[29] Carbon storage per hectare (£/ha)	[30] Gross carbon sequestration per hectare (t/yr/ha)	[31] Gross Carbon sequestration per hectare (£/yr/ha)
London Bridge BID	36	6.51	132.90	7971.95	1.40	84.20	734.93	44084.52	7.76	465.64	20.41	1224.57	0.22	12.93
South Bank BID	66.3	5	94.13	5648.70	0.18	10.63	1248.21	74901.76	2.39	141.00	18.83	1129.74	0.04	2.13
Victoria BID	42.2	5.45	77.15	4627.79	0.25	14.74	597.38	35833.53	1.90	114.09	14.16	849.14	0.04	2.70
Baker Street BID	25.6	5	41.35	2480.41	0.43	25.46	211.71	12699.67	2.18	130.36	8.27	496.08	0.09	5.09
Heart of London BID	23.2	3.21	49.90	2994.39	0.20	12.17	360.65	21641.70	1.47	87.96	15.55	932.83	0.06	3.79
Inmidtown BID	56.7	6.58	257.00	15421.61	0.92	54.67	2214.57	132888.30	7.88	471.05	39.06	2343.71	0.14	8.31
Fitzrovia BID	35.3	6.5	69.23	4154.48	0.25	14.87	375.99	22562.04	1.34	80.76	10.65	639.15	0.04	2.29
New West End BID	22.2	2.65	16.90	1014.47	0.41	24.31	141.58	8498.58	3.43	203.65	6.38	382.82	0.15	9.17
Paddington BID	25.9	5.84	99.77	5986.02	0.50	29.98	442.46	26547.60	2.22	132.97	17.08	1025.00	0.09	5.13
Vauxhall BID	77.2	6.4	57.48	3448.87	0.52	30.82	693.29	41601.93	6.21	371.74	8.98	538.89	0.08	4.82
Waterloo BID	79.4	4.18	53.52	3209.87	0.52	31.39	1016.62	60972.17	9.95	596.18	12.80	767.91	0.13	7.51
Total	490	57.32					8037.40	482231.81	46.73	2795.40	16.40	984.15	0.10	5.70

[24] (average carbon storage/BID study area)*total BID area
[25] (average carbon storage monetary value /BID study area)*total BID area
[26] (average gross carbon sequestration/BID study area)*total BID area
[27] (average carbon sequestration monetary value/BID study area)*total BID area
[28] ((average carbon storage/BID study area)*total BID area)/total BID area
[29] ((average carbon storage monetary value/BID study area)*total BID area)/total BID area
[30] ((average gross carbon sequestration/BID study area)*total BID)/total BID area
[31] ((average carbon sequestration monetary value/BID study area)*total BID area)/total BID area

5.4.3. Correlations between carbon storage and sequestration, and CO_2 emission

When it comes to comparing carbon storage and gross carbon sequestration per tree between areas, ANOVA (t-test) was performed to determine differences between individual BIDs (Grouping 11), and between the corresponding boroughs (Grouping 4). The analysis was conducted using the Kruskal-Wallis H test to test more than two independent samples. In sum, there is no significant difference in carbon storage and sequestration per tree among the corresponding boroughs (χ^2=2.527, p=0.470 / χ^2=24.745, p= 0.191), and BIDs (χ^2=10, p=0.440 respectively). The lowest carbon storage per tree was found in New West End BID, whereas the highest carbon storage per tree was found in South Bank. As for carbon sequestration per tree, Fitzrovia had trees with the lowest carbon sequestration capacity, but Waterloo had trees with the highest carbon sequestration capacity (see Table 5.6).

Table 5.6 Carbon storage and sequestration estimates per tree (tonne)

	Minimum	Maximum	Mean	Std. Deviation
Carbon storage per tree	5.66	40.26	25.9082	12.48488
Carbon sequestration per tree	0.07	0.39	0.1560	0.10370

Business Improvement District Name	carbon storage per tree (study area) (Tonne)	carbon sequestration per tree (study area) (Tonne)	carbon storage per tree (BID area) (Tonne)	carbon sequestration per tree (BID area) (Tonne)
London Bridge BID	2.95	0.031	16.33	0.172
South Bank BID	3.04	0.006	40.26	0.076
Victoria BID	4.68	0.015	36.20	0.115
Baker Street BID	2.12	0.022	10.86	0.112
Heart of London BID	3.84	0.016	27.74	0.113
Inmidtown BID	4.18	0.015	36.02	0.128
Fitzrovia BID	3.52	0.013	19.12	0.068
New West End BID	0.68	0.016	5.66	0.137
Paddington BID	3.89	0.019	17.24	0.086
Vauxhall BID	2.95	0.026	35.55	0.317
Waterloo BID	2.11	0.021	40.01	0.392

Correlation coefficients and significant relationships found between mean tree DBH, mean tree height, carbon storage, gross carbon sequestration in 2016, and CO_2 emissions per capita in the corresponding borough in 2015 from Department for Business (see Appendix 12) are shown in Table 5.7. Each variable came from the above measurements and calculations in i-Tree.

Mean tree DBH only showed a strongly positive correlation with mean tree height, which would be expected: stouter trees are taller. Mean tree heights were positively correlated to carbon storage per hectare, indicating that higher mean tree heights are generally found in BIDs that showed a higher carbon storage supply capacity per hectare. Carbon storage variable indicated a strong correlation with gross carbon sequestration per annum, meaning that trees in BIDs with a higher carbon storage supply capacity also had a higher carbon sequestration per hectare. Strong negative correlations were found between CO_2 emissions per capita in the corresponding borough, and carbon storage and gross carbon sequestration, meaning that there is a high possibility that BIDs with a higher carbon storage and sequestration capacity were found in boroughs with lower CO_2 emissions per capita.

Overall, mean tree DBH did not show a direct correlation with carbon storage and sequestration, and CO_2 emission per capita (Table 5.7), but given the strong correlation with mean tree height, it can be assumed that tree DBH has an indirect relationship with other variables. In addition, given the positive correlations between mean tree height and carbon storage per hectare, carbon storage and gross carbon sequestration, BIDs with larger tree DBHs and higher tree heights showed the most carbon storage and sequestration. Essentially, it can be inferred that the more BIDs or such areas in a borough, there is a high possibility that the borough would record lower CO_2 emissions per capita. This does not mean that all BIDs have more trees than non-BID areas in a borough, but there are is a high possibility that some BIDs maintain trees in a better condition (which is another contributor to carbon storage and sequestration capacity (Nowak *et al.*, 2013)), along with more diverse green infrastructure than in other areas within the borough. Some BIDs have small scale green infrastructure projects in partnership with the local authority (e.g. Team London Bridge BID), or green infrastructure within BID boundaries can be more well managed along with such activities as area improvements, cleanliness, area marketing, community engagement, environmental sustainability and regeneration (Department for Communities and Local Government, 2013). Given that those BIDs can be regarded as spatial samples for estimating total carbon storage and sequestration from trees in each borough, there is a possibility that a borough with BIDs indicating such high capacity would have low CO_2 emissions per capita.

Table 5.7 Correlation between variables

		Mean DBH (cm)	Mean height (m)	Carbon Storage (t)	Gross carbon sequestration (t/yr)	Carbon storage per hectare(t/ha)	Gross carbon sequestration per hectare (t/yr/ha)	Borough Emissions per capita (2015)
Mean DBH (cm)	Correlation Coefficient	1.000	**.855****	0.209	-0.427	0.591	-0.487	0.312
	Sig. (2-tailed)		**0.001**	0.537	0.190	0.056	0.128	0.350
Mean height (m)	Correlation Coefficient	**.855****	1.000	0.218	-0.355	**.718***	-0.336	0.351
	Sig. (2-tailed)	**0.001**		0.519	0.285	**0.013**	0.313	0.290
Carbon Storage (t)	Correlation Coefficient	0.209	0.218	1.000	**.627***	**.718***	0.051	**-.706***
	Sig. (2-tailed)	0.537	0.519		**0.039**	**0.013**	0.883	**0.015**
Gross carbon sequestration (t/yr)	Correlation Coefficient	-0.427	-0.355	**.627***	1.000	0.255	**.713***	**-.629***
	Sig. (2-tailed)	0.190	0.285	**0.039**		0.450	**0.014**	**0.038**
Carbon storage per hectare (t/ha)	Correlation Coefficient	0.591	**.718***	**.718***	0.255	1.000	0.083	-0.183
	Sig. (2-tailed)	0.056	**0.013**	**0.013**	0.450		0.809	0.591
Gross carbon sequestration per hectare (t/yr/ha)	Correlation Coefficient	-0.487	-0.336	0.051	**.713***	0.083	1.000	-0.092
	Sig. (2-tailed)	0.128	0.313	0.883	**0.014**	0.809		0.787
Borough Emissions per capita (2015)	Correlation Coefficient	0.312	0.351	**-.706***	**-.629***	-0.183	-0.092	1.000
	Sig. (2-tailed)	0.350	0.290	**0.015**	**0.038**	0.591	0.787	

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

5.5. Tree Management for Enhanced Provision of Regulating Ecosystem Services

The quantification of carbon storage and sequestration by urban trees is crucial as it is 'a major terrestrial carbon pool', helpful for setting climate change mitigation strategies (Zhao and Sander, 2015). Before or after the quantification of ecosystem service supply, mapping of vegetation is helpful for identifying potential areas to be studied, or tree-deficient areas. For instance, the mapping of street trees in Greater London would provide urban planners with information on tree-deficient areas. The Greater London Authority provides a 'London Tree Map (https://maps.london.gov.uk/trees/)' to provide information on locations and tree species, and to raise public awareness of the contribution of trees to the urban environment, provide operational benefits for tree managers, and supply necessary information for more effective tree management (https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/trees-and-woodlands/london-tree-map). In an effort to plant street trees in London, the Mayor's Street Tree Programme has been successfully applied in forty priority areas in London planting 10,000 street trees between 2008 and 2012 on the basis of 'street tree density, multiple deprivation, urban heat island effect, air quality, noise and areas of deficiency in access to nature' (Forestry Commission and Mayor of London, 2012). Since then, street trees have increasingly been planted in partnership with the Forestry Commission and Groundwork London, as well as London Borough councils and other organisations with land ownership. As for tree species selection, given the preferences of tree species within areas, trees with larger canopies, and tree species resilient to climate change, the following tree species were commonly planted (Forestry Commission and Mayor of London, 2012): *Pyrus*, *Prunus*, *Betula*, *Sorbus*, *Plane*, Lindens (or *Tilia*) and *Alnus*, which were mostly indicated in the category in Table 5.8, were also commonly found in central Business Improvement Districts, Inner London, and in the London i-Tree report datasets.

Table 5.8 Commonly planted trees in Inner and Outer London

Most commonly planted in Outer London	Plane (Platanus), Lime (Tilia or Lindens), Oak (Quercus), Ash (Fraxinus), Tulip(Liriodendron), Maple (Acer), Sweet gum (Liquidambar) (where space allows), Prunus (Prunus), Birch (Betula), Mountain-ash (Sorbus)
Others in Outer London	Alder (Alnus), Dawn redwood (Metasequoia), Shadbush (Amelanchier), Hornbeam (Carpinus), Walnut trees (Juglans), Privet (Ligustrum), Locust (Gleditsia)
Most commonly planted in Inner London	Pear (Pyrus), Prunus (Prunus), Birch (Betula), Mountain-ash (Sorbus), Apple (Malus), Hawthorn (Crataegus), Hazel (Corylus) (due to restricted space)
Others in Inner London	Plane (Platanus), Lime (Tilia or Lindens), Tulip (Liriodendron), Alder (Alnus) (where space allows)

As seen in Table 5.9, Inner London showed such values as 4326.81 tonnes and £6835.61 in carbon storage, and 136.60 tonnes and £224.26 in gross carbon sequestration on average, whereas BID indicated those values as 730.67 tonnes and £43839.25 in carbon storage, and 4.25 tonnes and £254.13 in gross carbon sequestration on average. As for comparison of carbon storage and sequestration estimates in BIDs and Inner London, data for which was obtained from the London i-Tree Eco Report datasets (Table 5.9) which data collection methods (i.e. a standardised field data collection method applying to each plot covering 0.04ha, a total of 476 plots in Greater London in 2014) are different from BID i-Tree data collection method. Figure

5.5 shows there is no overlap in error bars in Inner London and BIDs in the ecosystem service estimates. It can be inferred that there is a difference in such estimates in Inner London and BIDs.

Table 5.9 Mean and Standard Deviation Values of Carbon Storage and Sequestration Estimates in Inner London and BIDs

	Carbon storage estimates (t)	Carbon storage value (£)	Gross carbon Sequestration estimates (t)	Gross carbon sequestration value (£)
Inner London Mean	4326.81	6835.61	136.60	224.26
Inner London SD	7354.42	13754.66	156.13	347.93
BID Mean	730.67	43839.25	4.25	254.13
BID SD	594.38	35665.66	3.10	185.81

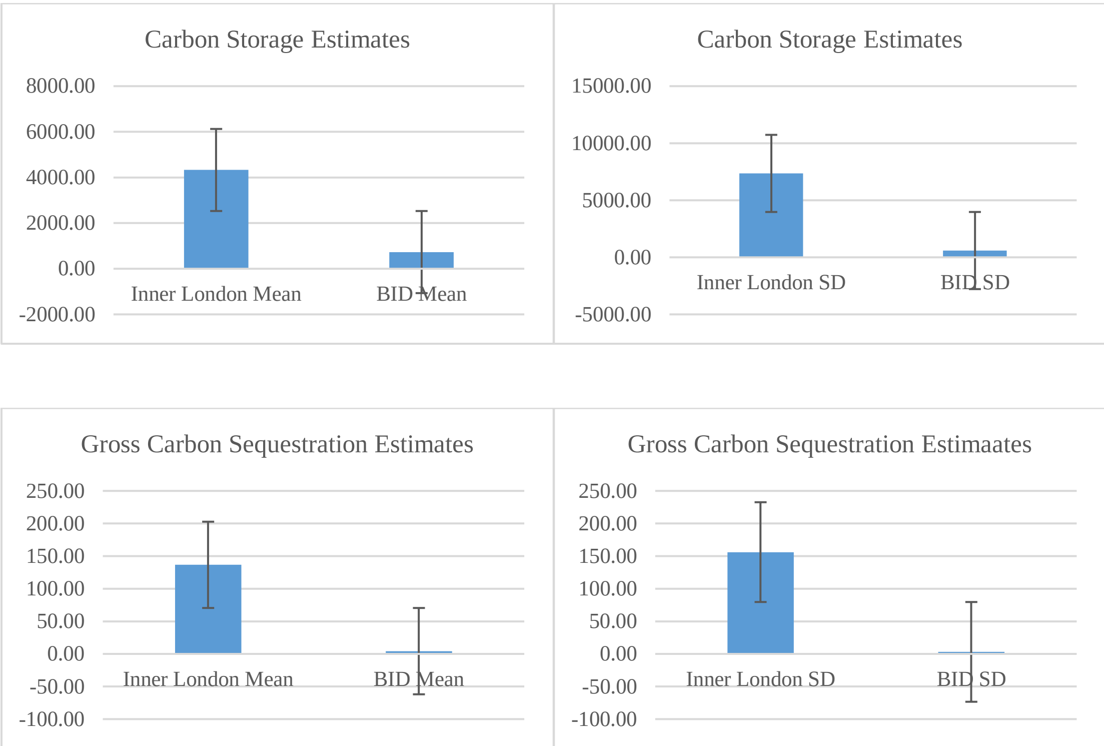


Figure 5.5 Mean and standard deviation values of carbon storage and gross carbon sequestration estimates and standard errors in Inner London and BID

A proper selection of tree species is crucial for higher carbon storage and sequestration service provision, given the projected future climate (Davies *et al.*, 2011; Roloff *et al.*, 2009) (e.g. heat- or drought-tolerant tree species), and offsetting carbon emissions from tree planting or replanting, establishment and removal (Nowak *et al.*, 2002). The variables influencing carbon storage and sequestration supply rates and amounts are size at maturity (i.e. the larger mature trees are, the more carbon sequestered), lifespan (i.e. the longer a tree's lifespan, the greater the carbon benefits), and growth rates affecting net sequestration (Nowak *et al.*, 2002). As for selection of tree species considered drought-tolerance, and native and non-native species, Gary Meadowcroft, Tree Services Manager, Southwark Council indicated in an interview in 2016:

> It's the trees that are more drought-tolerant, trees that are providing benefits in terms of warmer climate and can tolerate warmer climates. Equally, we need to maintain the mix in terms of the heat island effect, and which trees are big, to provide cooling and to break up wind speeds. We consider it, but we're often planting a lot more non-natives now.
>
> There's lines of Mediterranean trees. If you think of the reflective heat, they can tolerate hotter climates. In terms of amenity, the warmer the climate, the bigger certain flowers. If you've got hotter areas, you get better response in terms of trees. It's native and non-native. It's important we maintain our natives, but because climate change is upon us, our planting needs to adapt to reflect that.

The urban forest is already a mix of native and non-native tree species. The number of non-native species was higher than the native species number in major Nordic cities' streets and parks, except Oslo and Tampere, where the number of native species was higher in street environments, whereas the number of tree individuals belonging to native species was higher than the number of non-native individuals in all cities except Årĥus, in which non-native species dominate in parks (Sjöman *et al.*, 2012). The following genera were the most dominant in each city: *Tilia* in Årĥus, Copenhagen, Espoo, Gothenburg, Helsinki, Oslo and Stockholm; *Sorbus* in Malmo; and *Betula* in Tampere and Turku (Sjöman *et al.*, 2012).

The origins of tree species in BIDs are diverse, covering Europe, Asia, Europe & Asia, North America, South America, North & South America, and Australia. Even though 'the majority of the tree population consisted of native tree species' (Sjöman *et al.*, 2012, p.38), the tree population in BIDs indicated that the tree population consisting of non-native species was dominant, as some specific non-native species (e.g. London plane (*Platanus* × *acerifolia*) or Callery pear (*Pyrus calleryana*)) were mostly found in streets, and diverse non-native species were also found in parks. In a total of eleven BID study areas, the number of trees consisting of non-native species (75%) was far higher than the number of trees belonging to native-species (see Table 5.10). Tree numbers of non-native species recorded between 56 to 100%, whereas those belonging to native species ranged from 8 to 44%. Among BIDs, London Bridge BID and Waterloo BID showed a relatively higher tendency than other BIDs in terms of tree numbers from native species.

Table 5.10 Number of Native and non-native species (see Appendix 14)

	Native	**Non-Native**
Baker Street BID	3 (8%)	36 (92%)
Fitzrovia BID	12 (20%)	47 (80%)
Heart of London BID	4 (10%)	35 (90%)
Inmidtown BID	29 (24%)	94 (76%)
London Bridge BID	44 (32%)	92 (68%)
New West End BID	-	25 (100%)
Paddington BID	22 (28%)	56 (72%)
Southbank BID	25 (27%)	69 (73%)
Vauxhall BID	13 (17%)	65 (83%)
Victoria BID	-	33 (100%)

Waterloo BID	56 (44%)	71 (56%)
Total	**208 (25%)**	**623 (75%)**

The lifespan of trees also depends on planting locations allowing trees to ‘reach a large size at maturity, promote tree health, and minimise maintenance’ (Nowak *et al.*, 2002, p.118). Identifying locations for large trees is not an easy task for urban planners or tree managers as they have to consider factors such as distances between trees and buildings, species more resilient to extreme weather, tree size, and availability of space for the roots considering utility services. Such difficulties of planting street trees were identified in an interview with the Tree Services Manager of Southwark Council;

> We're looking at proximity, we're looking at size, and we’re looking at availability of the root space under the ground. As the industry progresses, there's a lot more cultivars coming through for street trees, trees that are better suited in street tree environments. Certainly in the city of London, where the footpaths are quite small, and the space is quite narrow, cultivars of trees are coming through to allow for that planting. What we need to be careful is we don't go from these big canopies to a lot of small trees. Again, it's finding that balance.
>
> We would change the palate to suit the environment. The open spaces are going to be the places where we're going to get our bigger trees. Where we have bigger trees and plants that subsequently have to be removed, it may not be possible due to retrofitted utility services.
>
> One of our biggest challenge is the available rooting space in which to put the tree in the first place, so that we're creating an underground void or underground vault for tree to go in that's going to be sustainable for the future. Equally in that tree it's the proximity of that passing widths for pedestrians. It's approximately of trees to buildings. There's numerous challenges in terms of street tree planting.
>
> If we have to take a tree out, we've not always been able to plant a big tree back in. We have to think outside the box. To give you an example, we recently deleted some parking base in a road and dug a big 26-meter trench by two meters, buy a meter deep and actually planted some London planes back in the road, rather than in the path so that we can accommodate them. It's about off the walk solutions and thinking outside the box in terms of tree planting. Sometimes creating build outs. I think street tree planting in general is a challenge. In open spaces provided you got the space then it's far easier.

Urban areas are carbon sources, and street trees are not enough for offsetting all emitted CO_2 emissions in urban areas. Another way to maximise the service supply and capacity comes from adjustments to external conditions. For instance, carbon sequestration ecosystem services from urban trees can be enhanced with minimal fossil fuel consumption and limited waste material decomposition (Davies *et al.*, 2011; Nowak *et al.*, 2002). When it comes to reduction of atmospheric carbon by urban trees, strategic location of trees around buildings provides lower building energy use leading to climate change mitigation. Given benefits derived from urban trees such as reduced energy consumption from buildings (Akbari, 2002; Nowak and Dwyer, 2007; Nowak *et al.*, 2002), further research can be expanded after calculating distances between street trees and buildings in urban areas. In addition, other urban vegetation types (e.g. woodland, shrubs, herbaceous, etc.) (e.g. quantification of ecosystem service provision by eight urban green space types in Rotterdam, Netherlands (Derkzen *et al.*, 2015)), above-ground carbon from public to private green spaces (e.g. examination of quantities and spatial patterns of above-ground carbon stored in the entire urban area of Leicester (Davies *et al.*, 2011)), below-ground biomass (Haynes and Gower, 1995; Næsset and Gobakken, 2008; Nadelhoffer and Raich, 1992), cycle of carbon emissions from tree planting, replanting or removal (Nowak and Crane, 2002) should also be considered when calculating the extent of the regulating ecosystem service supply rates and amounts.

