Urban green infrastructures: an assessment of urban bird diversity, abundance and behaviour associated with green walls and street trees in Manchester and Salford, UK

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Declaration of Originality

This thesis is presented as an original contribution for the Qualification of Master of Science by Research at the University of Salford, Salford, UK. To my knowledge the material featured in this thesis does not contain any materials previously published or written by another where the author has not been referenced and acknowledged.

ABSTRACT

Urban green infrastructures: an assessment of urban bird diversity, abundance and behaviour associated with green walls and street trees in Manchester and Salford, UK.

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Urbanisation is a worldwide process with serious wellbeing impacts on people and wildlife. Reconciliation ecology, a novel approach to conservation, is particularly relevant for urban conservation as new habitats can be established and maintained. Street trees and green walls are examples of interventions aiming to improve urban areas for people and wildlife, but questions remain over their design, placement and benefits. Using direct observational surveying, data were collected on bird species richness and abundance at sixteen sites across the cities of Manchester and Salford, UK, and, along with bird behaviours, at eight green walls and adjacent street trees. There was a strong negative relationship between bird species richness and abundance and noise level, along with a moderate correlation with distance to green spaces and no correlation with the area of sites. More bird activity and behaviours were observed on the street trees than on green walls. Height and area of the green wall were found to be positively correlated with bird species richness, abundance and behaviour while plant diversity and ecological value did not appear to influence these factors. While there were some positive relationships between green walls and opportunities for birds to feed and rest, street trees were observed to be the most suitable of the two interventions for urban birds. Compared with data in the literature, it appears in this study it reported fewer birds and behaviours associated with the green walls. This suggests that the green walls in Manchester and Salford are examples of unproductive walls not meeting wildlife-friendly criteria. The design and installation of green walls needs to be remodelled to meet ecological goals focused on biodiversity and, thereby, contribute to the wellbeing of birds.

COVID IMPACT STATEMENT

1) The COVID-19 (SARS-CoV-2) pandemic in 2020 and the result of the UK Government National Lockdown have disrupted this Master of Research programme. This study aimed to observe and monitor birds in the urban environment and their relationship with green infrastructures. The Government rule of 'stay at home' (23rd March 2020) limited travel to essential workers. As a result, it was not possible to complete the original planned observational period of October 2019 to June 2020 as the collection of observational field data from the sample sites in the cities of Manchester and Salford was prohibited. Surveying and data collection were only possible from October 2019 to March 2020. This resulted in three months' worth of data being lost, including potentially influential data during a highly active time of the sampling taxon; that is, observing birds' behaviours during their seasonal mating and nesting periods. British breeding birds' mating and nesting behaviours can occur between February to August, depending on the species, but the busiest months in terms of this activity and behaviours are March to July (BTO, 2021a; BTO, 2021b). These behaviours and higher activity were an important initial construct of the research.

The lockdown also caused a massive shift in human activity, as many people stayed indoors prohibited to undertake regular activities (Natural History Museum, 2020; Basile, et al., 2021). Urban areas turning 'quiet' would have likely had a major impact on bird behaviour and activity, due to the lack of people and their disturbances (Natural History Museum, 2020; Basile, et al., 2021; Oscar, et al., 2021). Even if data collection had continued in 2020, the birds' behaviours would be notably different compared to a 'normal year' and the 2020 breeding season would not have been representative of most years.

There was another national lockdown in late 2020/early 2021, with restrictions lifted from March 2021 to July 2021. Hence the gap in data from 2020 could not be filled during 2021. Further, data collected on one aspect (e.g., nesting) in one season would not be directly comparable with other data collected in a previous year. Hence, the ideal of data collected over full seasons (over one year) (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016) was not possible. Additionally, the level of human activity would not have been the same, especially as many people were still actively avoiding busy areas (Natural History Museum, 2020), such as the sample sites across the cities. Also, the previous lockdown had encouraged myself, to move back home in the North East of England, away from the sample sites in Greater Manchester, preventing access to the sample sites due to a long commute and no accommodation options. As a result, it was not possible to continue collecting data for the intended three months in 2021.

2) The original planned research was to be carried out throughout October to June, to follow seasonal bird observations in both winter and spring (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016). While some bird-related studies choose to use the active spring months (Strohbach, Haase, & Kabisch, 2009; Dallimer, et al., 2012; Strohbach, Lerman, & Warren, 2013; Belcher, et al., 2019), as an urban-related study, urban birds can be active throughout the year due to evolutionary adjustments (Sol, Lapiedra, & González-Lagos, 2013: Rivkin, et al., 2019). Using a longer observational period would have allowed comprehensive monitoring of urban bird behaviours for comparing green infrastructures (e.g., foraging, resting and general moving throughout the cities). In addition to monitoring courtship, mating and nesting behaviours to observe further affordances of the green infrastructures, a customary focal observation topic of other previous birds and green infrastructure studies (Fernández-Juricic, 2000; Chiquet, Dover, & Mitchell, 2012; Kane, Warren, & Lerman, 2015; Bolhuis Casas, 2016; Belcher, et al., 2019). The original plan was to contribute to knowledge by comparing and evaluating green infrastructures in the urban environment and determine their values to the urban bird community and urban conservation across a wider range of affordances. All this was not possible due to the limitations set out in parts 1 and 3 of this note.

3) Only six months of data, instead of nine months, were collected and analysed. While the collection of a full set of data was prevented – it was not possible to observe year-round seasonal bird behaviours (including mating and nesting) as intended – despite this data were still used to successfully compare bird activity and behaviours on the green infrastructures using a list of bird behaviours conveyed from previous work (Bolhuis Casas, 2016). In addition, the data allowed further questions to be formulated to extend the objectives and still achieve the aim of the research. For example, it was possible to explore urban bird association. Using the sample sites, the

research objectives further investigate bird richness and abundance as a whole city environment to determine environmental characteristics influencing bird activity, such as connectivity, noise and area (Evans, et al., 2011; Strohbach, Lerman, & Warren, 2013; Grafius, et al., 2017; Pena, et al., 2017; Leveau & Leveau, 2020). This was further used to determine the influence of green infrastructures on bird behaviours, along with exploring in-depth the influence of characteristics of the green walls, as there is a common perception that there are still many limitations for bird activity (Francis & Lorimer, 2011; Bolhuis Casas, 2016).

Overall, from the data it was possible to glean valuable insights that address some of gaps in knowledge due to the lack of previous research on bird association with green walls and street trees in the UK. The data were successfully used to compare green infrastructures, to determine which is the more suitable green infrastructure for urban birds and a better application towards urban conservation. Using the data it was possible to focus on the problems and implications of green infrastructures currently in cities, especially green walls, and make suggestions of how to improve them. In conclusion, the data allowed recommendations for extended and further research concerning green infrastructure and urban bird conservation.

1. CHAPTER 1 - INTRODUCTION

Urbanisation is expanding rapidly worldwide (Goddard, Dougill, & Benton, 2012; Partridge & Clark, 2018; Rivkin, et al., 2019) creating urban centres for the growing global human population in search of a prosperous, urban life (Radford & James, 2012; Madre, et al., 2013; Partridge & Clark, 2018). The process itself has become linked with a multitude of negative social and environmental impacts (Radford & James, 2012; Madre, et al., 2013; Rivkin, et al., 2019). It is associated with major landscape changes from habitat destruction and fragmentation (Brenneisen, 2004; Radford & James, 2012; Madre, et al., 2013; Bolhuis Casas, 2016; Rivkin, et al., 2019) that, consequently, cause a loss of biodiversity, along with a loss of connection between people and nature (Goddard, Dougill, & Benton, 2012; Lindo, 2018). Many human health and wellbeing benefits are seen to be related to contact with nature (Goddard, Dougill, & Benton, 2012; Cox & Gaston, 2015; Manchester City Council, 2019a). As people live increasingly urbanised lifestyles, it is important, more than ever, to connect people to nature and enable them to access these benefits (Goddard, Dougill, & Benton, 2012; Lepczk & Warren, 2012; Cox & Gaston, 2015; Grant & Gedge, 2019): a manifest motive for greener and sustainable urban environments (Francis & Lorimer, 2011; Lindo, 2018; EFB, 2019a).

There are, however, some negative perceptions of urban biodiversity including biotic homogenisation, dominant species and species diversity loss (Marzluff, Bowman, & Donnelly, 2001; Clergeau, et al., 2006; Sol, Lapiedra, & González-Lagos, 2013). Nonetheless, such viewpoints are being challenged, highlighting that while urban environments may appear homogenous, they can still offer a wide spectrum of different microhabitats which can accommodate a range of species (Lorimer, 2008; Goddard, Dougill, & Benton, 2012; Madre, et al., 2014; Lindo, 2018; Morelli, et al., 2018). Though it is apparent for biodiversity there is a wide difference in response to urbanisation and it depends on the species' relative ability to tolerate and take advantage of urban landscapes (Morelli, et al., 2018; Partridge & Clark, 2018). There are species that can easily adapt or respond to the challenges of urban living (Sol, Lapiedra, & González-Lagos, 2013). It is the many behavioural adjustments that has allowed these urban exploiters to deal with the urbanisation process, related to the use of new foraging opportunities, enhanced communication and reduction of fear to humans (Sol, Lapiedra, & González-Lagos, 2013). Though, there are still many species that become locally extinct as they cannot adapt to the urban environment (Bolhuis Casas, 2016; Partridge & Clark, 2018).

Some bird species have been found to thrive in the urban environment (Sol, Lapiedra, & González-Lagos, 2013; Lindo, 2018), with many species becoming strongly associated with urbanisation (Strohbach, Haase, & Kabisch, 2009; Evans, et al., 2011; Lepczk & Warren, 2012; Lindo, 2018; RSPB, 2019a). These bird species have adapted accordingly to local conditions and adjusted behaviourally to most anthropogenic factors: human disturbance; reduction of natural resources; human built infrastructure; anthropogenic noise; and artificial light (Sol, Lapiedra, & González-Lagos, 2013; Lindo, 2018; Morelli, et al., 2018). Despite the success of some bird species there are still more challenges that birds face in urban environments including poor nutrition, a decrease of vegetation cover, the lack of foraging and nesting opportunities (Chiquet, Dover, & Mitchell, 2012; Strohbach, Lerman, & Warren, 2013; Lindo, 2018). These impacts can affect bird species differently (Morelli, et al., 2018; Partridge & Clark, 2018) and there is an overall trend of decline in bird diversity (Chace & Walsh, 2006; Morelli, et al., 2018).

The ability to support biological conservation in urban environments is becoming a major challenge because the usual approach of preservation and restoration are both insufficient and not viable (Francis & Lorimer, 2011; Bolhuis Casas, 2016). Reconciliation ecology is a novel approach to biological conservation and is particularly relevant for urban conservation (Francis & Lorimer, 2011; Bolhuis Casas, 2016). It is a way to modify the anthropogenic environment to encourage biodiversity without compromising human land use (Francis & Lorimer, 2011). New habitats can be established and maintained in places where people live, work and play (Bolhuis Casas, 2016). A potential method to offset the negative impacts of urbanisation to reconcile urban expansion with the safeguarding of biodiversity and ecosystem services (Madre, et al., 2013; Madre, et al., 2014; Partridge & Clark, 2018).

There is a collaborative effort to draw together ecosystem services, natural capital and nature-based solutions to solve and improve issues concerning biodiversity, health and wellbeing and other environmental issues (Oppla, 2019; Reid, Jones-Morris, & Snell, 2019; Wainhouse, Wansbury, & Hicks, 2019). Nature-based solutions are innovative living designs using nature to simultaneously provide environmental, social and economic benefits, to help build resilient and sustainable urban environments (Elgizawy, 2016; EFB, 2019a). Green cities are a trending concept to incorporate more nature-based solutions in the urban landscape and more biodiversity considerations into urban planning for the protection and restoration of ecosystems (IUCN, 2017; Urban Pioneer, 2018; Manchester City Council, 2019b; Nature Greater Manchester, 2019).

City planners worldwide are increasingly embracing urban green interventions and installing green infrastructures (IUCN, 2017; Urban Pioneer, 2018; Manchester City Council, 2019b; Nature Greater Manchester, 2019). Green infrastructures are the use of natural (i.e., plant) elements to produce a network of natural and semi-natural areas, designed and managed as multifunctional resources capable of delivering a wide range of environmental and wellbeing benefits for society (European Environment Agency, 2019; Oppla, 2019; Reid, Jones-Morris, & Snell, 2019; Wheelwright & Walker, 2019). They can offer ecosystem protection to improve the provisions of ecosystem services that can ease environmental pressures (Elgizawy, 2016; European Commission, 2019). They can address the threats of biodiversity loss, offering various resources and opportunities including vegetation, space and connectivity (Elgizawy, 2016; Grafius, et al., 2017; European Commission, 2019; Reid, Jones-Morris, & Snell, 2019). This makes nature-based, green infrastructure a, potentially practical tool for urban biological conservation, especially bird conservation (Brenneisen, 2006; Fernandez-Canero & Gonzalez-Redondo, 2010; Carbó-Ramirez & Zuria, 2011; Chiquet, Dover, & Mitchell, 2012; Partridge & Clark, 2018).

Green infrastructures can be physically large, and contain conventional elements such as green spaces (e.g., parks and public gardens), which can be a major natural part of the urban environment (Strohbach, Lerman, & Warren, 2013). However, it is difficult to improve or enhance urban green areas due to a conflict for 'human' space, which often means many conservation goals cannot be met (Radford & James, 2012). Smaller conventional methods such as street trees, a more compact form of green infrastructure can be used. (Strohbach, Lerman, & Warren, 2013). As a structural green element, they can be distributed across the urban landscape, often outside larger green spaces, and can offer the benefits associated with green infrastructure over a broader scale (Dover, 2015). While street trees are a smaller, practical green infrastructure element compared to parks and public gardens, they still require adequate ground space (Dover, 2015).

The ground space that is often limited in an urban environment, means these conventional green methods are not always practical (Radford & James, 2012). More contemporary green infrastructures and green building technologies are progressively being used in cities (Madre, et al., 2013; IUCN, 2017). One emerging technology is green walls, which integrate vegetation onto a building with vertical wall systems (Köhler, 2008; Loh, 2008). Traditionally, such methods were used for their aesthetic value, but are gradually been seen to offer benefits for ecosystem services and biodiversity (Köhler, 2008; Chiquet, Dover, & Mitchell, 2012; Growing Green Guide, 2014). Now with more designs and systems, including living walls they can contribute to more ecological, economic and social benefits (Loh, 2008; Francis & Lorimer, 2011; Morton, 2011; Sheweka & Magdy, 2012; Manso & Castro-Gomes, 2015; Grant & Gedge, 2019).

Nonetheless, street trees are still an important green infrastructure, renowned for their ability to improve the urban environment, particularly by assisting with flood defence and cooling (Braverman, 2008; Dover, 2015; Salmond, 2016; Rivkin, et al., 2019). Street trees are also extremely beneficial to urban biodiversity as a source of habitat and food (Davis, Major, & Taylor, 2016; Grafius, et al., 2017; Pena, et al., 2017; Long & Frank, 2020; Wood & Esaian, 2020). While overall reducing the impact of urbanisation towards wildlife, including human disturbance and increase vegetation coverage and habitat connectivity (Braverman, 2008; Davis, Major, & Taylor, 2016; Grafius, et al., 2017; Pena, et al., 2017): they are important for urban birds (Long & Frank, 2020; Wood & Esaian, 2020). As a notable natural feature within the urban environment, they are regularly exploited by urban birds in various ways for place of safety and security, including accommodating for a range of nesting (Davis, Major, & Taylor, 2016; Surya, 2016; Pena, et al., 2017; Wood & Esaian, 2020). Unfortunately, they are seen by some people as a nuisance and even a health and safety risk (Dover, 2015; Salmond, 2016; Bartlett & Jain, 2019). It is becoming an issue that many local authorities mainly focus on the ornamental value of street trees rather than taking a wider, more wholistic view (Dover; 2015; Salmond, 2016).

Though a much different greening technology, green walls are also used to support urban biodiversity, both for plants and animals (Sheweka & Magdy, 2011; Elgizawy, 2016; Ansglobal, 2019a). They are slowly becoming a solution to help restore urban environments and to help mitigate the loss of habitat and species (Francis & Lorimer, 2011; Chiquet, Dover, & Mitchell, 2012; Elgizawy, 2016; Biotecture, 2018). They can be used as a habitat improvement technique, refining artificial urban habitats, while taking the form of novel habitats (Francis & Lorimer, 2011; Bolhuis Casas, 2016). An accepted alternative habitat that can provide water, food, protection and nesting opportunities (Elgizawy, 2016). A method with potential to help increase biodiversity through encouraging new and existing urban wildlife (Köhler, 2008; Sheweka & Magdy, 2011; Madre, et al. 2015; Elgizawy, 2016; Collins, Schaafsma, & Hudson, 2017; Mayrand & Clergeau, 2018).

Green walls, particularly, beneficial for birds (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al. 2019). They can provide them with supplementary ecological benefits such as resources opportunities (e.g., food and nesting sites) and increase habitat availability, in addition to good perching and roosting elements (Price, 2010; Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). Several studies have explored associated bird behaviours, including nesting, refuge and food, as well as monitoring bird richness and abundance, enlightening that green walls have the potential to support bird species (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). However, there are limited urban bird-related studies on green walls and their environment, and their impacts on the local bird communities are not well understood, especially their influence of design and placement on bird richness and abundance (Elgizawy, 2016; Partridge & Clark, 2018).

Both green infrastructures, green walls and street trees, are plausible methods for urban conservation and promising techniques to increase the greenery within urban areas, offering natural spaces and valuable resources not regularly available across the urban landscape (Francis & Lorimer, 2011; Dover, 2015; Bolhuis Casas, 2016; Partridge & Clark, 2018; Jackson, 2019). They can enhance the space used by people while simultaneously offering resources to wildlife, ultimately, valuable interventions that can be used for reconciliation ecology (Bolhuis Casas, 2016). However, there is a wide gap in the knowledge around the unexplored potential of green infrastructures when it comes to biological conservation.

Previous green walls and urban bird related studies have successfully assessed a positive relationship with bird biodiversity (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). Though such studies only have compared to non-vegetated walls, but was concluded that vegetated green walls were significantly better than concrete bare walls. It was then decided to expand on the idea and compare green walls with street trees, a more conventional green infrastructure, to determine any differences or similarity in values towards urban bird biodiversity. This study will fundamentally focus on the association between urban birds and the two green infrastructures: green walls and street trees, with intentions to investigate their uses by birds. Thereby further investigating their potential, while exploring possible factors, including design and placement, which can be influential on bird biodiversity (Elgizawy, 2016).

The following aims and objectives will be investigated by this study on urban green infrastructure and urban bird biodiversity:

Aim:

- To explore and evaluate urban bird association with urban green infrastructures: green walls and street trees.

Objectives:

- To analyse bird species richness and abundance across Manchester and Salford, UK.
- To understand how the type and amount of bird activity within a city varies by environment.
- To understand the relationships between bird activity and site characteristics including distance to other green spaces, noise levels and area of sites.
- To investigate the relationships between green infrastructures, bird activity and environmental variables such as green wall size and design, isolation and site characteristics.

Chapter two, ‘Literature Review’, introduces the process of urbanisation, the negative impacts on people and wildlife and the motivation for greener and sustainable urban environments. While the perception of urban biodiversity is often overlooked, it is more diverse than it is judged, as many organisms can thrive within the landscape (Sol, Lapiedra, & González-Lagos, 2013; Madre, et al., 2014), including urban bird communities, though they can still face various urbanised impacts (Lindo, 2018; Morelli, et al., 2018). The use of nature-based solutions and the growth of green infrastructures from their multitude of benefits, including their ecological properties are set out. The conclusion from the chapter is that, while there are ‘conventional’ green infrastructures such as street trees, a well distributed and natural source, there are ‘new’ green infrastructure such as green walls that are becoming a new application of reconciliation ecology. There is, though, a gap in knowledge regarding the biodiversity function of these two green infrastructure elements.

In Chapter three, ‘Methodology’, describes the methods which were used within this study to achieve the aims and objectives. The layout of the study is explained from the selected sixteen sampling sites across the cities, and the eight green walls and adjacent street trees. This is followed by details of the data collection methods, using direct observation surveying, to determine bird richness and abundance and behaviours. Finally the statistical methods of the data analysis are described and justified to compare data and determine relationships.

In Chapter four, ‘Results’, describes the data collected across the two cities and the comparison of green walls and street trees are described. Data relating to the bird species richness and abundance found in both cities using all sample sites is described, and their relationship between site variables (i.e., connectivity, noise level and area of the site). The bird richness and abundance and behaviours observed on the eight extant green walls and adjacent street trees are set out. The chapter ends with a description of the relationships between the green infrastructures, bird activity and site variables, and the relationships between green walls’ bird activity and their characteristics (i.e., height, area and the number of plant species).

Chapter five, ‘Discussion’, contains a review of the key findings from the study, starting with the diverse set of bird species found in the two cities and what is considered to be negative factors affecting the urban bird community. The comparison between bird activity on both green infrastructures is discussed, to determine which one is deemed more accessible and suitable for urban birds. While also discussing which environmental characteristics could also influence green infrastructure bird exploitation, particularly green wall design and placement. Overall, the difference of bird association on these types of green infrastructures in a city environment is explored, while noting the limitations of the study and setting out recommendations of further research.

2. CHAPTER 2 - LITERATURE REVIEW

2.1. Urbanisation

Urbanisation has become an ever-growing and expanding process turning massive amounts of rural land into urban centres (Marzluff, Bowman, & Donnelly, 2001; Goddard, Dougill, & Benton, 2012; Radford & James, 2012; Partridge & Clark, 2018; Rivkin, et al., 2019). The process continues to increase throughout the world associated with the rising global human population (Marzluff, Bowman, & Donnelly, 2001; Clergeau, et al., 2006; Radford & James, 2012; Elgizawy, 2016). Historically, people have moved from rural areas to the cities in search of work and housing (Lindo, 2018). Today this movement continues with people attracted to cities and towns for housing, employment, access to health and social care, education and cultural activities and the anticipation of prosperity (Radford & James, 2012; Madre, et al., 2013; Partridge & Clark, 2018).

Although such attractants are perceived to be positive for human living, urbanisation can be responsible for a multitude of negative social impacts including poverty, poor health and wellbeing, as well as serious environmental impacts (Radford & James, 2012; Rivkin, et al., 2019). Urbanisation is associated with major landscape changes and environmental alterations that can have a massive impact on the natural ecosystem (Clergeau, Jokimäki & Savard, 2001; Clergeau, et al., 2006; James, Norman, & Clarke, 2010; Radford & James, 2012; Elgizawy, 2016). From the high density of residential and industrial areas in cities and towns, there is a replacement of natural vegetation by built structures and impervious surfaces, and fragmentation of the landscape by buildings and roads (Sheweka & Magdy, 2011; Radford & James, 2012; Sol, Lapiedra, & González-Lagos, 2013; Partridge & Clark, 2018; Rivkin, et al., 2019). Futhermore, human activity causes other disturbances such as artificial light, noise and chemical pollution (Sol, Lapiedra, & González-Lagos, 2013; Lindo, 2018). When poorly managed, these issues result in many cities and towns facing challenges such as overheating, air pollution, local flooding and loss of biodiversity (Sheweka & Magdy, 2011; Radford & James, 2012; Bartlett & Jain, 2019; Illman, 2019; Rivkin, et al., 2019). These negative impacts are not just affecting people and the economy, but fundamentally jeopardising the environment and biodiversity (Madre, et al., 2013).

Habitat elimination and fragmentation, and natural resource consumption has caused a reduction in 'natural' and 'green' areas in the urban landscape (Brenneisen, 2004; Sheweka & Magdy, 2011; Radford & James, 2012; Madre, et al., 2013; Bolhuis Casas, 2016; Rivkin, et al., 2019). Ultimately resulting in a loss of biodiversity. Marzluff, Bowman, & Donnelly (2001) and Sol, Lapiedra, & González-Lagos (2013) demonstrate that urbanisation is one of the important drivers of extinction, as evidenced by the overall trend of species diversity loss. Urbanisation is influencing natural processes, causing more negative impacts including higher mortality incidents, lack of resources, poor quality habitats and connectivity (Lepczk & Warren, 2012; Radford & James, 2012; Bolhuis Casas, 2016; Partridge & Clark, 2018). It can be disruptive to invertebrate and vertebrate populations (Marzluff, Bowman, & Donnelly, 2001; James, Norman, & Clarke, 2010; Partridge & Clark, 2018), collectively representing a significant threat to local and global biodiversity (Clergeau, et al., 2006). The change in land use and configuration essentially changes species richness and composition, impacting species distributions and ecologies (Lepczk & Warren, 2012; Bolhuis Casas, 2016). The loss of biodiversity is associated with a loss of connection between people and nature (Goddard, Dougill, & Benton, 2012; Lindo, 2018).