When considering management plans, urban planners should consider potential impacts of vegetation on site conditions and regional or local problems, while determining benefits and costs over the corresponding urban areas in terms of aesthetics, meteorology, pest or fire risks, and air quality (Nowak and Dwyer, 2007). Street tree management plans require complex consideration before planning and delivery to maximise environmental, social, and economic and health benefits. For instance, some trees may have adverse effects such as emitting volatile organic compounds (VOCs) reacting with other airborne chemicals leading to air pollution. Even though chemicals emitted from trees contribute to microclimatic effects, and it is not clear to build atmospheric modelling for predicting interactions and consequences, careful selection of trees in proper locations at a local level is required for better regional air quality.

As for tree numbers found in each Business Improvement Districts, most BIDs had plenty of trees, or were planning to plant more trees, except for some BIDs; New West End BID (25 trees surveyed, and there is space for more to be planted); Victoria BID (33 trees surveyed and few trees near Victoria Station due to construction in 2016, high possibility of planting diverse species of trees for offsetting CO_2 emissions); Baker Street BID (high possibility of planting more trees, but not stouter trees such as London plane due to dense buildings and residential areas); and some commercial streets (shortage of trees near Paddington Station, then high possibility of planting small trees rather than large trees due to proximity of other buildings or buses) in Paddington BID.

As for study areas in BIDs, trees in Inmidtown BID stored the most carbon, followed by London Bridge BID (South Bank BID at a BID-whole level), whereas trees in New West End BID stored the least carbon, followed by Baker Street BID. In addition, trees in London Bridge BID (Waterloo BID at a BID-whole level) sequestered the most carbon, followed by Waterloo BID (Inmidtown BID and London Bridge BID at a BID-whole level), whereas trees in New West End BID (Fitzrovia BID at a BID-whole level) showed the opposite trend, followed by Victoria BID (Heart of London BID at a BID-whole level). The areas that showed high carbon storage and sequestration supply rates had greater tree species diversity (18-22 species) including the highest proportion of London plane (*Platanus* × *acerifolia*) in each area. On the other hand, the areas which showed low carbon storage sequestration supply rates had smaller number of tree species (e.g. 2-3 tree species diversity in Victoria and New West End BIDs), while planting trees less effective for carbon storage or sequestration (e.g. callery pear (*Pyrus calleryana*) and Italian alder (*Alnus cordata*) in Baker Street and New West End BIDs). Yet when it comes to gross carbon sequestration per hectare, New West End BID recorded the lowest carbon storage value per hectare but the second-largest carbon sequestration value per hectare, even though its tree numbers (25) were the lowest among BIDs. This means that tree species such as callery pear (*Pyrus calleryana*) (84% of the total trees in New West End BID study area), sweetgum (*Liquidambar styraciflua*) (6%), and Norway maple (*Acer platanoides*) (8%) are more effective in carbon sequestration than carbon storage.

In sum, it seems obvious that London plane (*Platanus* × *acerifolia*) mostly contributes to the capacity of carbon storage and sequestration, but species-specific planting cannot enhance such capacity. Thinner tree species such as callery pear (*Pyrus calleryana*) are suitable for narrow streets like Oxford Street, given its carbon sequestration capacity is high. In addition, as there is a less diverse tree species structure in one area, there is a high possibility that carbon storage and sequestration capacity become low.

Ecosystem resilience can be kept through the sustainable production of natural resources and ecosystem services in complex systems (Gunderson and Holling, 2002). Resilience for tree communities basically depends on tree species, and tree condition influenced by location, species diversity, and tree pests. When selecting species, it is not feasible for urban planners to consider carbon storage and sequestration only. Species selection should include the judgement of landscape architects, policy-makers and other profit or non-profit organisations, especially when considering factors such as site aspect/sun exposure, soil condition, available space, proximity of utilities or other structures, species diversity of nearby trees, appearance (i.e. size, shape, colour), native species, intended use, and likely pests and diseases (Conway and Vander

Vecht, 2015). Yet security of available space and intended use are crucial factors before selecting tree species (Conway and Vander Vecht, 2015). Urban planners should diversify tree composition which is effective for carbon storage and sequestration, as well as increase tree numbers and security of open space for planting diverse tree species (e.g. square, garden or pocket parks).

5.6. Conclusion

Valuating the ecosystem services provided by trees aims to 'increase the profile of the urban forest, ensure its value is maintained and improved, and help town planners, landscape architect and tree officers to plan' potential tree planting areas along with benefits (Rumble *et al.*, 2015, p.4). Regional development agencies have calculated the value of environmental resources, which can be crucial to economic prosperity, but the economic downturn has cut key agency budgets, and a lack of necessary expertise to deliver environment projects, eventually resulting in economic (e.g. properties, services and infrastructure) and environmental (e.g. lower ecological quality or increase of alien invasive species) damage (Rotherham, 2010). To overcome such barriers, more ecosystem service valuation methods have been employed in making economic arguments for environmental resources (e.g. i-Tree Eco or the Capital Asset for Amenity Trees (CAVAT)).

In this chapter, carbon storage and sequestration from street trees in economically active areas was evaluated which also proves three initial hypothesis; differences in tree composition and density leading to differential ecosystem service provision; correlation between per capita CO_2 emission in the corresponding four boroughs, and carbon storage and sequestration estimates influenced by DBH, number and species of trees in BIDs; and diverse estimates of carbon storage and sequestration allowing urban planners determine tree management and delivery practices. It is estimated that trees in eleven BIDs stored a total of 8,037.4 tonnes (£482,231.81) of carbon (16.4 tonne /£984.15 per hectare) and sequestered 46.73 tonnes per year (£2795.4) (0.1 tonne/ £5.7 per hectare) in 2016. Among BIDs, Inmidtown BID's trees stored the most, whereas New West End BID's tree stored the least. In terms of gross carbon sequestration, trees in Waterloo BID sequestered the most, whereas trees in Fitzrovia sequestered the least. Interestingly, trees in New West End BID recorded the lowest carbon storage value per hectare but the second largest carbon sequestration value per hectare, even though tree numbers (25) were the lowest among BIDs. This means that species such as callery pear (*Pyrus calleryana*) (84% of the total trees in New West End BID study area), sweetgum (*Liquidambar styraciflua*) (6%), and Norway maple (*Acer platanoides*) (8%) have greater effectiveness in carbon sequestration than carbon storage. Such quantification of the ecosystem service from street trees would allow urban planners or policy-makers to justify investment in more tree management and planting depending on location.

Unlike trees in forests or woodland, as part of urban green infrastructure management, urban tree management requires diverse considerations such as proper location for planting, consideration of appropriate species for maximum benefits, and provision of ecosystem services. Resilience for tree communities, and ultimately to local communities comes from understanding the function and limits of natural resources, along with provision of the consequent ecosystem services. In Chapter 6, green infrastructure management and governance in relation to the All London Green Grid will be handled in the framework of complex adaptive systems, as well as allowing an exploration of more diversified ecosystem service provisions from green infrastructure.

6. Analysis of Governance Innovations in the All London Green Grid

6.1. Introduction

Within the framework of the All London Green Grid, there have been diverse open space management projects (e.g. Bankside Urban Forest project in Southwark Bankside areas, Greenwood Theatre Pocket Park project in London Bridge, The Missing Link project in Vauxhall, and the Rubens Living Wall project in Victoria), led by stakeholders in diverse organisations such as local councils, Greater London Authority, Business Improvement Districts, Forestry Commission, Natural England, Cross River Partnership, among others. Even though each agency has common policy aims, individual organisations have different policy strategies and priorities when developing and implementing projects due to dissimilarities of local governance, socioeconomic conditions, environmental degradation, urban planning and so on. Such different approaches have led to the creation of different and diverse geographical landscape patterns in each borough or locale. Geographical features have guided urban open space planning or related policies. For instance, when it comes to open space strategy in City of London, considering the weekday population in the City of London and the existing low level of public open space, the most proper local standard is ‘the maintenance of the existing City-wide ratio of 0.06 hectares public open space per 1,000 week day day-time population’ (City of London, 2015, p.5). In addition, there are several areas in which open space management and project delivery take place in a more community-led environment, along with supplementary management plans led by councils or Business Improvement Districts.

Considering such complications, in this chapter, research was conducted on the role, status and interactions of each agency or agent, such as policy-makers and business improvement districts, in managing and delivering open space-related policies and projects within the framework of Complex Adaptive System (CAS) theory. Local communities have played a crucial role in the ALGG projects and policy shifts, and the intention of this chapter is to explore this in more depth. Four research objectives were specified, for which the collection of data from interviews and secondary data from documents, pamphlets, reports and webpages was performed. This led to clarification and investigation of stakeholders' intentions, motivations for developing open space projects, and green infrastructure management; as well as consideration of regulating ecosystem services such as carbon sequestration at a political level.

CAS theory arose from complexity theory (Booher and Innes, 1999; Eidelson, 1997; Emison, 1996), and has expanded its relevance from physical to social sciences in areas such as education, economics and spatial planning, focusing in particular on complex non-linear dynamics, uncertainties, and change (Bristow and Healy, 2014b). Even though CAS theory has complex and unstable features, it is not completely chaotic, and leads to social transformation and innovation, influenced by knowledge exchanged by agents (Booher and Innes, 1999). CAS theory is explained in more detail below, but it was considered that its theoretical framework would help to clarify the role and functions of agents or agencies as well as the processes by which agents or agencies respond and adapt to urban climate change impacts in particular. In this chapter, various stakeholder motives and perspectives on open space management, and the function of carbon sequestration in BIDs in the framework of the All London Green Grid were explored. Such efforts provide a good indicator as to whether they are on an appropriate path towards resilience in terms of environmental and socioeconomic perspectives. Such investigations are necessarily preliminary, given the complexity of London's socioecological system, and it is premature to consider the whole system. Investigation of CAS features such as agents, interactions, nonlinearity, system behaviour, robustness and adaptation in the project were conducted rather than modelling the whole system itself, so as to concentrate on the interactions and relationships of most interest in this context (Booher and Innes, 2010).

The remainder of this chapter is structured into five sections. Part 6.2 explains the theoretical framework, defining and exploring CAS, particularly in the realm of environmental policy, before detailing the research objectives of this chapter. Section 6.3 handles data acquisition processes and methods. In Section 6.4, primary and secondary data analysis is detailed. Section 6.5 elaborates shifts, development and patterns of governance found in the ALGG projects, in comparison with governance of previous other open space management projects. The chapter then concludes in Section 6.6.

6.2. Theoretical Framework and Research Objectives

6.2.1. Complex Adaptive Systems (CAS) in Environmental Policy

'Command and control' regulations, also called 'traditional' or 'top-down' and ultimately authoritative control policies, are increasingly recognised as having limitations for environmental triage situations and sustaining environmental improvements (Aalders and Wilthagen, 1997; Stavins, 2000; Tietenberg, 1990). The search for effective management approaches has led to the development of Complex Adaptive System (CAS) theory-based approaches (Emison, 1996) that accommodate diverse, complicated but interconnected demands from different stakeholders. This has largely arisen from the necessity for change in the current environment policy paradigm, from an 'ecosystem equilibrium' view to one that recognises system complexity and nonlinearity. The CAS theory allows ecosystems and resource governance to develop in tandem (Adger, 2000; Bone, 2016; Folke *et al.*, 2005). CAS theory originates from complexity theory, which initially appeared in physics but has become widely used in social sciences, offering opportunities to interpret adaptive governance for resilient resource management (Booher and Innes, 1999; 2010). Representations of CAS have appeared in disciplines such as natural or political ecology, spatial planning, economics and education, among others.

Eidelson (1997, p.43) considers complex adaptive systems to be ‘a large collection of diverse parts interconnected in a hierarchical manner such that organization persists or grows over time without centralized control’. Levin (1998, p.432) defines complex adaptive systems as ‘how complicated structures and patterns of interaction can arise from disorder through simple but powerful rules,’ which leads to other changes. In a later paper, Levin (2003, p.4) characterised complex adaptive systems by three features; ‘diversity and individuality of components’; ‘localized interactions among those components’; and ‘an autonomous process that uses the outcomes of those interactions to select a subset of those components for replication or enhancement.’ The system can also be viewed as an interconnected system in which there are diverse agents showing adaptive reactions to dynamics in the environment and agencies (Choi *et al.*, 2001; Pathak *et al.*, 2007).

Complex Adaptive Systems therefore have several common features, such as components with a common goal (e.g. a particular state or output), indeterminate levels of complication, non-linearity and dynamics, as well as path dependency as a result of non-linearity (Booher and Innes, 1999; Emison, 1996; Levin, 1998). According to Emison (1996), there are lots of components with shared objectives, in the pursuit of accomplishing common outcomes. Along with the complicated interrelationships among components evolving through feedback and learning, unexpected properties (i.e. self-organisation) emerge with wide-ranging and substantial impacts (Booher and Innes, 1999; 2010; Bristow and Healy, 2014a; Emison, 1996; Levin, 1998; Levin, 2003). When understanding the whole system, Emison (1996) suggests either simplifying the system without considering potentially important elements, or observing patterns and behaviours of adaptation, which are influenced by interactions among agents (Booher and Innes, 2010). As complex adaptive systems are non-linear and dynamic, the feature of path dependency emerges as outputs in a system become inputs in another. In the process, CAS become recursive and reflective via feedback loops (Booher and Innes, 2010) as well as dispersed control and decentralization (Bristow and Healy, 2014a).

CAS theory is particularly relevant for environmental management projects. Yet when it comes to application of this theory in environment management projects, different approaches are used. For instance, Booher and Innes (2010) applied CAS theory to examination of outcomes and experiences of a California water management project (CALFED) that ran from 1994 to 2003 with the objective of solving water challenges. They documented complex adaptive system components and various governance innovations emerging from CALFED as ‘patching’ hierarchy or a core-periphery structure, distributed network structure, collaborative interaction heuristics, nonlinear planning method, and self-organizing system behaviour, which conventional bureaucratic procedures cannot bring. Even though it is debatable to what extent CALFED has contributed to the resilience enhancement of water system in California, the emergence of governance innovations in CALFED can be distinguished from traditional environmental governance.

Unlike Booher and Innes, who interpreted governance innovations coming from the CALFED project as emerging from CAS, Bone (2016) used a CAS framework to interpret the Chinese government’s forest policy in terms of process concept. Bone (2016) focused on the four-phase adaptive cycle (exploitation, conservation, release, and reorganization) from the work of Holling

(Figure 6.1.) to indicate how China's forest policy has influenced environmental change during the last century. According to Bone (2016, p.141), the Chinese government's forest policy in two forest reform eras is about increases of system connectedness and (economic) potential in the system, as well as 'a high state of conservation in which the socioeconomic resilience on resource extraction was considerable.' The government has experienced the first reform in which there were massive deforestation practices, while gaining economic benefit but also an increasing vulnerability to natural disasters in the early 1980s. During the second reform there were efforts to protect forested land and increase overall forest biomass through the production of high-yield timber, reforestation and afforestation (Bone, 2016).

The All London Green Grid initiative is still ongoing, and it is too early to determine its outcomes in the framework of CAS, as shown in Bone (2016) and Booher and Innes (2010). Yet, during the interaction processes among agencies and agents within the ALGG initiative in unplanned and unexpected ways like complex adaptive systems, there is some evidence of CAS, such as widespread network systems, collaborative interactions among agencies and agents, nonlinear planning methods, and self-organizing system behaviour. Such features will be identified with case studies from the ALGG initiative in this chapter.

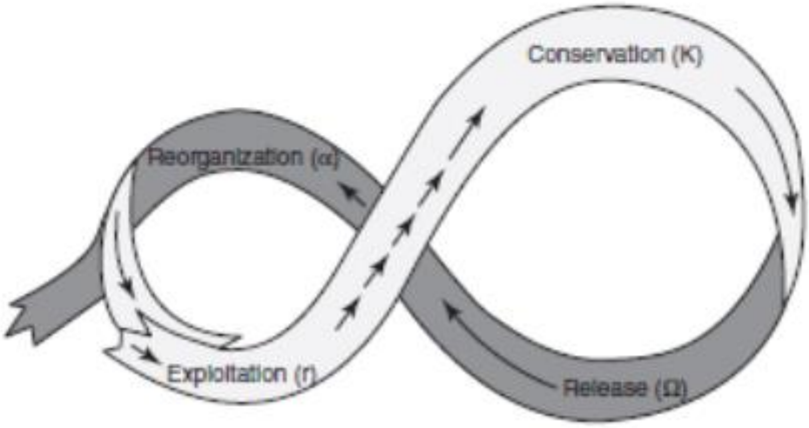


Figure 6.1 The adaptive cycle indicating the four phases of exploitation (r), conservation (K), collapse or release (Ω), and reorganization (α).

The arrows represent rate of change, with smaller arrows indicating slow change (such as the build-up of resources during the conservation (K) phase) and longer arrows indicating more rapid change (e.g. the system collapses and resources are released (Ω)). Reproduced from Holling (2001). © With permission from Springer. (Source: adapted from (Francis, 2017))

6.2.2. Research Objectives

(1) To determine stakeholder perception of the extent to which the All London Green Grid has impacted on resilience to climate change

As indicated in the aims and objectives of the ALGG, connectivity of open spaces is expected to foster resilience to climate change (e.g. lower frequencies of stormwater runoff and reducing urban heat island effects) and bring more economic benefits (e.g. positive effects on house values and more cost-effective control methods). The concept of resilience can also be found in urban planning and management focusing on green infrastructure and its related ecosystem services (McPhearson *et al.*, 2015). In the process of building environmental governance, it is hard to deny that stakeholders, particularly policy makers, play a crucial role in progressing such legally non-binding projects as the ALGG-related projects, so as to encourage participation in the private sector and communities. Even though the ALGG often features a bottom-up approach at a local level, there is still a lack of participation from some Business Improvement Districts and London councils due to low incentives for participation and low awareness of climate change and the benefits provided by ecosystem services. In this sense, the investigation of stakeholders' perspectives on ALGG projects, carbon storage and sequestration, and climate change strategies is a necessary process for figuring out the prospects of the project. In other words, the level of knowledge and recognition of such issues is crucial for estimating the progress and patterns of the project as well as the direction of climate change strategies within the framework of CAS.

(2) To establish the kinds of impacts and influences that participants have on the development of the All London Green Grid project along with climate change resilience policy.

In the CAS framework, levels of knowledge and awareness mostly contribute to building adaptive capacity within the ALGG project. This objective is to establish the ways in which the ALGG project has developed, and how stakeholders have contributed to this development, particularly in relation to climate change impacts. The number, quality, and development of related subprojects under the ALGG framework and climate change resilience will be used as an indicator for considering progress and reflecting on how this may feed into adaptive capacity.

(3) To gain information on stakeholder perceptions of the likelihood and value of ALGG project development, particularly with regard to overcoming governance barriers.

Another indicator for estimating the project's adaptive capacity comes from participants' willingness to continue developing the project and overcome governance barriers. Interviews and document-based analysis would allow some evaluation of how agencies consider and have willingness to further develop the project. Further, it is important to estimate stakeholders' capacity and willingness to develop the ALGG particularly in the pursuit of resilience to climate change. Such features are influenced by the level of finance, political support, public support and awareness, and other externalities. It is meaningful to figure out which factors are the most influential – and which therefore may provide both the most meaningful opportunities and barriers – when they design and deliver policies.

(4) To determine how stakeholders have built governance during the progress of the All London Green Grid.

Governance represents 'structures and processes in which there are accountability, transparency, responsiveness, rule of law, stability, equity and inclusiveness, empowerment, and wise participation', as well as 'the cultural and institutional environment where citizens and stakeholders interact each other and participate in public affairs' (UNESCO, http://www.unesco.org/new/en/education/themes/strengthening-education-systems/quality-framework/technical-notes/concept-of-governance/). According to UNESCO, governance can be interpreted as 'how power is distributed and shared, how policies are formulated, priorities set and stakeholders made accountable.' Specifically speaking, environmental governance can be defined as how the environmental regulation or law or mechanism is set, how accountability and empowerment are distributed and shared among stakeholders who influence environmental actions and outcomes (Lemos and Agrawal, 2006). This final objective is to analyse characteristics and patterns of governance in the framework of the All London Green Grid and try to indicate the governance in the ALGG features a different pattern from previous conventional environment governance. As the Green Grid framework has been developed from the original East London Green Grid, which mainly focuses on regional regeneration, it would be useful to assess how the governance has shifted to the current project.

6.3. Methodology

6.3.1. Process of Interview Data Acquisition

The methodological approach for this chapter was a mixed of desk study and semi-structured interviews with key stakeholders. The initial interview plan was acquisition of 20 interviewees from 7 different kinds of organizations during the period May to September 2016. The criteria for selecting interviewees was that they should hold relevant positions in public organisations involved in the All London Green Grid project, and ideally be responsible for the management of street trees and with an interest in or remit for climate change impacts and adaptation. After selecting potential interviewees and organisations, draft interview questions were prepared.

The interview request email including a brief explanation of the research, a request to clarify preferred interview methods, available dates for interviews, and willingness to participate in interviews was sent in early May. Out of twenty interviewees targeted, nine people from five organisations involved in ALGG-related projects accepted semi-structure qualitative interviews through either e-mail, telephone interviews or face-to-face. Details of interviewees, employed interview modes, and interview date can be found in Table 6.1. On occasions when interviewees requested interview questions in advance so as to give more complete and informed answers, the questionnaire sheet was e-mailed to then. Some potential interviewees did not want to have interviews because they felt they could not address the questions personally but suggested other sources or related information on their organisation’s websites. The interview process can be found in Figure 6.2. Many interviewees wished to remain anonymous.

Table 6.1 Summary of Interviewee, Interview Dates and Methods

Abbreviation for the Interviewees	**Position or Organisation**	**Date of Interview (or Date of Acquisition Interview Answers) and Interview Location**	**Interview Method**	**Speciality/main activities related to the ALGG**
A1	Anonymous	20th May 2016	Telephone	Delivery of local development for urban resilience
A2	Anonymous	25th May 2016	Telephone	Delivery of new green spaces, or new community woodlands in Greater London area
SC (Shane Clarke)	Deputy Chief Executive, London Bridge BID	27th May 2016 (London Bridge BID Office)	Face-to-Face	Delivery of public realm projects, planning, sustainability, environmental management, and resilience
A3	Anonymous	2nd June 2016	Telephone	Contribution to green space creation in Greater London
GM (Gary Meadowcroft)	Tree Services Manager, Southwark Council	7th June 2016 (Southwark Council)	Face-to-Face	Tree maintenance and management in Southwark areas
A4	Anonymous	8th June 2016	Telephone	Delivery of green infrastructure projects in Greater London
PM (Peter Massini)	Urban Greening Team Leader, Greater London Authority	14th June 2016 (Greater London Authority)	Face-to-Face	Green infrastructure and interconnecting policy along with practical delivery in Greater London
A5	Anonymous	13th July 2016	Email	Reviewing the ALGG, Coordination of green infrastructure/biodiversity research
A6	Anonymous	16th September 2016	Email	Necessary information provision for the delivery of green infrastructure in Greater London

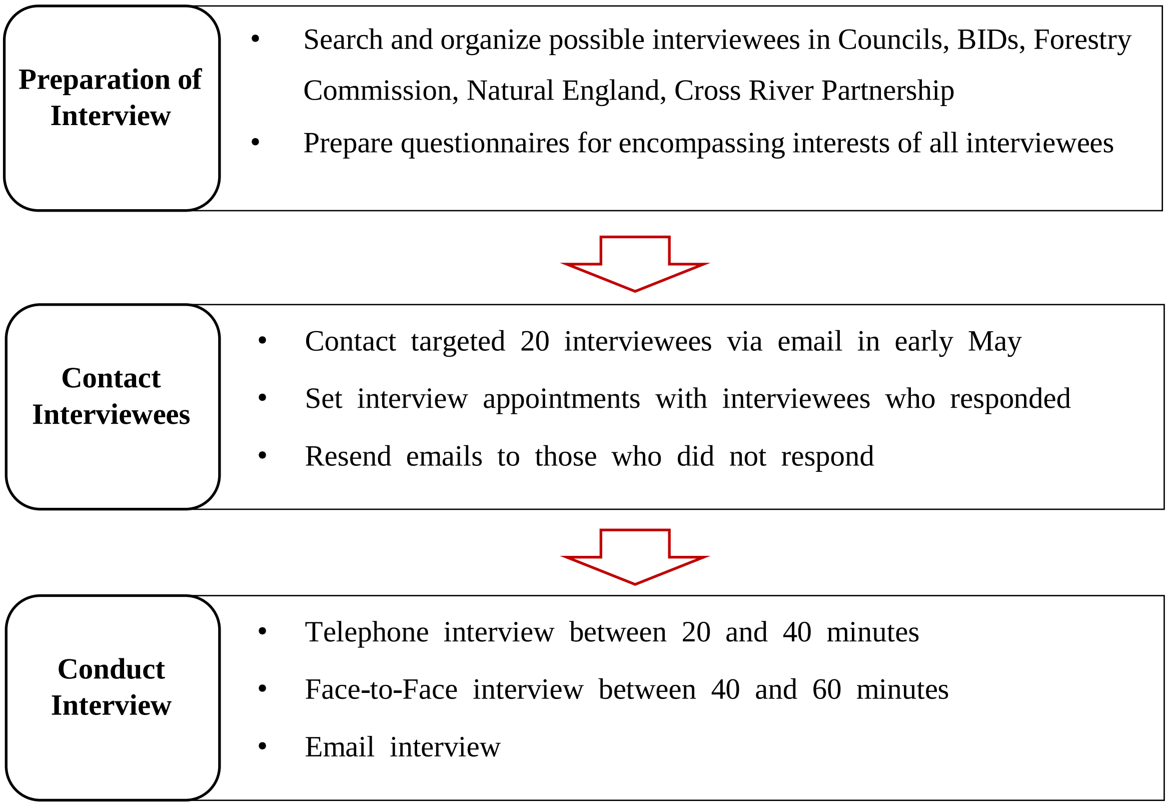


Figure 6.2 Flow Chart of Interview Process

6.3.2. Semi-Structured Interview Methods

Qualitative research methods are the best options for teasing out complicated and sensitive issues (Rakime Elmir, 2011). In particular semi-structured or unstructured interviews are a good means for assessing an interviewee's values, norms and experiences (Stephens, 2007) even though it is time-consuming and labour-intensive (Healey and Rawlinson, 1993). Data collection from semi-structured interviews, particularly on sensitive issues, depends on the researcher's ability to build a relationship with interviewees (Rakime Elmir, 2011) and prepare well for the interview, such as by doing research on a participant's work experiences or accomplishments. The success of interview, in other words, depends on 'the depth and quality of information and experiences revealed by participants' (Rakime Elmir, 2011, p.p.13).

Based on participants' requests, interviews were conducted either face-to-face, by telephone or email. Prior to embarking on the face-to-face and telephone interviews, several procedures were followed to ensure smooth progress. The first step was gaining permission to record the interviews, as some interviewees did not want to be recorded. In each interview, two recording devices were used in order to avoid technological problems. The second step is some introductory remarks to remind participants of the research topic, the interview objectives, structure of interview and expected duration. According to Burke and Miller (2001), effective introductory approaches include: introduction of researcher; identification of the sponsor of research; provision of the general research topic; confidentiality of participants' responses; explanation of how the data will be used; and estimating the interview's length. Having gained permission to record, and following the interview itself, audio records from face-to-face and telephone interviews were transcribed. When conducting such direct interviews, note-taking was utilised but a precisely written form is also required for detailed analysis of participants' perspectives.

Three participants chose face-to-face interviews. A face-to-face interview is the most suitable method for bringing more active interactions between interviewer and interviewee, allowing researchers to obtain more different styles of data than a simple questionnaire or survey (Rakime Elmir, 2011). Even though there can be some limitations such as time and financial investment, difficulty scheduling, and issues around suitable locations, this mode of interview is the most powerful due to its high flexibility. The characteristic of visibility (e.g. nonverbal language and cues) allows researchers and participants to have a closer relationship as well as diverse discussion or debate on other topics beyond prepared interview questions. For instance, after one official interview, the interviewee showed me how the open space management is going, and how the project has influenced various areas in person. The success of this kind of interview depends on the experiences, knowledge and eagerness of interviewees, as well as the experience and preparation of the interviewer.

Four interviewees chose telephone interviews due to geographical and time constraints. Telephone interviews have several strengths in terms of location, time, and financial costs (Stephens, 2007). Yet the influence of the interviewer is more limited than in a face-to-face interview, as interviewees have more control. In addition, this method has less flexibility than face-to-face interviews due to invisibility, or absence of nonverbal language cues, and thus can lower the interaction between researchers and participants. The lack of opportunity for open questioning could lead to shallow and simple information. Thus, this mode requires more preparation from interviewers, so as to draw more responses from participants in order to gain as much diverse data from this kind of interview as the face-to-face method.

Two interviewees chose email interviews due to their geographical limits and time availability. Email interviews have benefits for collecting data on sensitive topics, time management and location-free features. In addition, this mode allows interviewees enough time for full responses, even though it may take more time to receive responses than expected, or participants would change their mind about participating. In this sense, respondents have the most control over the interview. This mode also has the least flexibility, as interviewees would usually respond only to the written questions. Although there are possibilities to communicate or exchange ideas or questions between researchers and participants via email, more detailed and precise questions are strongly recommended to gain full responses.

Three different modes of interview are summarized in Table.6.2. The comparisons among three interview modes are based on Burke and Miller (2001), Oltmann (2016), Rakime Elmir (2011), and Stephens (2007) along with in-person interview experience from the nine interviews.

Table 6.2 Comparisons of three interview modes

	Face-to-Face Mode	Telephone Mode	Email Mode
Interviewer Context			
Time and Financial Costs	Substantial travel and time costs	Less time and lower costs than face-to-face; possibility for difficulty in adjusting interview time in terms of different time zones	Least time and costs than two other methods
Geographical Distribution	Occasional geographical limits	Less limits and easier access than face-to-face	No limits in terms of geographical boundary or time zones
Sensitive Topics	Can be awkward or difficult to progress	Less awkward than face-to-face	Least awkward among three modes
Technology problems	Low possibility of having technological problems except for recording devices	Possibilities of interruption, and recording problems	Few technological barriers
Note Taking	Possibility of being obstructive	Possibility of not being done obstructively	No need
Participant Context			
Scheduling	Possibility of feeling pressure to be available, and having lower dropout rates	Easier to reschedule, avoid time conflicts and cancel as well as less pressure than face-to-face	Flexible; highly dependent upon respondents' availability and willingness
Anonymity or Confidentiality	Dependent on interviewer integrity and data protection	High possibility of remaining anonymous or confidential	High possibility of remaining anonymous or confidential
Sensitive Topics	Possibility of becoming uncomfortable or embarrassed; potential to under-report	Possibility to ease discomfort, and enhance more precise reporting	High potential for disclosing intimate and personal experience to be awkward
Respondent Empowerment	More social pressure than other modes	More control to reschedule and proceed interview; more responsive to setting interview appointments than email	Possible for interviewee to ignore questions

Source: Burke and Miller (2001); Oltmann (2016); Rakime Elmir (2011); Stephens (2007)

6.4. Complex Adaptive System Governance in the All London Green Grid

The All London Green Grid initiative developed from the East London Green Grid planning and regeneration initiative, which started in 2006 and was formally incorporated in the London Plan, an urban regeneration scheme for London. The East London Green Grid was also one of several sub-regional landscape frameworks in the Thames Gateway, Europe and the UK's largest generation project, covering forty miles along the Thames from Canary Wharf in London to Southend in Essex and Sittingbourne in Kent, and pursuing the integration of economic growth into environmental improvement (National Archive 2017, no page). The East London Green Grid had the following aims (GLA, 2008, p.8):

- provide guidance on the implementation of policies in the London Plan to boroughs, partners and developers;
- set out a vision and spatial framework, of promoting cross boundary partnership working across 6 area groups within the sub-region;
- provide advice on delivery, of identifying the range of functions and benefits
- identify the deficiencies in the provision of public open space and in access to nature, and of identifying strategic open space opportunities.

The All London Green Grid Supplementary Planning Guidance (2012) follows the same concepts (e.g. multifunctional green infrastructure as means for providing such diverse ecosystem services for recreational purposes, access to nature, diverse biodiversity and adaptation to and mitigation of climate change impacts) as the East London Green Grid SPG. However, as it covers the whole of Greater London, the ALGG's aims are more general, focusing on the extension of green networks and the subsequent benefits that accrue. Some issues such as land ownership and security of project finances have become difficult to handle, and the ALGG incorporates a more complicated and complex network, consisting of a huge number of agencies and agents. This network is now explored in more detail.

6.4.1. Agency and Agents in the All London Green Grid

Complex adaptive systems can be interpreted as a kind of governance requiring interactions between diverse stakeholders. The crucial role of agencies and agents interacting with each other in complex adaptive systems is continuously reviewed as they 'evolve through feedback and learning' (Bristow and Healy, 2014a). Compared to the East London Green Grid, the All London Green Grid requires more diverse and extensive partnerships. The East London Green Grid partnership encompasses diverse stakeholders such as central government, the Greater London Authority, City of London, London Development Agency, Department for Communities and Local Government, Natural England, Environment Agency, London Thames Gateway Development Corporation, Bexley Regeneration and Woolwich Regeneration Partnerships, and ten London boroughs (National Archives 2017: http://webarchive.nationalarchives.gov.uk/20110118113709/http://www.cabe.org.uk/case-studies/east-london-green-grid; GLA, 2008). The successful delivery of ALGG visions requires a broader range of diverse participation from stakeholders such as public agencies, private agencies, volunteers and London Boroughs (Councils). Transport for London, Environment Agency, Natural England, Forestry Commission, English Heritage, Groundwork London, London Wildlife Trust, Greenspace Information for Greater London (GiGL); Business Improvement Districts and Cross River Partnership; and volunteers with community ownership of assets and neighbourhood planning are also involved. Key agencies and their roles within the ALGG are now examined in more detail

Greater London Authority is one of the most important agencies as it provides guidance for planning green infrastructure as well as general and detailed strategies and aims on the basis of data and knowledge on the likely climate change impacts that London is to experience at diverse scales. As interviewee A5 commented,

> we know the likely impacts of climate change on the city, e.g. in terms of overheating, rainfall, drought, etc. And we are in the process of gathering data on what that is likely to mean at a finer scale, e.g. Borough level or finer. Our general aim is to increase the resilience of the city to these risks. This may be in the form of grey infrastructure (e.g. Thames Tideway Tunnel) and/or green infrastructure (e.g. green roofs). In terms of green infrastructure, we aim to increase the amount, quality, and functionality of green spaces across the city. This will be reflected in the proposed London Environment Strategy, which will bring the existing statutory and non-statutory environment strategies together into one document (subject to an Environment Advisor being appointed and approving this).

In particular, the guidance such as the Supplementary Planning Guidance to the London Plan (e.g. the ALGG, London's Foundations for the London Geodiversity Partnership and Sustainable Design and Construction) can become criteria for other agencies and agents to evaluate projects or development proposals against (Jones and Somper, 2014). Though limited, such supporting capabilities were highlighted in the interview with Pete Massini, GLA's Green Infrastructure Principal Policy Officer:

> GLA does not have direct delivery capacity because it's the boroughs who own and manage the land in London [but it can try to] make sure that when the boroughs do project, they are doing the project in a more joined-up way.

As ***Borough Councils*** have land ownership, their role is the most crucial in delivering the ALGG initiative. When leading on green infrastructure, such local authorities take action: 'development of green infrastructure strategies for preventing floor risk and urban heat island, and providing spaces for trees, and walking and cycling; working with local strategic partnerships (e.g. planners, regeneration officers, tree officers, landowners, education and health officials, etc.); creation of local area agreements related to climate change adaptation and mitigation; and use the planning system to have impacts on urban restructure and security of funding for space management' (National Archive 2017: http://webarchive.nationalarchives.gov.uk/20110118130044/http://www.cabe.org.uk/sustainable-places/green-infrastructure/leadership). Each borough council has policies and strategies for maintaining and promoting open spaces which are specified in Development Plan Documents (DPDs). The Documents are in line with the Government's National Planning Policy Framework (NPPF) which provides guidance for councils to produce the Documents. The Documents should entail consultation with local communities and an examination from an independent Planning Inspector (https://www.kingston.gov.uk/info/200157/planning_strategies_and_policies/285/development_plan_documents).

Transport for London (TfL) plays a role in helping to improve air quality and noise issues and published its sub-regional Transport Plans in 2010 in partnership with the Mayor's Air Quality Strategy (supported by the Mayor's Transport Strategy). TfL is also involved in landscape management. There are several green transport link projects for delivering the ALGG initiative. For instance, Legible London, a programme to encourage people to walk around Greater London, in cooperation with local boroughs, BIDs, and other landowners, and Strategic Walk Network, a programme consisting of seven routes such as The Capital Ring, the London LOOP, the Green Chain, the Jubilee Walkway and Jubilee Greenway, the Thames Path and the Lee Valley, established by Walk London and funded by TfL.

Greenspace Information for Greater London (GiGL) helps the ALGG initiative to identify locations with deficiencies of green infrastructure, and so the potential for building green networks. In this sense geographical data plays a crucial role in allowing potential projects to be identified as well as aiding the progress and realisation of existing projects. In other words, the formation of an evidence base for the ALGG depends on accurate and up-to-date information, provided at least in part by the GLA (GLA, 2012). As an environmental data provider, and data analysist, their database covers species, habitats, open spaces and other green infrastructure in Greater London. This environmental data centre for Greater London leads the ALGG Evidence Partnership, and it is chaired an ALGG Evidence Base group, providing a great number of datasets for providing the formation of the ALGG areas and strategic links. Green infrastructure information from GiGL was used extensively in Chapter 4.

Business Improvement Districts (BIDs) can play a role in encouraging more participation from industry, government and NGOs in their local areas, so as to do extensive infrastructure projects. Peter Williams, CEO of Better Bankside BID, described that BIDs allows businesses 'the means of identifying and funding priorities for the place where they are located. They are a powerful tool for directly involving local businesses in local activities and allowing the business community, local authorities and other stakeholders to work together to improve the local environment. Through aligning the interests of these different sectors, BIDs can realise new forms of resource to aid cities' liveability [sic.]' (pbctoday, 2017, http://www.pbctoday.co.uk/news/planning-construction-news/business-improvement-districts-regeneration/29482).

Their motivations for developing the ALGG related projects are different, and geographical and economic situation also contributes to differences in project implementation. For instance, Baker Street Quarter Partnership BID focuses more on air pollution improvements (via means such as emissions-based parking charges, and installing more electric vehicle charging points) and building partnerships (e.g. Marylebone Low Emissions Neighbourhood, building a partnership with Westminster City Council, businesses, residents, TfL and other organisations in Marylebone) (Baker Street Quarter Partnership homepage, http://www.bakerstreetq.co.uk/services-and-projects/article/better-air-quality/) rather than benefits from green infrastructure. Such a lack of green infrastructure benefits also comes from the fact that management of green infrastructure in the area is of the responsibility of the borough council. As the land for green infrastructure mostly belongs to the council, conflict between the council and the BID is not found. The BID focuses more on regulation of air quality through traffic reduction (e.g. Baker Street Two Way Project as described in the interview with A1), but this BID does not deny the positive roles of trees and urban green infrastructure in terms of local and regional air quality (e.g. temperature reduction and removal of air pollutants, energy consumption impacting from presence of trees (Arestis *et al.*, 2015). Rather, they are willing to be involved in greening the BID, for example in installing more green infrastructure and trees in collaboration with Westminster City Council (Arestis *et al.*, 2015). Other BIDs such as Team London Bridge, South Bank, Victoria, and Vauxhall actively participate in managing and delivering green infrastructure in their areas. The initial motivation for BIDs to take action is to allow residents to enjoy a more pleasant environment. In this sense, it can be inferred that such different patterns would arise from the aspirations of each local community.

Cross River Partnership is a voluntary association comprising of agencies from local authority, business organisations and other strategic agencies in London, building a public-private partnership for delivery of regeneration projects in London. This association has close relationships with 18 BIDs in Inner London to handle green infrastructure issues through collaboration, fundraising and strategic support for installing small-scale green infrastructure such as pocket parks, green walls, green roofs and rain gardens (e.g. delivery of 117 green infrastructure in the four years to March 2016), so as to follow the ALGG initiative (Cross River Partnership, 2016; Estates Gazette, 2016). Funding for delivering projects has several sources. During 2016/17, for instance, they anticipated funds from the European Social Fund, Job Centre Plus, landowners, local authorities, the London Enterprise Panel, Mayor’s Air Quality Fund, New Homes Bonus, Section 106 Planning Gain, Seventh Framework Programme, Transport for London, and URBACT (Cross River Partnership, 2016). During 2017/18, it expects to receive funding from BIDs, central Government departments, employers, Greater London Authority, Job Centre Plus, landowners, local authorities, the London Enterprise Panel, Mayor’s Air Quality Fund, New Homes Bonus, Section 106 Planning Gain, Seventh Framework Programme, Transport for London, and URBACT (Cross River Partnership, 2017).

The Environment Agency is a non-departmental public organisation with sponsorship mostly from the Department for Environment, Food and Rural Affairs (DEFRA). Its remit is mostly on environmental protection and enhancement in England as well as flood and coastal risk management. It plays a regulating role for maintaining the quality of air, land and water. In this sense, the EA’s role in the ALGG related projects cannot be limited to one specific position but relates to several different elements. ***Natural England*** is also an independent public agency sponsored by DEFRA. Their responsibilities are ‘promoting nature conservation and protecting biodiversity; conserving and enhancing the landscape; securing the provision and improvement of facilities for the study, understanding and enjoyment of the natural environment; promoting access to the countryside and open spaces and encouraging open-air recreation; and contributing in other ways to social and economic well-being through management of the natural environment’ (Natural England, https://www.gov.uk/government/organisations/natural-england/about). Its activities cover provision of funds to green infrastructure projects through local regional partnerships as well as promotion of the green infrastructure concept for facilitating public recognition that green infrastructure is also an important component in urban regeneration. The ***Forestry Commission*** is a non-ministerial government department with different remits such as a legal statuary obligation (e.g. the Forestry Act), to provide forest services for sustainable land management, and forest research. As a case study of their involvement in the green infrastructure projects, there is a RE:LEAF Programme for tree planting promotion and woodlands improvement across Greater London, supported by the Mayor of London. According to interviewee A2, their role is basically delivery of green spaces while contributing to some outcomes of the ALGG project, as well as its related research. And interviewee A2 commented on the method of contribution from a delivery perspective that they,

> …contribute to the project by working with landowners and metal extraction companies in this area, to try and secure those sites for long-term public access and the creation of woodland onto those resulting, restored sites.