2.2. People and Nature

Biodiversity conservation in an urban setting has been a recent development, becoming more common from the 1990s (Rivkin, et al., 2019). When it became acknowledged that there can be such thing as urban biodiversity, and the importance support and encourage urban wildlife, while helping connect people with nature (Goddard, Dougill, & Benton, 2012; Lindo, 2018). Many human health and wellbeing benefits are now understood to be related to contact with nature (Dallimer, et al., 2012; Goddard, Dougill, & Benton, 2012; Cox & Gaston, 2015; Cox, et al., 2017; Manchester City Council, 2019a). As people in developed and developing countries live increasingly urbanised lifestyles, it is important now more than ever to connect people to nature and enable them to access these benefits (Goddard, Dougill, & Benton, 2012; Lepczk & Warren, 2012; Cox & Gaston, 2015; EFB; 2019a; Grant & Gedge, 2019).

A greener environment is linked to happier people as biophilia creates an instinctive bond with nature (Biotecture, 2018). A biophilic design can offer many benefits beyond aesthetics (Ansglobal, 2019b). It can enhance and enrich the environment with calming and restorative properties (Biotecture, 2018). The increase of greenery can ultimately benefit people's wellbeing, directly and indirectly (Dallimer, et al., 2012; Manchester Institute for Collaborative Research on Ageing, 2016; Cox, et al., 2017; European Commission, 2019). Exposure to nature, even observing vegetation, can promote mental health by reducing stress levels, the likelihood of high blood pressure and depression (EFB, 2019a; Manchester City Council, 2019a).).

Yet, while nature is evidently important to people, Lutz, Simpson-Housley, & Deman (1999) found that there is a mixture of appreciation of nature by urban inhabitants. For example, while many people in the UK will choose to encourage wildlife, others may take actions to prevent wildlife through creating barriers and traps (Lindo, 2018). This is because many people still hold a negative perception of urban wildlife, which they believe is largely comprised of only pigeons (*Columba*), rats (*Rattus*) and foxes (*Vulpes*), which they believe are feral and vermin and should be destroyed (Lorimer, 2008).

2.3. Urban Biodiversity

Throughout the world, urban areas are uniform environments, as cities can be similar to one another in many biotic and abiotic environmental characteristics (Groffman, et al., 2014; Rivkin, et al., 2019). Urbanisation has amplified the effect of biotic homogenisation increasing similarities across communities in space and time among urban locations (Marzluff, Bowman, & Donnelly, 2001; Møller, 2012; Morelli, et al., 2018). However, Morelli, et al. (2018) explains that urban environments may appear homogenous but can offer a wide spectrum of different microhabitats. There is a variety of habitats in these human-associated spaces from gardens to parks, street trees to urban forests and heathlands to brownfield sites which all can accommodate a range of species (Lorimer, 2008; Goddard, Dougill, & Benton, 2012; Madre, et al., 2014; Lindo, 2018). There have been examples where urban areas have occasionally been used for the conservation of endangered species (Kowarik, 2011; Madre, et al., 2014) with opportunities to sustain biodiversity provided by substitute habitats and even by the creation of new ecological niches (Brenneisen, 2004; Ernstson, 2012).

Though It is apparent that there is a wide difference in response to urbanisation; this depends on the species' relative ability to tolerate and take advantage of urban landscapes (Morelli, et al., 2018; Partridge & Clark, 2018). Historically, urban biodiversity has been able to develop and thrive in human-dominated areas. For example, the well-known house sparrow (*Passer domesticus*) is historically a major part of UK cities that unfortunately went through a declined over the last century (Lindo, 2018; RSPB, 2019a). A process that is reflected in many invertebrate and vertebrate communities in urban areas, as pressures from humans and a lack of resources can push certain wildlife away (Lindo, 2018). As cities become more inhospitable to wildlife, species can disappear as they do not have the tolerance to survive and succeed (Sol, Lapiedra, & González-Lagos, 2013; Madre, et al., 2014; Lindo, 2018). Conversely, there are species that can easily adapt or respond to the challenges of urban living (Sol, Lapiedra, & González-Lagos, 2013). Species that are little affected by the urbanisation process or have been able to take advantage of any ecological opportunity, can proliferate and even expand their range (Sol, Lapiedra, & González-Lagos, 2013). These are urban exploiters' that can live independently of natural areas, they have highly flexible diets, are behaviourally flexible or have co-evolved with humans (Partridge & Clark, 2018; Rivkin, et al., 2019).

Urbanisation has, as a result, caused a shift in the diversity and richness of urban biodiversity. It has caused a chain reaction to the structure of biodiversity modifying the composition of biological communities by increasing the biodiversity productivity in dominant, non-native and/or generalist species due to species and habitat homogeneity (Radford & James, 2012; Bolhuis Casas, 2016; Partridge & Clark, 2018), and decreasing biodiversity productivity associated with more sensitive or urban avoiders species which are adversely affected by the lack of space, inappropriate habitats and human disturbance (Clergeau, et al., 2006; Bolhuis Casas, 2016; Partridge & Clark, 2018).

It is often a behavioural adjustment that has allowed urban exploiters to deal with the urbanisation process (Sol, Lapiedra, & González-Lagos, 2013). This a complex and slow process, which ultimately allows an organism to colonise and thrive in urban environments (Strohbach, Haase, & Kabisch, 2009; Rivkin, et al., 2019). The process can even lead to genetic and behavioural differences between individuals of a species living in urban areas and their rural counterparts (Strohbach, Haase, & Kabisch, 2009; Sol, Lapiedra, & González-Lagos, 2013). The high rate of evolution and adjustment which has allowed wildlife to establish in an anthropogenic environment is driven by urban challenges (Sol, Lapiedra, & González-Lagos, 2013). While this does differ from species to species due to their tolerance to this environmental alteration, Sol, Lapiedra, & González-Lagos (2013) found the most consistent changes in behaviour are related to the use of new foraging opportunities, enhanced communication and reduction of fear of humans.

2.4. Birds and the Urban Environment

Some bird species have been found to thrive in the urban environment (Strohbach, Haase, & Kabisch, 2009; Evans, et al., 2011; Lindo, 2018). There are around 620 species of bird and over 200 breeding species in the UK (BOU, 2019), and it is believed that any bird species, resident or migrant, can be seen in an urban area (Lindo, 2018). Though some species can be more strongly associated with urbanisation than others, such as the blackbird (*Turdus merula*), blue tit (*Cyanistes caeruleus*), great tit (*Parus major*), starling (*Sturnus vulgaris*) and woodpigeon (*Columba palumbus*) (Lepczk & Warren, 2012). While species house sparrow and feral pigeon (*Columba livia domestica*), and non-native ring-necked parakeet (*Psittacula krameria*), are three of the relatively few species that are ecologically associated with humans (Lepczk & Warren, 2012; Lindo, 2018; RSPB, 2019a).

Birds adapt genetically to local conditions, which have led to the evolution of their traits and behaviours (Møller, 2012; Morelli, et al., 2018; Rivkin, et al., 2019). Many bird species are becoming more adaptable to the anthropogenic changing conditions (Evans, et al., 2011; Surya, 2016; RSPB, 2019a) and have adjusted behaviourally to the urban environment (Strohbach, Haase, & Kabisch, 2009; Sol, Lapiedra, & González-Lagos, 2013). It is now common for urban birds to behaviourally adjust accordingly to most anthropogenic factors such as: human disturbance, lack of natural food sources, built infrastructure, anthropogenic noise and artificial light (Møller, 2012; Lindo, 2018; Morelli, et al., 2018; Rivkin, et al., 2019). The most successful urban bird species efficiently exploit local resources, choosing to live in proximity to humans to gain preferred favourable conditions such as higher food availability, warmer open areas and lower predation risks (Surya, 2016; Lindo, 2018; Morelli, et al., 2018; Partridge & Clark, 2018).

Humans can be still a predatory threat to urban birds. Indirectly humans can be disruptive. Tolerance to human disturbance is key of successful urban establishment as it means birds can save time and energy, otherwise allocated for unnecessarily escaping from approaching humans (Sol, Lapiedra, & González-Lagos, 2013; Morelli, et al., 2018). There are examples of some birds (e.g., blackbird) changing their spatial activity when it comes to human disturbances, such as by shortening flight initiation distances to approaching humans (Sol, Lapiedra, & González-Lagos, 2013; Morelli, et al., 2018). The ability to recognise when humans are a problem or not has ultimately modified some species foraging and/or nesting behaviour in urban areas, particular examples are the magpie (*Pica pica*) and feral pigeon (Sol, Lapiedra, & González-Lagos, 2013). However, some species, for example, the house sparrow still tend to avoid very high human densities even if highly dependent on human-associated food (Sol, Lapiedra, & González-Lagos, 2013).

An urban landscape, in which 'natural' sources of food are either in short supply or non-existent, has driven birds to find novel food sources or adjust foraging opportunities to avoid the risk of starvation (Partridge & Clark, 2018). Many bird species have adapted their diet to include human-associated food including human litter, artificial feeders, and ornamental fruiting vegetation (Sol, Lapiedra, & González-Lagos, 2013). There is still debate over the benefits or harm associated with human-derived food resources for urban wildlife, but there are reports of its importance for bird populations, for example, the blackbird which has achieved much higher winter survival rates thanks to human feeding. In addition, it is associated with higher densities of birds such as pigeons and gulls compared to their rural counterparts (Sol, Lapiedra, & González-Lagos, 2013).

Alongside human activity, birds must also adjust to avoid human-associated artefacts such as vehicles, overhead lines, houses, skyscrapers and windows, which have all been associated with high mortality of birds (Sol, Lapiedra, & González-Lagos, 2013). There have been examples of species that can adopt human-made structures because of their evolutionary history. Birds that are native to rocky habitats are able to take advantage of a city's impervious surfaces and vertical structures (Johnston & Janiga, 1995; Lundholm & Marlin, 2006; Rivkin, et al., 2019). In the UK, many bird species such as swallows (*Hirundo rusticia*), house martins (*Delichon urbicum*), swifts (*Apus*

apus) and sparrowhawks (*Accipiter nisus*) can adjust to nesting and perching on urban crevice and ledges of built structures which are similar to their natural environment (Edwards, 1994; Lindo, 2018).

Anthropogenic noise originating from human activity and built structures can have negative effects on acoustic bird communication (Sol, Lapiedra, & González-Lagos, 2013). It can interfere with the acoustic signals and limits its distance of transmission, a disadvantage for birds that use song and calls for warning, mating and territorial behaviours (Catchpole & Slater, 2008; Sol, Lapiedra, & González-Lagos, 2013). There have been reports that birds can change their acoustic signals by singing louder, using higher frequencies than the background noise and in the gaps between anthropogenic noise (Slabbekoorn & den Boer-Visser, 2006; Halfwerk et al., 2011; Slabbekoorn, 2013). Subsequently, studies suggest that there is a difference in bird song frequency between urban and rural bird species, for example, the urban great tit now sing at a noticeably higher frequency than those in rural environments (Halfwerk & Slabbekoorn, 2009). Increased artificial lighting is another anthropogenic factor which is known to alter birds' activity patterns (Sol, Lapiedra, & González-Lagos, 2013). It is debated though if this has been a negative or positive factor, as some bird species that rely on insect diet have been able to increase prey capture by feeding on insects attracted to artificial lights (Sol, Lapiedra, & González-Lagos, 2013). The prolonged lights have also allowed some diurnal birds, like gulls and pigeons, to forage during the later hours of night, thereby enabling them to fulfil their daily food requirements (Sol, Lapiedra, & González-Lagos, 2013). In addition, artificial lighting has altered birds to sing their dawn chorus earlier, which has been associated to increased reproductive rates and opportunities (e.g., blue tit) (Miller, 2006; Kempernaers et al., 2010).

Despite their many successes in adapting to urban challenges, there are still many bird species that face: pollution, poor nutrition, a decrease of vegetation cover, the lack of foraging and nesting opportunities (Chiquet, Dover, & Mitchell, 2012; Strohbach, Lerman, & Warren, 2013; Lindo, 2018). Food and habitat specialist bird species have the tendency to struggle as they cannot adapt to the urban environment and/or the absence of the specific resources they require (Clergeau, et al., 2006). For examples, some British insectivorous bird species, such as swallows (Hirundinidae), warblers (Parulidae) and woodpeckers (Picidae), which rely on certain insect species for their diet (Chiquet, Dover, & Mitchell, 2012). The process of urbanisation has affected invertebrate populations (Madre, et al., 2013), because a decrease in vegetation is associated with their declines, and in turn, there has been a drop in urban insect feeding bird species (Chace & Walsh, 2006; Strohbach, Lerman, & Warren, 2013). Other bird guilds including migratory birds have also struggled in urban environments. They require suitable habitats to roost, breed and/or nest, and the lack of space and poor resources has ultimately left them unable to cope (Surya, 2016; Partridge & Clark, 2018).

While bird species differ in their urban tolerance, there has been an overall decline in urban bird diversity (Strohbach, Haase, & Kabisch, 2009; Evans, et al., 2011; Morelli, et al., 2018; Partridge & Clark, 2018). Chace & Walsh (2006) and Strohbach, Lerman, & Warren (2013) explain that species diversity of birds is much lower in densely built areas than in rural areas, while Clergeau, et al. (2006) reports that the number of species decreases from the peri-urban (surrounding urban) to the urban centre areas. Urbanisation is changing the functional aspect of the bird community with considerable pressures on sensitive/specialist species, as urbanised areas provide limited habitats and are only inhabited by a few capable species (e.g., dominant/generalists). Thus, urban bird biodiversity is structurally simple and homogenised (Clergeau, et al., 2006; Strohbach, Lerman, & Warren, 2013; Sol, Lapiedra, & González-Lagos, 2013; Bolhuis Casas, 2016; Partridge & Clark, 2018).

2.5. Reconciliation Ecology

Reconciling the often-competing requirements of urban conservation and the needs of humans requires appropriate strategies and implementation (Grafius, et al., 2017). The traditional conservation approach has been the preservation of natural habitat remnants (Bolhuis Casas, 2016; Li, et al., 2018; Rewilding Britain, 2019) and the restoration or rehabilitation of degraded ecosystems (Francis & Lorimer, 2011; Greater Manchester Biodiversity Project, 2011; Radford & James, 2012; Root-Bernstein, Gooden, & Boyes, 2018). However, supporting biological conservation in urban environments is becoming a major challenge (Francis & Lorimer, 2011), as the urban landscape is often fragmented and restoring the ecological function to fragments may not be an ideal approach (Bolhuis Casas, 2016; Li, et al., 2018; Rewilding Britain, 2019). Francis & Lorimer, 2011, demonstrated that preservation and restoration are insufficient to prevent the forthcoming extinction cascade and proposed reconciliation ecology. Biological conservation in such a highly transformed place, where preservation and restoration methods may not be viable, another strategy needs to be considered (Bolhuis Casas, 2016).

Reconciliation ecology is a novel approach to conservation and is particularly relevant for urban conservation (Francis & Lorimer, 2011; Bolhuis Casas, 2016). Rosenzweig (2003) believed that the anthro-environment may be modified to encourage non-human use and biodiversity without compromising human land use, as it does not attempt to re-create or stimulate a previous ecosystem state or condition (Francis, 2009; Francis & Lorimer, 2011). A solution to establish and maintain new habitats and conserve the diversity of species in places where people live, work and play (Bolhuis Casas, 2016). Reconciling urban expansion with the preservation of biodiversity and ecosystem services can help towards more sustainable and healthier urban environments that could offset the negative impacts of urbanisation (Sheweka & Magdy, 2012; Madre, et al., 2014; Elgizawy, 2016). The European Commission (2019) agrees that a network of healthy ecosystems that provide cost-effective alternatives is better compared to 'grey' infrastructures. The urban area can become a safer environment with functioning ecosystems which are better at preventing floods, storing carbon and providing residents with clean air, water and food (Rewilding Britain, 2019). This new approach has caused a rise of urban conservation to reorient biological conservation, as well as the adaptation to climate change and its ecological implication (Lorimer, 2008; Greater Manchester Biodiversity Project, 2011; Radford & James, 2012).

Through new knowledge and thinking, there is a collaborative effort drawing together ecosystem services, natural capital and nature-based solutions (Oppla, 2019; Wainhouse, Wansbury, & Hicks, 2019), to solve and improve issues concerning biodiversity, health, wellbeing and other environmental issues (Reid, Jones-Morris, & Snell, 2019). Nature-based solutions involve living design that simultaneously provides environmental, social and economic benefits, to help build resilient and sustainable urban environments (Elgizawy, 2016). Their use has caused the rise of 'Green Cities': a dynamic approach to create an innovative urban design using nature-based ideas into the urban landscape (IUCN, 2017; Urban Pioneer, 2018; Manchester

City Council, 2019b; Nature Greater Manchester, 2019). The International Union for Conservation (IUCN) has a growing interest in working with cities. Their hope is to raise awareness for the value of greener urban areas for the protection and restoration of ecosystems, critical to improving the health and wellbeing of the growing number of people inhabiting cities (IUCN, 2017; EFB, 2019a). European Environment Agency has also promoted the need for urban greening investment in cities to be able to adapt locally to climate change and to officially address biodiversity loss (EFB, 2019a).

2.6. Urban Green Infrastructures

Cities worldwide are embracing urban green intervention, as an essential requirement for achieving sustainable cities and to tackle the many environmental issues of urban living (EFB, 2019a; Rivkin, et al., 2019). Over the last 20 years, there has been a global encouragement for the development of urban greening policies and incentives within towns and cities. Nature-based green infrastructures are an example of green interventions becoming increasingly popular (IUCN, 2017; Urban Pioneer, 2018; Manchester City Council, 2019b; Nature Greater Manchester, 2019). Global associations such as the World Health Organisation (WHO) and the European Union (EU) are steadily promoting the importance of green infrastructures (IUCN, 2017; European Commission, 2019), along with the European Commission developing a Green Infrastructure Strategy (European Commission, 2019).

Green infrastructures are artificial elements to produce a network of natural and semi-natural areas (European Environment Agency, 2019). They are method of integrating more greenery and vegetation into the customarily ‘grey’ built-up areas (Oppla, 2019; Reid, Jones-Morris, & Snell, 2019; Wonderwall, 2019). These networks are designed and managed as multifunctional resources capable of delivering a wide range of ecosystem services creating environmental and quality benefits for society (European Environment Agency, 2019; Oppla, 2019; Reid, Jones-Morris, & Snell, 2019; Wheelwright & Walker, 2019). They fundamentally offer ecosystem protection, creating richer ecosystems improving the provisions of ecosystem services to ease environmental externalizations (e.g., pollution, water runoff and urban heat island effect) for a sustainable and green economy (Elgizawy, 2016; European Commission, 2019). A viable mitigation solution to climate change at a local level in an attractive and environmental way (Bartlett & Jain, 2019; Illman, 2019; Reid, Jones-Morris, & Snell, 2019).

Green infrastructure can be a way to address threats of biodiversity loss (Reid, Jones-Morris, & Snell, 2019). Just offering a variety of vegetation and plants can help protect and enhance urban biodiversity, by increasing the capacity to support a larger range of taxa and the provisions of improving links for biodiversity (Brenneisen, 2006; Grant, 2006; Kadas, 2006; Köhler, 2008; Dunnett, Nagase, & Hallam, 2008; Francis & Lorimer, 2011; Elgizawy, 2016; Grafius, et al., 2017; Mayrand & Clergeau, 2018; Reid, Jones-Morris, & Snell, 2019). It makes green infrastructures a potentially practical tool for reconciliation ecology and urban biological conservation including bird conservation (Brenneisen, 2006; Fernandez-Canero & Gonzalez-Redondo, 2010; Carbó-Ramirez & Zuria, 2011; Chiquet, Dover, & Mitchell, 2012; Partridge & Clark, 2018).

2.7. Conventional Green Infrastructure

2.7.1 Urban Green Spaces

Green spaces, such as parks and public gardens, are a major green infrastructure component of the urban landscape, providing ecosystem services for the city dwellers and supporting biodiversity (Braverman, 2008; Strohbach, Lerman, & Warren, 2013). In many cities, green spaces are large areas, while the rest are smaller patches like pocket parks, private gardens or street trees (Strohbach, Lerman, & Warren, 2013). Due to a variety of sizes and distribution, some - especially the smaller green spaces - become isolated within the matrix of the built landscape, which influences their ability to support urban wildlife, including birds (Strohbach, Lerman, & Warren, 2013; Barth, FitzGibbon, & Wilson, 2015; Grafius, et al., 2017). Patch size is one of the most important factors for explaining bird diversity in green space, as predicted by the island theory of biogeography (Strohbach, Lerman, & Warren, 2013). Smaller spaces are expected to be less valuable for birds, as there is more edge habitat and less habitat diversity, providing less cover from predators and human disturbance, and only support smaller populations (Clergeau, Jokimäki & Savard, 2001; Strohbach, Lerman, & Warren, 2013).

However, Strohbach, Lerman, & Warren (2013) found that small green spaces of a few hundred square metres were still associated with an increase in bird richness. In addition, several researchers agree that green areas do hold potential as urban biodiversity hotspots (Strohbach, Lerman, & Warren, 2013; Morelli, et al., 2018). Donnelly & Marzluff (2004) in Seattle, USA, estimated that 42ha allowed native forest bird species to persist in green space patches, and Fernández-Juricic & Jokimäki (2001), in Finland and Spain, found that parks between 10 and 35 ha in size contain most bird species found in the overall city's area. These small areas have been found to be beneficial for specialist insectivore birds for feeding, migrant birds as migratory stopover sites and as opportunities for nesting and foraging (Partridge & Clark, 2018). These urban green spaces, regardless of size, can encourage and support a higher amount of wildlife, helping those that are urban dwellers, utilizers and possibly avoiders, as an area of greenspace can offer resources that are more or less limited across the built landscapes (Strohbach, Lerman, & Warren, 2013; Morelli, et al., 2018; Partridge & Clark, 2018).

Pećarević, Danoff-Burg, & Dunn (2010) explain that urban green spaces are becoming a common urban habitat, due to their large expanse, and are one of the most common settings for human interaction with nature and wildlife. In the UK, urban greenspaces are the sites of daily interaction between people and biodiversity. It is becoming increasingly necessary to enhance the quantity and quality of these green infrastructures to reduce the otherwise hostility of the urban matrix (Lepczk & Warren, 2012; Radford & James, 2012; Madre, et al., 2013; Madre, et al., 2014). However, it is difficult to improve or enhance urban green areas due to a conflict for space in a dense concrete environment which means that conservation goals cannot be met (Radford & James, 2012). Conventional methods, such as traditional planting, are not always practical (Radford & James, 2012) and innovative ideas for urban conservation is required.

2.7.2 Street Trees

Even as a conventional green infrastructure, street trees are a more compact and the most prevalent feature across both urban and suburban environments (Braverman, 2008; Strohbach, Lerman, & Warren, 2013; Dover, 2015). Unlike other green spaces, they can be more dispersed across the landscape, found in various places: alongside roads, roundabouts, pathways, pedestrian zones and buildings, either surrounded by concrete or an assortment of other vegetation (e.g., bushes, flowers and grasses) (Dover, 2015). They can be assembled in small or large groups or even place singularly, in a bunch or linearly depending on where and how they are planted, as some are historical, *in situ* street trees and others are newer, deliberately planted street trees, meaning they can also vary in maturity and species (Dover, 2015).

Street trees are well-known to provide amenity for aesthetical and cultural values but are becoming an important feature to mitigate and improve the urban environment (Braverman, 2008; Salmond, 2016; Grafius, et al., 2017). Trees are a natural component to tackling current climate impacts. They are extremely effective in offsetting pollutants, improving local air quality, and create a good source of drainage capable of reducing flooding (particularly flash flooding). They also provide extensive shading able to aid in the cooling effect of heatwaves and avert heat stress (Armson, Stringer, & Ennos, 2013; Dover, 2015; Salmond, 2016; Pena, et al., 2017; Manchester City Council, 2019a). Though not as vast and dense as urban forests, street trees dispersed across the city offer a boarder scale to offset the ongoing issues of urban living, improving the overall health of the city and people (Armson, Stringer, & Ennos, 2013; Dover, 2015; Salmond, 2016; Pena, et al., 2017; Lindo, 2018; Rivkin, et al., 2019).