English Heritage is a charity that manages historic buildings, monument and sites in England, but it used to be a non-departmental public agency. It provides grants or funds to developers to progress green infrastructure projects in some areas or conduct green infrastructure audits to evaluate ecosystem services. Groundwork is a national charity working with communities to help them to create better living conditions and places, but in the ALGG initiative, ***Groundwork London*** participates in several green infrastructure projects by providing landscape design, volunteering, and geospatial and data services. For example, in the Climate Proofing Housing Landscapes project in Hammersmith & Fulham and Drain London, Groundwork and the European Commission have cooperated. ***London Wildlife Trust*** is part of the Wildlife Trusts, the UK largest voluntary organisation conserving the UK's habitats and species, and a charity for protecting the wildlife and wild spaces in the city, as well engaging with diverse communities through nature reserves, campaigning, and volunteering.

6.4.2. Interaction and Nonlinearity in the All London Green Grid Network

Traditional environmental governance generally utilises command-and-control and market-based instruments (e.g. eco-taxes, government subsidies, and cap-and-trade). The command-and-control policy instruments in governance have been favourably used on the basis of three conditions: obtaining sound information for policy-makers; low possibility of government failure; and positive outcomes from imposing standards on polluters (Hepburn, 2006). In a new form of environmental governance, information-based instruments (e.g. EU eco-labelling) and voluntary regulations (e.g. ISO 14000 environmental management standard) have gained status as powerful means for engaging more stakeholders and encouraging them to take *voluntary* action for environmental improvements. The UK has already taken on more 'integrated regulatory and permitting policies with cooperative initiatives between the government and policy' (Fiorino, 2006, p.4), and more collaborative and nonlinear structures in environmental governance.

Bauer and Steurer (2014) explore this, noting that English regional climate change adaptation partnerships (e.g. Climate South West, Climate South East, London Climate Change Partnership) have a feature of stakeholder-led partnership governance with 'bottom-up' organisations, whereas Canadian adaptation partnerships (the Regional Adaptation Collaborative Programs such as Preparing for Climate Change: Securing British Columbia's Water Future, Prairie Regional Adaptation Collaborative, and Atlantic Climate Adaptation Solutions Project) feature more a top-down approach and hierarchical steering. In other words, English partnerships feature more collaborative interaction, and nonlinear planning and feedback. Information is a huge contributor to building a collaborative interaction in a governance system. It should freely flow in the governance system, so as to increase certainty when problems occur (Green *et al.*, 2016). Interactions occur when there are information and energy exchanges on the basis of heuristics that locally organise the interactions among agents, bringing widespread effects and system memory as a result (Booher and Innes, 2010). Nonlinearity refers to 'the fact that the local rules of interaction change as the system evolves and develops', which brings out *path dependency* (Levin, 1998, p.433). As the behaviours in a complex adaptive system come from 'the complex interaction of loosely coupled variables', these behaviours shows a non-linear response to changes, meaning large changes as input but small changes as output, and vice versa (Choi *et al.*, 2001, p.356). Such governance featuring these characteristics is regarded as 'new governance' or 'network governance' as it brings partnership formations requiring participation from state, business and local communities (Bauer and Steurer, 2014).

The ALGG network also displays such bottom-up governance. Prior to the creation of interactions, guidance allows agencies and agents to set their own strategies in a more harmonised way. According to the former Mayors of London, Liane Harris in the East London Green Grid Framework Supplementary Planning Guidance foreword, and Boris Johnson in the All London Green Grid Supplementary Planning Guidance foreword, the role of Supplementary Planning Guidance is to provide 'direction on where and how the Green Grid should develop, and describes how to integrate open space networks into planning the regeneration of East London' (GLA, 2008, p.5), and 'to explain how the planning process can help to deliver some fundamental principles' (GLA, 2012, p.8), as set out in the ALGG SPG. Such a non-statutory approach can become a double-edged sword when it comes to further development of the ALGG initiative. If agencies and agents cannot find economic arguments or do not have strong local support for conducting green infrastructure projects, they can be dropped from local plans.

Yet if they find economic and environmental stimuli for keeping the projects, it is possible to attract more stakeholders.

The local partnerships in the East London Green Grid were reinforced after the production of Area Frameworks presenting the local geography and cross-boundary working for proceeding projects, though some previously set priority projects in the Lee Valley were removed due to the initiative's timescale (National Archive 2017, http://webarchive.nationalarchives.gov.uk/20110118144640/http://www.cabe.org.uk/case-studies/east-london-green-grid/evaluation). Such local partnerships also work in the ALGG, but formally there is no third party or institutions to monitor or evaluate the process and outcomes of the ALGG related green infrastructure project, except for a quarterly meeting of stakeholders. Interviewee A5 commented on how it works in the ALGG:

> Each of the eleven Green Grid Areas has developed an Area Partnership and produced an Area Framework containing information on the local context of the Area and projects that are identified as necessary to deliver the ALGG. There is no formal monitoring or evaluation mechanism: there is a quarterly ALGG meeting convened by the GLA to share best practice and aid in problem solving. The ALGG's evidence base is currently under review and so the monitoring situation may change in future.

In order to bring a more harmonised collaborative partnership among agencies and agents, the ALGG should meet objectives of such strategies and proposals as Open Space Strategies, Tree and woodland Strategies, Development Planning Frameworks in relation to Green Grid Area Frameworks and Open Space Strategies, Development Plan Documents, Supplementary Planning Documents, Area Action Plans, and Neighbourhood Plans (Figure 6.3). In addition, such detailed planning and policy mechanisms as local nature partnerships[32] (LNPs), the

[32] Local nature partnerships are 'stakeholder partnerships that drive local development decisions by helping decision makers to positively manage the environment', and the London LNP allows communities and conservationists to have a forum for promoting biodiversity and green spaces in the Greater London. Jones, Sarah and Somper, Carol

Community Infrastructure Levy [33], Section 106 agreements [34], strategic environmental assessments[35] (SEAs) and environmental impact assessments (EIAs) can encourage more active partnership with stakeholders (Jones and Somper, 2014).

Figure 6.3 Planning Policy Framework (Adapted from GLA (2012))

(2014). The role of green infrastructure in climate change adaptation in London. *The Geographical Journal* **180**(2): 191-196..

[33] The Community Infrastructure Levy is 'a planning charge, introduced by the Planning Act 2008 as a tool for local authorities to in England and Wales to help deliver infrastructure to support of the development of their area' (Planning Portal, 2017, no page, https://www.planningportal.co.uk/info/200126/applications/70/community_infrastructure_levy). Landowners are responsible for the levy, but any stakeholders are liable for payment of the levy if they are involved in development (UK Government, 2017, https://www.gov.uk/guidance/community-infrastructure-levy)'

[34] Section 106 is 'an agreement made under section 106 of the Town and Country Planning Act 1990 between a local authority and developer. The agreement will contain a planning obligation to enable the local authority to secure, or the developer to offer, restrictions on the use of the land or the operation of the development or to make contributions towards the local infrastructure and facilities.' (Thomson Reuters Practical Law, 2017, no page, https://uk.practicallaw.thomsonreuters.com/2-381-9662?transitionType=Default&contextData=(sc.Default)&firstPage=true&bhcp=1)

[35] Strategic Environment Assessments are 'environmental reports on the proposed revocation of the regional strategies. It is the government's policy to revoke existing regional strategies outside London. However, any final decision on this must take account of assessments of, and consultation on, the possible environmental effects of revocation of each of the existing regional strategies.' (UK Government 2017, https://www.gov.uk/government/collections/strategic-environmental-assessments)

The collaborative interaction among agencies shows a nonlinear pattern as in Figure 6.4, which displays simpler interactions than the reality. There are more agencies and agents to be considered and counted in the real network, as the ALGG initiative has been conducted primarily at a local scale in Greater London. Even though it is not easy to draw clear flows of interaction among stakeholders, it is obvious that there is nonlinear feedback obtained from published reports, green infrastructure project-related meetings and seminars, and so on. Such feedback can be more influential in some areas than others depending on local conditions. In other words, collaborative interactions do not occur in a closed system, but in a more open-ended way through meetings, seminars, and events related to delivery and management of green infrastructure (e.g. Greater London Authority's Green Infrastructure Event, London Tree Officers Association led seminars or events). In terms of the cooperative interactions among the GLA, BIDs, and the Cross River Partnership, interviewee A5 commented;

> The Cross River Partnership engages with many BIDs on green infrastructure issues, and several BIDs (particularly Team London Bridge) host events that showcase best practice. The GLA has previously directed its BID funding towards the commissioning of green infrastructure audits for central London BIDs, as this is often where the greatest need for green infrastructure is. However, now that many central London BIDs have undertaken these audits, our focus is moving towards the outer London BIDs. The CRP's Greening the BIDs publication and video are also useful in engaging other BIDs with the greening agenda.

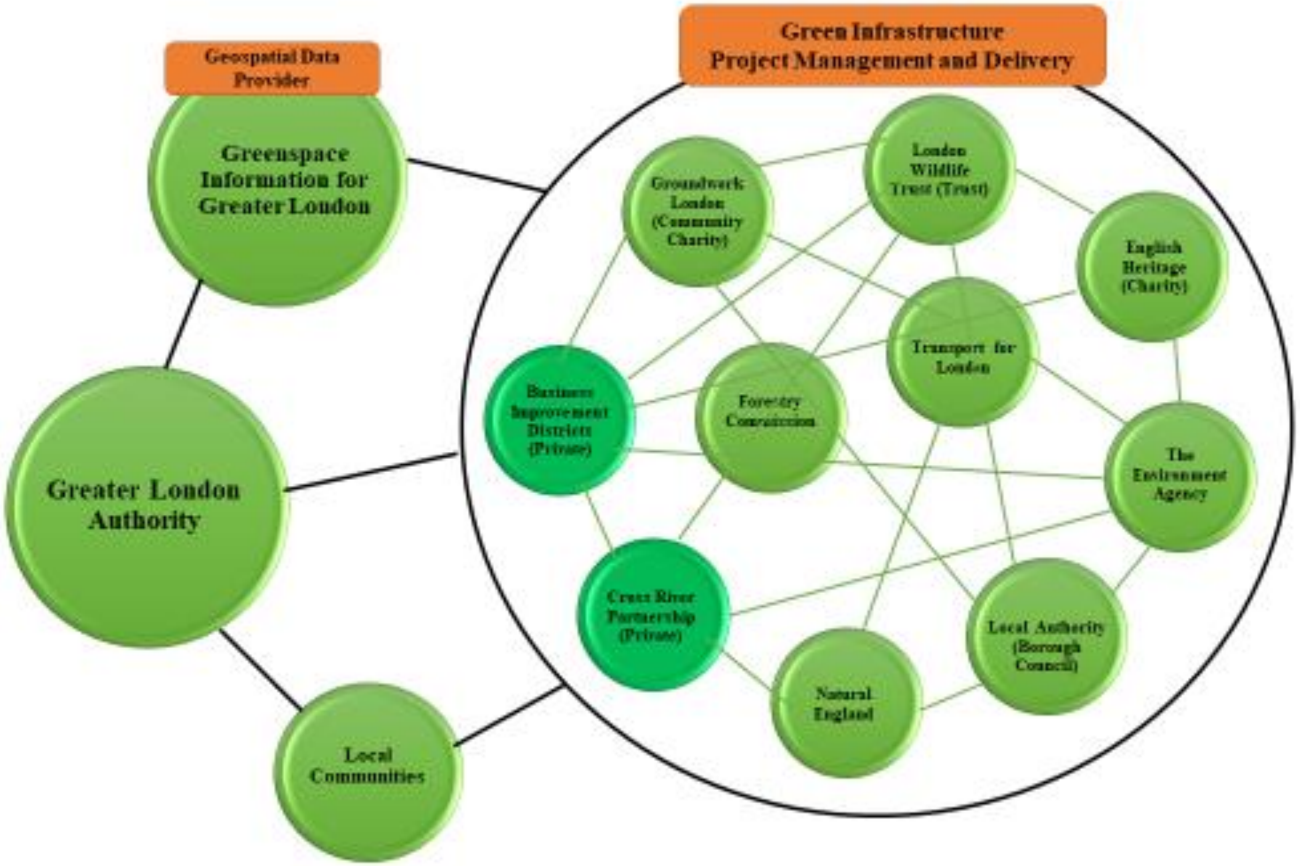


Figure 6.4 Collaborative and Nonlinear Interactions among Key Agencies of the ALGG initiative

Figure 6.5 Lavender field in Tower Bridge junction with Queen Elizabeth Street, in Team London Bridge BID area

(Source: Author)

The London borough councils have their own green infrastructure strategies for urban greening, and some of them closely cooperate with some BIDs (e.g. Southwark Council with Team London Bridge and the Better Bankside BID or Victoria BID), other public and private agencies, and volunteers for filling green-deficient areas. Such collaborative interactions can be found in Team London Bridge's green infrastructure projects, such as landscape planting in Tower Bridge Road junction with Queen Elizabeth Street, and the Street Trees project in the London Bridge area. As seen in Figure 6.5, lavender field was planted in 2013 on the derelict site on Tower Bridge Road in partnership with Natural England (funder), the City of London, St. Mulgo's Putting Down Roots, volunteers, Southwark Council and Team London Bridge. The installation of green infrastructure provides a cultural ecosystem service which residents and visitors can enjoy, as well as habitat or supporting ecosystem service which provides a foraging space for bees and invertebrates. Such positive feedbacks from local communities, and benefits from the enhancement of biodiversity, allows stakeholders to more readily build another governance network for proceeding other green infrastructure projects

Figure 6.6 White's Grounds Community Garden in Team London Bridge BID area

(Source: Author)

The BIDs also try to engage with the local communities to encourage participation and interest in green infrastructure in their areas as well as reminding people of the benefits of such infrastructure. Through such cooperative interaction, BID teams can acquire more detailed information on local communities and build trust with each other as well as providing the local community with green infrastructure management knowledge, which allows BIDs and local communities to reduce future management costs for green infrastructure. For instance, Team London Bridge conducted a community gardening project with residents in White's Ground Community Garden, while educating them how to manage the garden as well (Figure 6.6). In addition, this Community Garden built stronger communities during the process.

Another collaborative interaction was found in the Living Wall at The Rubens at the Palace (Figure 6.7) in the Victoria BID area, covering 350 square metres with total of 10,000 native herbaceous plant species, as this project required diverse stakeholders, and further encouraged more installations of this type of wall on buildings in central London, on the basis of its proven multi-functionality. It was designed by Gary Grant of Green Roof Consultancy, and installed and maintained by TreeBox Ltd, supported by Greening the BIDs programme of the ex-Mayor of London Boris Johnson with the coordination of the Cross River Partnership (De Zeen, 2017 https://www.dezeen.com/2013/08/21/londons-largest-living-wall-will-combat-flooding/). It was selected as a suitable location during the Victoria BID Green Infrastructure Audit, which aims to outline multi-functional benefits of green infrastructure to society, economy and the environment, as well as identifying opportunities for improvement and increase of green infrastructure. The Wall provides supporting, regulating and cultural ecosystem services such as attraction of insect pollinators and wildlife habitat, improvement of air quality (e.g. trapping microscopic pollutants), minimisation of the hotel's impact on the environment, pleasing aesthetics and finally economic benefits for the hotel (e.g. energy costs reduction from cooling in summer and warmth in winter) (Rubens Hotel, 2017 https://www.rubenshotel.com/about/the-living-wall). This wall also has 'irrigation tanks to rainwater harvested from the roofs' for handling drainage and reducing the surface water flooding risks in the neighbourhood (Tree Box, 2017 http://www.treebox.co.uk/news/rubens-at-the-palace-hotel-unveils-one-of-londons-largest-and-most-colourful-living-walls.html).

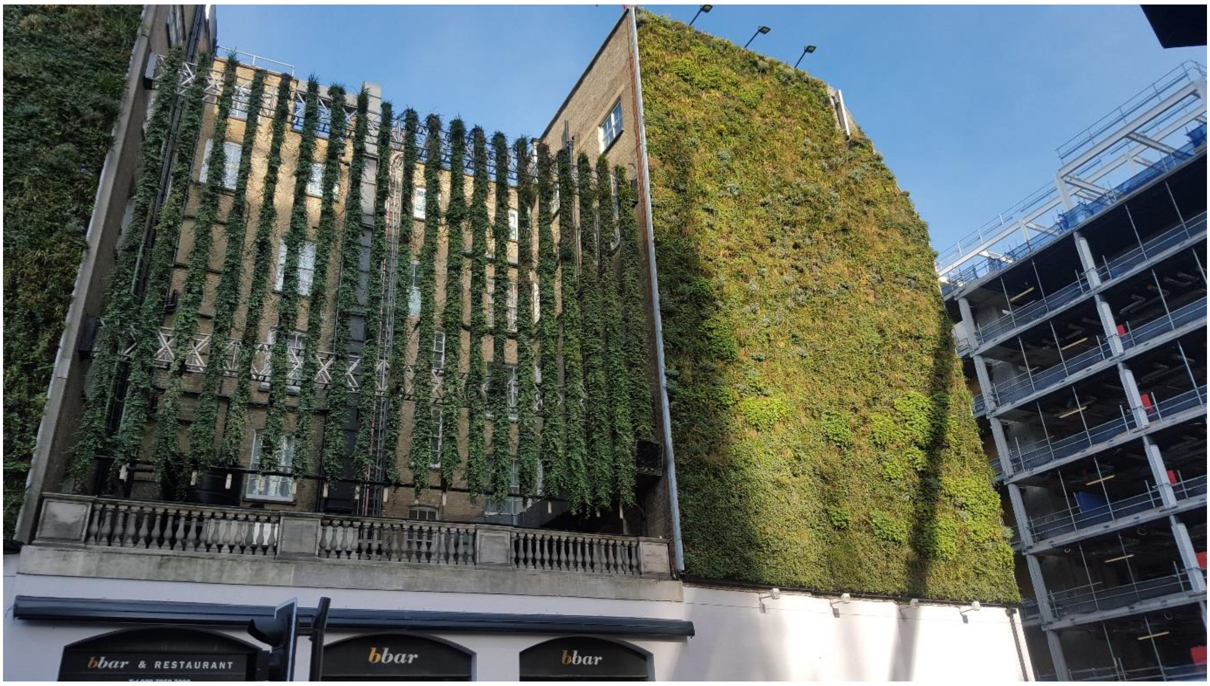


Figure 6.7 Living wall on the side of The Rubens at the Palace Hotel, in Victoria BID area
(Source: Author)

6.4.3. Self-Organised System Behaviour and Adaptation

The All London Green Grid system behaviour features of self-organisation after the cooperative and nonlinear interactions among stakeholders involved in their own urban green infrastructure projects. Self-organisation is ‘a process where new structures, patterns, and properties emerge without being externally imposed on the system’, coming out of interactions between entities, and between environments (Barton, 1994; Eidelson, 1997; Pathak *et al.*, 2007, p.550). It spontaneously appears from the ‘bottom-up’ by interactions and decisions among agents while continuously building its adaptive capacity (Bristow and Healy, 2014a). The starting point is the necessity of regenerating East London area, and motivation for keeping the initiative going have come from the willingness of diverse agencies from the Greater London Authority, local councils, Cross River Partnership to BIDs to be involved.

Monitoring processes, and socioeconomic and ecological factors in an initiative are essential for ‘providing system feedbacks and informing adaptation’ (Green *et al.*, 2016, p.86). There is no official monitoring system or mechanism in the ALGG initiative, but agencies and agents autonomously monitor and evaluate each other when conducting small-scale green infrastructure projects. In addition, the East London Green Grid initiative has fulfilled its role in providing a networking for knowledge generation and information sharing from all stakeholders, as well as criteria for estimating the related green infrastructure project’s feasibility and effectiveness. This kind of forum and criteria are not formerly set, but agencies and agents have self-organized behaviour within their own differentiated governance when progressing each green project with different agencies and agents. For instance, through greening the BIDs programme under the ALGG policy framework, the Greater London Authority worked in partnership with businesses and the Cross River Partnership for auditing green infrastructure in 15 central London BIDs, which brings “a technical and informed document talking about ecosystem services" (Interviewee SC from London Bridge BID). According to the interviewee SC, in addition, there is the Green Network in which around 60 people meet and talk about diverse environment issues and ecosystem services every three months or quarterly. There is also the London Tree Association to which most boroughs belong, and in which tree managers or tree related organisations (e.g. people from the London Wildlife Trust, Friends of Groups for open spaces, local community groups) "discuss urban tree management, urban tree planting, pest and disease and i-Tree CAVAT (Capital Asset Value Amenity Trees)", as well as discussing "management ideas and even to benchmark against certain boroughs, what other boroughs are doing, what money they have and how it's invested. I would say that a lot of what we do is using each other's models and ideas and looking at what works" (Interviewee GM, Tree Services Manager, Southwark Council).