Street trees can be extremely beneficial to urban biodiversity as a great source of habitat and food, (Davis, Major, & Taylor, 2016; Long & Frank, 2020; Wood & Esaian, 2020), but overall reducing the impacts of urbanisation including human disturbance and noise (Fernández-Juricic, 2000; Braverman, 2008; Pena, et al., 2017) and improving connectivity in the urban matrix (Grafius, et al., 2017; Mayrand & Clergeau, 2018). They are important for urban birds, particularly woodland birds, migratory birds and insectivorous birds (Fernández-Juricic, 2000; Barth, FitzGibbon, & Wilson, 2015; Davis, Major, & Taylor, 2016; Pena, et al., 2017; Leveau & Leveau, 2020; Long & Frank, 2020; Wood & Esaian, 2020; Villaseñor, Escobar, & Hernández, 2021). They are especially key for nesting birds, as they can help accommodate for a range of nesting techniques including cavity, cup, platform and pendant (Kane, Warren, & Lerman, 2015; Surya, 2016). They offer the structure and resources, providing shade from sun, wind and rain, safety from disturbances and predators and access to nesting material (Fernández-Juricic, 2000; Kane, Warren, & Lerman, 2015; Surya, 2016) which, ultimately, leads to the successful rearing of broods.

Despite the obvious benefits of street trees, they can be considered a problem as they are seen as a nuisance (Dover, 2015). Trees produce sap and leaves that can conflict with pedestrians using paths and car owners, and produce pollen that affects many people who are susceptible to hay fever (Braverman, 2008; Dover, 2015; Bartlett & Jain, 2019). As an attractant to wildlife, they can be a pest due to swarms of insects and bird defecation (Braverman, 2008). They are also associated with health and safety hazards including obscuring view which can potentially jeopardise people's safety from criminal activity, and their collapse or falling branches causing property damage (e.g., buildings and vehicles) or potentially an injury/death of a person (Braverman, 2008; Bartlett & Jain, 2019). There have been some instances where street trees have bought about large amounts of pest and disease that can impact other plant species (Braverman, 2008).

There is a constant battle with street trees, and while they are a smaller practical green infrastructure compared to parks and public gardens, they still require ground space. The current concerns that there is still an insufficient number of trees in urban areas, and it is becoming evident there is not enough support to compete with the street tree planning and administrating (Braverman, 2008; Dover, 2015; Leveau & Leveau, 2020; Villaseñor, Escobar, & Hernández, 2021). Many local authorities do not appear to grasp the full value of street trees, which can be difficult as they are expensive to maintain, which ultimately has led to a national (UK) poor investment with a lack of maintenance and an out-of-date inventory, and, consequently, mainly leave them as ornamental features (Braverman, 2008; Dover 2015; Salmond, 2016).

2.8. Green Wall Technology

2.8.1 Systems and Designs

Greening buildings are a growing urban greening method (Madre, et al., 2013). These green infrastructures are an approach between architecture and the environment (Elgizawy, 2016), and a collaboration to construct and manage buildings in a sustainable and environmentally friendly way (Sheweka & Magdy, 2011; 2012). While vegetation on buildings have been used for a millennia, such as self-adhering climbing plants colonising vertical surfaces, green walls are an emerging technology that integrate vegetation onto a building with vertical wall systems (Köhler, 2008; Loh, 2008; Morton, 2011; Chiquet, Dover, & Mitchell, 2012; Growing Green Guide, 2014; Living Roofs, 2019; Urban Green-Blue Grids, 2019). Green wall designs are constantly evolving but can be distinguished into two forms: green façade (Francis & Lorimer, 2011; Manso & Castro-Gomes, 2015) and living walls (Bolhuis Casas, 2016; Elgizawy, 2016; Grant & Gedge, 2019). Green façades involve climbing or hanging plants which are rooted in the ground or planter and trained to grow directly to the wall surface or indirectly onto a supporting structure on the wall (Francis & Lorimer, 2011; Manso & Castro-Gomes, 2015). Living walls differ as they support vegetation that is either rooted on the wall or in the substrate attached to the wall (Francis & Lorimer, 2011; Morton, 2011). They can either be a continuous system based on screens into which plants are inserted individually or modular growing inside modules located on the surface of the wall separated by an impermeable membrane (Francis & Lorimer, 2011; Manso & Castro-Gomes, 2015).

Living walls are a relatively recent innovation, but prevalent in green architecture designs over the last 15 years, becoming a reliable and useful approach to greening buildings (Köhler, 2008; Manso & Castro-Gomes, 2015; Living Roofs, 2019). Living walls are more modular as plants can be partially grown on individual sections before mounting, thereby, facilitating easy replacement (Francis & Lorimer, 2011). They allow the integration of greenery on high buildings, covering exposed large and hard surfaces rapidly with a variety of plant species (Sheweka & Magdy, 2011; Manso & Castro-Gomes, 2015). They are a fitted technology that is flexible with a self-watering function designed with a hydroponic system where water and nutrients are circulated into the wall via a mean of mechanical irrigation (Loh, 2008) enabling large displays with little maintenance (Francis & Lorimer, 2011; Inleaf, 2019; Wonderwall, 2019). However, such a system frequently uses material with high environmental impacts and, as a result, are often a more expensive system when compared to green façade systems (Elgizawy, 2016).

2.8.2 Multitude of Benefits

Traditionally, vegetation on walls have been used to decorate buildings for visual amenity value, with only secondary value for ecosystem services and biodiversity, and any other recreational and health benefits (Köhler, 2008; Chiquet, Dover, & Mitchell, 2012; Growing Green Guide, 2014). The arrangement of colourful plants are valued for their aesthetic qualities and scent but can be attractive to wildlife too with its dense foliage, good for both foraging and nesting opportunities for a variety of birds and invertebrates (Köhler, 2008; Coma, et al., 2017; Living Roofs, 2019). Though these infrastructures have been questioned, including the objections regarding moisture and nuisance from wildlife (e.g., invertebrates entering homes), and concern that climbing plants can be destructive, especially with buildings with previous damage (Chiquet, Dover, & Mitchell, 2012; Urban Green-Blue Grids, 2019). However, the vegetation can actually protect the building by improving temperature and humidity, while the dense vegetation shades the building lowering the internal temperature (Loh, 2008; Sternberg, Viles, & Cathersides, 2011; Chiquet, Dover, & Mitchell, 2012; Growing Green Guide, 2014; Urban Green-Blue Grids, 2019).

The new green wall systems have followed example to protect buildings, and are now well known for many other benefits: ecological, economic and social benefits (Loh, 2008; Francis & Lorimer, 2011; Morton, 2011; Chiquet, Dover, & Mitchell, 2012 ; Sheweka & Magdy, 2012; Manso & Castro-Gomes, 2015; Bolhuis Casas, 2016; Grant & Gedge, 2019). They are a nature-based solution that can respond to the current challenges in the urban environment (EFB, 2019a). For instance, they can help improve local temperature, improve air quality, and enhance surface water management, as well as contributing to energy-saving benefits to buildings, improving human health and wellbeing and provision of habitat (Ong, 2003; Cornelis & Hermy, 2004; Francis & Lorimer, 2011; Chiquet, Dover, & Mitchell, 2012; Bartlett & Jain, 2019; Grant & Gedge, 2019).

Green walls have the ability to improve local urban climate (Brenneisen, 2004; Biotecture, 2018; Partridge & Clark, 2018). The selection of plants offer a cooling mechanisms through evapotranspiration that can help lower the outdoor temperature and has been seen to reduce the urban heat island (UHI) effect by around 2°C (Loh, 2008; Sheweka & Magdy, 2012; 2012; Elgizawy, 2016). Plants are also effective against gaseous and particulate pollutants, filtering and absorbing airborne particles that can become trapped in urban street canyons ultimately improving the local air quality (Köhler, 2008; Loh, 2008; Sheweka & Magdy, 2011; Elgizawy, 2016; EFB, 2019b; Grant & Gedge, 2019). Reports suggest that green walls can reduce air pollution at street levels by 40% and particulates by 60% (Brenneisen, 2004; Partridge & Clark, 2018; Grant & Gedge, 2019). Green walls can help mitigate storm water by reducing heavy storm water flows, a way to combat local flooding (Köhler, 2008; Loh, 2008; Roehr & Laurenz, 2008; Price, 2010; Sheweka & Magdy, 2011; Madre, et al., 2013; Elgizawy, 2016; Living Roofs, 2019). Flooding occurs when drainage is incapable of storing and distributing storm water levels specifically after extreme weather events (Sheweka & Magdy, 2011). Covering impervious surfaces with plants, soil or plant medium, is a better way to retain water to control water runoff and slowing storm water (Sheweka & Magdy, 2011; Partridge & Clark, 2018; Grant & Gedge, 2019). They can also collect wastewater to be drained away, where all the water is practically used up by the plants meaning there is very little waste (Elgizawy, 2016).

There are some economic benefits associated with green walls as the ethical and recreation values enhances branding and increases value of the property (Liu, 2002; Sheweka & Magdy, 2011; Madre, et al., 2013; Ansglobal, 2019a). However, the majority of the economic benefits are associated with the environmental benefits (Sheweka & Magdy, 2011). For instance, there are many energy-saving properties (Köhler, 2008; Price, 2010; Sheweka & Magdy, 2011; Elgizawy, 2016; Coma, et al., 2017). They can lower energy consumption, saving up to 5 to 10% of electricity consumption and reduce greenhouse gas emission (Loh, 2008; Sheweka & Magdy, 2012; Madre, et al., 2013; Biotecture, 2018). Green walls can control indoor temperature through insulation and cooling mechanisms able to decrease temperature on and inside buildings (Köhler, 2008; Loh, 2008; Price, 2010; Sheweka & Magdy, 2011; Elgizawy, 2016; EFB, 2019b). Treebox (2014) reports that there is a temperature difference of up to 17^{0}C between hard conventional walls and vegetated walls, as the vegetated shading prevents building surface from absorbing solar radiation and reradiating it back. Green walls can save energy by providing 3°C insulation in winter and 3°C of shading in summer (Köhler, 2008).

As a multifunctional green infrastructure, green walls also provide social benefits (Loh, 2008; Sheweka & Magdy, 2011; Ansglobal, 2019a). They are an aesthetic visual amenity providing a visual contrast as a relief on a ‘grey’ environment, softening the built environment with greenery (Köhler, 2008; Sheweka & Magdy, 2011; 2012;

Ansglobal, 2019a). It can make the local surroundings more comfortable by lowering ambient temperatures and moderating the harsh nature of the urban structures, creating a healthier local environment to promote human health and human-nature interactions (Loh, 2008; Elgizawy, 2016). Green walls offer city dwellers a sense of closeness and connection to nature within the urban world, bringing a range of direct and indirect benefits to health and wellbeing, along with improving morale and education towards nature and the environment (Köhler, 2008; Loh, 2008; Sheweka & Magdy, 2011; Elgizawy, 2016). They can be tools to teach about the environment, facilitating the next generation to learn about the environmental concerns of today and how to address them, using them for ecological observations and growing plants and produce (Sheweka & Magdy, 2011).

2.8.3 Wildlife Friendly

Green walls are seen to support urban biodiversity for both plants and animals (Sheweka & Magdy, 2011; Madre, et al., 2015; Elgizawy, 2016; Collins, Schaafsma, & Hudson, 2017; Mayrand & Clergeau, 2018). They are systems which are either left to be spontaneously colonised by wildlife or deliberately established (Lorimer, 2008). They can be a valuable solution to help restore and mitigate the loss of habitats and species, due to the increase of urbanisation (Francis & Lorimer, 2011; Chiquet, Dover, & Mitchell, 2012; Elgizawy, 2016; Biotecture, 2018; Partridge & Clark, 2018; Belcher, et al., 2019). They can be a habitat improvement technique refining the artificial urban habitats (e.g., walls and pavements) so that species from comparable natural habitats (e.g., rocks and cliffs) can be supported (Francis & Lorimer, 2011; Bolhuis Casas, 2016; Mayrand & Clergeau, 2018). Or can also take the form of novel habitats by altering the urban landscape composition and configuration which some species can be sensitive to (Bolhuis Casas, 2016). Especially as they create spaces, which are generally undisturbed; located above ground level disturbances creating a quieter and remote setting (Madre, et al., 2014; Partridge & Clark, 2018).

Green walls are becoming accepted alternative habitats, providing water, food, protection and places to bear and raise offspring (Price, 2010; Sheweka & Magdy, 2011; Chiquet, Dover, & Mitchell, 2012; Mayrand & Clergeau, 2018; Elgizawy, 2016). There is potential that they could help increase biodiversity through encouraging new and existing urban wildlife, even native species (Köhler, 2008; Loh, 2008; Francis &

Lorimer, 2011; Collins, Schaafsma, & Hudson, 2017; Mayrand & Clergeau, 2018; EFB, 2019b). The selection of vegetation, which can improve the look of the infrastructure through a range of colours, shapes and patterns (Francis & Lorimer, 2011; Living Roofs, 2019), are particularly useful for pollinators, food production and nesting areas for many insects, birds and bats (Loh, 2008; Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Biotecture, 2018; Ansglobal, 2019a; Belcher, et al., 2019). They are ultimately a source to encourage biodiversity in areas of high urban development density, enriching the ecological quality and health of the environment (Loh, 2008; Sheweka & Magdy, 2011; Elgizawy, 2016).

Green walls have been found as a useful resource for birds: either utilizing all resources or for selected amenities (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Collins, Schaafsma, & Hudson, 2017; Belcher, et al., 2019; Grant & Gedge, 2019). The vegetated accumulated biomass provides them with supplementary ecological benefits such as resource opportunities (e.g., food and nesting sites) and increasing habitat availability, in addition to good perching and roosting elements (Price, 2010; Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). Bird exploitation can vary between species, for example, hummingbird species (Trochilidae) forage on flowering plants, while sparrow species (Passeridae) forage on *sedum* plants (Bolhuis Casas, 2016). Sparrow species can also forage on the extra surfaces (i.e., wall edges and window ledges) and were found using them for reproductive activities (e.g., tending chicks) (Bolhuis Casas, 2016). In the UK, sparrows, along with starlings and blackbirds, have been recorded to roost and nest in green walls (Chiquet, Dover, & Mitchell, 2012). As urbanisation can have negative impacts on bird population density (Madre, et al., 2013; Strohbach, Lerman, & Warren, 2013), due to their requirement for forage, cover and nesting opportunities, green walls are a potential tool for bird conservation, especially as species of concern (i.e., UK Red List species) were found using them (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019).

2.8.4 Ecological Mitigation Values

Green walls can be a plausible method of urban conservation by offering new natural spaces and valuable resources not regularly available across the urban landscape (Francis & Lorimer, 2011; Partridge & Clark, 2018). They can form appropriate habitats for plants and animals that can colonise the area, mainly invertebrates (e.g., wild bees, beetles and spiders), birds and bats (EFB, 2019a). These habitats on buildings tend to be isolated from ground level habitats, so the species identified are mostly able to fly where the urban landscape cannot efficiently limit their movement, dispersal or colonisation (Madre, et al., 2013; Mayrand & Clergeau, 2018; EFB, 2019a). Conserving these green wall exploiters, like the many in the arthropod community, is becoming imperative in the urban environment as they are facing massive declines due to urbanisation (Madre, et al., 2013). The supportive properties of green walls towards arthropods could fundamentally improve the quality of biodiversity and habitats across the urban landscape (Madre, et al., 2013; Partridge & Clark, 2018). This will successively support urban birds, particularly the specialist insectivorous species - a struggling urban taxon (Partridge & Clark, 2018). However, with their limiting accessibility, in addition to their smaller area, their role in sheltering biodiversity would appear to be more suitable for certain organisms (Madre, et al., 2014; Madre, et al., 2015). This could create some ecological limitations as some species may not be able to colonise due to their dispersal capabilities or size (Baumann 2006; Francis & Lorimer, 2011).

Nonetheless, green walls are a promising technique to increase the greenery within urban environments (Mitsch, 2012; Madre, et al., 2013). They can offer greenery where otherwise would be bare concrete walls, creating new use of existing space (Chiquet, Dover, & Mitchell, 2012; Partridge & Clark, 2018; Belcher, et al., 2019). It is a valuable application for reconciliation ecology, able to produce valuable habitats and resources in a landscape previously naked of vegetation (Francis & Lorimer, 2011; Bolhuis Casas, 2016; Partridge & Clark, 2018). A practise that is becoming more and more difficult as space in the urban environment is costly (Chiquet, Dover, & Mitchell, 2012; Inleaf, 2019; Living Roofs, 2019; Urban Green-Blue Grids, 2019). In contrast to urban green spaces at ground level, green walls are not in competition with building activity and do not undergo land-use pressure (Madre, et al., 2014). Using these higher and vertical places, rather than on the ground within an environment where buildings are close together with little opportunity for ground level greenery, they are a way to improve urban habitats (Köhler, 2008; Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; European Commission, 2019; Inleaf, 2019; Urban Green-Blue Grids, 2019). They can reduce the urban landscape's hostility creating new spaces for wildlife directly on buildings (Madre, et al., 2014), that constitute higher quality opportunities than the conventional walls (Bolhuis Casas, 2016) allowing an additional type of ecosystem to be incorporated into the urban environment (Francis, 2011; Chiquet, Dover, & Mitchell, 2012; Ansglobal, 2019a). A process that enhances the space used by people while simultaneously benefiting wildlife (Francis & Lorimer, 2011; Bolhuis Casas, 2016).

3. CHAPTER 3 - METHODOLOGY

3.1. Sampling Area and Sites

3.1.1 Manchester and Salford Cities

The research was undertaken in the cities of Manchester and Salford, two of the ten districts which comprise the metropolitan region of Greater Manchester (GM) (53° 30N′, 2° 15′ W) in the Northwest of England (Figure 1). GM holds a total human population of 2.8 million; with the City of Manchester holding a human population of 550,000 and the City of Salford holding 250,000 (Office for National Statistics, 2020). These two cities consist of a mixture of high-density urban and suburban areas responsible for housing, education, health and social care, along with business, employment and tourism – the product of historical urbanisation and industrialisation of the 19th century (Radford & James, 2012; Greater Manchester Combined Authority, 2019).

Greater Manchester is currently one of the leading locations for urban greening policies and practises in the UK (Grant & Gedge, 2019; Living Roofs, 2019; Nature Greater Manchester, 2019). GM was the location of the Urban Pioneer, one of four pioneers of the three-year DEFRA Pioneer project, as part of the UK Government 25-Year Environmental Plan (YEP) strategy as of January 2018 (Urban Pioneer, 2018; Nature Greater Manchester, 2019). The 25-YEP is a strategy for tackling environmental issues which includes improving the urban environment. The Urban Pioneer focused on improving the urban environment through improved decision making, to maximise people's health and increasing economic benefits through investment in the natural area (Urban Pioneer, 2018; Nature Greater Manchester, 2019). As the Urban Pioneer, it has encouraged the Greater Manchester Combined Authority (GMCA), along with 11 key partners across the ten districts including the Environment Agency, to sign up to European Nature-based projects to help accelerate the 25-YEP through the Urban Pioneer (Greater Manchester Combined Authority, 2019). The project aimed to provide a model for investors, around the world, to help promote 'green finance' for urban green and blue infrastructure (Greater Manchester Combined Authority, 2019).

Greater Manchester has acknowledged that the solutions lie in substantial retrofit programmes of urban nature-based solutions to combat the issues of urbanisation, and has the ambition to become a 'Green City' (Urban Pioneer, 2018; Manchester City Council, 2019b; Urban Innovative Actions, 2019). Through developing an Infrastructure Strategy, investment is being put into existing green and blue infrastructures (e.g., parks and canals), while highlighting value and functionality on new green infrastructure technology (Greater Manchester Combined Authority, 2019: Manchester City Council, 2019b). More collaborative approaches are being brought about, including the IGNITION projects Living Lab at the University of Salford, Manchester (Hollyman, 2018; Greater Manchester Combined Authority, 2019; Urban Innovative Actions, 2019). IGNITION is a €6 million project, led by the GMCA and through the EU's nature-based solution programme, it sets a target of a 10% increase in green infrastructure in Greater Manchester by 2038 (Greater Manchester Combined Authority, 2019; Urban Innovative Actions, 2019). The project aims to help promote green infrastructures to be invested, across Greater Manchester, as climate change adaptation features by offsetting flooding and urban heat, in addition to air pollution and human health and wellbeing (Hollyman, 2018; Greater Manchester Combined Authority, 2019; Urban Innovative Actions, 2019).

3.1.2 Green Infrastructure Sites

A total of 16 green infrastructure sample sites were selected within the two cities (Figure 2). The eight green wall sample sites, that were selected due to the available green walls in the cities (September 2019). Eight additional sites were then selected due to accessibility and similarity to the green wall sites (e.g., area size, urban activity, and urban form). A further eight sample sites were chose for a comparative study on a larger survey to observe and explore urban bird activity by monitoring bird species richness and abundance. The eight green wall sites were separately used to observe and explore bird association by monitoring biodiversity and behaviour on the green walls and in adjacent street trees.

There are multiple names, definitions, and systems, for instance living walls, green facades or vegetated walls (Köhler, 2008; Loh, 2008; Manso & Castro-Gomes, 2015). The one term 'green wall' was used, to categorise them together as the available selected green walls all differed due to system, size and design (Figures 3 to 10). On these eight green wall sites, for each green wall there was a street tree counterpart to directly compare. Streets trees are condensed trees dispersed across the urban environment, that vary in numbers, species and age, depending on where and when they were planted (Fernández-Juricic, 2000; Strohbach, Lerman, & Warren, 2013; Dover, 2015; Pena, et al., 2017). All green walls were close to street tree(s) on the same sample site (mean=21m; SD=10). The street tree(s) was specifically selected within the perimeter of the site, which offered a similar equivalent to the green wall on the same site such as height. The selection did depend on the size of the green wall and the trees that were available on the site, so some street tree counterparts either were one, two or several (Figures 3 to 10).

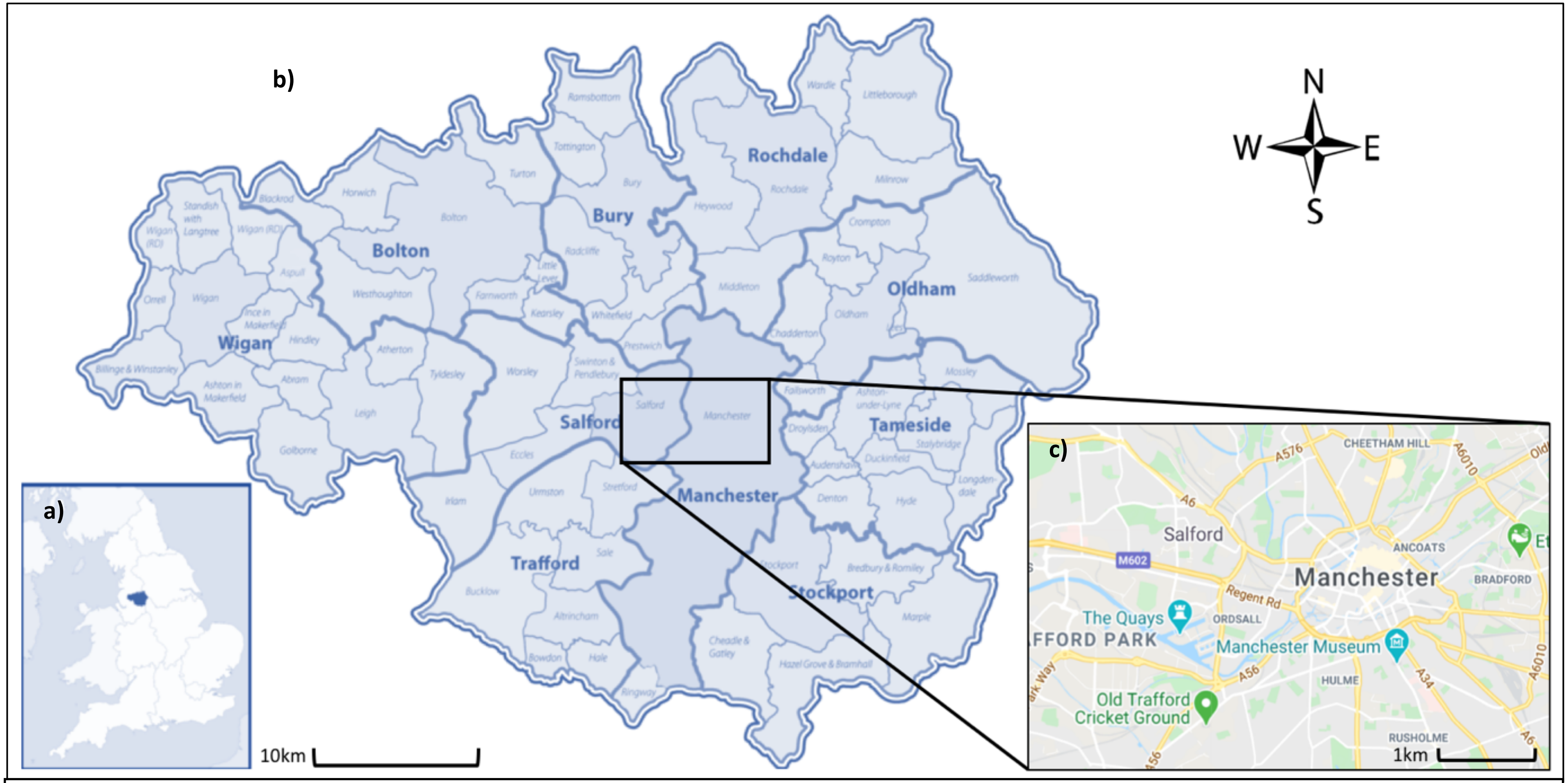

Figure 1. Sample location of the study.
a) Location of Greater Manchester, UK (Frietjes, 2019), b) Ten districts of Greater Manchester (Frietjes, 2019), c) Location of study and sample sites in Salford and Manchester City Centres (Google Maps, 2020).