Yet there are common barriers to be continuously overcome for continuing green infrastructure or open space projects under the ALGG initiative. Ekstrom and Moser (2013) found several barriers to adaptation in five cases in the State of California such as City of Hayward, City and Country of San Francisco, County of Marin, County of Santa Clara and Bay Area Joint Policy Committee. The most common barriers to adaptation are related to institutional and governance issues such as poor coordination driven by sector-based structure of agencies, legal barriers and limited jurisdictions, followed by such barriers as

> attitudes, values, and motivations like lack of interest, status-quo mind-set, inability to accept change, narrow self-interest that hinders or delays adaptation processes from advancing, and resource and funding issues driven by the economic crisis of recent years, inaccessible funding sources, and cuts with implications for staff [also] […] lack of political will and rivalry.
> (Ekstrom and Moser, 2013, pp.102-103)

Such barriers can determine attitudes or strategies of agencies and agents towards green infrastructure projects. As for continuing ALGG-related projects, seven interviewees named funding as the biggest barrier followed by political willingness to proceed such projects. Comments included:

> capital and revenue funding (for creation/enhancement and long-term maintenance); lack of staff (either in local authorities or amongst contractors) with the required skills and knowledge; development pressure (increases the cost of land for green space creation, and increases pressure to build on existing green spaces); lack of time, resources, an sometimes permission (there can be a culture of just getting things done), to think creatively about how to deliver multifunctional green spaces, that not only cater for recreational needs but also for climate change adaptation (interviewee A5)

> Largely political will to grant planning applications for mineral extraction companies to re-restore pieces of land in this area. We face funding issues. (Interviewee A2)

> one of the issues that still is quite difficult to overcome is that most stuff in terms of infrastructure benefits, they are long-term benefits, which are less easy to get people to accept and buy into than short-term benefits. (Peter Massini, GLA)

Security of financial incentives or funds from several sources allows planners to progress more projects. As mentioned, funding is mainly from local authorities as they are the landowners who want to see their neighbourhood more physically and economically attractive, and can provide BIDs with their Planning Commission and their permission via partnerships (Interviewee SC from London Bridge BID). However some projects require investment from the private sector as many small-scale green regeneration projects are also connected to business sustainability strategies. According to the UNFCCC (2007), even though it is difficult to estimate the adaptation costs to climate change impacts due to its widespread and heterogeneous measures, securing public or private funding is crucial for supporting responses to climate change impacts, particularly highlighting the role of private sector investments, which would consist of 86% of the whole international investment and financial flows. In other words, the influence of the private sector is profound for building public climate governance (Bulkeley and Newell, 2015) .

The involvement of the private sector is found in the All London Green Grid initiative. Compared to economically-focused regeneration projects, the ALGG initiative is facing difficulty attracting more investment from boroughs and central government agencies, as visible economic and environmental impacts sometimes require at least 10-20 years to emerge, depending on local conditions. As a representative of private stakeholders in local areas, BIDs have brought good business cases and more sound economic arguments as to why green infrastructure should be invested in), along with support from Greening BID programmes supported by the GLA. Besides BID-led green infrastructure projects, other kinds of collaborative network governance have been naturally formed due to the necessity to restore and conserve nature or handle threats from climate change. For instance, the redevelopment project of a nature reserve, Woodberry Wetlands, conducted by Berkeley Homes, London Wildlife Trust, Thames Water, and London Borough of Hackney brought rich and diverse wildlife and public access to nature. As a climate change adaption solution for existing social housing landscapes, Climate Proofing Housing Landscapes (partnership of Groundwork, London Borough of Hammersmith & Fulham, Drain London, European Commission) showed how 'retrofitting open spaces on housing estates (e.g. incorporating green roofs and integrated Sustainable Urban Drainage Systems) can be a cost effective solution to improving London's resilience to climate change', along with other notable outcomes such as 100% of rainfall being diverted from storm drain systems, 89% of rainfall landing on green roofs absorbed, job creation, trees, shrubs and hedges, and food growing beds planted, as well as active participation from local residents (https://www.groundwork.org.uk/sites/urbanclimateproofing and https://www.groundwork.org.uk/Sites/urbanclimateproofing/Pages/ucp-evaluation)

As an alternative to overcoming finance issues, as Peter Massini mentioned in his interview, "the creation of a compelling economic argument about why you invest in parks" should be suggested by developing strong business cases for investment in green infrastructure. For instance, even though it is not enough to give a business case, an i-Tree report for Greater

London allowing people to understand the value of young forest in terms of regulating ecosystem series or the Green Infrastructure Audit in BIDs identifying green infrastructure within the boundaries can play a role as a raising awareness tool. Peter also indicated the GLA's efforts to secure more funding, arguing that,

> We are now trying to develop things like natural capital accounting and ecosystem services, to say actually investing in parks isn't just about making the place look nice. It's about fundamental things like climate change mitigation, better green travel, walking and cycling, which has an economic benefit rather than just being something that's nice.
>
> When people are making their arguments for a budget at a local authority, they've now got this evidence to say if you provide this service and you fund these programs, these are the long-term economic benefits.

When creating and increasing green infrastructure in public land, considerable financial and physical issues should be resolved as well. Planting street trees represents a good example. Traditionally trees have been regarded as a good means for physically connecting green spaces, creating habitat corridors through the landscape (Manning *et al.*, 2006; Rossi *et al.*, 2016; Tratalos *et al.*, 2007). Yet there have been issues when planting trees, particularly related to economic costs. Along with its cost benefit analysis, urban planners have been looking for opportunities to reduce such costs, as well as precise examination before tree removal or planting. This can be seen as an example of how urban dwellers build adaptive capacity by managing green infrastructure within limited urban areas in a cost-effective way. For example, interviewee A5 pointed out that street trees present difficulties for planning and managing:

> The main factor is economic cost. Digging up a street can be extremely expensive, and mapping of subsurface utilities is not always precise, so larger/different areas may need to be dug than anticipated. However, where the pavement is already being dug up, for example to repair or install cabling or pipes, we strongly encourage the consideration of sustainable drainage installation (e.g. Stockholm's tree pits and raingardens at the same time). This means that the cost of installing green infrastructure can be greatly reduced.

Along with diversification of vegetation, different types and forms of green infrastructure equipped with functions of adaptive capacity to climatic changes are widely used across the city to improve carbon sequestration, cooling effects, biodiversity enhancement, rainwater run-off reduction and air quality. These include vertical rain gardens on buildings (e.g. Fair Street vertical rain garden in Team London Bridge BID area) using the water supply from downpipes; 700 green roofs covering an area of over 175,000m^2 in central London; and living walls on the façades of buildings (e.g. in Edgware Road underground station, Westfield shopping centre, Shepherd's Bush, and Crossrail site on Park Lane). Interviewee A5 highlighted the importance of diversifying vegetation types on streets, and not only focusing on planting trees;

> London is already a very green city. However, land prices and the density of existing development mean that the opportunity to create new green spaces in inner London boroughs is very limited. Because of this, we need to green the public realm, including streets. Street trees are important for this, but there are often considerable difficulties in planting them, for example because of sub-surface utilities, such as pipes and cables, which might be damaged by roots. Because of this, street greening may need to include other vegetation types, such as grassland…. And green roofs and species-rich grassland could be complementary to the provision of street trees.

As a crucial component for adaptive co-management and adaptive capacity, self-organisation can be diversified within multi-layered or polycentric governance (Olsson, 2003). Even though self-organisation shapes different forms depending on interactions of stakeholders, governance pattern, and nonlinear planning methods, another emergent property appears. In other words, self-organisation brings social memory which contributes to another reorganisation following change at a different temporal and spatial scale (Folke *et al.*, 2003), leading to enhancement of adaptive capacity. Within the ALGG initiative, it is clear from the above that self-organisation of the network has emerged to facilitate cooperative development of fine-scale green infrastructure, and this enhances adaptive capacity by ensuring that when non-green infrastructure projects are being developed, elements of green infrastructure that can support ecosystem services and which can be shown to have economic benefits, can be included. Stakeholders have different issues to confront, along with their own different adaptive strategies, as well as building more adaptive capacity (e.g. diversification of green infrastructure forms, installation of diverse forms of green infrastructure in buildings or on streets in a cost effective way, and security of finances for conducting green infrastructure projects). Such social memory is built from the previous green infrastructure project, which can be interpreted as knowledge building and transfer or information exchange, based on previous trial and error, and can contribute to reorganisation at a different scale.

6.5. Urban Green Regeneration for Building Urban Resilience

Urban regeneration is a holistic way to build resilience in urban areas. Urban resilience can be defined as the capacity to persist in changes or to absorb changes (Holling, 1973) within urban areas. Changes can include unexpected natural or socioeconomic disturbances, or external shocks of various kinds. Urban regeneration aims to create a space in which people can have better living conditions, naturally leading to the build-up of capacity to adapt to or absorb such disturbances. Urban regeneration has been recognised as an important UK policy agenda since the late 1990s (Tallon, 2013) and links closely to the 'economic and infrastructural development' agenda that developed in the early 1990s (Davies, 2002). Urban regeneration is all about effective spatial management for bringing economic, physical, social and environmental benefits to local people. Urban regeneration is defined as;

> area-based intervention which is a public sector initiated, funded, supported, or inspired, aimed at producing significant sustainable improvements in the conditions of local people, communities and places suffering from aspects of deprivation, often multiple in nature. (Leary and McCarthy, 2013, p.9)

> comprehensive and integrative vision and action which seeks to resolve urban problems and bring about a lasting improvement in the economic, physical, social and environmental condition of an area that has been subject to change or offers opportunities for improvement. (Roberts, 2016, p.18)

Regeneration has been more focused on economic and social development, but its boundaries have expanded to the environmental domain as well. Urban regeneration policy in the UK has seen changes in terms of its partnership and its priorities; a large scale of redevelopment in inner city slum areas and overpopulation through the public-driven policy in 1960s; economic growth in 1970s and property development with the use of public funds for encouraging market investment in the 1980s; and urban regeneration with more focusing on environmental awareness via the private-public partnership in the 2000s (Tallon, 2013). Yet the networking concept of collaboration between local authorities and business elites to bring economic growth had gained its popularity in the 1990s in the pursuit of economic and social regeneration development (Davies, 2002). Though not overtly stated, much of the recent expansion of urban regeneration to address environmental concerns links to urban resilience, or the capacity of the city and its citizens to cope with environmental changes and persist in physical and social function.

Broad-scale urban renewal or regeneration projects are hard to find in Greater London, perhaps because, particularly in Inner London, people seem reluctant to change the landscape and there is a general lack of regeneration funding. In this sense, a massive regeneration project in East London can be regarded as a comparatively rare and unique case. Deficiency rates of green infrastructure in East London were higher than in other London areas, as well as general economic and social deprivation comparatively. Under these circumstances, the East London Green Grid initiative came along with the Thames Gateway initiative, and the 2003 Sustainable Communities Plan, a spatial plan for the whole of England, with several regeneration policies (Massini, 2016). The impact of green regeneration through connection of green networks in the current grid initiative can be identified in the process of building urban resilience in terms of socioeconomic (e.g. creation of economic opportunities in local communities, or a better mental and physical wellbeing for local people through an easier access to nature) and environmental (e.g. biodiversity conservation and rural livelihood improvement) resilience. Such linkages between green regeneration and urban resilience can be found in comments from interviewee A2 participating in a part of the ALGG initiative,

> We're really helping the local, delivering that benefit to local people. Also, the more of those open, green spaces we can connect, the further people are able to walk and travel between sites and off-road. That provides walking routes, cycling routes, horse-riding routes. In terms of environmental benefits, the transformation that the planting brings and the woodlands, the scrubs, the grass glades, it all creates new habitat for a range of species. When connected with other sites, it provides green corridors, broader landscape improvements, and it really helps to reduce the effects of fragmented habitats. The last benefit is probably to do with economy. A number of our woodlands are well-used by local people but also by local businesses, so we've got walking groups that use one of our woodlands. We've got bee owners that use our woodlands and that really helps to drive some economic benefit in the area, directly to those people. We also allow small businesses and local communities to use our woodlands for their own purposes. That's a direct benefit, and then indirect benefit is probably by creating a local attractive area, you can increase the value of house prices. It brings more visitors and tourists to the local area so therefore, they might spend more in the local shops or stay the night. By improving the look of an area, or the look of an area or the attractiveness of an area, it does have a knock-on impact in terms of economic benefits. Although, that's indirect and obviously over a longer period.

As many environmental experts and policy-makers point out that London already shows a relatively high amount and density of green space in general, a fundamental question emerges: why should the All London Green Grid initiative be applied in a city already rich in green infrastructure? The answer can be found in overcoming existing environmental and socioeconomic inequality as well as building resilience to climatic changes from green infrastructure. London is a unique city in terms of patterns of landscape, varying street by street. In a single neighbourhood, for instance, some residential areas might be well-managed, but others even on an adjacent street may show relatively lower management practices, or there may be derelict sites. As Bulkeley (2013b) points out, estimation of where there are infrastructure deficits in cities and urban areas is crucial as those places are mostly occupied by the poorest and most marginal communities who are often neglected in terms of responses to disaster or provision of adequate services. In this sense, green regeneration projects provide planners with opportunities to regenerate economically and socially deprived areas. Such cases can be found in Better Bankside BID areas, namely the Low Line project. Through Bankside Urban Forest project, one of the Greening the BIDs initiative, the Low Line project has partners such as Network Rail, Bankside Neighbourhood Forum, Southwark Council, and the Better Bankside BID, focusing on 'the rail arches that have been part of Bankside for over 150 years', and aiming to 'transform the public realm' by opening up a pedestrian and car-free walkway along the base of the Victorian rail viaducts in the area (Better Bankside, 2017, http://www.betterbankside.co.uk/buf/the-low-line; pbc today, 2017, http://www.pbctoday.co.uk/news/planning-construction-news/business-improvement-districts-regeneration/29482). This project allows local communities to build more economic and social resilience as they could explore economic opportunities (e.g. job creation) and create a safer and more vivid environment for economic activities (e.g. lower crime) within the area, as well as better environmental quality through pedestrian-friendly streets. This can be found in the words of Peter Williams, Better Bankside CEO:

> …with inspiring new public spaces, a new food and music hub in railway arches at Flat Iron Square, and a home to two theatres and several new restaurants. As well as bringing new names to the neighbourhood, opening up these previously inaccessible stretches and increasing pedestrian footfall supports our strategy of pulling social and economic activity away from a crowded riverside, while increasing the supply of space to give small, independent businesses the opportunity to thrive.

Resilience is not a process for a system to develop adaptive capacity to changes (Bristow and Healy, 2014a; Magis, 2010). Therefore a precise measurement of following profits and benefits, in particular benefits from green infrastructure, is rather harder than other low carbon technology-based policy or practices. In local communities, delivery and management of small-scale of green regeneration projects would bring more easily and quickly visible socioeconomic and environmental benefits leading to urban resilience than outcomes from a large scale of projects. Then such positive feedback will bring other processes and outcomes for building adaptive capacity for other stakeholders in the same or different local communities.

6.6. Conclusion

This chapter has outlined complex adaptive system components of the All London Green Grid initiative within the framework of complex adaptive system theory, so as to determine perception towards, and impacts and influences of stakeholders on the development of the initiative, climate change resilience policy and its governance making processes. As shown in Figure 6.8, the ALGG governance has complex adaptive system features such as interaction of multiple stakeholders, nonlinear pattern and process, capacity to self-organise, and regularities that contribute to governance pattern, and positive (or negative) feedback that influences building adaptive capacity. As a successor of the East London Green Grid Planning, the ALGG initiative has been developed in diverse ways from a smaller scale project to a larger scale (e.g. greening BID programme supported by the Greater London Authority, or Bankside Urban Forest project in Southwark mainly led by BID or tree programme in borough mainly led by councils), while indicating loss and benefits, and learning processes for other stakeholders less willing to develop green infrastructure.

This chapter also highlighted the role of ALGG-related projects as a driver for boosting urban green generation and building resilience. Urban regeneration initially aims to bring economic, physical, social and environment benefits to local people in deprived areas. In the sense, regeneration projects are related to equity as local people in areas of deprivation have the same right to good living conditions as any other. Installation of green infrastructure does not remain a means for providing aesthetics only in local areas and has influence on social, economic and environmental development. As it is impossible to completely prevent impacts, practicality and achievability are essential for setting management aims (Francis, 2017). In the sense, complex adaptive system approaches or systems thinking highlighting 'patterns, relationships, and interactions between components, rather than the isolated study of particular components or processes' (Francis, 2017, pp.7-8) will become a more powerful tool for understanding governance of environmental projects requiring diverse components.

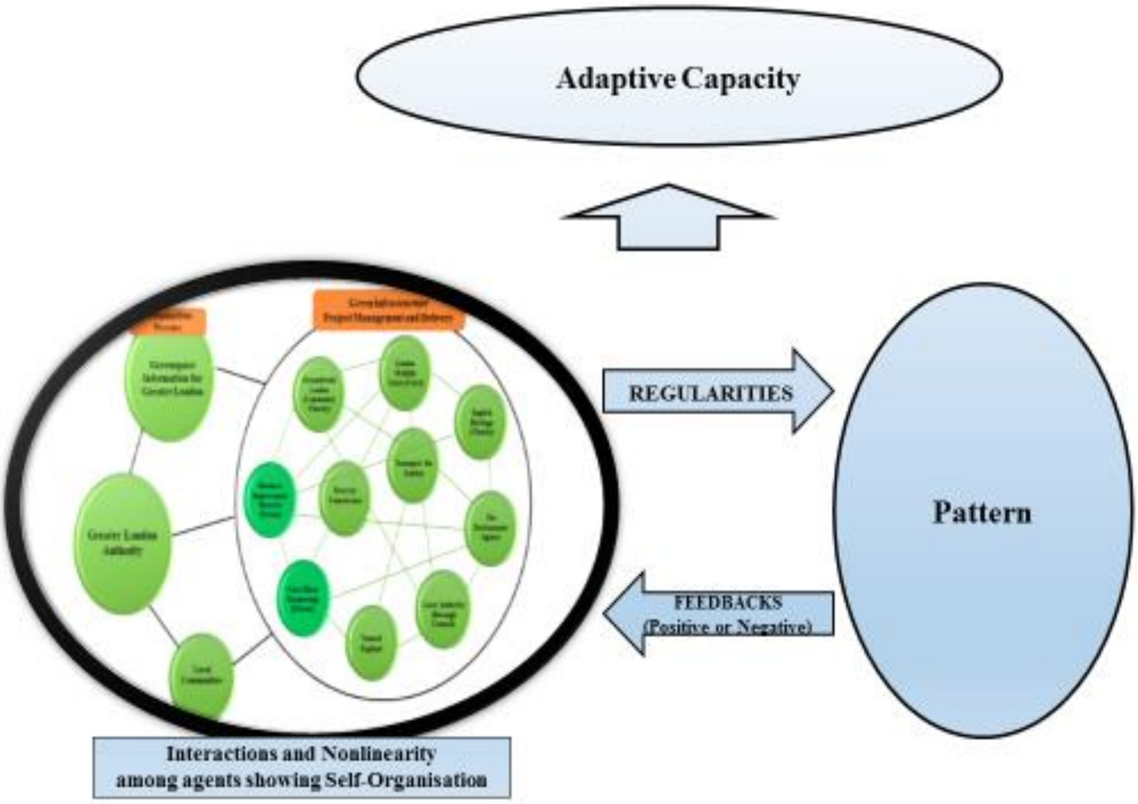


Figure 6.8 Complex adaptive system and the ALGG Governance

7. Conclusion

7.1. Summary of Contributions

This research has explored the current status of urban resilience in Greater London through ecosystem service management, in particular looking for the first time in detail at: (1) green space configuration and composition in Greater London and its correlations between socioeconomic variables; (2) estimation of carbon storage and sequestration supply rate and its monetary value in central Business Improvement Districts; and (3) analysis of the All London Green Grid's governance innovations for building urban resilience within the framework of complex adaptive systems.

Chapter 4 handled a broad range of benefits of ecosystem service management by determining the influence of the landscape-scale urban green infrastructure in terms of both quantitative and qualitative views. Landscape-scale spatial analysis (at the landscape and class levels) was conducted using ArcGIS and FRAGSTATS programmes. Then ANOVA was analyses were performed to determine differences in landscape metrics between Inner and Outer London, and the different sub-regions. Overall, Inner London maintained a smaller and more fragmented configuration of green infrastructure compared to Outer London, as would be expected in a major global city, but per capita green space was high in both areas overall. Besides the expected provision of ecosystem services such as temperature regulation, carbon storage and sequestration, biodiversity conservation and storm water run-off by this green network, it also provides urban dwellers with higher quality of life (e.g. lower stress levels or more opportunities for relaxation), better social integration, and higher house prices. Prior to clarifying the associations between urban green spaces and socioeconomic variables though non-parametric Spearman correlation analysis in SPSS, the correlation of green space metrics with socioeconomic variables using non-parametric Spearman rank correlations suggested that London boroughs with high population density, and a younger, highly-educated and multicultural population has access to fewer but smaller and denser green spaces, which has also suggested links to lower life quality, higher crime rates and house prices. As for landscape composition, amenity was the most abundant class of green space, whereas cemeteries and churchyards were the least abundant in Greater London, even though there is a slight difference in composition between Inner and Outer London. As for value of green space classes, amenity was found to be the most valuable green space class, mainly due to benefits in (male) life expectancy and quality of life. These findings highlight the areas that are most in need of green infrastructure development (Inner London), and the type of infrastructure that might be most useful (increasing connecting patches of green space, with amenity perhaps being most socioeconomically beneficial).