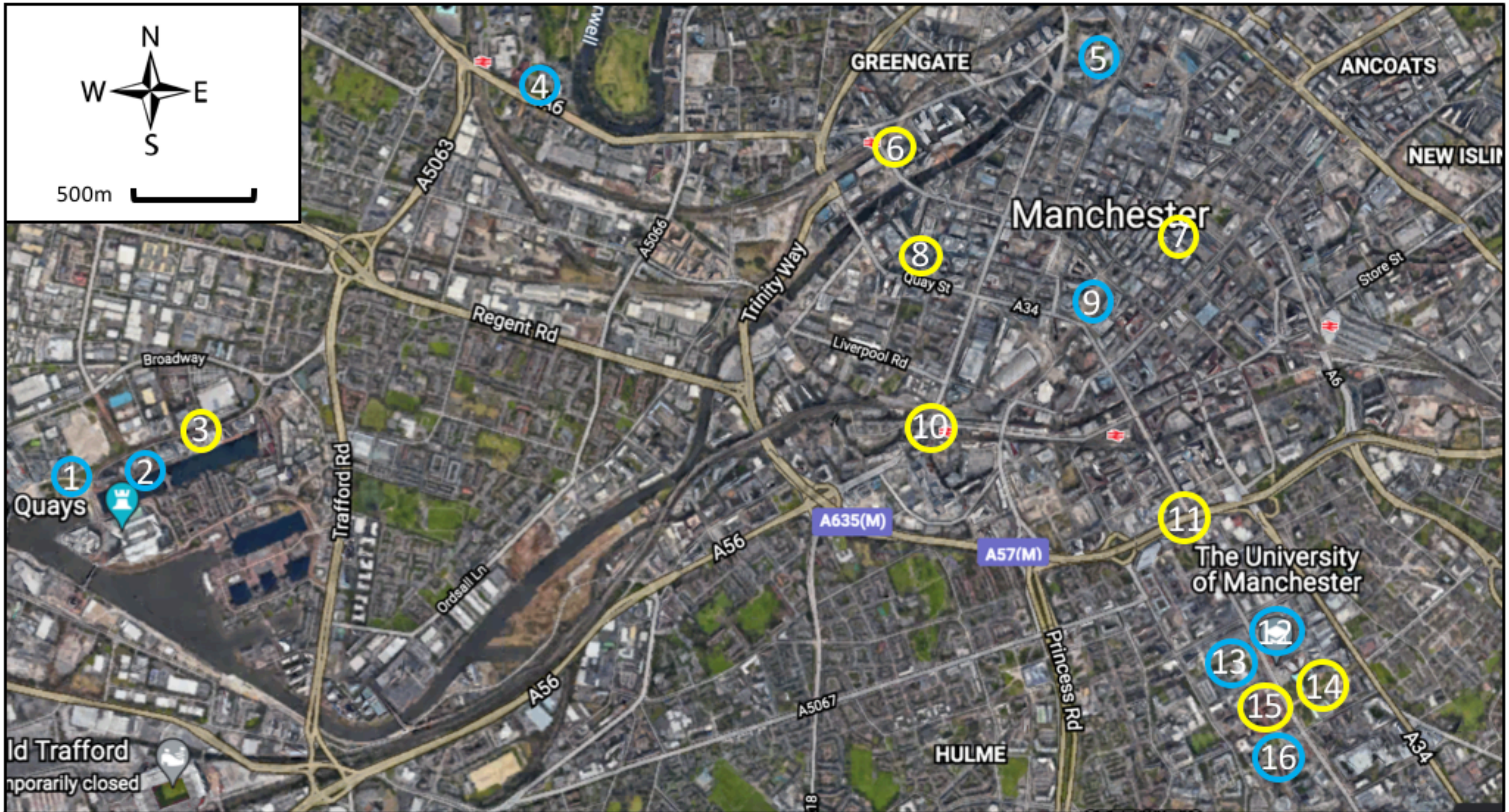

Figure 2. Map image of all selected sample sites. The original eight green walls sites (yellow circle) and eight additional sites (blue circle), situated across the sampling location of Manchester and Salford city centres (sources: Google Earth (2019)).
1) Media, 2) Quays, 3) Victoria, 4) UoS, 5) Cathedral, 6) AO, 7) Exchange, 8) IVY, 9) St Peter's, 10) Deansgate, 11) Hatch, 12) Computer, 13) Alliance, 14) Rutherford, 15) Beyer, 16) Man Library.

Figure 3. Victoria. A living wall placed on both sides of the Victoria Building, Media City, Salford. It is a recent development (2019) with the plants not in leaf at the start of the observations (October 2019) (top left) and in leaf after (July 2020) (bottom left). The wall is presented with a 'V' for the company's name, and placed slightly above ground, mirroring the entrance (top right). It was adjacent to a main road and tramway and street trees placed side of the building (bottom right).

Figure 4. AO. A living wall placed on the entrance of the AO.com corporate building, Salford. The wall was part of the main entrance, alongside the ramp access (top left). A couple of street trees were located next to the rail, alongside a road to a car park (top right). The wall had an unique design using different plants (bottom left) which were observed to be more vibrant after the study (July 2020) (bottom right).

Figure 5. Exchange. A living wall placed on the front of the Exchange Office Building, Manchester. The wall was part of the entrance placed at ground level alongside a pedestrian path (top left). It was near a busy one-way road in the middle of the city, with a long line of potted street trees down the entire street (top right). The wall had a diagonal pattern with various plants to create colours and texture, and a LED light strip across the top (bottom left). The building was also adjacent to a bus stop that was generally used to park cars, and even the pedestrian path of the green wall (bottom right).

Figure 6. IVY. A green façade that surrounded an entire building, of the restaurant, IVY, Manchester (top left). The walls were made up of planters and climbers (bottom left). The building was part of Hardman Square in the middle of Spinningfield surrounded other infrastructures and seating areas (bottom middle). The square also held a small green area with several street trees that were bare in winter (top right) and in leaf in spring (bottom right).

Figure 7. Deansgate. A living wall placed on the stairway/elevator access of the Castlefield Tram stop, Manchester (top left). The wall was part of the viaduct and adjacent to a main pedestrian crossing (top middle) on top of the canal (bottom left), covered with a selection of street trees and vegetation (top right). The walls had a wavy pattern which were different colours in winter (bottom middle) and summer (bottom right).

Figure 8. Hatch. A living wall placed on the front fence of the leisure establishment, the Hatch, Manchester. The wall was at ground level aside a pedestrian path (top left), adjacent to bus stop along Oxford Road (bottom left), while also nestled under the Mancunian way (top middle). The wall was a random pattern with grown plants for various textures (top right). All the green infrastructures were near parts of the establishment active with people (bottom right).

Figure 9. Rutherford. A living wall placed on the external wall of the Rutherford Theatre (Schuster building) as part of the University of Manchester Campus. The living wall was placed on the small building that was surrounded by street trees (top left) as part of a green space popular for students (bottom left). The wall had a wavy patterned design (top middle) composed of several plants that changed, along with the trees, according to the seasons: in leaf for the spring (top right) and bare in winter (bottom right).

Figure 10. Beyer. A green façade placed on the Beyer Building in the Old Quadrangle at the University of Manchester campus. The green façade was a deciduous IVY clade wall, that changed colours depending on season including green (top), autumnal (bottom left) and bare (bottom right). The courtyard also served as a seating area and car park (bottom right).

3.2. Data Collection

3.2.1 Sampling Taxon

Birds were chosen for this project as one of the best-studied taxon group (Wheater, Bell, & Cook, 2011) that are becoming a popular sampling choice due to effort and ease with good access and visibility (Marzluff, Bowman, & Donnelly, 2001). They can be present throughout the day, seasons, and various environments across the globe, while also being conveniently present within a human distance (Ardley, 1980; Hayman & Burton, 1982). They are appropriately easy to detect, identify and record, and there are currently various techniques to observe and monitor birds as part of research (Wheater, Bell, & Cook, 2011).

Birds were also chosen as research on urban bird biodiversity currently requires more input and monitoring in cities (Chiquet, Dover, & Mitchell, 2012; Lindo, 2018; RSPB, 2019a). Birds are currently becoming the organism of choice to monitor within urban green infrastructures: both conventional green spaces (James, Norman, & Clarke, 2010; Strohbach, Lerman, & Warren, 2013) and new green technologies (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Partridge & Clark, 2018; Belcher, et al., 2019). From their mobility and resilience, birds are an ideal sampling subject and becoming evident users, including green walls (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Collins, Schaafsma, & Hudson, 2017; Partridge & Clark, 2018; Belcher, et al., 2019; Grant & Gedge, 2019). This includes foraging and nesting opportunities (Köhler, 2008; Coma, et al., 2017; Living Roofs, 2019) as well as using them as habitat substitutes (EFB, 2019a). Though, unfortunately, there are still limited studies on bird behaviour on green walls (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019).

During the study, all bird species detected were recorded, including both native and non-native species within all orders (e.g., Passeriformes, Corvidae, Anseriformes, Columbiformes and Charadriiformes) (Dallimer, et al., 2012). The observed birds were listed under the BOU ‘The British List’ and recorded to the British vernacular name, along with the scientific name (British Ornithologists’ Union, 2017). All observed birds were then labelled under the categories: their UK Status of Concern, a generalists or specialist species, their diet guild (i.e., granivore, insectivore, omnivore or frugivore) and their feeding guild (i.e., ground, active or forager) (RSPB, 2015; DEFRA, 2018;

RSPB, 2019b). This was a way to characteristically explore the general urban bird biodiversity, to understand which bird species were active and using the green infrastructures.

3.2.2 Pilot Study

A pilot study was carried out; this included visiting all sample sites to determine accessibility, site area and viewpoint of the observer. It was also a time to confirm the selected sample sites and the available green walls in Manchester and Salford cities. The pilot study monitored the birds' activity to determine what dedicated observational time periods were appropriate for the study (e.g., dawn and dusk, morning and evening only, or all day). It also monitored the bird activity to determine the behaviours and their appropriate categories.

3.2.3 Observational Schedule (Covid-19 National Lockdown)

During October 2019 to March 2020, all sites were surveyed to conduct all direct observational surveys to monitor and record the birds in Manchester and Salford cities (see COVID Impact Statement, p. ix).

The observational surveys were routinely carried out during the chosen time periods of the morning (6:00 to 9:00), afternoon (10:30 to 13:30) and evening (15:00 to 18:00).. Some studies such as Bolhuis Casas (2016) did the entire day (7:00 to 17:00) to conduct their bird and green wall study. Other bird researchers use the dawn to dusk time period (Chiquet, Dover, & Mitchell, 2012; Partridge & Clark, 2018) or surveying only in the morning as this is when birds are suggested to be the most active and want the maximum species in their studies (Dallimer, et al., 2012; Strohbach, Lerman, & Warren, 2013; Belcher, et al., 2019). However, the pilot study showed birds were active during the afternoon. Hence, as per Bolhuis Casas (2016), it was decided to observe throughout the day.

All observational surveys were carried out routinely each week of each month to ensure that all sites and surveys were completed. This was done by creating a timetable following the academic year (2019/2020) designed to alternate between the numbered sites and the three periods of time (Table 1). It was a way to schedule where and when surveys could be performed, especially as the sites were spread out across the cities and to counteract other possible obstacles that could prevent an observation (e.g., weather, physical prevention). A schedule was created to a ensure that any missing day(s) would not impact on the data collection. The observational surveys could be carried out any day within the weeks allocated for a specific month. Observations were random (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016) as long as all sites and surveys were carried out within each month in their allocated period of time.

Table 1. **The structure of the methodological timetable for the shorten observation study period (October 2019 to March 2020).**
1) Media, 2) Quays, 3) Victoria, 4) UoS, 5) Cathedral, 6) AO, 7) Exchange, 8) IVY, 9) St Peter's, 10) Deansgate, 11) Hatch, 12) Computer, 13) Alliance, 14) Rutherford, 15) Beyer 16) Man Library.

	Observational Time Period		
Month (2019/2020)	**Morning**	**Afternoon**	**Evening**
October (Weeks 2-5)	1, 2, 3, 4, 6	5, 7, 8, 9, 10	11, 12, 13, 14, 15, 16
November (Weeks 6-9)	5, 7, 8, 9, 10	11, 12, 13, 14, 15, 16	1, 2, 3, 4, 6
December (Weeks 10-13)	11, 12, 13, 14, 15, 16	1, 2, 3, 4, 6	5, 7, 8, 9, 10
January (Weeks 14-17)	1, 2, 3, 4, 6	5, 7, 8, 9, 10	11, 12, 13, 14, 15, 16
February Weeks 18-21	5, 7, 8, 9, 10	11, 12, 13, 14, 15, 16	1, 2, 3, 4, 6
March (Weeks 22-26)	11, 12, 13, 14, 15, 16	1, 2, 3, 4, 6	5, 7, 8, 9, 10

3.2.4 Observational Methods

All observations were carried out when weather was to a certain standard; for example, fieldwork was excluded if it was raining, snowing, with wind over 21 kmh (13 mph) or a temperature of less than 0°C. This was checked using the Met's Office website beforehand. It is a common choice to avoid bird surveys in the rain and/or wind to minimise the effect of the study, as bad weather can mean birds are less detectable

(Wheater, Bell, & Cook, 2011; Chiquet, Dover, & Mitchell, 2012; Partridge & Clark, 2018; Belcher, et al., 2019). Observations were made with a designated viewpoint for each site (decided during pilot study) to ensure there was an open and clear view of the entire area with no obstructions (Belcher, et al., 2019). For observing the green walls and street trees, the viewpoint was 15 to 20 metres away to ensure the infrastructures could specifically be observed, particularly during the bird behaviour surveys (Chiquet, Dover, & Mitchell, 2012). The observer wore plain neutral colours (Chiquet, Dover, & Mitchell, 2012), stayed still and quiet at the viewpoint of the site (Wheater, Bell, & Cook, 2011) and avoided any public or site interaction to minimise bird disturbance (Campbell, 2010). Before observations were carried out some environmental conditions were noted (Belcher, et al., 2019). This included the current location temperature (degrees Celsius), wind speed (miles per hour) and weather (e.g., sunny, cloudy, misty, clear skies) using the Met's Office website.

All sites were busy settings regularly active with pedestrians and/or vehicles. All surveys lasted for 30 minutes. Though guides suggest 5-10 minutes is enough time to survey birds (Wheater, Bell, & Cook, 2011; Bolhuis Casas, 2016) and similar studies surveyed for a duration of 20 minutes (Fernández-Juricic, 2000: Chiquet, Dover, & Mitchell, 2012; Belcher, et al., 2019). It was decided 30 minutes for the survey duration to increase the opportunity for data collection, especially as there would be times of increased footfall or vehicles which would disperse and then followed by bird activity.

All observational surveys were done by direct observations which involves counting all bird individuals in a specific area (Wheater, Bell, & Cook, 2011). It is one of the simpler methods and the most popular way of observing birds which is useful for ornithological studies, for example, the foundational method for the Breeding Bird Survey (Wheater, Bell, & Cook, 2011). It has been an effective method with previous studies that have used it to carry out their avian research to visually identify and record all bird individuals within their sight (Chiquet, Dover, & Mitchell, 2012; Dallimer, et al., 2012; Strohbach, Lerman, & Warren, 2013). Visual identification was used to record the bird species and abundance. Throughout each observation, general comments on the site were noted down for possible future discussion such as vegetation conditions (e.g., change of season), people activity (e.g., dog walkers and smokers), noise activity (e.g., construction work and music) and other animals present (e.g., squirrels).

3.2.5 Observational Surveys

a) Bird Richness and Abundance

Bird detection and identification were done visually, and sound was only used as a cue to locate detected birds. All birds were recorded if observed anywhere within the perimeter of the sample site, either on the ground, on features, on other vegetation, on other infrastructure and flying through but not flying over (Strohbach, Lerman, & Warren, 2013; Belcher, et al., 2019). The name of the observed bird species was recorded, along with the maximum number of individuals observed at the same time of a single species within the sample area and observational period. Only the maximum number of individuals was recorded to avoid recounting and a way to cancel out the excessive number of individuals, as the same bird can appear, disappear and reappear multiple times within the time of observation (Strohbach, Lerman, & Warren, 2013; RSPB, 2019c).

b) Bird Behaviours

Birds were recorded when any bird was detected making physical contact, either on a green wall or a street tree. The specific wall zones were not monitored (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016).

The bird species and the maximum number of individuals (following the same rule for bird richness/abundance survey) was recorded when any bird was detected on either green wall and/or street tree, and was noted separately. This observation was done to evaluate if it was a specific type or a multitude of species were using the infrastructures (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016). The bird richness and abundance were also compared between green walls and street trees to determine if one green infrastructure was used more than the other.

A timed duration was recorded when a bird(s) was detected on either green wall and/or street tree, using a stopwatch, one for each selected green infrastructure. Time would start once any bird(s) was detected on the selected green infrastructure. The stopwatch was paused when the bird(s) departed and timing resumed when a bird returned (the same or a different bird each time). Time was recorded for any type of species, the number of species or individuals, so long as a bird made physical contact with any part of the green wall or tree counterpart. This observation was done to evaluate if birds had a frequent or infrequent involvement with the green infrastructures. The timed duration was compared between green walls and street trees to recognise if one was used longer than the other or if it was similar.

All bird behaviours on both green walls and street trees were recorded (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). Once a bird(s) was detected performing anywhere on either green wall and/or street tree, the bird species and their behaviour was recorded, separately according to the selected green infrastructure. The actions observed were classified into eight categories of behaviours formalised off a similar list of Bolhuis Casas (2016). The behaviours included:

a) Calling – a bird creating noise normally as song or call
b) Chasing – an act of bird(s) following another bird(s) to fight or ward them off
c) Climbing – a bird ascending across the infrastructure normally using jump motions
d) Foraging – an act of a bird actively looking and consuming food
e) Loafing – a bird sitting normally in a relaxed state for a period of time
f) Moving – a bird actively travelling across the infrastructure using short flights or jumps particularly between other infrastructures
g) Perching – a bird stationary normally at rest
h) Roosting – a bird settled at rest and/or sleep

This observation was done to evaluate green walls and street trees regarding how they are used by birds and to understand which attributes they provide. The behaviours were compared to determine if any behaviours were shared and which type of green infrastructure offered more opportunities for the birds.

3.2.6 Environmental Characteristics

The mean distance of the sample sites to nearby green spaces was measured. This was to determine their potential connectivity: a factor that is seen to influence birds in the urban environment (Madre, et al., 2014; Grafius, et al., 2017; Mayrand & Clergeau, 2018) and has previously been reported as influencing green wall activity (Bolhuis Casas, 2016). Measurements were made using the ruler tool in Google Earth at a camera elevation of 1,500-1,700m. The ten nearest green spaces to each sample site were measured and recorded in metres. A recognised green space was a visible green patch (e.g., group of trees, lawn of grass, gardens and parks) seen within the proximity of the site. All recorded distances were summed and averaged (mean) to get a mean distance (metres) for each sample site.

The mean noise level of the sample sites was measured. This was to determine the potential negative effect of noise in the urban environment to bird biodiversity (Pena, et al., 2017; Leveau & Leveau, 2020). Measurements were made using a decibel meter app (provided by LQH Apps on smartphone). During each observation survey at all sample sites, the sound was measured for one minute at the start and end of an observation to record the average and maximum decibel (dB) reading. All readings recorded by the app were averaged (mean) to get a mean noise level (dB) for each sample site.

The area size of the sample sites was measured. This was to determine if area size of a space can affect bird activity, as larger areas are better than small (James, Norman, & Clarke, 2010; Strohbach, Lerman, & Warren, 2013). Measurements were made using the Area Calculator courtesy of FreeMapTools.com. This tool allowed to set out the perimeter of the sample sites' observation space to get a recording of the area size in metre squared (m^2).

Each site was also described according to its activity (the various human disturbances existing on the sites), the urban form (low or high rise buildings) and vegetation (the other greenery existing on site along with the green wall and street trees). All these measurements were used to describe each sites' characteristics to determine any relationships and accountability between environmental factors and bird activity.

The green walls had several measurements carried out to determine possible relationships between the properties of the green walls and the behaviours of birds. This included height, area and plant richness, which are considered to be influential characteristics to bird activity (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019; Grant & Gedge, 2019; Urban Green-Blue Grids, 2019). The measurement tool on Google Earth was used to measure the height and width of the green walls. Height was measured using the elevation points. This was worked out using the recorded height from the top of the wall's elevation, subtracted to the bottom of the wall's elevation, to get a recorded height of the green wall in metres (m). Width was measured using the ruler tool to record the width of the green wall in metres (m). The measured height and width were used to calculate the area size of the green wall in metre squared (m^2). This method was used on green walls that did not have their measurements provided by their manufacturer, while some green walls measurements were provided, courtesy of their manufacturer (Ansglobal, 2020; HYWERT, 2020; Inleaf, 2020). The plant richness of the green walls was recorded, visually counting and recording the number of plants species. Again, some companies offered a list of plants species used for their green walls that were used to record a total (HYWERT, 2020; Inleaf, 2020). The area of the green wall and the number of plant species were used to calculate an index score, by multiplying both sums together to get an ecological value score (BREEAM, 2011).

3.3. Data Analysis

3.3.1 Statistical Analysis: Manchester/Salford Cities Bird Survey

The recorded number of species and individuals from the bird richness and abundance surveys were placed in tables to analyse the bird biodiversity in the two cities. A main table was made to display, in order of frequency, all the bird species observed according to what was recorded at the sample sites. This was followed by more detailed tables to describe the variation of bird species and the sample sites. All recordings for all the sample sites were listed together, including their species richness (number of species), bird abundance (number of individuals) and mean number of individuals per species (total number of species subtracted by total number of individuals) to get a value of number of birds observed within each sample sites. Along with the sites' recorded environmental characteristics (i.e., mean distance to green spaces (m), mean noise level (dB) and area size of sites (m^2)). Another table showed each species distribution and abundance across the sample sites, and mean number of individuals per active site (number of individuals subtracted number of its distributed sites). A final table was made to display the observed bird species and their species characteristics: their UK Status of Concern, a generalists or specialist species, their diet guild and their feeding guild.

A test of normality was performed on all cities' bird survey data to determine if the data followed a normal distribution. The analysis was perform on Minitab using the Anderson-Darling test to statistically measure how well the data followed a particular distribution and to determine whether the data meets the assumption of normality. It tested if the data followed a normal distribution comparing the *P*-value to the significance level ($P<.05$) to assess the null hypothesis - the data does follow a normal distribution. If the data did not follow a normal distribution, the data was still used to further be analysed (e.g., correlation coefficient). It was possible that all data may not follow a normal distribution, but all data needed to be compared using the same analysis.

A Pearson correlation coefficient analysis was performed to determine the relationships between the variables, including the cities' species richness and bird abundance, in addition to cities' species richness and bird abundance and the site's environmental characteristics (i.e., distances, noise and size). The analysis was performed on Microsoft Excel to provide a scatter graph and regression line, and to calculate a r^2 value to determine the relationship between the variables. To determine if the Pearson correlation coefficient was statistically significant, the corresponding t-score and *P*-value was calculated using Microsoft Excel. The t-score of a correlation coefficient (r) was:

$$t = r\sqrt{(n-2)} \,/\, \sqrt{(1-r^2)}$$

The *P*-value was calculated as the corresponding two-sided *P*-value for the t-distribution with n-2 degrees of freedom. The *P*-value was used to conclude if the correlation coefficient was statistically significant ($P<.05$).

3.3.2 Statistical Analysis: Green Wall and Street Tree Survey

To analyse bird association on the green walls and street trees, all observational data from the behaviour survey were organised, including bird species, duration and bird behaviours. One table displayed all bird species observed according to green wall sample sites and each sites' green wall and street tree, to visually show records of number of species and individuals. Another table displayed the birds behaviours showing the eight behaviours according to green wall sample sites and each sites' green wall and stree tree. It revealed which behaviours were recorded at green walls and street trees to explore where certain behaviours were observed to determine if any behaviours were shared between the two green infrastructures. The recorded duration of birds on all green walls and street trees were summed (seconds) and plotted onto a bar graph for a visual representation and compare the amount of bird duration spent for each green wall and street tree.

A test of normality was performed on all behaviour survey data to determine if the data followed a normal distribution. The same test of normality method from the cities bird survey statistical analysis was used. Again, if the data did not follow a normal distribution, the data was still used to further be analysed (e.g., correlation coefficient). The duration data were tested for normal distribution to perform a statistical comparison test, either a paired t-test or a Mann-Whitney test on Minitab, to determine whether there was any difference between means/medians. The comparison test was used to determine if there was a difference between the variables: time duration on green walls and street trees, to compare if there was statistically significant difference. A test of normality (Anderson-Darling test) was performed to determine if data followed a normal distribution to decide if a parametric test (Paired t-test) or non-parametric test (Mann-Whitney test) was performed to test differences. The parametric Paired t-test was performed if data tested did follow a normal distribution. It determined whether the differences between the means of timed association was statistically significant comparing the *P*-value to the significance value ($P<.05$) to assess the null hypothesis stating the means are equal. The non-parametric Mann-Whitney test was performed if data did not follow a normal distribution. It determined whether the difference between the medians of timed association was statistically significant comparing the *P*-value to the significance value ($P<.05$) to assess the null hypothesis stating the means are equal.

Correlation coefficient analysis was performed to determine the relationship between the variables, including the green infrastructures' species richness, bird abundance, bird behaviours and bird durations, along with the sites' environmental characteristics (i.e., distances, noise and size). The analysis was used to determine the relationship between the green walls' species richness, bird abundance, bird behaviours and bird durations. In addition to green walls activity and the green walls' characteristics (i.e., height, area, plant richness and their ecological score). The same correlation coefficient method from the cities bird survey statistical analysis was used to determine the relationship and the significance.

4. CHAPTER 4 - RESULTS

4.1. Manchester and Salford Cities Bird Survey

4.1.1 Bird Richness and Abundance

Between October 2019 and March 2020, monitoring all sample sites (n=16), 21 species were observed (Table 2). Across all 16 sites the mean species richness was nine species, and the mean abundance was 23 individuals. Thirteen was the most species observed at the sample sites including Media (Site 1), Computer (Site 12), Rutherford (Site 14) and Man Library (Site 16) (Table 3). Man Library had the highest species richness, along with abundance with 35 individual birds recorded (Table 3). The least number of species observed at a site was two species, the Hatch (Site 11) observing two species and four individuals (Table 3). Other sites with low species richness and abundance included the Exchange (Site 7) – three species and six individuals – and St Peter's (Site 9) – four species and 18 individuals, with the majority of the recordings being feral pigeon (n=13) (Table 3). Overall, there was a mean of 2.6 individuals per species observed across all the sample sites, ranging from 1.63 individuals at Victoria (Site 3) to 4.17 at AO (Site 6) (Table 3). Data for species richness and bird abundance recorded across all sample sites in the cities survey followed a normal distribution (Table 4). There was a significant correlation between species richness and bird abundance (P=0.001) and showed a strong positive linear (r^2=0.7404) (Figure 11).

The most frequent bird species observed were feral pigeon and blue tit both found at 15 sites, followed by magpie and carrion crow (*Corvus corone*) found at 14 sites (Table 5). The least frequent bird species observed were lesser redpoll (*Acanthis cabaret*), house sparrow, jay (*Garrulus glandarius*), great tit and mallard (*Anas platyrhynchos*) each found at only one site (Table 5). The most abundant species were feral pigeon with a total of 68 individuals, followed by blue tit with 45 individuals and magpie with 39 individuals (Table 5). While the least abundant species were jay, great tit and mallard with only one individual. Other less frequent bird species were more abundant, with the lesser redpoll recorded a total of ten individuals and house sparrow recorded a total of eight individuals (Table 5). Overall, there was a mean of 2.8 individuals per active site (Table 5). Both the lesser redpoll (ten individuals per active sites) and house sparrow (eight individuals per active sites) were found as a flock but only at one site, while jay, great tit and mallard occurred as singletons at one site only (Table 5). The robin (*Erithacus rubecula*) and wren (*Troglodytes troglodytes*) were normally observed with one individual but were present at more sites (Robin = 7 individuals, 6 sites; Wren = 5 individuals, 4 sites) (Table 5).

All observed bird species were UK residents with their own UK conservation concern status (RSPB, 2015; DEFRA, 2018; RSPB, 2019b). Five species observed were red-listed – herring gull (*Larus argentatus*), mistle thrush (*Turdus viscivorus*), lesser redpoll, house sparrow and grey wagtail (*Motacilla cinerea*); three amber-listed species – black-headed gull (*Chroicocephalus ridibundus*), dunnock (*Prunella modularis*) and mallard, and the remaining 13 species were green-listed (Table 6). Of the 21 species, five were specialist species - goldfinch (*Carduelis carduelis*), pied wagtail (*Motacilla alba*), grey wagtail, lesser redpoll and jay, while the remaining 16 species were generalists (Table 6). All the observed birds were from four types of food guilds - 11 insectivores, five granivores and five omnivores (Table 6). In addition to seven species that are described as having two diet types due to seasonality with five frugivore (Table 6). There were three feeder guilds with eight active feeders, seven ground feeders and six foragers (Table 6).

4.1.2 Environmental Characteristics

The mean distance of all 16 sample sites to other nearby green spaces was 289m (SD=123). The lowest (123m) was the Man Library (Site 16) being the closest to other green spaces (Table 3). Whereas the highest (594m) was the Exchange (Site 7) being the furthest to other green spaces (Table 3). The distances recorded across all sample sites in the cities survey followed a normal distribution (Table 4). There was a significant correlation between species richness and distance (P=0.03) and showed a moderate negative relationship (r^2=0.5376) concluding there was 54% of species richness accounted for distance to green spaces (Figure 12). Whereas there was not a significant correlation between bird abundance and distance (P=0.06) and showed a weak to moderate negative relationship (r^2=0.4746) (Figure 13).

The mean level of noise of sample sites was 73 dB (SD=3). The lowest was 67 dB at Beyer (Site 15) and Man Library (Site 16) being the quietest, and the highest was 81 dB at Hatch being the loudest (Site 11) (Table 3). The noise levels recorded across all sample sites in the cities survey followed a normal distribution (Table 4). There was not a significant correlation between species richness and noise level (*P*=0.12) and showed a weak negative relationship (r^2=0.3971) (Figure 14). Whereas there was a significant correlation between bird abundance and noise level (*P*=0.01) and showed a strong negative relationship (r^2=0.6037) concluding there was a 60% of bird abundance accounted for noise level (Figure 15).

The mean area size of all sample sites was 2460m^2(SD=1583). The smallest site was 639m^2 at the the Hatch (Site 11), followed by Exchange (Site 7) and Beyer (Site 15) at 651m^2 and AO (Site 6) at 672m^2 (Table 3). The largest site was 5651m^2 at Rutherford (Site 14) (Table 3). The area size of sites recorded across all sample sites in the cities survey followed a normal distribution (Table 4). There was not a significant correlation between both species richness (*P*=0.79) and bird abundance (*P*=0.48) to area of sites, both showed positive but no linear relationships (r^2=0.0786; r^2= 0.1916) (Figure 16 and 17).

Table 2. **Bird species richness and abundance, in order of the most frequent, observed across all sixteen sample sites of Manchester and Salford cities. Green infrastructure Sites: Yellow = Green wall sites, Blue = Additional sample sites 1) Media, 2) Quay, 3) Victoria, 4) UoS, 5) Cathedral, 6) AO, 7) Exchange, 8) IVY, 9) St Peter's, 10) Deansgate, 11) Hatch, 12) Computer, 13) Alliance, 14) Rutherford, 15) Beyer, 16) Man Library**

British (English) Vernacular Name	Scientific Name	Green Infrastructure Sites															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feral pigeon	*Columba livia domestica*	3	0	1	2	9	8	3	4	13	4	3	3	3	5	5	2
Blue tit	*Cyanistes caeruleus*	4	2	2	2	5	1	2	3	2	2	0	5	3	4	3	5
Magpie	*Pica pica*	1	3	2	4	1	1	0	3	1	2	0	5	3	5	2	6
Herring gull	*Larus argentatus*	0	2	2	1	2	3	0	2	2	4	0	2	2	1	1	2
Goldfinch	*Carduelis Carduelis*	4	3	0	2	0	0	0	3	0	0	0	4	0	4	0	5
Woodpigeon	*Columba palumbus*	4	0	0	4	0	0	0	0	0	3	0	5	1	1	3	2
Carrion crow	*Corvus corone*	2	3	2	2	1	1	1	0	0	1	1	1	1	2	1	3
Black-headed gull	*Chroicocephalus ridibundus*	0	3	1	0	1	11	0	0	0	1	0	0	3	0	0	2
Blackbird	*Turdus merula*	2	1	1	0	1	0	0	0	0	2	0	4	1	1	3	3
Long-tailed tit	*Aegithalos caudatus*	2	0	0	0	2	0	0	0	0	0	0	0	2	4	5	0
Mistle thrush	*Turdus viscivorus*	2	0	2	0	0	0	0	0	0	0	0	2	0	2	4	2
Lesser redpoll	*Carduelis cabaret*	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Pied wagtail	*Motacilla alba*	2	0	0	0	0	0	0	0	0	0	0	1	1	2	1	2
House sparrow	*Passer domesticus*	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Robin	*Erithacus rubecula*	2	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1
Dunnock	*Prunella modularis*	0	0	0	0	0	0	0	0	0	1	0	1	2	0	2	0
Grey wagtail	*Motacilla cinerea*	2	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0
Wren	*Torglodytes troglodytes*	2	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
Jay	*Garrulus glandarius*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Great tit	*Parus major*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mallard	*Anas platyrhynchos*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Table 3. Variations between the sixteen sample sites: the recorded species richness and bird abundance and recorded environmental characteristics.
Green infrastructure Sites: Yellow = Green wall sites, Blue = Additional sample sites

Survey Sites (From W to E and N to S)		Species Richness (Number of Species)	Bird Abundance (Number of Individuals)	Individuals per Species	Mean Distance to Green Spaces (m)	Mean Noise Level (dB)	Area Size of Sites (m^2)
1	Media	13	32	2.46	295.48	71.15	2276
2	Quays	9	26	2.89	265.69	71.23	1974
3	Victoria	8	13	1.63	291.25	75.33	2276
4	UoS	9	28	3.11	213.39	73.94	4554
5	Cathedral	8	22	2.75	384.86	75.68	2270
6	AO	6	25	4.17	303.14	74.85	672
7	Exchange	3	6	2.00	593.72	77.87	651
8	IVY	5	15	3.00	375.49	71.80	3055
9	St Peter's	4	18	2.75	503.77	73.41	4389
10	Deansgate	12	25	2.08	277.44	76.77	1563
11	Hatch	2	4	2.00	279.25	80.55	639
12	Computer	13	24	1.85	191.28	73.11	756
13	Alliance	12	35	2.92	183.39	71.22	4271
14	Rutherford	13	32	2.46	195.25	71.95	5651
15	Beyer	11	31	2.82	140.35	67.52	651
16	Man Library	13	35	2.69	123.14	67.31	3707

Table 4. Test of normality values for all data from the cities bird survey to assess distribution of data.
(H^0 - data does follow a normal distribution)

Test of Normality	Anderson-Darling Score	
Manchester/Salford Cities Bird Survey Data	*P*-Value	
All Sample Sites		
Species Richness	0.12	Normal Distribution
Bird Abundance	0.27	Normal Distribution
Mean Distance to Green Spaces	0.14	Normal Distribution
Mean Noise Level	0.83	Normal Distribution
Area Size of Sites	0.13	Normal Distribution
Green Wall Sample Sites		
Mean Distance to Green Spaces	0.13	Normal Distribution
Mean Noise Level	0.89	Normal Distribution
Area Size of Sites	0.03*	Not Normal Distribution

Table 5. **Species distribution and abundance of all observed bird species according to where it was recorded in the sixteen sample sites.**

British (English) Vernacular Name	Scientific Name	Distribution (Number of sites (n=16)	Abundance (Number of Individuals)	Individuals per active site
Feral pigeon	*Columba livia domestica*	15	68	4.53
Blue tit	*Cyanistes caeruleus*	15	45	3.00
Magpie	*Pica pica*	14	39	2.79
Carrion crow	*Corvus corone*	14	22	1.57
Herring gull	*Larus argentatus*	13	26	2.00
Blackbird	*Turdus merula*	10	19	1.90
Woodpigeon	*Columba palumbus*	8	23	2.88
Goldfinch	*Carduelis Carduelis*	7	25	3.57
Black-headed gull	*Chroicocephalus ridibundus*	7	22	3.14
Robin	*Erithacus rubecula*	6	7	1.17
Mistle thrush	*Turdus viscivorus*	6	14	2.33
Pied wagtail	*Motacilla alba*	6	9	1.50
Long-tailed tit	*Aegithalos caudatus*	5	15	3.00
Dunnock	*Prunella modularis*	4	6	1.50
Wren	*Torglodytes troglodytes*	4	5	1.25
Grey wagtail	*Motacilla cinerea*	3	5	1.67
Lesser redpoll	*Carduelis cabaret*	1	10	10.00
House sparrow	*Passer domesticus*	1	8	8.00
Jay	*Garrulus glandarius*	1	1	1.00
Great tit	*Parus major*	1	1	1.00
Mallard	*Anas platyrhynchos*	1	1	1.00

Table 6. **Species characteristics of the 21 bird species observed across all sixteen sample sites.**

British (English) Vernacular Name	UK Status of Concern	Generalists/ Specialists	Diet Type	Feeding Type
Feral pigeon	Green	Generalist	Granivore	Ground
Blue tit	Green	Generalist	Insectivore/Frugivore	Active
Magpie	Green	Generalist	Omnivore	Forager
Carrion crow	Green	Generalist	Omnivore	Forager
Herring gull	Red	Generalist	Omnivore	Forager
Blackbird	Green	Generalist	Insectivore/Frugivore	Ground
Woodpigeon	Green	Generalist	Granivore	Ground
Goldfinch	Green	Specialist	Granivore	Active
Black-headed gull	Amber	Generalist	Omnivore	Forager
Robin	Green	Generalist	Insectivore / Frugivore	Active
Mistle thrush	Red	Generalist	Insectivore / Frugivore	Ground
Pied wagtail	Green	Specialist	Insectivore	Active
Long-tailed tit	Green	Generalist	Insectivore	Active
Dunnock	Amber	Generalist	Insectivore / Granivore	Ground
Wren	Green	Generalist	Insectivore	Ground
Grey wagtail	Red	Specialist	Insectivore	Active
Lesser redpoll	Red	Specialist	Granivore	Active
House sparrow	Red	Generalist	Granivore	Ground
Jay	Green	Specialist	Insectivore / Frugivore	Forager
Great tit	Green	Generalist	Insectivore / Granivore	Active
Mallard	Amber	Generalist	Omnivore	Forager

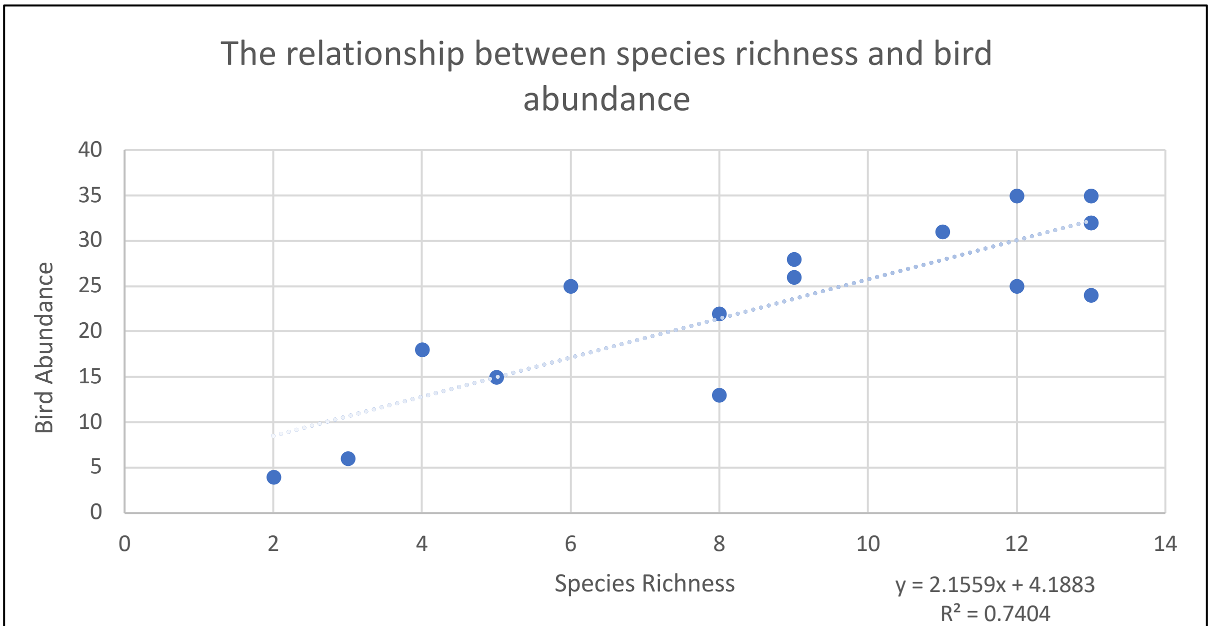

Figure 11. The Pearson correlation coefficient between species richness (number of species) and bird abundance (number of birds observed) that had a positive strong relationship with a r^2 value of 0.7404 and a significant *P*-value of 0.001***

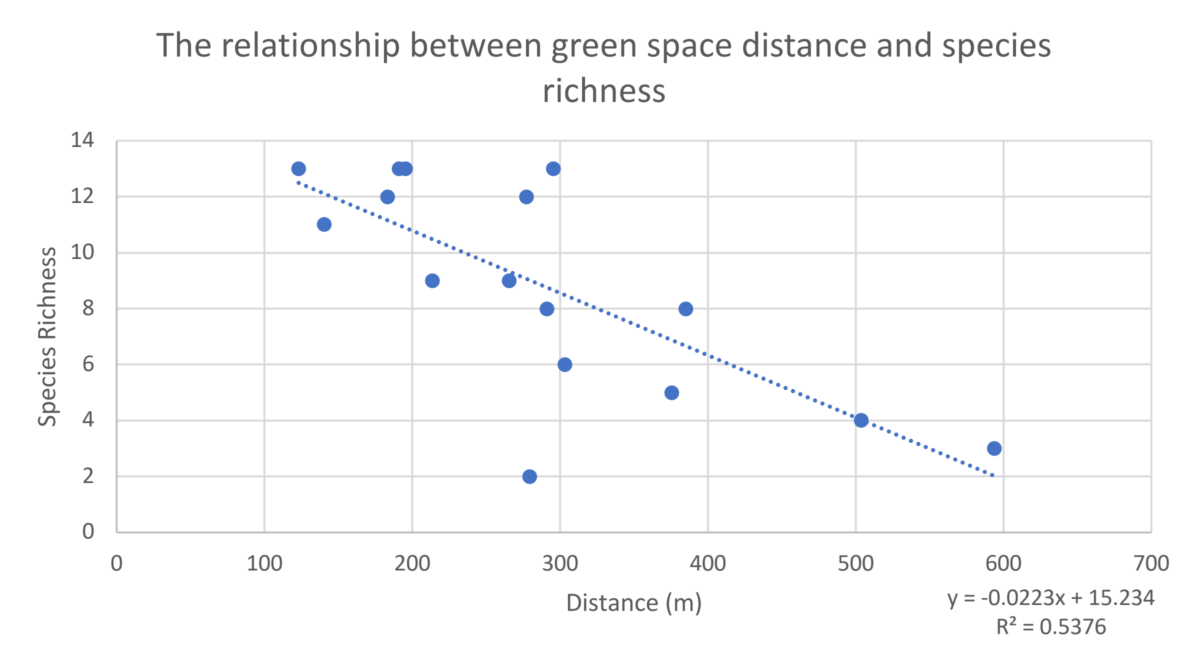

Figure 12. The Pearson correlation coefficient between species richness (number of species) and distance (mean distance to other green spaces) that had a negative moderate relationship with a r^2 value of 0.5376 and significant *P*-value of 0.03*

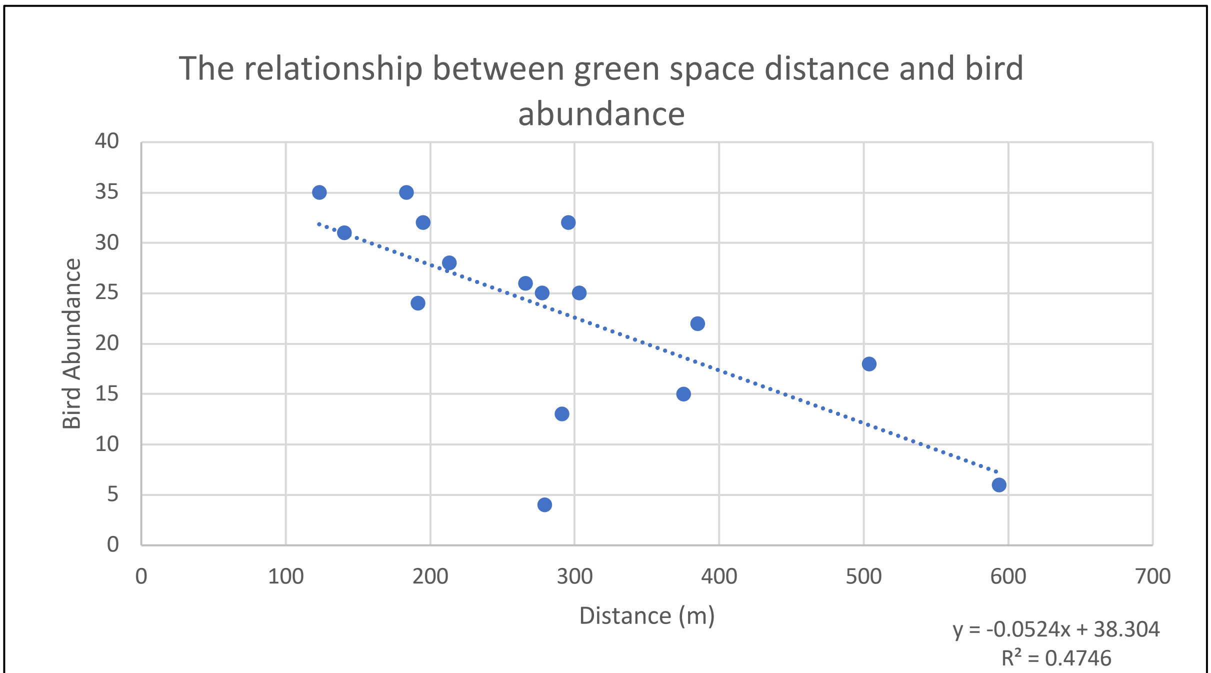

Figure 13. The Pearson correlation coefficient between bird abundance (number of birds observed) and distance (mean distance to other green spaces) that had a negative weak/moderate relationship with a r^2 value of 0.4746 and a non-significant *P*-value of 0.06