Valuation of a regulating ecosystem service provides urban planners with an economic argument for developing and managing natural capital. In Chapter 5, valuation of carbon storage and sequestration from urban street trees in central eleven Business Improvement Districts was conducted through the i-Tree programme, utilising appropriate species-specific algorithms to relate tree dimensions to carbon stored and sequestered, followed by stratified sampling and measurement (e.g. DBHs, heights, tree species and tree condition) of urban street trees. A total of 8037.4 tonnes (£48,2231.81) of carbon (16.4 tonne /£984.15 per hectare) was stored, and 46.73 tonnes per year (£2,795.40) (0.1 tonne/£5.7 per hectare) was sequestered in 2016 in eleven BIDs. As for carbon storage estimates, Inmidtown BID’s trees stored the most carbon, whereas New West End BID’s tree stored the least carbon. For gross carbon sequestration in 2016, trees in Waterloo BID sequestered the most carbon, and trees in Fitzrovia the least. Even though trees in New West End BID recorded the least carbon storage value per hectare, they showed the second-largest carbon sequestration value per hectare in spite of the lowest number of trees (25) among BIDs. It can be interpreted that tree species such as callery pear (*Pyrus calleryana*) (84% of the total trees in New West End BID study area), sweetgum (*Liquidambar styraciflua*) (6%), and Norway maple (*Acer platanoides*) (8%) have a high capacity of carbon sequestration compared to carbon storage. Another remarkable point is that central London BIDs had more trees from non-native species rather than those with native species, which were mostly found in street locations (e.g. London plane *Platanus* × *acerifolia* or callery pear *Pyrus calleryana*), and in park environments. Such quantification of the ecosystem service and estimation of tree species which have carbon storage or sequestration effectiveness would allow urban planners or policy-makers to make an economic argument for further tree management and planting in deficit areas. This research indicates that street trees should be enhanced in London to improve climate resilience potential, in particular those that may have potential for increased carbon storage; that BIDs may be effective units for achieving this as there is capacity in such areas and there are clear economic benefits; and also that when green space creation/enhancement is being considered, trees should be incorporated as far as possible.

Chapter 6 outlined complex adaptive system components (e.g. the interaction of multiple stakeholders, nonlinear patterns and processes, the capacity to self-organise, and regularities influencing governance patterns, and positive (or negative) feedback) found in the All London Green Grid initiative. Such analysis was conducted on the basis of primary sources, such as interview content from agents who are (in)directly involved in the All London Green Grid through semi-structured interviews, and secondary sources (e.g. public and private documents, and webpages covering information about green infrastructure projects contributing to the ALGG initiative). The interviews proceeded in terms of perspectives, evaluation, and capacity for participation in the ALGG and climate change strategies. Prior to the ALGG initiative, the

East London Green Grid Planning, stimulated by high deficiency rates of green infrastructure in East London and economic and social deprivation, was proceeded with the Thames Gateway initiative, and the 2003 Sustainable Communities Plan (Massini, 2016). Followed by the large-scale regeneration project, the ALGG initiative has covered a far larger area: the whole of Greater London. In this sense, projects in the initiative have shown diverse patterns and have grown from smaller to larger scale projects, along with interactions between diverse agents and agencies depending on the location, characteristic and scale of projects (e.g. greening BID programme (e.g. green infrastructure auditing in BIDs for clarifying the current status and green space deficient areas supported by the Greater London Authority, or Bankside Urban Forest project in Southwark mainly led by BID or tree programme in boroughs mainly led by councils). Even though the ALGG initiative does not maintain an official monitoring and evaluation mechanism, it has been developed through indication of loss and benefits, learning processes, trial and error, and stimulus of other stakeholders with less willingness to develop green infrastructure. Yet when it comes to the development of the initiative, financial security is a major barrier compared to the absence of a monitoring and evaluation mechanism. The funding sources for projects are diverse, ranging from the public (e.g. GLA or local authorities) to the private sector (e.g. local businesses). As the private sector influences building public climate governance, and vice versa (Bulkeley and Newell, 2015), its partnership would be crucial for acquiring stable investment and financial flows contributing to progress of green infrastructure projects.

7.2. Implications of the Research

When rating resilience in cities, this depends on how they are less or more vulnerable to and resilient to shocks (e.g. hazards of health, infrastructure, natural, societal, and security) and stresses (e.g. climate change, urbanisation, migration, peak oil and other fossil fuel depletion, globalisation, terrorism, health and crime issues and changes in the workforce) (Field *et al.*, 2016). As seen in Figure 7.1 and 7.2, London is currently rated as relatively high status in terms of resilience (84 percent resilience rating) by some sources, and shows a moderate growth in its resilience gap, which refers to a gap between resilience demands and capacity for the city. The resilience status and gap are affected by decision priorities (Field *et al.*, 2016).

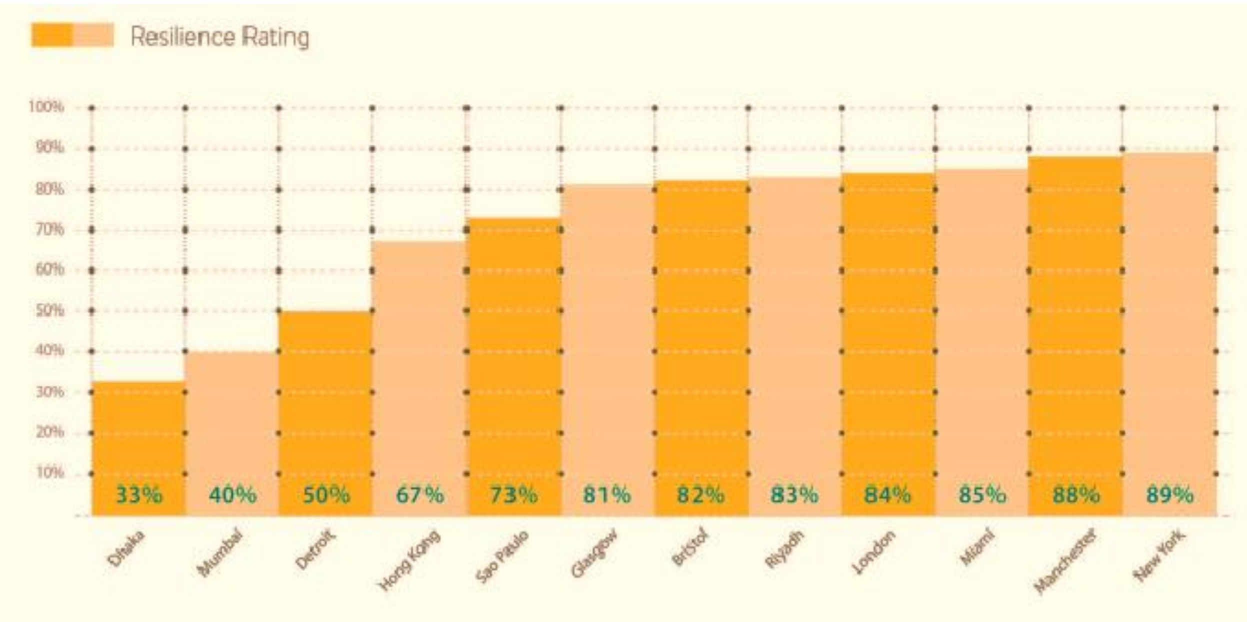


Figure 7.1 Resilience rating comparisons among twelve cities

(Adapted from Field *et al.* (2016, p.28))

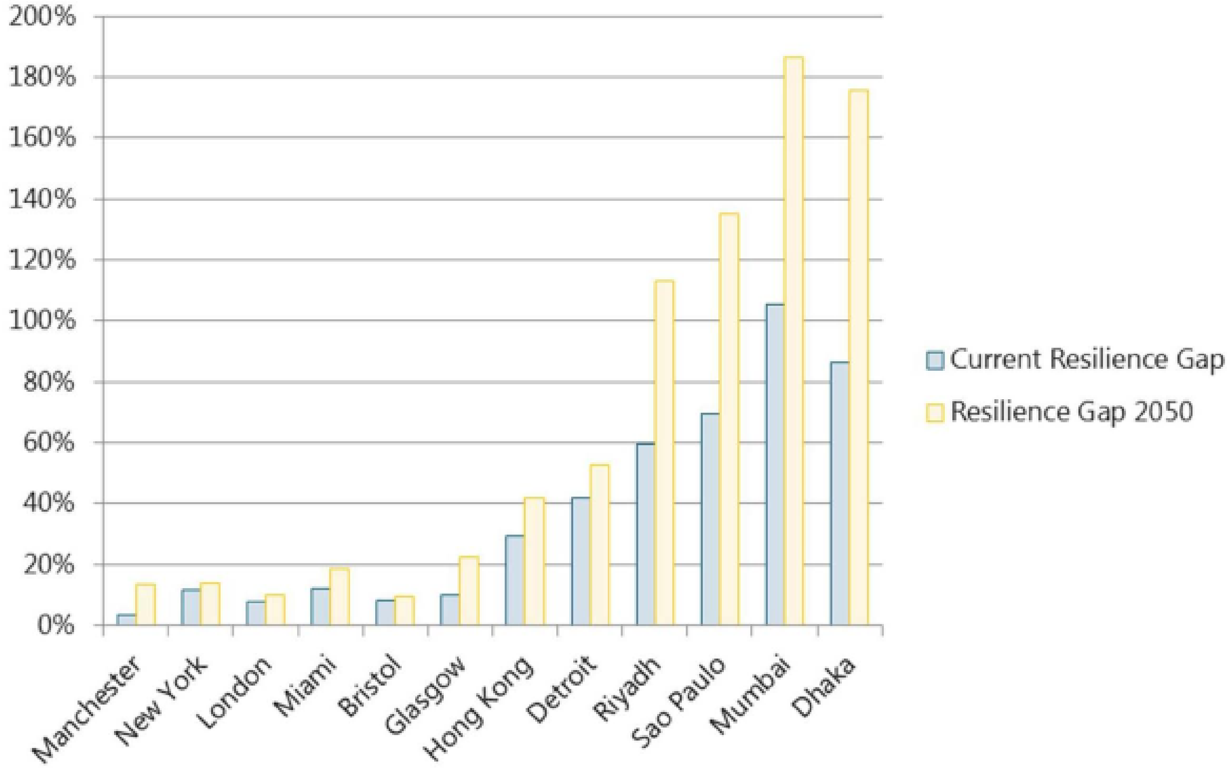


Figure 7.2 Current and future resilience gaps for 12 Cities

(Adapted from *Field et al. (2016, p.32)*)

Recent international climate change conferences have shown slow but steady progress in setting binding procedural commitments under the Paris Agreement highlighting that 'each party shall prepare, communicate and maintain successive [NDCs] that it intends to achieve' (http://bigpicture.unfccc.int/printtool.html?article[60][]=60). Yet in the situation where the United States, which is the second GHG emitter in the world, may leave or stay in the Paris Agreement, 'the guidelines for nationally determined mitigation and adaptation plans, the global stocktake for assessing progress in reaching the agreement's long-term goals, and the mechanism to facilitate implementation and promote compliance' (https://www.iied.org/cop23-outcomes-call-for-faster-action-higher-ambition-keep-paris-track) were not brought in at the 2017 UN Climate change conference (COP23) in Bonn, Germany, but delayed until the next

COP. In a sense, there is a long way to go to create coordinated outcomes at an international level.

As for guidelines for locally determined mitigation and adaptation plans, there are international networks or partnerships between local governments or cities (e.g. the International Council for Local Environmental Initiative, or C40 Cities Climate Leadership Group) for building an 'eco-city' integrating urban ecology into urban development within a sustainability framework (Roseland, 2001). This allows them to exchange information and knowledge on adaptation and mitigation approaches and methods as well as automatic monitoring for their achievements, and acquisition of opportunities for benchmarking successful climate policy and strategies.

Yet urban socioecological sustainability requires an interdisciplinary approach integrating biology, sociology, and other sciences for better urban planning and management (Folke *et al.*, 2003; Tzoulas *et al.*, 2007). Such an interdisciplinary approach needs strong scientific evidence in the climate change mitigation and adaptation field, and there has been substantial growth in the literature on mitigation (e.g. low carbon technology, energy efficient equipment or buildings). Yet the scientific community has limited literature on adaptation success, partly due to 'the long neglect of adaptation science, and the relative newness of the topic in practice' (i.e. lack of successful case studies) (Moser and Boykoff, 2013, p.8). Responses to climate-induced impacts are limited by 'cuts to key agencies, by a loss of critical knowledge and understanding of issues as senior staff leave, and by the lack of an overall political vision' as well as by dilemmas between 'the need for investment is now' and 'the real threats and the consequent benefits' being longer-term (Rotherham, 2010, p.35).

In this sense, this research has contributed to feasibility verification for creating green infrastructure networks across a city for maximising ecosystem service benefits and building urban resilience, as well as contributing to scientific evidence. In other words, based on research in three empirical chapters, Greater London has shown diverse and holistic tools, practices, strategies and policies in relation to green infrastructure for building an enhanced resilient capacity to socioeconomic (e.g. financial failure, changes in geo-political stability, and population growth), health-related (e.g. mental condition, obesity, and life expectancy) and environmental (e.g. heat wave and flooding) shocks. Further improvements would benefit from the advances made in this thesis, in terms of greater spatial awareness of the abundance and distribution of types of green space, further consideration of where trees may best be planted and which ones are most effective contributors for climate resilience, and the varied governance perspectives that need to be considered as well as a broad picture and barriers for progressing the ALGG for investors and urban planners.

The All London Green Grid initiative eventually provides urban residents with more access to greenspaces for improving their welfare. In this sense, the conducted correlation analysis of greenspaces configuration and composition, and socioeconomic variables will provide urban planners and practitioners with a strong evidence for validating the ALGG initiative. Then practitioners could get more stimulus or motivation for further progressing the initiative. As for the estimation of regulating ecosystem services, in the form of carbon storage and sequestration, it offers strong evidence for drawing more attention and investments from private and public urban planners, which was mentioned in an interview from the Greater London Authority. Even though this research only focuses on small scales of areas such as Business Improvement Districts, it will provide urban planners in non-BID areas with more stimulus and motivation for urban green regeneration development. The expansion of BID area boundaries can be regarded as an example of ongoing success in improving these areas.

In the next section, some limitations and agendas for future research are discussed. This further research would usefully contribute to building the literature and evidence base on socioecological sustainability in urban areas.

7.3. Limitations of the research and agendas for the future research

This research has shown limitations and agendas for future research in each empirical chapter. As for estimation of configuration and composition of green spaces, and association between socioeconomic variables and green space patterns, there are several limits such as possible spatial changes over time, lack of available literature on correlation analysis between green spaces and socioeconomic variables in other cities that would have provided greater context for the analysis, lack of detailed correlation analysis in boroughs at a smaller scale, and an absence of detailed socioeconomic data for more precise research on impacts of green infrastructure on residents' welfare, and possibilities for further research. First, the time of spatial data acquisition from Greenspace Information for Greater London (GiGL) was in May 2015, but it is possible that since then some green spaces might have been altered (e.g. increase or decrease of spatial extent, or creation or disappearance of open space). In this sense, data acquisition from remotely sensed data (e.g. sensor and image from the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite for a greater spatial detail, or the Landsat sensor series for higher and more detailed spatial resolution images (Wulder *et al.*, 2004)) at high spatial resolution might be a useful supplementary method to obtain precise and up-to-date vegetation cover data, which can be updated and integrated with the acquired spatial data from GiGL. Second, associations between open space composition and configuration, and socioeconomic variables can be further expanded. For instance, as for the correlation between open space fragmentation and connectivity, and quality of life, it could be explored at different population age ranges (10s, 20-30s, 30-50s, 50-70s, >70s) (e.g. impacts of green space, or green space composition on children's health, or on children's physical activity), and gender (e.g. open space's influence on middle-aged women or men's physical or mental health). Other future research could include clarification of associations between green spaces and housing prices at finer scales (e.g. BID-level scale or borough-level scale or Inner (East and West) and Outer London (East and North East, South, and West and North West) under the Nomenclature of Territorial Units for Statistics). In each case, more specific and detailed socioeconomic data would be required (e.g. data acquisition from each local council, or from surveys from different ages or genders) for the analysis.

For valuation of the regulating ecosystem services from urban street trees, limitations come from the focus on a single component of green infrastructure. Fuller quantification of carbon storage and sequestration requires consideration of more variables that influence carbon fluxes in urban areas. Inclusion of other green infrastructure components (e.g. grass, shrubs, lawns, and green walls) would allow more precise estimates of carbon storage and sequestration from vegetated areas, even though trees are the main store of above-ground carbon, and shrubs and herbaceous vegetation make limited contributions to carbon storage supply (Derkzen *et al.*, 2015). The second limitation comes from a lack of literature review on each tree species' function, effectiveness, and resilience to pests, etc. This research suggested which tree species are the most and least dominant, as well as high and low possibilities of influencing regulating ecosystem service capacity. More detail on each tree species would allow tree managers or urban planners to make a decision on tree species selection and proper location selection for tree species. The third limitation or recommendation can be comparisons of BIDs and non-BIDs in terms of tree density, tree species, green space composition and configuration, and the consequent carbon storage and sequestration supply rates, as this research focuses on tree data collection solely in BIDs. Even though BIDs are important units for evaluating ecosystem service, such a comparison would allow investigation of different patterns and structures of green space, deficiency of green spaces, and green space management and practices, as well as corresponding governance patterns. In addition, data collection from BIDs and non-BIDs would become fundamental information for more precisely calculating the whole carbon storage and sequestration estimates in the corresponding borough. The fourth limitation or recommendation comes from monetary values ascribed to carbon storage and sequestration. It would be worth determining how such monetary value of carbon storage and sequestration can offset the costs of tree management or tree planting, or even the costs of climate change mitigation (e.g. costs from Carbon Capture and Storage (CCS)) or adaptation practices (e.g. installation of green walls). The fifth limitation is limited elaboration on the contribution of urban street trees (along with green spaces in which there are trees) to enhancing urban resilience. It would be valuable to find out how urban street trees (or urban forest) contribute to strengthened urban resilience in terms of regional climate regulation (e.g. cooling or improved air quality), health (e.g. mental and physical), building energy savings (when trees are located next to buildings), and so on. Other limitations come from the lack of literature review on carbon storage and sequestration from urban trees. Even though there is increasing literature on estimating monetary value of ecosystem services from natural capital, there is a necessity to have sounder evidence and stronger research on its valuation so as to boost soft engineering in the built environment. The more frequent use of i-tree programme for valuing ecosystem services can allow urban planners and researchers to have more diverse and comparable research outcomes in different cities. It would be necessary for the programme developer to expand its coverage of weather and air pollution data in other cities such as Asian and European countries as the programme is mostly applicable in the US, UK and Australia.

As for estimation of governance innovations in the All London Green Grid, there are several issues to be further researched. Rather than focusing on its whole development, it would be worthwhile to consider public stakeholders and private holders separately. As businesses and financial organisations regard climate change-related issues as a potential opportunity, they contribute to building governance of climate change through self-regulation such as codes of conduct, standards, reporting, and certification (Bulkeley and Newell, 2015). In addition, even though the local community's role was not highlighted in this research, it has a high possibility of contributing to green infrastructure project management in local areas in partnership with local authorities or Business Improvement Districts. Ultimately, the ALGG initiative is about provision of a better and sustainable life to urban dwellers as well as enhanced environmental ecosystems. As there are limits in securing public finances from local authorities or the central Government, involvement of private actors in the green infrastructure projects would contribute to a sounder finance mechanism for proceeding projects, as well as voluntary and automatic monitoring of its development in local areas. Another possible research focus could be governance comparisons between the East London Green Grid and the All London Green Grid, as well as evaluation of each initiative. Such comparisons would provide some knowledge of how the recent initiative can gain a stronger stimulus for proceeding green infrastructure network projects. Yet there is still a lack of literature on the effectiveness of such green infrastructure network initiatives across different countries as some cities do not have a strong motivation for developing such adaptive management and practices due to the lack of funds and interest for developing and connecting green infrastructure. For instance, the Mayor of Seoul built a green network in front of the Seoul Station on the old and abandoned bridge, rather than destroying the bridge. After the installation, the Seoul residents were not favourable to such installation as they regarded as a waste of tax and a potential place for crime. The neighbourhood is always infamous for air pollution, but the public regards installation of green infrastructure as unnecessary and wasteful practices as green infrastructure does not bring immediate and visible effects for reducing air pollution, particularly when it is partly built in air polluted, crowded and busy areas. For such cities which have lack of importance of green infrastructure, a richer and diverse literature and research on benefits from green infrastructure networks in other cities should be followed. In other words, international comparisons between the ALGG initiative and other green infrastructure network initiatives in other cities (e.g. The Liveable Green Network in Sydney or green network creation in the Five Finger Plan in Copenhagen) would represent such a valuable research.

Appendices

Appendix 1. POLICY 2.18 Green Infrastructure: the multi-functional network of green and open spaces

Strategic		
A	The Mayor will work with all relevant strategic partners to protect, promote, expand and manage the extent and quality of, and access to, London's network of green infrastructure. This multifunctional network will secure benefits including, but not limited to, biodiversity; natural and historic landscapes; culture; building a sense of place; the economy; sport; recreation; local food production; mitigating and adapting to climate change; water management; and the social benefits that promote individual and community health and well-being.	
B	The Mayor will pursue the delivery of green infrastructure by working in partnership with all relevant bodies, including across London's boundaries, as with the Green Arc Partnerships and Lee Valley Regional Park Authority. The Mayor has published supplementary guidance on the All London Green Grid to set out the strategic objectives and priorities for green infrastructure across London.	
C	In n areas of deficiency for regional and metropolitan parks, opportunities for the creation of green infrastructure to help address this deficiency should be identified and their implementation should be supported, such as in the Wandle Valley Regional Park1.	
Planning decisions		
D	Enhancements to London's green infrastructure should be sought from development and where a proposal falls within a regional or metropolitan park deficiency area (broadly corresponding to the areas identified as "regional park opportunities"), it should contribute to addressing this need.	
E	Development proposals should:	
	a	incorporate appropriate elements of green infrastructure that are integrated into the wider network
	b	encourage the linkage of green infrastructure including the Blue Ribbon Network, to the wider public realm to improve accessibility for all and develop new links, utilising green chains, street trees, and other components of urban greening (Policy 5.10).
LDF preparation		
F	Boroughs should:	
	a	set out a strategic approach to planning positively for the creation, protection, enhancement and management of networks of green infrastructure by producing green infrastructure strategies that cover all forms of green and open space and the interrelationship between these spaces. These should identify priorities for addressing deficiencies and should set out positive measures for the design and management of all forms of green and open space. Delivery of local biodiversity action plans should be linked to these strategies
	b	ensure that in and through DPD policies, green infrastructure needs are planned and managed to realise the current and potential value of these to communities and to support delivery of the widest range of linked environmental and social benefits
	c	London's urban fringe support, through appropriate initiatives, the vision of creating and protecting an extensive and valued recreational landscape of well-connected and accessible countryside around London for both people and wildlife

Source: GLA (2016b)

Appendix 2. Aims and Functions of ALGG

		ALGG Functions												
		1	2	3	4	5	6	7	8	9	10	11	12	13
		Adapt to climate change	**Increase access to open space**	**Conserve and enhance biodiversity**	**Improve sustainable travel connections**	**Promote healthy living**	**Conserve and enhance heritage features, Etc.**	**Enhance distinctive destinations**	**Promote sustainable design**	**Enhance green space skills**	**Promote sustainable design**	**Improve air quality and soundscapes**	**Improve quality and access to urban fringe**	**Conserve Thames riverside spaces**
Aims of the ALGG														
Aim 1	To protect and enhance London’s strategic network of green and open natural and cultural spaces, to connect the everyday life of the city to a range of experiences and landscapes, town centres, public transport nodes, the countryside in the urban fringe, the Thames and major employment and residential areas;		•	•	•	•	•	•			•		•	•
Aim 2	To encourage greater use of, and engagement with, London’s green infrastructure, popularising key destinations within the network and fostering a greater appreciation of London’s natural and cultural landscapes, enhancing visitor facilities and extending and upgrading the walking and cycling networks in between to promote a sense of place and ownership for all who work in, visit and live in London;		•	•	•	•	•	•	•		•		•	•

Aim 3	To secure a network of high quality, well designed and multifunctional green and open spaces to establish a crucial component of urban infrastructure able to address the environmental challenges of the 21st century-most notably climate change	•		•		•	•		•	•	•	•		

Source: GLA (2012, p.14)

Appendix 3. Public Open Space Categories

Type	Description	Size	Distances from homes
Regional Parks	Large areas, corridors or networks of open space, the majority of which will be publicly accessible and provide a range of facilities and features offering recreational, ecological, landscape, cultural or green infrastructure benefits. Offer a combination of facilities and features that are unique within London, are readily accessible by public transport and are managed to meet best practice quality standards.	4000 hectares	3.2 to 8 kilometres
Metropolitan Parks	Large areas of open space that provide a similar range of benefits to Regional Parks and offer a combination of facilities at a sub-regional level, are readily accessible by public transport and are managed to meet best practice quality standards	60 hectares	3.2 kilometres
District Parks	Large areas of open space that provide a landscape setting with a variety of natural features providing a wide range of activities, including outdoor sports facilities and playing fields, children's play for different age groups and informal recreation pursuits	20 hectares	1.2 kilometres
Local Parks and Open Spaces	Providing for court games, children's play, sitting out areas and nature conservation areas	2 hectares	Distances from homes 400 metres
Small Open Spaces	Gardens, sitting out areas, children's play spaces or other areas of a specialist nature, including nature conservation areas	Under 2 hectares	Less than 400 metres
Pocket Parks	Small areas of open space that provide natural surfaces and shaded areas for informal play and passive recreation that sometimes have seating and play equipment.	Under 0.4	Less than 400 metres
Linear Open Spaces	Open spaces and towpaths alongside the Thames, canals and other waterways; paths, disused railways; nature conservation areas; and other routes that provide opportunities for informal recreation. Often characterised by features or attractive areas which are not fully accessible to the public but contribute to the enjoyment of the space.		

Appendix 4. Classification of Inner and Outer London under the Nomenclature of Territorial Units for Statics

Inner London - West	Camden and City of London Westminster Hammersmith and Fulham and Kensington and Chelsea Wandsworth
Inner London - East	Hackney and Newham Tower Hamlets Haringey and Islington Lewisham and Southwark Lambeth
Outer London - East and North East	Bexley and Greenwich Barking & Dagenham and Havering Redbridge and Waltham Forest Enfield
Outer London - South	Bromley Croydon Merton, Kingston upon Thames and Sutton
Outer London - West and North West	Barnet Brent Ealing Harrow and Hillingdon Hounslow and Richmond upon Thames

Appendix 5. Open Space Category and Ranges

Open Space Category	Ranges of Open Spaces
Parks and Gardens	urban parks, country parks and formal gardens
Natural and Semi-Natural Urban Greenspaces	woodlands, urban forestry, scrub, grasslands (e.g. downlands, commons and meadows) wetlands, open and running water, wastelands and derelict open land and rock areas (e.g. cliffs, quarries and pits);
Green Corridors	river and canal banks, cycleways, and rights of way;
Outdoor sports facilities (with natural or artificial surfaces and either publicly or privately owned)	tennis courts, bowling greens, sports pitches, golf courses, athletics tracks, school and other institutional playing fields, and other outdoor sports areas
Amenity Greenspaces (mostly commonly)	informal recreation spaces, greenspaces in and around housing, domestic gardens and village greens
Provision for children and teenagers	play areas, skateboard parks, outdoor basketball hoops, and other more informal areas (e.g. 'hanging out' areas, teenage shelters)
Allotments, community gardens, and city (urban) farms	
Cemeteries and churchyards;	
Accessible countryside in urban fringe areas	
Civic spaces	civic and market squares, and other hard surfaced areas designed for pedestrians

Source: Planning Policy Guidance 17: Planning for open space, sport and recreation

Appendix 6. Landscape metrics in Inner and Outer London

Landscape Level of Inner London Boroughs

Boroughs	Area Metric		Aggregation Metrics						Shape Metrics	
	TA	AREA_AM	NP	PD	LSI	ENN_ AM	CONTAG	SHAPE_AM	CONTIG_MN	PAFRAC
Camden	532.6861	119.3635	258	48.4338	17.0533	80.2238	72.2223	2.1286	0.8653	1.1392
City of London	58.6694	2.1312	315	536.9068	22.0516	32.8498	64.5092	2.1345	0.8611	1.2159
Hackney	512.6222	17.1329	309	60.2783	20.8558	122.8833	64.5774	1.9433	0.8168	1.1182
Hammersmith and Fulham	362.442	24.5263	138	38.0751	15.2308	136.5032	62.9849	2.113	0.8131	1.1282
Haringey	822.1871	19.3333	400	48.6507	24.4847	165.9206	58.598	2.115	0.7679	1.1236
Islington	202.4763	2.0211	741	365.9688	43.5028	119.8624	62.7301	2.4277	0.8795	1.2523
Kensington and Chelsea	244.7594	7.9938	510	208.3679	26.0419	362.939	60.8073	2.1238	0.7753	1.1314
Lambeth	563.3789	10.8351	636	112.8903	38.3609	178.0668	59.1559	2.5499	0.8491	1.1847
Lewisham	781.7646	22.8687	647	82.7615	28.6535	268.8517	56.2038	2.2783	0.6727	1.1341
Newham	1051.5575	62.1215	326	31.0016	22.4248	170.919	56.4631	2.7225	0.7716	1.1019
Southwark	677.3237	27.7948	215	31.7426	18.4391	148.6223	54.3547	2.3998	0.8491	1.1159
Tower Hamlets	569.2255	68.2424	393	69.0412	26.1886	60.9781	61.2633	4.4036	0.9141	1.2023
Wandsworth	1113.236	30.3583	2166	194.5679	44.8367	117.5451	59.1804	2.664	0.7495	1.2113
Westminster	630.3994	106.1662	315	49.9683	16.9029	65.8618	74.6214	1.7299	0.9131	1.1375

Landscape Level of Outer London Boroughs

Boroughs	Area Metrics		Aggregation Metrics						Shape Metrics	
	TA	AREA_AM	NP	PD	LSI	ENN_AM	CONTAG	SHAPE_AM	CONTIG_MN	PAFRAC
Barking and Dagenham	1274.8106	52.5812	924	72.4814	26.7278	200.1941	53.131	2.5203	0.6036	1.195
Barnet	3265.0916	55.0488	499	15.2829	28.1882	175.4572	59.7211	2.2366	0.8525	1.1159
Bexley	2499.7201	92.5012	366	14.6416	25.8181	125.1424	54.0044	2.8221	0.8257	1.1306
Brent	962.1654	21.4101	321	33.3622	29.1294	156.3582	56.9833	2.6862	0.8816	1.2026
Bromley	8624.5099	124.2619	1147	13.2993	35.901	65.9826	66.7939	2.4738	0.7909	1.1085
Croydon	2788.3595	72.3761	704	25.2478	23.4324	166.3319	65.4818	2.2533	0.5686	1.0994
Ealing	1723.853	24.1011	745	43.2171	33.7501	112.4268	59.8278	3.3111	0.7395	1.1201
Enfield	3986.1687	107.9292	831	20.8471	33.5157	87.3433	59.4678	3.106	0.7842	1.1677
Greenwich	1978.5373	70.1856	1451	73.337	38.3598	98.0273	55.7703	2.8879	0.7628	1.1621
Harrow	1619.7407	32.7869	640	39.5125	27.7925	98.8655	59.607	2.2353	0.8699	1.1521
Havering	6757.5346	101.6029	1015	15.0203	32.049	92.2908	61.9881	2.2475	0.8126	1.1436
Hillingdon	5199.5233	83.9836	643	12.3665	28.358	144.6302	58.8186	2.3904	0.669	1.1223
Hounslow	2122.0808	45.2116	730	34.4002	26.707	152.8409	58.1476	2.0688	0.6876	1.1204
Kingston upon Thames	1375.741	47.3614	358	26.0223	20.7754	127.3014	61.3499	2.3432	0.6455	1.124
Merton	1350.3414	42.8894	510	37.7682	25.4835	127.747	60.08	2.4895	0.6896	1.1477
Redbridge	2275.0105	83.9873	608	26.7252	19.592	99.3664	58.0195	1.9692	0.6185	1.1256
Richmond upon Thames	3350.1175	291.92	669	19.9694	22.8313	84.293	61.8688	2.268	0.7028	1.1347
Sutton	1484.9193	50.869	897	60.4073	27.1222	162.8498	60.1913	2.1496	0.7831	1.1277
Waltham forest	1344.7755	30.8281	580	43.1299	27.9475	111.6438	62.1663	2.4036	0.7854	1.1559

Appendix 7. Class Metrics in Inner and Outer London

Total Area in Inner London

Area name	East-West	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Hackney	East	52.1245	18.0578	225.7136	1.9372	27.9267	186.8624
Haringey	East	310.9453	84.5444	220.2363	23.3845	160.902	22.1746
Islington	East	48.4304	3.8521	101.6192	5.9048	28.1911	14.4787
Lambeth	East	154.8172	18.8755	213.0575	66.2742	7.6406	102.7139
Lewisham	East	208.4102	52.937	125.4561	102.3852	272.5925	19.9836
Newham	East	213.1806	116.2094	166.8337	16.2502	132.2182	406.8654
Southwark	East	60.2327	141.5424	32.5968	114.4875	235.3379	93.1264
Tower Hamlets	East	208.4132	21.1759	67.9726	4.9238	55.3296	211.4104
Camden	West	4.6795	19.3229	363.8582	15.8187	25.2713	103.7355
City of London	West	4.2888	7.6919	23.7496	0.2179	22.248	0.4732
Hammersmith and Fulham	West	33.1676	4.4961	40.0061	7.8957	166.3556	110.5209
Kensington and Chelsea	West	118.757	37.0118	38.9228	10.0122	37.6111	2.4445
Wandsworth	West	374.9907	373.4804	143.1128	1.3922	144.9138	75.3461
Westminster	West	444.8053	16.0029	95.2339	0.0001	4.4128	69.9444

Total Area in Outer London

Area name	ENSW	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	East and North East	199.7131	248.7038	216.8546	275.0022	26.2487	308.2882
Bexley	East and North East	552.5135	360.8274	604.5081	25.6687	485.5382	470.6642
Enfield	East and North East	349.5009	1466.0817	1373.6238	172.3464	544.7409	79.875
Greenwich	East and North East	743.0989	163.4224	299.4004	53.1442	419.7089	299.7625
Havering	East and North East	3580.8518	848.4286	1168.3586	570.8732	54.4521	534.5703
Redbridge	East and North East	803.1875	34.3846	493.0421	215.7663	122.2778	606.3522
Waltham Forest	East and North East	88.5177	446.2545	609.2117	35.7546	61.2152	103.8218
Bromley	South	234.2528	42.5715	1885.6106	279.5228	4866.7291	1315.8231
Croydon	South	1062.0266	176.5141	1254.27	33.1623	66.7005	195.686
Kingston upon Thames	South	569.065	18.6957	473.7298	140.5006	113.0229	60.727
Merton	South	609.6256	80.1505	31.4438	154.9459	97.193	376.9826
Sutton	South	611.4342	25.0253	92.2536	89.6035	202.5027	464.1
Barnet	West and North West	1591.5434	135.1317	231.7813	308.9399	730.3341	267.3612
Brent	West and North West	208.5029	137.1731	18.1038	41.7724	227.8402	328.773
Ealing	West and North West	826.3158	159.7807	67.8024	49.9012	311.5676	308.4853
Harrow	West and North West	698.6579	289.8097	97.0069	26.775	108.1274	399.3638
Hillingdon	West and North West	1285.9747	32.5025	343.1775	373.0113	1820.9995	1343.8578
Hounslow	West and North West	307.001	121.5293	775.1611	34.0042	251.4886	632.8966
Richmond upon Thames	West and North West	1645.131	152.9529	881.2703	67.7083	325.3543	277.7007

PLAND in Inner London

Area name	East-West	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Hackney	East	10.1682	3.5226	44.0312	0.3779	5.4478	36.4523
Haringey	East	37.8193	10.2829	26.7866	2.8442	19.57	2.697
Islington	East	23.919	1.9025	50.1882	2.9163	13.9232	7.1508
Lambeth	East	27.4801	3.3504	37.8178	11.7637	1.3562	18.2318
Lewisham	East	26.6589	6.7715	16.0478	13.0967	34.8689	2.5562
Newham	East	20.2728	11.0512	15.8654	1.5453	12.5736	38.6917
Southwark	East	8.8927	20.8973	4.8126	16.9029	34.7453	13.7492
Tower Hamlets	East	36.6135	3.7201	11.9412	0.865	9.7202	37.14
Camden	West	0.8785	3.6274	68.3063	2.9696	4.7441	19.474
City of London	West	7.3101	13.1106	40.4804	0.3714	37.921	0.8066
Hammersmith and Fulham	West	9.1511	1.2405	11.0379	2.1785	45.8985	30.4934
Kensington and Chelsea	West	48.5199	15.1217	15.9025	4.0906	15.3666	0.9987
Wandsworth	West	33.6847	33.5491	12.8556	0.1251	13.0173	6.7682
Westminster	West	70.5593	2.5385	15.1069	0	0.7	11.0953

PLAND in Outer London

Area name	ENSW	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	East and North East	15.6661	19.5091	17.0107	21.572	2.059	24.1831
Bexley	East and North East	22.103	14.4347	24.183	1.0269	19.4237	18.8287
Enfield	East and North East	8.7678	36.7792	34.4598	4.3236	13.6658	2.0038
Greenwich	East and North East	37.558	8.2598	15.1324	2.686	21.2131	15.1507
Havering	East and North East	52.9905	12.5553	17.2897	8.448	0.8058	7.9107
Redbridge	East and North East	35.3048	1.5114	21.6721	9.4842	5.3748	26.6527
Waltham Forest	East and North East	6.5823	33.1843	45.3021	2.6588	4.5521	7.7204
Bromley	South	2.7161	0.4936	21.8634	3.241	56.4291	15.2568
Croydon	South	38.0879	6.3304	44.9824	1.1893	2.3921	7.018
Kingston upon Thames	South	41.3643	1.359	34.4345	10.2127	8.2154	4.4141
Merton	South	45.146	5.9356	2.3286	11.4746	7.1977	27.9176
Sutton	South	41.1763	1.6853	6.2127	6.0342	13.6373	31.2542
Barnet	West and North West	48.7442	4.1387	7.0988	9.4619	22.368	8.1885
Brent	West and North West	21.6702	14.2567	1.8816	4.3415	23.6799	34.1701
Ealing	West and North West	47.9342	9.2688	3.9332	2.8947	18.0739	17.8951
Harrow	West and North West	43.1339	17.8924	5.989	1.653	6.6756	24.656
Hillingdon	West and North West	24.7326	0.6251	6.6002	7.174	35.0224	25.8458
Hounslow	West and North West	14.467	5.7269	36.5283	1.6024	11.851	29.8243
Richmond upon Thames	West and North West	49.1067	4.5656	26.3057	2.0211	9.7117	8.2893

Number of Patch in Inner London

Area name	East-West	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Hackney	East	36	10	166	2	14	81
Haringey	East	224	11	63	4	76	22
Islington	East	60	11	555	3	71	41
Lambeth	East	71	9	428	75	12	41
Lewisham	East	361	12	113	84	62	15
Newham	East	83	9	78	8	52	96
Southwark	East	14	43	34	55	53	16
Tower Hamlets	East	108	19	184	6	23	53
Camden	West	9	31	123	24	4	67
City of London	West	71	33	31	1	174	5
Hammersmith and Fulham	West	10	3	29	9	30	57
Kensington and Chelsea	West	175	8	158	10	156	3
Wandsworth	West	1954	48	107	13	28	16
Westminster	West	109	4	161	1	12	28

Number of Patch in Outer London

Area name	ENSW	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	East and North East	42	105	555	96	5	121
Bexley	East and North East	155	43	63	30	51	24
Enfield	East and North East	155	67	403	25	167	14
Greenwich	East and North East	927	147	80	8	239	50
Havering	East and North East	154	62	435	44	26	294
Redbridge	East and North East	334	31	78	104	43	18
Waltham Forest	East and North East	86	40	330	13	30	81
Bromley	South	187	25	437	69	182	247
Croydon	South	102	43	320	25	30	184
Kingston upon Thames	South	137	5	47	50	47	72
Merton	South	173	28	39	35	190	45
Sutton	South	325	10	328	121	54	59
Barnet	West and North West	243	16	107	34	49	50
Brent	West and North West	93	10	17	7	65	129
Ealing	West and North West	277	115	61	25	126	141
Harrow	West and North West	376	21	162	16	26	39
Hillingdon	West and North West	326	9	64	97	76	71
Hounslow	West and North West	35	107	432	20	58	78
Richmond upon Thames	West and North West	72	50	330	23	108	86

Patch Density in Inner London

Area name	East-West	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Hackney	East	7.0227	1.9508	32.3825	0.3902	2.7311	15.8011
Haringey	East	27.2444	1.3379	7.6625	0.4865	9.2436	2.6758
Islington	East	29.6331	5.4327	274.1062	1.4817	35.0658	20.2493
Lambeth	East	12.6025	1.5975	75.9702	13.3125	2.13	7.2775
Lewisham	East	46.1776	1.535	14.4545	10.7449	7.9308	1.9187
Newham	East	7.8931	0.8559	7.4176	0.7608	4.945	9.1293
Southwark	East	2.067	6.3485	5.0198	8.1202	7.8249	2.3622
Tower Hamlets	East	18.9731	3.3379	32.3246	1.0541	4.0406	9.3109
Camden	West	1.6896	5.8196	23.0905	4.5055	0.7509	12.5778
City of London	West	121.0171	56.2474	52.8384	1.7045	296.5771	8.5223
Hammersmith and Fulham	West	2.7591	0.8277	8.0013	2.4832	8.2772	15.7267
Kensington and Chelsea	West	71.4988	3.2685	64.5532	4.0856	63.7361	1.2257
Wandsworth	West	175.5243	4.3118	9.6116	1.1678	2.5152	1.4373
Westminster	West	17.2906	0.6345	25.5394	0.1586	1.9036	4.4416

Patch Density in Outer London

Area name	ENSW	Amenity	Cemeteries and Churchyards	Green Corridors	Natural and Semi-natural Urban Greenspace	Other and Unknown	Parks and Gardens
Barking and Dagenham	East and North East	3.2946	8.2365	43.5359	7.5305	0.3922	9.4916
Bexley	East and North East	6.2007	1.7202	2.5203	1.2001	2.0402	0.9601
Enfield	East and North East	3.8884	1.6808	10.11	0.6272	4.1895	0.3512
Greenwich	East and North East	46.8528	7.4297	4.0434	0.4043	12.0796	2.5271
Havering	East and North East	2.2789	0.9175	6.4373	0.6511	0.3848	4.3507
Redbridge	East and North East	14.6813	1.3626	3.4286	4.5714	1.8901	0.7912
Waltham Forest	East and North East	6.3951	2.9745	24.5394	0.9667	2.2309	6.0233
Bromley	South	2.1682	0.2899	5.067	0.8	2.1103	2.8639
Croydon	South	3.6581	1.5421	11.4763	0.8966	1.0759	6.5989
Kingston upon Thames	South	9.9583	0.3634	3.4163	3.6344	3.4163	5.2335
Merton	South	12.8116	2.0735	2.8882	2.5919	14.0705	3.3325
Sutton	South	21.8867	0.6734	22.0887	8.1486	3.6366	3.9733
Barnet	West and North West	7.4424	0.49	3.2771	1.0413	1.5007	1.5314
Brent	West and North West	9.6657	1.0393	1.7668	0.7275	6.7556	13.4073
Ealing	West and North West	16.0687	6.6711	3.5386	1.4502	7.3092	8.1794
Harrow	West and North West	23.2136	1.2965	10.0016	0.9878	1.6052	2.4078
Hillingdon	West and North West	6.2698	0.1731	1.2309	1.8656	1.4617	1.3655
Hounslow	West and North West	1.6493	5.0422	20.3574	0.9425	2.7332	3.6756
Richmond upon Thames	West and North West	2.1492	1.4925	9.8504	0.6865	3.2238	2.5671