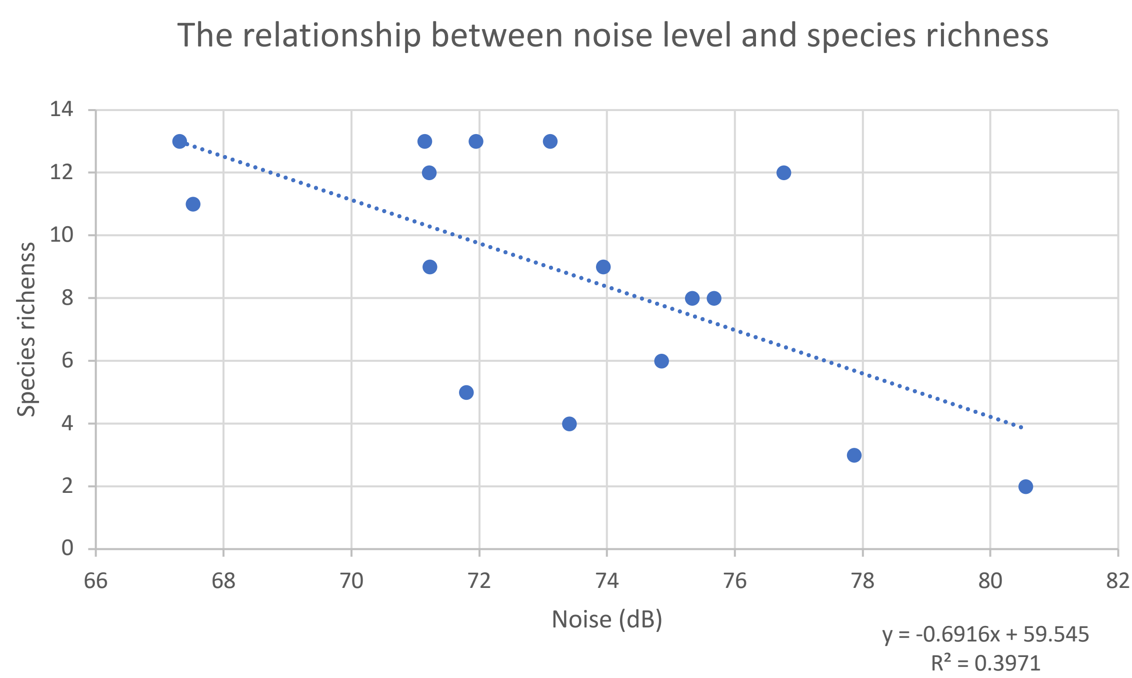

Figure 14. The Pearson correlation coefficient between species richness (number of species) and noise (mean sound level) that had a negative weak relationship with a r^2 value of 0.3971 and a non-significant *P*-value of 0.12

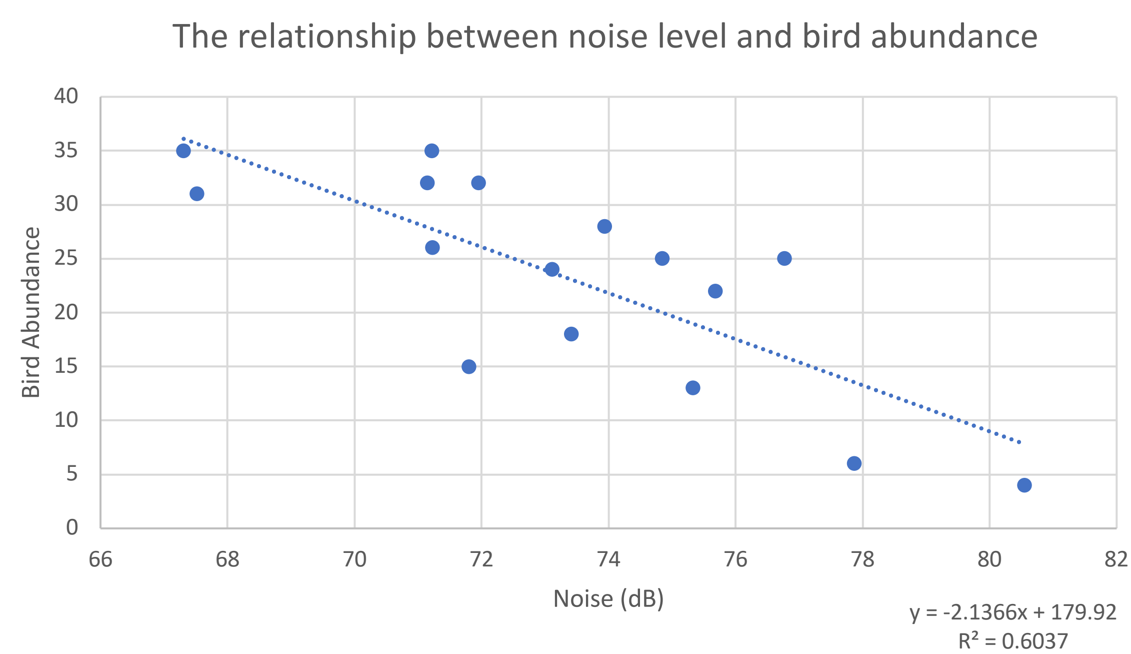

Figure 15. The Pearson correlation coefficient between bird abundance (number of birds observed) and noise (mean sound level) that had a negative strong relationship with a r^2 value of 0.6037 and a significant *P*-value of 0.01**

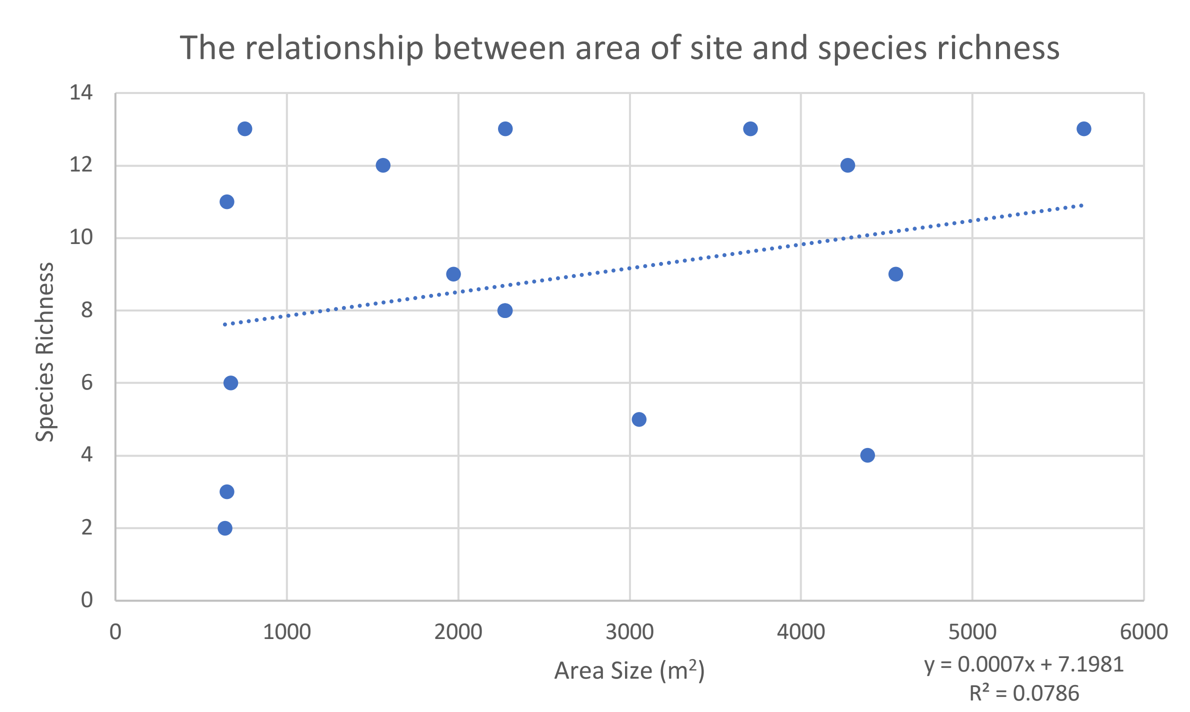

Figure 16. The Pearson correlation coefficient between species richness (number of species) and area size (size of survey sites) that has a positive no linear relationship with a r^2 value of 0.0786 and non-significant *P*-value of 0.79

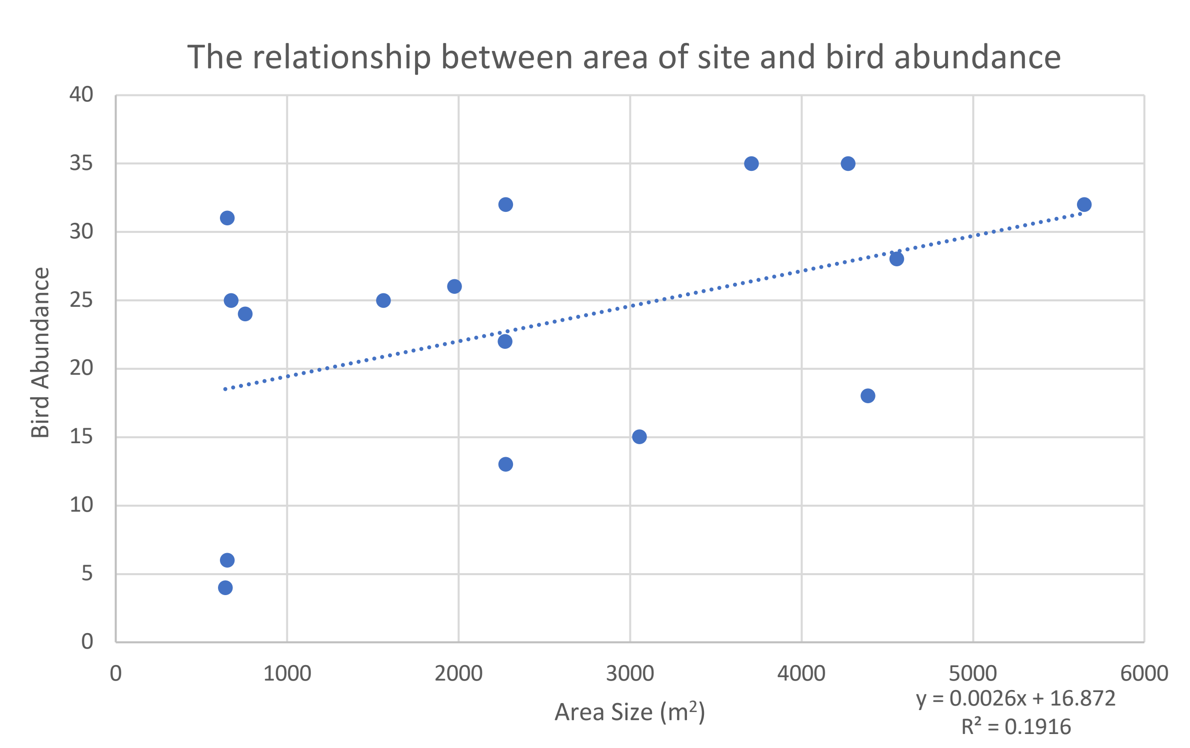

Figure 17. The Pearson correlation coefficient between bird abundance (number of birds observed) and area size (size of survey sites) that had a positive no linear relationship with a r^2 value of 0.1916 and a non-significant *P*-value of 0.48

4.2. Green Wall and Street Tree Survey

4.2.1 Bird Richness and Abundance

Between October 2019 and March 2020, at the eight green wall sites, a total of 18 species were observed (Table 2). The Rutherford site had the highest richness and abundance with 13 species and 32 individuals, followed by Deansgate at which 12 species and 25 individuals were recorded (Table 3). The Hatch site had the least bird richness and abundance with two species and four individuals (Table 3).

The most frequent bird species observed at these green wall sites was the feral pigeon which was seen at all eight sites: a total of 33 sightings (Table 2). This was substantially higher than the next most frequent birds: the blue tit (n=17) and magpie (n=15) (Table 2). There were three species for which only one individual was recorded: the wren and mallard only observed at the Deansgate site, and the great tit was only found at the Rutherford site (Table 2).

There were four sites that observed specialist species: Rutherford (4 goldfinch, 2 pied wagtail, 1 grey wagtail), IVY (3 goldfinch), Deansgate (2 grey wagtail) and Beyer (1 pied wagtail) (Tables 2 and 6). There were six sites that observed red-listed species: Beyer (1 herring gull, 4 mistle thrush), Deansgate (4 herring gull, 1 grey wagtail), Victoria (2 herring gull, 2 mistle thrush), AO (3 herring gull), Rutherford (1 herring gull, 1 mistle thrush, 1 grey wagtail) and IVY (2 herring gull) (Tables 2 and 6).

4.2.2 Bird Activity and Behaviours

Comparing the bird association on the green walls and street trees, only half of the green walls (n=4) were visited by birds (Table 7). Whereas birds were observed at six of the street trees (Table 7). Of the four green walls visited by birds, four bird species were observed with a total of 12 individuals: feral pigeon (n=2), blue tit (n=3), magpie (n=4) and mistle thrush (n=3) (Table 7). At six street trees 11 species and 41 individuals were observed: feral pigeon (n=5), blue tit (n=8), magpie (n=1), mistle thrush (n=3), house sparrow (n=2), blackbird (n=2), woodpigeon (n=4), robin (n=1), long-tailed tit (*Aegithalos caudatus*) (n=8), goldfinch (n=5) and pied wagtail (n=2) (Table 7).

Table 7. All bird species and number of individuals observed interacting with the green walls and street trees at each of the green wall sites.

			Green Wall Sites															
	Total		Victoria		AO		Exchange		Deansgate		IVY		Beyer		Rutherford		Hatch	
British (English) Vernacular Name	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree
Feral Pigeon	2	5	0	0	0	0	0	0	2	0	0	0	0	4	0	1	0	0
Blue tit	3	8	0	1	0	0	0	3	0	1	1	2	2	1	0	0	0	0
Magpie	4	1	0	0	0	0	0	0	0	0	2	0	0	0	2	1	0	0
Goldfinch	0	5	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0
Woodpigeon	0	4	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0
Blackbird	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Long-tailed tit	0	8	0	0	0	0	0	0	0	2	0	0	0	6	0	0	0	0
Mistle thrush	3	3	0	2	0	0	0	0	0	0	0	0	3	1	0	0	0	0
Pied Wagtail	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
House Sparrow	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Robin	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Total	12	41	0	6	0	0	0	3	2	6	3	7	5	15	2	4	0	0

Four categories of behaviour were observed at the four interactive green walls: climbing, foraging, loafing and perching (Table 8). While seven categories of behaviours were observed at the six interactive street trees: calling, chasing, foraging, loafing, moving, perching and roosting (Table 8). The most frequent behaviours for green walls were foraging and loafing observed at two walls (foraging = IVY and Beyer; loafing = Deansgate and Rutherford) (Table 8). The most frequent behaviours for street trees were moving observed at all six trees and loafing seen at five trees (Table 8). Foraging, loafing and perching were behaviours observed both on green walls and street trees. There was a larger number of specific behaviours observed only on street trees rather than green walls (e.g., calling, chasing, moving and roosting), while climbing was the one behaviour observed only on green walls (Table 8).

The total time birds spent expressing action on the green walls was 1910 seconds (i.e., over 13 minutes) with a mean of 238 seconds (i.e., just under 4 minutes). The green wall with the longest duration was the Deansgate wall (787 seconds, i.e., just over 13 minutes) and Rutherford wall had the shortest time duration (74 seconds, i.e., just over 1 minute) (Figure 18). Whereas, the total time birds spent on the street trees was 8498 seconds (i.e., over 2 hours and 35 minutes) with a mean of 1062 seconds (i.e., over 17 minutes). The street tree with the longest duration was on the Beyer site (4330 seconds, i.e., just over 72 minutes), and at the Rutherford site had the shortest duration (125 seconds, i.e., just over 2 minutes) (Figure 18).

Comparing the bird durations on the green walls and street trees, it was found there was not a significant difference. A test of normality showed that the duration data had a significant value (P=0.01) (Table 9) meaning the data did not follow a normal distribution, rejecting the null hypothesis - data follows a normal distribution. A non-parametric test equivalent, Mann-Whitney test, was used to determine the difference between the times. The test achieved a 95.94% confidence between the medians, where the green walls had a lower median of time (37 seconds i.e., under a 1 minute) compared to the street trees (255 seconds i.e., just over 4 minutes). The test concluded there was not a statistical difference (P=0.26 (with adjusted ties)) between the medians (Table 9).

Table 8. **All observed bird behaviours, according to the eight categorised behaviours, expressed on each green wall and street tree at the green wall sites.**
(• = that behaviour was observed on the selected green infrastructure)

Behaviours Observed	**Calling**		**Chasing**		**Climbing**		**Foraging**		**Loafing**		**Moving**		**Perching**		**Roosting**	
Sites	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree	Wall	Tree
Victoria				•								•				
AO																
Exchange										•		•				
Deansgate		•						•	•	•		•				
IVY		•					•			•		•	•			
Beyer				•	•		•	•		•		•				•
Rutherford									•	•		•		•		
The Hatch																

Table 9. **The timed bird durations (seconds) on each green wall and street tree at the green wall sites, and the statistical duration comparison: test of normality and a non-parametric test.**

Duration Recordings		
Sites	**Time on Green Walls (sec)**	**Time on Street Tree(s) (sec)**
Victoria	0.0	322.2
AO	0.0	0.0
Exchange	0.0	188.4
Deansgate	786.6	2300.4
IVY	557.5	1232.4
Beyer	489.0	4330.2
Rutherford	73.8	124.8
The Hatch	0.0	0.0
Median	36.9	255.3
Duration Comparison Test		
Duration Comparison	**Test of Normality Anderson-Darling**	**(Non) Parametric Test Mann-Whitney**
Green Wall and Street Tree	Green wall times: P=0.01** Street trees times: P=0.01**	P=0.26

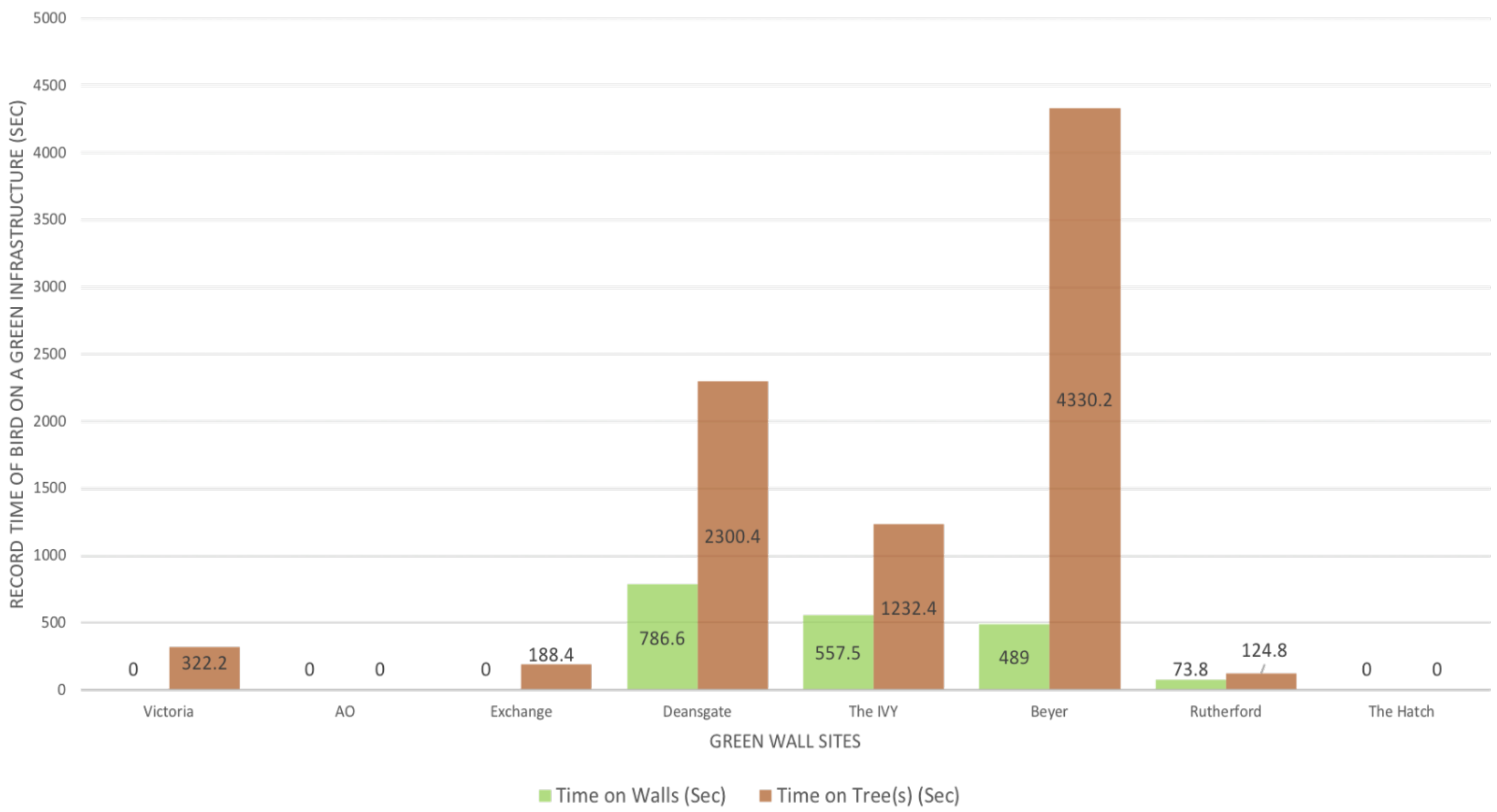

Figure 18 . The recorded duration (seconds) of bird association on each green wall and street tree at the green wall sample sites.

Table 10. **Test of normality values for all data from the green wall and street tree bird survey to assess distribution of data.**
(H^0 – data does follow a normal distribution)

Green Wall and Street Tree Survey Data		
Green Walls Bird Activity		
Species Richness	0.27	Normal Distribution
Bird Abundance	0.05	Normal Distribution
Behaviours	0.03*	Not Normal Distribution
Duration	0.01**	Not Normal Distribution
Street Trees Bird Activity		
Species Richness	0.66	Normal Distribution
Bird Abundance	0.24	Normal Distribution
Behaviours	0.55	Normal Distribution
Duration	0.01**	Not Normal Distribution
Green Wall Characteristics		
Height	0.11	Normal Distribution
Area	0.02*	Not Normal Distribution
Number of Plants	0.23	Normal Distribution
Ecological Score	0.005***	Not Normal Distribution

Table 11. **Pearson correlation analysis for green infrastructures' activity and behaviour variables.**

Bird Activity and Behaviours	**Trend**	**r^2 Value**	**Relationship**	***P* Value**
Green Walls' Relationships				
Behaviours and Species Richness	Positive	1	Strong	0.001**
Behaviours and Bird Abundance	Positive	0.9167	Strong	0.001**
Durations and Species Richness	Positive	0.5863	Moderate	0.12
Durations and Bird Abundance	Positive	0.5135	Moderate	0.19
Behaviours and Durations	Positive	0.5863	Moderate	0.12
Street Trees' Relationships				
Behaviours and Species Richness	Positive	0.7889	Strong	0.01*
Behaviours and Bird Abundance	Positive	0.787	Strong	0.01*
Durations and Species Richness	Positive	0.6239	Strong	0.1
Durations and Bird Abundance	Positive	0.8167	Strong	0.01*
Behaviours and Durations	Positive	0.6805	Strong	0.06

The green infrastructures' species richness and bird abundance data followed normal distribution, along with street trees' bird behaviour data (Table 10). The green walls' bird behaviour data did not follow a normal distribution, along with both green infrastructures' bird duration data (Table 10).

There was a significant correlation between the number of behaviours and the species richness (*P*=0.001) and bird abundance (*P*=0.001) observed at the green walls. Both variables showed strong positive relationships (r^2=1; r^2=0.9167) (Table 11). There was also a significant correlation between the number of behaviours and the species richness (*P*=0.01) and bird abundance (*P*=0.01) observed at the street tree. Both variables showed strong positive relationships (r^2=0.7889; r^2=0.787) but slightly less compared to green walls (Table 11).

There was not a significant correlation between the bird duration and the species richness (*P*=0.12) and bird abundance (*P*=0.19) observed at the green walls, but both showed moderate positive relationships (r^2=0.5863; r^2=0.5135) (Table 11). There was not a significant correlation between bird duration and the species richness (*P*=0.1), observed at street trees, but a significant correlation for bird abundance (*P*=0.01). Both still showed strong positive relationships (r^2=0.6239; r^2=0.8167) much higher than green walls (Table 11).

There was not a significant correlation between the number and duration of behaviours for both green walls (*P*=0.12) and street trees (*P*=0.06), though street trees was closer to be significant. Green walls still showed a moderate positive relationship (r^2=0.5863) while street trees showed a higher strong positive relationship (r^2=0.6805) (Table 11).

Table 12. **The recorded environmental characteristics of the green wall sites (distance, noise level and area) alongside with description of sites' urban activity, urban form and vegetation coverage.**

Green Wall Sites	Mean Distance to green spaces (m)	Mean Noise Level (dB)	Area of Site (m2)	Urban Activity (Human Disturbance)	Urban Form	Vegetation Coverage
Victoria	291.25	75.33	2276	Offices Carpark Tram stop	High rise Main road Open	Grass Bushes Trees
AO	303.14	74.85	672	Commute trail Carpark Construction	High rise Main road Enclosed	Trees
Exchange	593.72	77.87	651	Commute trail Office Bus stop	High rise Main road Enclosed	Trees
Deansgate	277.44	76.77	1563	Pedestrian crossing Train station Tram stop	Low rise Main road Open	Bushes Trees Canal
IVY	375.49	71.8	3055	Commute trail Office Entertainment	High rise Pedestrian Zone Open	Grass Flowers Bushes Trees
Beyer	140.35	67.52	651	Car park Seating area Student area	High rise Courtyard Enclosed	Grass Flowers Bushes Trees
Rutherford	195.25	71.95	5651	Seating area Student area	Low rise Pedestrian Zone Open	Grass Flowers Bushes Trees
The Hatch	279.25	80.55	639	Commute trail Bus stop Entertainment	Low rise Main road Enclosed	Flowers Trees

4.2.3 Environmental Characteristics

Describing the general disturbance activity occurred at each green wall sites (Table 12), four sites were on commuter routes (AO, Exchange, IVY and Hatch), three sites had offices (Victoria, Exchange and IVY) and three sites had a carpark (Victoria, AO and Beyer). Additionally, two sites contained a bus stop (Exchange and Hatch), two sites had a tram stop (Victoria and Deansgate) and one near a train station (Deansgate). Deansgate was also centred by a pedestrian crossing, while other sites were mostly entertainment areas (IVY and Hatch) and a student area with seating (Beyer and Rutherford). The AO was the only site with ongoing construction.

Regarding the urban form (Table 12), five are described as a high-rise site (Victoria, AO, Exchange, IVY and Beyer), while three were described as low rise (Deansgate, Rutherford and Hatch). Additionally, four sites were on a main road (Victoria, AO, Exchange, Deansgate and Hatch), two were part of a pedestrian zone (IVY and Rutherford) and Beyer was a courtyard. Overall, four were open sites (Victoria, Deansgate, IVY and Rutherford) and four were enclosed sites (AO, Exchange, Beyer and Hatch).

The type of vegetation found in addition to the green wall and street trees on the sites (Table 12) included some sites (e.g., AO and Exchange) only had a few additional trees (that were not adjacent to the green walls and therefore not monitored), and some planted flowers at the Hatch. While other sites had more extensive greenery, for instance, the IVY, Beyer and Rutherford comprised of flowers, bushes and trees; grass, bushes and trees at Victoria and trees, bushes and a canal at Deansgate.

The mean distance from the green wall sites to other nearly green spaces was 307m (SD=127). The shortest distance was Beyer (140m) and the furthest was Exchange (594m) (Table 12) The distances recorded across the green wall sample sites followed a normal distribution (Table 4). There was not a significant correlation between species richness and bird abundance to the distance for both green walls (P=0.7; P=0.52) and street trees (P=0.49; P=0.69) and both showed negative but no linear relationships (Table 13). There was also no significant correlation between number and duration of behaviours for both green walls (P=0.7; P=0.88) and street trees (P=0.81; P=0.62) to distance, with both showing negative but no linear relationships (Table 13).

The mean level of noise of the green wall sites was 75 dB (SD=4). The quietest site was the Beyer (67 dB) and the loudest the Hatch (81 dB) (Table 12). The noise level recorded across the green wall sample sites followed a normal distribution (Table 4). There was not a significant correlation for green walls between species richness and noise level (P=0.09) but there was a significance between bird abundance and noise level (P=0.04). Both still showed strong negative relationships (r^2=0.6324; r^2=0.7096) (Table 13). There was not a significant correlation for street trees between both species richness and bird abundance to noise level (P=0.26; P=0.09), but abundance showed a higher significance. Bird abundance showed a strong negative relationship (r^2=0.6324), whereas species richness showed a weak negative relationship (r^2=0.4461) (Table 13). When it came to the green infrastructures' bird behaviours and durations, there was not a significant correlation for both green walls (P=0.09; P=0.74) and street trees (P=0.24; P=0.3) to noise level (Table 13). Green walls' number of behaviours and noise level still showed a strong negative relationship (r^2=0.6324), while street trees was weak (r^2=0.4727). Then bird duration and noise level was a weak negative relationship for street trees (r^2=0.416) and no linear relationship for green walls (r^2=0.1441) (Table 13).

The mean area of the green wall sites was 1895 m^2 (SD=1654). The smallest sites were Exchange and Beyer at (651 m^2) followed by AO (672 m^2), and the largest site was Rutherford (5651m^2) (Table 12). The area of sites recorded across the green wall sample sites did not follow a normal distribution (Table 4). There was not a significant correlation between species richness and bird abundance to the area for both green walls (P=0.83; P=0.94) and street trees (P=0.92; P=0.99) and both showed positive (mostly straight) no linear relationships (Table 13). There was also no significant correlation between number and duration of behaviours for both green walls (P=0.83; P=0.99) and street trees (P=0.89; P=0.91) to area, with both showing positive and negative no linear relationships (Table 13).

Table 13. **Pearson correlation analysis for green infrastructures' activity and behaviours (species richness, bird abundance, behaviours and duration) between environmental characteristic variables (green space distance, noise level and area of site).**

Environmental Characteristics	Trend	r^2 Value	Relationship	*P* Value
Green Walls' Relationships				
Green Space Distance and Species Richness	Negative	0.1605	None	0.70
Green Space Distance and Bird Abundance	Negative	0.2675	None	0.52
Green Space Distance and Behaviours	Negative	0.1605	None	0.70
Green Space Distance and Durations	Negative	0.0602	None	0.88
Noise Level and Species Richness	Negative	0.6324	Strong	0.09
Noise Level and Bird Abundance	Negative	0.7096	Strong	0.04*
Noise Level and Behaviours	Negative	0.6324	Strong	0.09
Noise Level and Durations	Negative	0.1441	None	0.74
Area of site and Species Richness	Positive	0.0882	None	0.83
Area of site and Bird Abundance	Positive	0.0322	None	0.94
Area of site and Behaviours	Positive	0.0882	None	0.83
Area of site and Durations	Straight	0.0002	None	0.99
Street Trees' Relationships				
Green Space Distance and Species Richness	Negative	0.2889	None	0.49
Green Space Distance and Bird Abundance	Negative	0.1699	None	0.69
Green Space Distance and Behaviours	Negative	0.1029	None	0.81
Green Space Distance and Durations	Negative	0.2085	None	0.62
Noise Level and Species Richness	Negative	0.4461	Weak	0.26
Noise Level and Bird Abundance	Negative	0.6272	Strong	0.09
Noise Level and Behaviours	Negative	0.4727	Weak	0.24
Noise Level and Durations	Negative	0.416	Weak	0.30
Area of site and Species Richness	Positive	0.0369	None	0.92
Area of site and Bird Abundance	Straight	0.0003	None	0.99
Area of site and Behaviours	Positive	0.0627	None	0.89
Area of site and Durations	Negative	0.0521	None	0.91

The eight monitored green walls were all different sizes depending on design and building, with a mean height of 10m (SD=9), mean width of 27m (SD=36) and a mean area of 171m^2 (SD=192). The highest was the Beyer (30m) which was substantially higher than the others, and the smallest was the Hatch (2m) (Table 14). The widest was the IVY (125 m) which was substantially wider than the others, and the narrowest walls were Hatch and Victoria (both 2.5m) (Table 14). The largest according to area was the Beyer (570m^2), compared to the smallest which was the Hatch (6m^2) a substantially smaller green wall compared to the others (Table 14). The height of the green walls recorded followed a normal distribution while the area of green walls did not follow a normal distribution (Table 10).

There was a significant correlation between green walls' height and bird activity including species richness (P=0.01), bird abundance (P=0.008) and number of behaviours (P=0.01), but not a significant correlation between height and bird duration (P=0.3) (Table 15). This variable showed a weak positive relationship (r^2=0.4244), while other variables showed much stronger relationships including species richness (r^2=0.7864), abundance (r^2=0.9296) and bird behaviours (r^2=0.7864) (Table 15). There was a significant correlation between green walls' area and all bird activity including species richness (P=0.03), bird abundance (P=0.007), number of behaviours (P=0.03), and bird duration (P=0.05) (Table 15). All variables showed strong positive relationships including species richness (r^2=0.7319), bird abundance (r^2=0.8471), bird behaviours (r^2=0.7319) and durations (r^2=0.6865) (Table 15).

Each green wall contained a mixture of plant species, with a mean of 6.5 plants species per wall (SD=2). The IVY wall had the greatest plant species richness (10 species), whereas the Beyer, an ivy clade green façade, was the only wall with one species (Table 14). Using the area of green walls and number of plant species, each green wall's ecological value was scored. The IVY's score was the largest (3000) being the third highest area size and had the most plant species. The Hatch scored the lowest (31), having the lowest area size and second from the lowest number of plant species (Table 14). The number of plants on the green walls recorded followed a normal distribution while the ecological score of green walls did not follow a normal distribution (Table 10).

There was not a significant correlation between the green walls' plant richness and bird activity including species richness (*P*=0.94), bird abundance (*P*=0.67), number of behaviours (*P*=0.94), and bird duration (*P*=0.94), with all variables showing negative but no linear relationships (Table 15). There was not a significant correlation between the green walls' ecological value and the bird activity including species richness (*P*=0.27), bird abundance (*P*=0.62), number of behaviours (*P*=0.27), and bird duration (*P*=0.08) (Table 15). The variable duration was the only to show a strong positive relationship (r^2=0.6421), while both species richness (r^2=0.4421) and behaviours (r^2=0.4421) showed a weak relationship, and bird abundance show no linear relationship (r^2=0.2102) (Table 15)

Table 14. **The recorded characteristic measurements on the eight green walls: height, area, plants and ecological score.**

Green Walls	Height (m)	Width (m)	Area of vegetation (m^2)	Number of Plants	Index Score (Area x No. Plants)
Victoria	7	2.5	+25	8	200
AO	3	14	42	8	336
Exchange	2.5	19.2	*48	*6	288
Deansgate	11	30	330	6	1980
IVY	16	124.5	+300	10	3000
Beyer	30	19	570	1	570
Rutherford	9	7.15	^50	^8	400
The Hatch	2	2.5	*6.25	*5	31.25

Reference:
+ Ansglobal, 2020
* HYVERT, 2020
^ Inleaf, 2020

Table 15. **Pearson correlation analysis for green walls' bird activity and behaviours (species richness, bird abundance, behaviours and duration) between green wall characteristics variables (height, area, number of plants and ecological score).**

Green Wall Characteristics	Trend	r^2 Value	Relationship	*P* Value
Height and Species Richness	Positive	0.7864	Strong	0.019**
Height and Bird Abundance	Positive	0.9296	Strong	0.008***
Height and Behaviours	Positive	0.7864	Strong	0.019**
Height and Durations	Positive	0.4244	Weak	0.300
Area of wall and Species Richness	Positive	0.7319	Strong	0.039*
Area of wall and Bird Abundance	Positive	0.8471	Strong	0.007***
Area of wall and Behaviour	Positive	0.7319	Strong	0.039*
Area of wall and Durations	Positive	0.6865	Strong	0.058*
Number of Plants and Species Richness	Negative	0.0315	None	0.944
Number of Plants and Bird Abundance	Negative	0.1803	None	0.669
Number of Plants and Behaviours	Negative	0.0315	None	0.944
Number of Plants and Durations	Negative	0.0279	None	0.944
Ecological Score and Species Richness	Positive	0.4421	Weak	0.275
Ecological Score and Bird Abundance	Positive	0.2102	None	0.618
Ecological Score and Behaviours	Positive	0.4421	Weak	0.275
Ecological Score and Duration	Positive	0.6421	Strong	0.087

5. CHAPTER 5 - DISCUSSION

5.1. Manchester and Salford Cities Bird Survey

5.1.1 Bird Richness and Abundance

The bird richness and abundance of Manchester and Salford cities, surveying the 16 sample sites, found a mean richness of nine species (range 2–13 species) and a mean abundance of 23 individuals (range 4–35 individuals) (Table 2). Some sites saw higher species richness than others (e.g., Media, Computer, Rutherford and Man Library (Table 3)), though bird richness and abundance were similar across the majority of sites. All sites showed a mean of 2.6 individuals per species (range 1.63-4.17). Overall, there was a strong positive and significant relationship (Figure 11), where bird abundance found in the cities was accounted for bird richness.

Using the National Biodiversity Network Trust (NBN) Atlas, it is possible to set these findings in context. According to the NBN database, 94 species were recorded in the two cities (National Biodiversity Network Trust, 2020). While a much larger amount, these records are over a longer time period and covered more habitats than those in this study. These figures do, however, give a comparison in terms of the birds observed in this study and the birds regularly recorded in the cities. The observed 21 bird species, according to the NBN, were part of the most frequently recorded bird species in the cities, indicating that these bird species were expected to be present.

It also gave an idea of which species were potentially missed. The NBN reports more waterfowl species (e.g., Canada goose (*Branta canadensis*)) but it was expected that these species were not going to be recorded in this study. This was because there were not many sample sites located near water, and these species are active around the canal and river. All the smaller-bodied bird species most frequent in the NBN were recorded in this study, except for greenfinch (*Chloris chloris*) and chaffinch (*Fringilla coelebs*). Both species are accepted to be active in cities as generalists (DEFRA, 2018) but probably meant these sample sites did not offer the right resources for them to be present. The similar reason applies for the absence of starling: a popular urban bird (Lepczk & Warren, 2012), not recorded once in this survey. They prefer wider areas especially grasslands and fields, obviously that these sample sites were not suitable for them.

Overall, while other urban city studies will observe a larger amount of bird species, this is either from more biodiverse and rich countries (Pena, et al., 2017; Belcher, et al., 2019) or studies that are a much longer period (Fernández-Juricic, 2000; Strohbach, Lerman, & Warren, 2013), the number of bird species recorded gave an idea of typical bird activity in metropolitan cities like Manchester and Salford in the North West of England, UK. In this study, some expected species were missing or less abundant, the overall amount and good assortment, can be useful to evaluate urban bird biodiversity over the available sample sites and observational period.

In this study, the most frequent city species were feral pigeon and blue tit, found at 15 sites, followed by magpie and carrion crow found at 14 sites (Table 5). The most abundant, by far, was the feral pigeon with 68 individuals (Table 5). The feral pigeon is a major urban bird notorious for inhabiting human-dominated environments, making it one of the most written-about urban birds throughout a range of urban wildlife literature (Johnston & Janiga, 1995; Lepczk & Warren, 2012; Sol, Lapiedra, & González-Lagos, 2013; RSPB, 2019a). They have adapted to all urban challenges by decreasing wariness to humans, exploiting local resources and overall saving energy and time (Johnston & Janiga, 1995; Morelli, et al., 2018; Rivkin, et al., 2019). As a result, are regularly observed in towns and cities, and are present in even the most congested cities, active alongside people. The Quay site was the only site without feral pigeons. It was a quiet site with little human activity adjacent to the Salford Quays, suggesting it may not be a suitable site with the preferred resources lacking.

The least frequent city species observed were the lesser redpoll, house sparrow, jay, great tit and mallard, only found at one site in total (Table 5). The lesser redpoll and jay (both found on the UoS site) (Table 2) were observed in the winter, as active winter seasonal birds (BTO, 2020a; RSPB,2020b). The great tit, recorded at the Rutherford site (Table 2), which like their counterpart the blue tit, is known as a garden bird and was expected to be observed, according to the NBN, more frequently than it was (National Biodiversity Network Trust, 2020). The mallard was recorded at the Deansgate site (Table 2), which was close to the canal and as an urban waterfowl was found crossing the site, so its presence was probably not related to the green infrastructures available. The house sparrow was only recorded at the Quays (Table 2), which as the most historical urban bird it was expected to be observed at more sites. All species scored an average of 2.8 individuals per active site (Table 5), with the least frequent recorded species: house sparrow (8 individuals recorded per active site) and lesser redpoll (10 individuals recorded per active site) being exclusively higher as a common flock species (Lepczk & Warren, 2012; Lindo, 2018; BTO, 2020a). There were examples of more solitary species, including the robin and wren, both regular observed as individuals (Table 5).

The majority of observed bird species in the cities were generalists, with a total of 16 species (Table 6). Generalists are known to function well within any habitats, including those in the urban environment, with their broad spectrum of resource intake (Hayman & Burton, 1982; Strohbach, Lerman, & Warren, 2013; Bolhuis Casas, 2016). Generalist species such as the feral pigeon, blue tit and magpie, are examples of urban exploiters: bird species with urban tolerance that have adjusted behaviourally to adapt to urban living (Sol, Lapiedra, & González-Lagos, 2013; Partridge & Clark, 2018). These high frequent and abundant species, including blue tit (n=45) and magpie (n=39) (Table 5), are good examples how bird species have adapted and developed in city environments (Sol, Lapiedra, & González-Lagos, 2013). They are successful species able to colonise, able to withstand such challenges of urbanisation and making them a benefit (Morelli, et al., 2018). Such like the feral pigeon, magpies are becoming tolerant of human activity, recognising when humans are a threat and modifying their foraging and nesting behaviours in urban areas (Sol, Lapiedra, & González-Lagos, 2013). The blue tit has adapted to the urban environment by using human-derived food to avoid starvation, and using artificial light to increase reproduction rates (Sol, Lapiedra, & González-Lagos, 2013; RSPB, 2019a).

The blue tit, usually seen as a garden bird, has become well-adapted as a city resident too (Lepczk & Warren, 2012; Sol, Lapiedra, & González-Lagos, 2013; Grafius, et al., 2017; RSPB, 2019a). They were even active on sites that were mostly devoid of other species such as the Exchange and St Peter's (Table 2). The blue tit was more active than the much larger and boisterous magpie – an extremely adaptable scavenger (Lepczk & Warren, 2012) – which were particularly active at the more campus style sites (e.g., UoS, Man Libray and Alliance), but were not active at the Exchange (Table 2). Magpie and blue tit were not present at the Hatch (Table 2). The Hatch was one of the busier sites, being congested with pedestrians and vehicles, maybe too hectic an environment for even the most obvious urban birds. The feral pigeon, however, was active on the Hatch site, able to adapt to the presence of pedestrians and vehicles. Implying that this bird species is an example of one of the true high tolerant birds (Lindo, 2018) compared to the blue tit and magpie and the rest of the birds observed.

This study recorded five specialist species in the cities (Table 6). This included the pied wagtail and grey wagtail both insectivore specialists, the goldfinch a farmland specialist and lesser redpoll and jay, both woodland specialists (DEFRA, 2018). The lack of specialists recorded is reflected by their lower ability to adapt to urban living (Clergeau, et al., 2006). It was expected as the requirements of many specialists are not naturally available in urban areas (Hayman & Burton, 1982; Clergeau, et al., 2006; Strohbach, Lerman, & Warren, 2013). However, the fact that some specialists were observed can suggest that the urban environment is not totally hostile to them and some are becoming adapted as a slow evolutionary process (Rivkin, et al., 2019). For example, the goldfinch was the fifth most abundant bird species (Table 5). They were active at seven sites, regularly seen in larger groups of individuals (3.57 individuals per active site) (Table 5). Such active sites were mainly the quieter locations, but were recorded at the IVY, a city-centre site surrounded by buildings (Table 2). They are becoming an example of a specialist species that are persistent in urban cities (Lindo, 2018). Goldfinch were most active using the available trees, whereas the pied wagtail, another active specialist example, was observed regularly across six sites (Table 5) and was always found walking on pedestrian zones and diving across from adjacent buildings.

The other specialists were observed less frequently, including the grey wagtail recorded only at three sites (Table 5). This is probably due to their preference of being near water (RSPB, 2020a). Both lesser redpoll and jay were observed only once. Though there are growing reports of these species slowly becoming fixed urban residents. For instance, the BTO (2020a) reports that the lesser redpoll has increased its visitation to urban gardens, steadily becoming a common garden bird, so possibly have slowly become active in towns and cities from this study's records. According to RSPB (2020b), the jay can be found in urban/suburban areas but are more commonly woodland birds. Both birds were only observed at the UoS site (Table 2), one of the larger sites with many tall trees, implying the suitability of this site, being able to support these woodland specialists.

The presence of specialists can support that cities can create positive habitats for a range of bird communities, where both food and habitats specialists can inhabit (Clergeau, et al., 2006). Specialists can be affected more by the threats of urbanisation, for example, the current concerns of declines in insectivore specialists from the decline of the urban insect community (Madre, et al., 2013; Strohbach, Lerman, & Warren, 2013). However, there are large declines in these specialist species populations across all habitats, not just within the urban environment (RSPB, 2019a; Chiquet, Dover, & Mitchell, 2012). Overall, there are low population trends of all bird biodiversity in urban environments (Morelli, et al., 2018) and there should be a drive to support and encourage all urban birds, both generalists and specialists (Partridge & Clark, 2018).

This study recorded five red-listed species in the cities (Table 6). Red-listed species are a priority conservation concern (RSPB, 2015; RSPB, 2019b). The red-listed species include the specialists grey wagtail and lesser redpoll, and some generalists, including the mistle thrush, which is facing declines from the current farmland concern, but are another example of a species becoming a usual urban bird (BTO, 2020b). There were also examples of more long-term urban birds on the Red List such as the herring gull and house sparrow (RSPB, 2015). Many gull species face declines due to coastal concerns and have emigrated more inland, preferring various urban habitats and resources (Ardley, 1980; RSPB, 2015; Lindo, 2018). The house sparrow, one of the true historical urban birds, are red-listed due to the massive drop from past population numbers which have not returned to the original level but are still a common and prosperous urban resident (Lindo, 2018). These red-listed species are threatened from impactful ongoing cases, and it can be a positive outlook that there have been examples of birds of concern taking advantage of the urban habitats.

As a whole, most of the observed birds were generalists and green-listed (Table 6), indicating the tendency towards a ‘homogenised’ and ‘simple’ urban bird community due to the dominance of a few species capable of living in the urban environment (Clergeau, et al., 2006; Strohbach, Lerman, & Warren, 2013). Though, not as rich compared to other ecosystems, it is an insight into the potential diversity and that is not only the typical generalists, omnivores, dubbed city species - such as feral pigeons – that are active in the urban areas (Johnston & Janiga, 1995; Lindo, 2018; Morelli, et al., 2018). This study, along with other records (e.g. NBN), shows there are cases of birds succeeding in urban areas. These 21 recorded species are all urban species (Lindo, 2018), either exploiters or utilizers (Partridge & Clark, 2018), which are successful and active, taking advantage of the urban cities. It is hoped that urban studies can highlight the value of a city landscape for the urban bird community. It could be implied that there may be not as many limitations in the urban environment, including the cities, as there are thought to be. This study suggests that this includes feeding resources from the recorded range of different diets and feeder guilds. There was an even spread of granivores, insectivores, omnivores and frugivores, as well as active, ground and scavenger feeders (Table 6). As there were absence of various specialists and woodland species, that are common UK species, it could mean there are some features that are still missing or urban features which are just too great for some birds. The data, though, can take into account that an urban city environment is not always a dominant homogenised environment it is considered to be (Morelli, et al., 2018).

5.1.2 Environmental Characteristics

Connectivity, the network of movement for organisms, has been shown to affect bird activity, especially in cities (Grafius, et al., 2017; Mayrand & Clergeau, 2018). The vast built landscape and the lack of natural spaces and associated resources (e.g., nesting and feeding sites) can make it hard for some bird species to be active (Sol, Lapiedra, & González-Lagos, 2013; Madre, et al., 2014; Grafius, et al., 2017; Mayrand & Clergeau, 2018). As mobile animals, they require a substantial functional network for movement (Grafius, et al., 2017; Mayrand & Clergeau, 2018). This can be achieved through green infrastructures (e.g., parks, gardens, lawns, street trees and green walls/roofs) which have all been shown to increase bird occupation, improving species richness and abundance (Chiquet, Dover, & Mitchell, 2012; Grafius, et al., 2017; Partridge & Clark, 2018; Oppla, 2019 Reid, Jones-Morris, & Snell, 2019). The richest sample site, Man Library, showed the lowest distance (123m) to other green spaces (Table 3), suggesting that this characteristic of connectivity contributed to having the highest number of bird species and individuals. The same then goes for the lower performing site, Exchange, which was the least well connected (594m) to other green spaces (Table 3), potentially influencing the much lower bird richness and abundance. However, there was only a moderate negative relationship between bird richness and abundance accounted for distance to greening opportunities (Figures 12 and 13). This possibly was influenced by the Hatch, a site with low bird richness and abundance while having a low distance to other green spaces (279m) (Table 3). This site was surrounded by green spaces, unlike the Exchange site located in the middle of Manchester City Centre, and was part of the campus area of the two major Universities.