Appendix 8. % of public green space (parks and gardens)

City	Figure	Date	Source
Dubai	2.00%	2015	Dubai Culture and Arts Authority
Istanbul	2.20%	2015	Istanbul Metropolitan Municipality
Mumbai	2.50%	2011	Tata Institute of Social Sciences
Shanghai	2.80%	2014	Shanghai Theatre Academy
Taipei	3.60%	2014	Parks and Street Lights Office, Taipei City
Bogota	4.40%	2013	Alcaldia Mayor de Bogota, Departamento Administrativo del Espacio Publico
Los Angeles	6.70%	2012	Greater Los Angeles County Open Space for Habitat and Recreation Plan
Tokyo	7.50%	2015	Bureau of Urban Development - Tokyo Metropolitan Government - "Survey of City Planning Park and Green Space in Tokyo 2015"
Buenos Aires	8.90%	2013	CABA
Melbourne	9.00%	2015	Metropolitan Planning Authority
Paris	9.50%	2013	IAU
Toronto	12.70%	2012	Toronto Parks, Forestry and Recreation Park Plan 2012-2017
Amsterdam	13.00%	2015	Statistics Netherlands/TNO
San Francisco	13.70%	2012	San Francisco Recreation and Parks Department Community Report/US Census Bureau
Berlin	14.40%	2011	Berlin.de
Montreal	14.80%	2013	Ville de Montreal, Direction des grands parcs et du verdissement
Austin	15.00%	2015	City of Austin
Edinburgh	16.00%	2009	Edinburgh City Council
Warsaw	17.00%	2015	Head Office of Geodesy and Cartography
Brussels	18.80%	2015	IBGE
Johannesburg	24.00%	2002	State of the Environment Report, City of Johannesburg 2009
Seoul	26.60%	2015	Seoul Metropolitan Government
New York	27.00%	2010	New York City Department of City Planning Land Use
Rio de Janeiro	29.00%	2013	SIG Florestas do RIO
London	33.00%	2013	Greenspace Information for Greater London CIC
Rome	34.80%	2014	Roma Capitale
Madrid	35.00%	2014	Archivo del Area de Gobierno de Las Artes, Deportes y Turismo. Ayuntamiento de Madrid
Hong Kong	40.00%	2015	Agriculture, Fisheries and Conservation Department
Stockholm	40.00%	2014	Stockholm Stad
Shenzhen	45.00%	2013	Shenzhen Statistical Yearbook 2014
Vienna	45.50%	2014	Vienna Annual Statistics 2014
Sydney	46.00%	2010	New South Wales Department of Planning
Singapore	47.00%	2011	National Parks Board
Moscow	54.00%	2013	Department of natural resources

Source: World Cities Culture Forum http://www.worldcitiescultureforum.com/data/of-public-green-space-parks-and-gardens, Accessed on 17th August 2017

Appendix 9. Green area per capita in selected OECD member Cities

Variables	Green area per million people (square meters per million person)[36]				
Unit	Ratio				
Year	**2010**	**2011**	**2012**	**2013**	**2014**
Vienna	231.12	228.81	226.52	224.24	221.99
Brussels	297.1	294.12	291.17	288.23	285.32
Zurich	277.6	275.33	273.06	270.8	268.55
Prague	275.68	272.84	269.96	267.03	264.05
Berlin	207.17	206.89	206.61	206.31	206
Copenhagen	382.85	381.18	379.52	377.85	376.18
Madrid	26.36	25.83	25.3	24.76	24.23
Helsinki	79.63	79.06	78.5	77.94	77.38
Paris	91.55	90.9	90.24	89.59	88.93
Athens	0.96	0.97	0.97	0.97	0.97
Budapest	417.03	415.9	414.72	413.5	412.23
Rome	232.7	230.73	228.76	226.77	224.78
Amsterdam	215.21	213.19	211.18	209.17	207.16
Oslo	307.31	302.8	298.35	293.96	289.63
Warsaw	1041.76	1036.99	1032.16	1027.27	1022.32
Lisbon	65.6	65.12	64.62	64.11	63.58
Stockholm	117.77	116.99	116.21	115.43	114.66
Ljubljana	953.12	945.43	937.78	930.18	922.61
London	36.97	36.51	36.06	35.61	35.16
New York	39.81	39.7	39.6	39.49	39.39
Tokyo	4.68	4.65	4.62	4.59	4.56
Seoul Incheon	5.92	5.79	5.65	5.51	5.34
Sydney	49.38	48.81	48.11	47.3	46.47

Source: Organisation for Ecologic Co-operation and Development (2016) OECD.Stat. online database

[36] Variables collected: Land in the metropolitan area covered by vegetation, forest and parks in 2000 (source: MODIS MCD12Q1), divided by the population of the metropolitan area and then multiplied by million.

Appendix 10. Green space per capita in Inner and Outer London

Inner London

Boroughs	East-West	Total Green Space Area in Boroughs (2014)	GLA Population estimate/ projection (2016)	Total area per capita (ha)	Total area per capita (m2)
Hackney	East	512.6222	261500	0.0020	20
Haringey	East	822.1871	267600	0.0012	12
Islington	East	202.4763	220400	0.0049	49
Lambeth	East	563.3789	318100	0.0018	18
Lewisham	East	781.7646	290500	0.0013	13
Newham	East	1051.5575	326300	0.0010	10
Southwark	East	677.3237	302900	0.0015	15
Tower Hamlets	East	569.2255	280500	0.0018	18
Camden	West	532.6861	233700	0.0019	19
City of London	West	58.6694	7900	0.0170	170
Hammersmith & Fulham	West	362.442	180400	0.0028	28
Kensington and Chelsea	West	244.7594	155700	0.0041	41
Wandsworth	West	1113.236	314700	0.0009	9
Westminster	West	630.3994	231000	0.0016	16

Outer London

Boroughs	ENSW	Total Green Space Area in Boroughs (2014)	GLA Population estimate/ projection (2016)	Total area per capita (ha)	total area per capita (m^2)
Barking & Dagenham	East and North East	1274.8106	198900	0.0064	64
Bexley	East and North East	2499.7201	238700	0.0105	105
Enfield	East and North East	3986.1687	324800	0.0123	123
Greenwich	East and North East	1978.5373	266900	0.0074	74
Havering	East and North East	6757.5346	244700	0.0276	276
Redbridge	East and North East	2275.0105	292900	0.0078	78
Waltham forest	East and North East	1344.7755	270200	0.0050	50
Bromley	South	8624.5099	321500	0.0268	268
Croydon	South	2788.3595	376700	0.0074	74
Kingston upon Thames	South	1375.741	168900	0.0081	81
Merton	South	1350.3414	206100	0.0066	66
Sutton	South	1484.9193	198700	0.0075	75
Barnet	West and North West	3265.0916	375000	0.0087	87
Brent	West and North West	962.1654	321700	0.0030	30
Ealing	West and North West	1723.853	346300	0.0050	50
Harrow	West and North West	1619.7407	246900	0.0066	66
Hillingdon	West and North West	5199.5233	292100	0.0178	178
Hounslow	West and North West	2122.0808	267400	0.0079	79
Richmond upon Thames	West and North West	3350.1175	193800	0.0173	173

Appendix 11. Overview of Data Variables - Ecosystem Services Relationships descriptions

	DERIVED VARIABLES		ECOSYSTEM SERVICES										
DIRECT MEASURES	Leaf Area	Leaf Biomass	Carbon Storage	Gross Carbon Sequestration	Net Carbon Sequestration	Energy Effects	Air Pollution Removal	Avoided Runoff	Transpiration	VOC Emissions	Compensatory Value	Wildlife Suitability	UV Effects
Species	D	D	D	D	D	D	I	I	I	D	D		
Diameter at breast height (DBH)			D	D	D						D	D	
Total height	D	D	D	D	D	D	I	I	I	I		D	
Crown base height	D	D	C				I	I	I	I			
Crown width	D	D	C				I	I	I	I			
Crown light exposure (CLE)				D	D								
Percent crown missing	D	D	C			D	I	I	I	I			
Crown health (condition/dieback)				D	D						D	D	
Field land use			D	D	D						D	D	
Distance to building						D							
Direction to building						D							
Percent tree cover						D	D	D				D	D
Percent shrub cover												D	
Percent building cover						D							
Ground cover composition												D	

D Directly used   I Indirectly used   C Conditionally used

Source: i-Tree homepage, 2017
https://www.itreetools.org/eco/resources/v6/Ecov6_data_variables_ES_relationships.pdf

Appendix 12. Local authority and regional CO_2 emissions in Inner London (2015) (kt CO_2)

	Industry and Commercial Total	**Domestic Total**	**Transport Total**	**LULUCF Net Emissions**	**Grand Total**	**Population ('000s, mid-year estimate)**	**Per Capita Emissions (t)**
Camden	694.34	302.67	148.58	0.37	1145.97	241.06	4.75
City of London	787.74	14.94	57.36	0.03	860.08	8.76	98.18
Hackney	288.91	302.09	150.29	0.31	741.59	269.01	2.76
Hammersmith and Fulham	357.98	264.44	161.59	0.27	784.28	179.41	4.37
Haringey	212.76	364.76	172.65	0.49	750.67	272.86	2.75
Islington	416.96	279.61	124.60	0.24	821.41	227.69	3.61
Kensington and Chelsea	590.77	295.18	154.97	0.22	1041.14	157.71	6.60
Lambeth	393.80	415.34	229.69	0.43	1039.25	324.43	3.20
Lewisham	186.01	395.94	233.69	0.66	816.29	297.33	2.75
Newham	550.90	335.50	294.52	0.51	1181.44	332.82	3.55
Southwark	620.36	350.12	225.49	0.53	1196.51	308.90	3.87
Tower Hamlets	894.89	269.88	261.54	0.36	1426.66	295.24	4.83
Wandsworth	309.07	459.81	226.86	0.62	996.35	314.54	3.17
Westminster	1484.73	344.00	294.92	0.36	2124.00	242.30	8.77

Source: Hoyt (2003) UK local authority and regional carbon dioxide emissions national statistics https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics

Appendix 13. Heights of Street Trees in Field and from Google Earth in Baker Street

Baker Street		Height (Abney Level) (cm/m)	Height (Google Earth) (m)
T1	Pyrus	1102.87 (11)	10
T2	Pyrus	1123.22 (11)	8
T3	Pyrus	1454.87 (15)	11
T4	Pyrus	1277.31 (13)	12
T5	Pyrus	1223.94 (12)	13
T6	Pyrus	1202.16 (12)	11
T7	Prunus	448.73 (4)	5
T8	Prunus	423.54 (4)	5
T9	Pyrus	1349.24 (13)	14
T10	Pyrus	1199.54 (12)	12
T11	Pyrus	1160.98 (12)	10
T12	Alnus	1604.92 (16)	24
T13	Alnus	713.77 (7)	9
T14	Platanus x Hispanica	1464.75 (15)	15
T15	Alnus	1669.83 (17)	17
T16	Platanus x Hispanica	1789.65 (18)	18
T17	Alnus	626.77 (6)	7
T18	Pyrus	962.15 (10)	10
T19	Alnus	1338.07 (13)	12
T20	Alnus	1208.11 (12)	14
T21	Alnus	1483.83 (15)	18
T22	Alnus	1943.24 (19)	18
T23	Alnus	1653.49 (17)	20

Appendix 14. Surveyed tree species, population and origin in BIDs

BID	Tree Species	Tree Number	Origin
Baker	Hedge maple	1	native
Baker	plum spp	2	native
Baker	Callery pear	20	nonnative
Baker	Ginkgo	1	nonnative
Baker	Italian alder	11	nonnative
Baker	London plane	3	nonnative
Baker	Pere david's maple	1	nonnative
Fitzrovia	Hedge maple	12	native
Fitzrovia	Black locust	2	nonnative
Fitzrovia	Callery pear	7	nonnative
Fitzrovia	Italian alder	2	nonnative
Fitzrovia	London plane	36	nonnative
HeartofLondon	ash spp	3	native
HeartofLondon	Littleleaf linden	1	native
HeartofLondon	Callery pear	4	nonnative
HeartofLondon	Laurel bay	1	nonnative
HeartofLondon	London plane	26	nonnative
HeartofLondon	magnolia spp	1	nonnative
HeartofLondon	mulberry spp	1	nonnative
HeartofLondon	Photinia	1	nonnative
HeartofLondon	Sour cherry	1	nonnative
Inmidtown	ash spp	1	native
Inmidtown	Common lime	3	native
Inmidtown	English holly	3	native

Inmidtown	English yew	1	native
Inmidtown	European hornbeam	1	native
Inmidtown	European white birch	10	native
Inmidtown	Hedge maple	1	native
Inmidtown	Littleleaf linden	1	native
Inmidtown	oak spp	2	native
Inmidtown	Oneseed hawthorn	1	native
Inmidtown	plum spp	3	native
Inmidtown	Whitebeam	1	native
Inmidtown	Wych elm	1	native
Inmidtown	Baldcypress	1	nonnative
Inmidtown	Black locust	1	nonnative
Inmidtown	Boxelder	1	nonnative
Inmidtown	Cherry plum	1	nonnative
Inmidtown	Dove tree	1	nonnative
Inmidtown	Higan cherry	1	nonnative
Inmidtown	London plane	78	nonnative
Inmidtown	Sweet chestnut	2	nonnative
Inmidtown	Tree of heaven	8	nonnative
LondonBridge	ash spp	3	native
LondonBridge	Bigleaf linden	3	native
LondonBridge	European beech	4	native
LondonBridge	Littleleaf linden	8	native
LondonBridge	Sweet cherry	25	native
LondonBridge	Whitebeam	1	native
LondonBridge	Black locust	1	nonnative

LondonBridge	Black mulberry	1	nonnative
LondonBridge	Caucasian ash	1	nonnative
LondonBridge	Evergreen oak spp	1	nonnative
LondonBridge	Grey alder	1	nonnative
LondonBridge	Horse chestnut	5	nonnative
LondonBridge	Indian paper birch	13	nonnative
LondonBridge	Italian alder	1	nonnative
LondonBridge	London plane	30	nonnative
LondonBridge	Oriental planetree	9	nonnative
LondonBridge	Red ash	2	nonnative
LondonBridge	Scarlet oak	17	nonnative
LondonBridge	Silver maple	3	nonnative
LondonBridge	Tree of heaven	7	nonnative
NewWestEnd	Callery pear	21	nonnative
NewWestEnd	Norway maple	2	nonnative
NewWestEnd	Sweetgum	2	nonnative
Paddington	Bigleaf linden	3	native
Paddington	Crabapple	4	native
Paddington	Downy birch	3	native
Paddington	Oneseed hawthorn	4	native
Paddington	plum spp	8	native
Paddington	Dawn redwood	2	nonnative
Paddington	golden chain tree spp	2	nonnative
Paddington	Italian alder	9	nonnative
Paddington	London plane	27	nonnative
Paddington	Oriental planetree	6	nonnative

Paddington	pear spp	1	nonnative
Paddington	Robinia spp	2	nonnative
Paddington	Swedish whitebeam	5	nonnative
Paddington	Sweet chestnut	2	nonnative
Southbank	Bigleaf linden	5	native
Southbank	Black poplar	1	native
Southbank	European ash	1	native
Southbank	Hedge maple	7	native
Southbank	Littleleaf linden	9	native
Southbank	oak spp	1	native
Southbank	plum spp	1	native
Southbank	Black locust	3	nonnative
Southbank	Black mulberry	1	nonnative
Southbank	catalpa spp	1	nonnative
Southbank	Ginkgo	1	nonnative
Southbank	Grey alder	1	nonnative
Southbank	Indian paper birch	9	nonnative
Southbank	katsura tree spp	1	nonnative
Southbank	London plane	28	nonnative
Southbank	magnolia spp	1	nonnative
Southbank	Northern red oak	2	nonnative
Southbank	Oriental planetree	16	nonnative
Southbank	Plumleaf hawthorn	1	nonnative
Southbank	Silver maple	1	nonnative
Southbank	Sweet almond	1	nonnative
Southbank	Tree of heaven	2	nonnative

Vauxhall	Bigleaf linden	7	native
Vauxhall	European ash	1	native
Vauxhall	plum spp	1	native
Vauxhall	Sweet cherry	4	native
Vauxhall	Horse chestnut	12	nonnative
Vauxhall	London plane	36	nonnative
Vauxhall	Norway maple	4	nonnative
Vauxhall	pear spp	4	nonnative
Vauxhall	Smoothleaf elm	7	nonnative
Vauxhall	Sycamore maple	2	nonnative
Victoria	Ginkgo 'autumn gold'	1	nonnative
Victoria	London plane	32	nonnative
Waterloo	alder spp	1	native
Waterloo	Common lilac	5	native
Waterloo	European bird cherry	16	native
Waterloo	European hornbeam	5	native
Waterloo	European white birch	9	native
Waterloo	Littleleaf linden	4	native
Waterloo	plum spp	9	native
Waterloo	Whitebeam	7	native
Waterloo	basswood spp	1	nonnative
Waterloo	Callery pear	14	nonnative
Waterloo	Chinese birch	3	nonnative
Waterloo	Common pear	1	nonnative
Waterloo	Ginkgo	9	nonnative
Waterloo	Horse chestnut	5	nonnative

Waterloo	Italian alder	6	nonnative
Waterloo	London plane	30	nonnative
Waterloo	Oriental planetree	1	nonnative
Waterloo	Swedish whitebeam	1	nonnative

Appendix 15. Interview Questionnaires

I want to thank you for taking the time to participate in my research interview.
My name is Yu Kyung Oh, a PhD candidate in King's College London.
I would like to talk to you about your points of views or experiences while you are participating in the All London Green Grid (ALGG) project or any related project in the Greater London.
My research is focused on climate change adaptation in London through ecosystem services management (e.g. carbon sequestration). I am primarily concerned with looking at the potential for small urban green spaces in London Business Improvement Districts to sequester carbon, as well as effectiveness of carbon sequestration from the ALGG project.
As part of this research I am interested in obtaining the perspectives of those involved in some form of governance or management of London's green spaces, and associated climate change strategies. In specific, the interview contents consist of three parts: Perspectives on the All London Green Grid Project, and Climate Change Strategies; Evaluation of the All London Green Grid Project, and Climate Change Strategies; and Capacity for Participating in the All London Green Grid Project in the pursuit of Resilience to Climate Change.
Before starting to answer interview questions, would you let me know whether your name and affiliation would be kept anonymous or not?
If you have any inquiries about interview questions, or anything else, would you let me know please? Once again, I appreciate for your participation.

Interview Questions

Brief Information about Interviewee

1. How long have you worked in your organisation?

2. What are your main tasks in the organisation?

Perspectives on the All London Green Grid Project, and Climate Change Strategies

3. Are you familiar with concepts of "connectivity of open spaces" and "carbo

n sequestration"?

If so, how could you have known those concepts?

4. Are you involved in the project?
   4.1. If so, how do you contribute to the project?
   4.2. If possible, would you let me know any kinds of open space projects related to climate change adaptation, or at least the All London Green Grid?

5. To what extent or how do you recognise risks and impacts from climate change while proceeding projects in London?

6. When working on open space related projects, does the issue of climate change impacts and adaptation have a high priority?
   6.1. If not, could you explain why, and which factors are highly prioritized?

7. Do you think that connectivity of open spaces can contribute to carbon sequestration and climate change adaptation?

Evaluation of the All London Green Grid Project, and Climate Change Strategies

8. Is there any third-party or institutions to monitor and evaluate the process and outcomes of the project, or green infrastructure project related to the ALGG?
   8.1. If so, what kinds of procedures are passed through?

9. As for the evaluation of the projects, do you think that the projects are suc cessful so far in terms of provision and connectivity of green spaces?
    9.1. If so, how have the projects contributed so far?
    9.2. How has your organization contributed to its proliferation?
10. When it comes to open space data creation, how have you obtained the inf ormation?
    10.1. And what kinds of difficulties have you faced in the process of its acquisition?
11. When it comes to building a baseline evidence for further progressing the ALGG project, what kinds of evidence have been shown to other stakehold ers?
    11.1. Are the quality and quantity of the data enough for them to be convinced with certainty about the project?
12. As for the evaluation of the project, do you think to what extent the projec t is helpful for carbon sequestration and air quality?
    12.1. Do you have any good case for the effectiveness?
13. Would you suggest any good business cases in Greater London showing a good balance among economic, environment and social welfare while progre ssing projects?

14. How has the project been financed while working on the project?

    14.1. Do you think the given finance is enough for proceeding the project?

    14.2. If you think the finance is not enough for proceeding the project, wha t kinds of funding options have a feasibility to attract more financial assistance?

15. How do you collaborate with other organizations such as the Greater Londo n Authority, councils, Business Improvement Districts, Cross River Partnersh ip and Transport for London or other related organizations? Could you expl ain how each stakeholder plays a role in the projects?

16. When it comes to connectivity of open spaces, do you think that street tree s are a good means for achieving the goal?

    16.1. As for creation of tree data inventory in Greater London, what kinds of difficulties have you experienced while collecting and managing tre e data?

    16.2. As for i-Tree project, how is the project able to contribute to the AL GG project?

17. Even though each council has a separate strategy for urban greening, there is a limit to cover all areas in each borough. In the situation, the role of Business Improvement District has gained more attention and importance in terms of open space provision and management in specific areas as well a s more detailed open space data. Yet some BIDs are still not active in urb an greening projects but concentrate on more visible and short-term outcom es such as air quality improvement. What kinds of motivations or incentives can be suggested to other BIDs in order to make them more participate in urban greening?

Thanks for allowing your time for my research

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