Other sample sites on this campus setting were Computer, Alliance, Rutherford, Beyer and Man Library. Noticeably, these sites had more greening opportunities building an aesthetic environment for students and workers, which can be beneficial for birds. The Hatch, though, was a much busier site. It was part of a main road that had a range of human disturbances (e.g., pedestrians, vehicles, elevated motorway and music) which overall made it the loudest site (81db) (Table 3). Noise pollution can negatively affect bird activity, particularly their communication (Sol, Lapiedra, & González-Lagos, 2013; Pena, et al., 2017; Lindo, 2018; Leveau & Leveau, 2020). Bird call and song is naturally used as communication for warning, mating and territory behaviours and can easily be masked by by high levels of noise associated with chaotic urban activity (Catchpole & Slater, 2008; Sol, Lapiedra, & González-Lagos, 2013; Pena, et al., 2017; Leveau & Leveau, 2020). While some bird species have adapted to the noise created by people, traffic and construction, many are left to struggle and tend to avoid loud areas (Sol, Lapiedra, & González-Lagos, 2013). The quietest sites (67db) were the Beyer and Man Library (Table 3). Again, these sites had some of the highest bird species richness and abundance, being part of the quietest side of the campus. While noise seems to affect bird activity, it was found that there was only a strong negative relationship between noise level and bird abundance (Figure 13), whereas there was a weak negative relationship for species richness (Figure 14). The noise of the sites accounted for the number of individuals, but not the number of species. There was a mixture of bird species regardless of the noise of sample site. For instance, Deansgate (77db) with 12 species, IVY (72db) with 5 species and Computer (73db) with 13 species (Table 3). It could suggest that noise levels are not preventing bird species from being present but influencing the number of individuals, observing a lower amount of abundance at louder sites.

It is also thought the area size of green spaces can influence bird activity, the probable effect that a smaller site will have the lower bird richness and abundance (James, Norman, & Clarke, 2010; Strohbach, Lerman, & Warren, 2013). This was observed at small sample sites such as the Hatch (629m^2), Exchange (651m^2) and AO (672m^2) (Table 3). However, other small sample sites such as Beyer (651m^2) and Computer (756m^2) had a higher bird species richness and abundance (Table 3). The larger the site also did not mean the highest bird performance. While it did for Rutherford (5651m^2) being the largest site and one of the richest, other large sample sites like St Peter's (4389m^2) showed the least richness with 4 species in total, while smaller sample sites such as Alliance (4271m^2) and Man Library (3707m^2) showed a higher richness (Table 3). Again, the IVY (3055m^2) showed a richness of 5 species, while smaller sites Media (2276m^2) and Deansgate (1562m^2) showed a higher richness (Table 3). Site size is not as influential for birds, with a positive but no linear relations between the variables (Figures 16 and 17). It can still be argued any size space is valuable for bird richness and abundance, with small urban spaces of a few hundred square metres can be associated positively with bird richness (Strohbach, Lerman, & Warren, 2013).

Seen by example of the sample sites such as the Hatch, Exchange and AO, the urban environmental factors – connectivity, noise and area – can influence potential bird species richness and abundance (Radford & James, 2012; Sol, Lapiedra, & González-Lagos, 2013; Lindo, 2018; Morelli, et al., 2018). However, birds were active at sites regardless of the area size, and though implied that the other environmental characteristics of the sites (i.e., connectedness and noise) can influence bird activity, there was a mixture of strong to weak influence. It is notable that sites in the city centre (e.g., Cathedral, AO, Exchange, IVY, St. Peter's and Deansgate) were some of the loudest and most isolated sites, with high levels of human activity and with limited nearby vegetation, and consequently had some of the lowest bird richness and abundance. Even though Cathedral and Deansgate were isolated (386m and 277m) and noisy (76db and 77db) both sample sites had a high bird species richness (8 and 12 species) and abundance (22 and 25 individuals) (Table 3). Potentially from their substantial amount of vegetation coverage on-site and nearby, but also their urban form. Urban form, if an area was open or enclosed, can be a factor influencing connectivity. For sites located in the city centre, they were much more open areas, whereas other city sites were enclosed areas surrounded by large built infrastructures. This included the IVY, though one of the quietest sites with a selection on vegetation on site, it had a low number of species (5 species and 15 individuals) being enclosed in the middle of a business sector and was isolated (375m) (Table 3).

It was then notable that sites south of Manchester City Centre, in the campus area (e.g., Computer, Alliance, Rutherford, Beyer and Man Library), had some of the quietest and better-connected sites (Table 3) being located in the greener area for the academics and away from the city centre. All sites recorded the highest richness and abundance, except the Hatch, which was a very busy site affected by high levels of noise and human activity. The sites UoS, Media, Quays and Victoria had intermediate levels of human activity and vegetation. Bird species richness and abundance was above average at these sites, particularly the sample site Media being the richest (13 species) - a quiet (71db) and well connected site (295m) with a vast area of vegetation on-site (Table 3).

Though the effects of site variables studied are not definite, they are suggestive that they influence the bird species richness and abundance in the cities, and that some bird activity may be limited due to the environmental characteristics of the site (Madre, et al., 2014; Lindo, 2018; Morelli, et al., 2018). It seems, though, any place in the city could have the potential to be beneficial towards birds (Strohbach, Lerman, & Warren, 2013; Partridge & Clark, 2018). However, birds still require appropriate habitats, with resources and security, and will avoid areas that do not accommodate those needs (Fernández-Juricic, 2000; Morelli, et al., 2018; Partridge & Clark, 2018).

5.2. Green Wall and Street Tree Survey

5.2.1 Bird Richness and Abundance

Across the eight green wall sample sites, 18 bird species were observed (Table 2). While there were three species not recorded from the wider city survey, these sites on their own saw a similar mean richness (range 2-13 species) but saw a lower mean abundance of 19 individuals (range 4-32) (Table 2). They also saw similar trends in the most frequent species. The feral pigeon, was the dominant species seen at all eight sample sites with 33 individuals, followed by the blue tit (n=17) and magpie (n=15) (Table 2). Only four green wall sample sites observed three specialist species (i.e., goldfinch, pied wagtail and grey wagtail) (Table 2), potentially not accommodating for the two woodland specialists: lesser redpoll and jay. Six sample sites were able to observe three red-listed species (grey wagtail, herring gull and mistle thrush) (Table 2). Again, not accommodating enough for the lesser redpoll, but potentially for the house sparrow, which while they were absence during the bird richness and abundance survey, they were observed during the bird behaviour survey (Table 7), demonstrating the species are occurring.

5.2.2 Bird Activity

Surveying the green infrastructures (Table 7), four bird species were seen exploiting green walls: feral pigeon (green-listed), magpie (green-listed), blue tit (green-listed) and mistle thrush (red-listed). These birds are similar in that they are generalist species. While representing all the four diet guild categories: granivore (feral pigeon) and omnivore (magpie), as well as two insectivores that are also frugivores (blue tit and mistle thrush) (Table 6). Also representing all three feeding guild categories: two ground feeders (feral pigeon and mistle thrush), a forager (magpie) and an active feeder (blue tit) (Table 6).

Previous green walls studies give good examples of what bird species are seen on green walls. The findings reported here (Table 7) are comparable with those of Chiquet, Dover, & Mitchell (2012), who during their green wall bird association study in the UK, found that green walls were used by common UK urban birds, with the majority being generalists, green-listed species and being members of various diet guilds. All similar green wall studies observed bird species were from various diet guilds, though in tropical countries (Bolhuis Casas, 2016; Belcher, et al., 2019) nectarivore bird species were also observed. All reported green wall bird species observed are mostly urban exploiters and utilizers, as common urban residents of the study's cities, and as most were generalists they were species seen not of conservation concern (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019).

However, Chiquet, Dover, & Mitchell (2012) did record one specialist species, the starling, a red-listed species along with the house sparrow. Both species are iconic urban birds that are commonly found around in both built and humanised areas (Chiquet, Dover, & Mitchell. 2012; Lepczk & Warren, 2012). Moreover, other studies Bolhuis Casas (2016) and Belcher, et al. (2019) also found species of starling (*Sturnidae*) and sparrow (Passerellidae or Passeridae) exploiting their green walls. Surprisingly, this study reported neither common starling nor house sparrow using the green walls. It puts into question why these examples of urban birds were not using this study's green walls as well as a more regular observation. Especially as these species are capable of living in the urban terrain, regardless of country, with all studies suggesting they were the predominant species (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). For example, Bolhuis Casas (2016) most observed species exploiting their green walls was the Rufous-collared sparrow (*Zonotrichia capensis*).

It seems the bird species diversity recorded in this study was poor compared to that in other studies. While feral pigeon was observed in this study (Table 7) and other studies, other Columbidea species were also present, mostly dove species (e.g., collared dove (*Streptopelia decaocto*) (Chiquet, Dover, & Mitchell, 2012), eared dove (*Zenaida auriculata*) (Bolhuis Casas, 2016) and spotted dove (*Spilopelia chinensis*) (Belcher, et al., 2019), which were absent in this study. Chiquet, Dover, & Mitchell (2012) also observed blackbird and robin using their green walls. While this study did not observe these species using the available green walls, unlike the fully absence of starling, house sparrow and collared dove, both robin and blackbird were observed on the green wall sites (Table 2). This could indicate that these bird species may potentially be exploiting green walls. The mistle thrush was observed though (Table 7), offering valid support that these green walls are used by similar birds (Turdidae species) especially compared to other wall studies, observing the blackbird (Chiquet, Dover, & Mitchell, 2012) and great thrush (*Turdus fuscater*) (Belcher, et al., 2019). Overall, it can be important to point out that even though only four species were recorded in this study (Table 7), other studies also only recorded six bird species associated with their green walls (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019).

Surveying the other green infrastructure, street trees (Table 7), the data obtained found that there was a larger number of bird species, 11, were observed exploiting the street tree(s) than the green walls: feral pigeon (green-listed), magpie (green-listed), blue tit (green-listed), mistle thrush (red-listed), woodpigeon (green-listed), blackbird (green-listed), robin (green-listed), house sparrow (red-listed), goldfinch (green-listed), long-tailed tit (green-listed) and pied wagtail (green-listed). These species were all generalists, apart from two specialist species (goldfinch and pied wagtail). All species also came from the four-diet guild categories, but in different numbers to those at the green walls, with four granivores (feral pigeon, woodpigeon, house sparrow and goldfinch), four alternating insectivores/frugivores (blue tit, mistle thrush, blackbird and robin) and one omnivore (magpie), along with two true insectivores (long-tailed tit and pied wagtail) (Table 6). Similarly, there were five active feeders (blue tit, goldfinch, robin, long-tailed tit and pied wagail), five ground feeders (feral pigeon, mistle thrush, woodpigeon, house sparrow and blackbird), and one forager (magpie) (Table 6).

There is, unfortunately, an absence of studies of street tree bird association in the UK, but the positive influence of street trees on the urban avifauna is largely recognised worldwide. Particularly in the southern hemisphere of richer ecosystems, such as Pena, et al. (2017) able to record 73 bird species exploiting street trees in Brazil. Other studies recorded relatively high species richness: 21 species (Barth, FitzGibbon, & Wilson, 2015) and 14 species (Fernández-Juricic, 2000). In Spain, Fernández-Juricic (2000) offered a similar comparison of bird species occupation on street trees, including blue tit, magpie, woodpigeon, blackbird and white wagtail (pied wagtail). Likewise to this study (Table 7), all street trees studies reviewed found that their birds were common urban utilizers in their cities, mostly generalists (Barth, FitzGibbon, & Wilson, 2015; Davis, Major, & Taylor, 2016; Pena, et al., 2017). Though several specialists species (Fernández-Juricic, 2000) and migratory birds (Wood & Esaian, 2020) were observed using street trees. There were specialists birds recorded on the street trees compared to green walls in this study (Table 7). This can demonstrate the better value of street trees, than green walls. Specialists are becoming meaningful urban utilizers, but due to the stricter living necessities it can be challenging in the urban environment (Clergeau, et al., 2006; Strohbach, Lerman, & Warren, 2013), so being active on these green infrastructures is important.

The larger bird species richness and abundance associated with street trees gives a better understanding of the difference between these two green infrastructures, and the active value of the green walls. Other studies such as Chiquet, Dover, & Mitchell (2012) and Belcher, et al. (2019) compared green walls to only control, concrete walls, which has left out identifying the true usefulness compared to other recognisable suitable urban vegetation (e.g., trees and shrubs). This study overall, showed that the street trees seemed to perform better for bird species richness and abundance compared to green walls (Table 7). Trees are a natural green infrastructure, environmentally used by many bird species. This can include specific species, for example, woodland species (DEFRA, 2018; Long & Frank, 2020), observing blackbird, blue tit, long-tailed tit and robin (Table 7). Generally, all birds will exploit trees in some way, for instance, pied wagtail, that was mostly found using the built surfaces (on ground and buildings). but was also using the street trees. Though trees are used by insectivore bird species as a feeding resource as it attracts insects (Long & Frank, 2020). The selected street trees encouraged a variety of bird species, both generalists and specialists, and exploiters and utilizers, whereas the green walls had a smaller bird occurrence. Street trees are more suitable for bird activity, compared to green walls, as they are more exploitable towards birds. They are higher and have safer features, as well as been larger, therefore, offering room for more birds at once, particularly flocks.

5.2.3 Bird Behaviours

The four bird species seen exploiting the green walls were observed climbing, foraging, loafing and perching (Table 8). All the behaviours observed were probable due to the many green wall attributes as identified by Loh, (2008), Francis & Lorimer (2011) and Grant & Gedge, (2019). Foraging is a common behaviour of bird observed on green wall studies (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). Green walls offer feeding opportunities dependant on the plant species, either producing seeds and berries (Chiquet, Dover, & Mitchell, 2012), nectar (Belcher, et al., 2019) or as habitats for invertebrates (Bolhuis Casas, 2016). Perching was also observed on the green walls. This is beneficial for birds allowing them to rest and offering security from predators or inclement weather (Bolhuis Casas, 2016). Nesting was not observed in this study, a consequence of the cessation of field work for this study due to COVID-19 national restrictions (see COVID Impact Statement, p. ix), preventing data collection during the nesting season. Both Chiquet, Dover, & Mitchell (2012) and Belcher, et al. (2019) focused on nesting and found evidence of such behaviour. Bolhuis Casas (2016) did not record any green wall nesting, although, they did note the use of green walls as a source of nesting materials.

Each bird species used the green walls differently (Bolhuis Casas, 2016; Belcher, et al., 2019). For instance, the feral pigeon and magpie were seen loafing, the blue tit and mistle thrush were seen climbing and foraging, while both magpie and blue tit were perching. This study found that the blue tit and mistle thrush were the only species foraging and climbing the walls, using them as an opportunity in search of food resources on the foliage, presumably for insects, as active and/or insectivore feeders. Whereas the larger-bodied birds, feral pigeon and magpie, were only using it as a resting feature, preferably not using it as a food resource. Elsewhere, Belcher, et al. (2019) observed that Rufous-collared sparrows were the only species that used the wall to nest, while also foraging on the *sedum* plants (e.g., for seeds and insects), whereas the hummingbird species were only foraging on the flowering plants (e.g., nectar). This illustrates bird species specific green wall behaviours.

At the street tree counterparts, in addition to the behaviours at the green walls (loafing, perching and foraging), calling, chasing, moving and roosting were also observed (Table 8). It was expected that there was going to be more behaviours observed on the street trees. A prediction based on both the larger number of species active on the trees compared to the green walls, and the many known attributes of street trees. Street trees are known to offer a variety of food resources, from fruit, pollen, leaves, while also attracting invertebrate and vertebrate prey species for the birds to feed on (Wood & Esaian, 2020; Villaseñor, Escobar, & Hernández, 2021). A lot of the street tree studies, including Barth, FitzGibbon, & Wilson (2015), Pena, et al. (2017) and Wood & Esaian (2020) observed bird foraging behaviours for insects, but Wood & Esaian (2020) emphasise the importance of street trees and their berry and seed resources. The foraging behaviours in this study were mostly from the woodpigeon, foraging for berries and seeds (Table 8). Nesting behaviours have been observed on street trees (Barth, FitzGibbon, & Wilson, 2015; Pena, et al., 2017), especially by cavity nesters (Fernández-Juricic, 2000; Kane, Warren, & Lerman, 2015) and woodland birds (Long & Frank, 2020). As with the green walls, nesting behaviour was not observed (see COVID Impact Statement, p. ix). Roosting, though, was observed (Table 8), an important bird behaviour, with street trees providing a place for birds to settle and to sleep. Chasing was another behaviour observed (Table 8) and was interpreted as a territorial behaviour suggesting birds were actively protecting their roost or feeding areas. It could have also been a display of courtship, in preparation for breeding and nesting behaviours.

Green walls and street trees share some attributes. Both green infrastructures were used for foraging, perching and loafing (Table 8), which is worthwhile knowledge in terms of the mutual values between the street trees and green walls. However, it seems that more birds expressed those behaviours more frequently on street trees. There are more opportunities for birds on the street trees than the green walls, and hence more behaviours were observed. This included roosting and chasing, as well as other important behaviours calling and moving (Table 8). Within an urban environment, particular cities, it is a pressing matter that birds have the opportunity to communicate and travel, as the built and busy environment is becoming a barrier for some bird species (Grafius, et al., 2017; Mayrand & Clergeau, 2018; Leveau & Leveau, 2020). The difference in bird behaviours expressed between the green infrastructures supports the higher worth of the street trees, compared to green walls, towards urban birds.

5.2.4 Environmental Characteristics

The common urban environmental characteristics can also influence bird activity on green infrastructures, consequently factoring their performance. At these green wall sample sites, there was more human activity and disturbances, with many of the nearby setting consisting of a larger amount of buildings and built infrastructures (Table 12). Since green walls are a green infrastructure that uses the vertical surface of a building, many of the sites were surrounded by more of these built infrastructures. Ultimately creating an environment more isolated (mean 307m, higher than 289m city mean), disturbed and noisy (mean 75dB, higher than 73dB city mean) and more enclosed and smaller (mean 1895 m^2, lower than 2460m^2 city mean) (Table 12).

Looking at the relationships between environmental characteristics and the green infrastructures' bird activity and behaviours, it was found there was not much of a correlation. The study showed there was a negative relationship with green space distance, similar findings to Bolhuis Casas (2016) who found a negative relationship between distance to other ecological features, but there was no correlation between these variables and being a no linear trend (Table 13). This study also showed a positive relationship with area of sites, similar to (Marzluff, Bowman, & Donnelly, 2001; Strohbach, Lerman, & Warren, 2013), but again, there was no correlation between these variables and being a no linear trend (Table 13). There was, though, a strong negative relationship with noise level and bird abundance for both green walls and street trees (Table 13), and though not a significant correlation there were strong negative relationships for noise level to species richness and bird behaviours for green walls. There was a weak negative relationship with street trees' species richness and behaviours (Table 13). There was then a weak negative relationship for duration at street trees and there was no relationship for green wall durations (Table 13).

Noise can be the most negative factor for the urban bird community and can decrease bird diversity (Pena, et al., 2017; Leveau & Leveau, 2020). While there is no work about noise and green walls, Pena, et al. (2017) expresses that the influence of street trees can reduce the negative effects of noise, which may suggest the weaker relationships between noise and street trees (Table 13). The loudest green wall sites, Hatch (81dB) and AO (75dB) (Table 12), had no bird activity on either green walls and street trees (Table 7), whereas other loud green wall sites, Exchange (78dB) and Victoria (75dB) only had bird activity on the street trees (Table 7). Implying that noise can factor green infrastructure bird activity, and that street trees have a better chance to counteract the impacts of noise. The only exception was the Deansgate site, where despite a noise level of 77dB (Table 12), there was bird activity at both street tree (4 species) and green wall (1 species) (Table 7). Nonetheless, the street trees quality supported more species, able to counteract the noise, and the one species on the green wall was feral pigeon – a bird species comfortable with heavy noise.

5.2.5 Green Wall Characteristics

The green walls themselves, face their own factors, as a man-made construct they vary greatly in design and purpose which ultimately affects their ecological function (Sheweka & Magdy, 2011). They vary greatly, in terms of shape, size and height. The eight observed green walls ranged in height from 2m to 30m (Table 14).

Other green walls by previous studies also varied in height: from 2m to 6m (Chiquet, Dover, & Mitchell, 2012), 2.2m to 26m (Bolhuis Casas, 2016) and 12m to 145m (Belcher, et al., 2019). It was found that there was a strong positive relationship between the height of the green walls and their bird activity and behaviours (Table 15). Though there was a weak positive relationship between duration and height of wall (Table 15), indicating that time spent on the wall was applied regardless of the height. Though, height can still influence the numbers of bird species and individuals, and what behaviours performed. Other studies also agreed that height can be an important factor to birds, able to affect birds and is important to support specific species groups (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016). Green walls that are placed higher are preferred by birds (Edwards, 1994; Bolhuis Casas, 2016; Surya, 2016; Belcher, et al., 2019). Chiquet, Dover, & Mitchell (2012) found that all birds observed on green walls were found on the upper half of the wall irrespective of their height. This can be related to nesting, as nesting activities are always restricted to higher sections of a green wall normally observed between 3m to 21m in height (Chiquet, Dover, & Mitchell, 2012; Surya, 2016; Belcher, et al., 2019). Overall, a higher green wall is ideal as a refuge, a vantage point and for reducing disturbance and risk (Chiquet, Dover, & Mitchell, 2012).

The area of the green wall was also found to be an important factor. There was a large range in the area of the green walls in this study: $6m^2$ to $570m^2$ (Table 14), with other studies seeing a range of: $3m^2$ to $20m^2$ (Chiquet, Dover, & Mitchell, 2012), $17m^2$ to $570m^2$ (Bolhuis Casas, 2016) and $75m^2$ to $1010m^2$ (Belcher, et al., 2019). A strong positive relationship was found between green wall area and their bird activity and behaviours, including duration of birds though slightly lower (Table 15). An area of the green wall can contribute to bird performance, especially as a larger wall can offer more vegetation coverage which generates a greater availability of insects and other feeding resources (Bolhuis Casas, 2016), which is particularly important considering forage is the main attractant for birds (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). This study also measured width, as there was were green walls that were more wide than tall (e.g., AO: 3m high and 14m wide, Exchange: 2m high and 19m wide) (Table 14). Width is not a factor that is much discussed and had no relationship between bird activity and behaviours. Although, of course, width does contribute to the area size.

Green walls can then be made up of various plants. The list of useable plants species is expanding and are used to create various designs. Though it is becoming evident that more green walls are installed for aesthetic purposes and made up of ornamental plants (Bolhuis Casas, 2016). This is to make them look visually pleasing and overlooks the plants for wildlife purposes. There is yet to be an exclusive list of which plants are best for encouraging wildlife (Loh, 2008). The eight observed green walls saw a range of 1 species (e.g., the ivy clade wall) to 10 species (e.g., an overgrown of plants on an entire building) (Table 14). However, the number of species of plant was not important, even though it was a positive trend, saw no relationships between the green walls' bird activity and behaviours (Table 15). This corresponds with the findings of Bolhuis Casas (2016) who also reported that the number of plants was not important, emphasising that it is an overstated claim regarding living walls and biodiversity, and that the presence of appropriate plants is more important. Chiquet, Dover, & Mitchell (2012) saw that vegetation can affect birds. They compared ivy clade green facades, that were either evergreen or deciduous species, and concluded that evergreen plants were more attractive for shelter and refuge. They also found more bird activity on green walls in winter, and it appeared that evergreen green walls were more valuable in that season as they provide fruit. There is a consensus among studies of green walls where vegetation can influence bird activity as specific plants supports different species groups (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019).

In this study an ecological value, based on the area of the green wall and number of plant species used was calculated for each green wall. The ecological values ranged from 31 to 3000 (Table 14). There was a weak but positive relationship between the bird activity and behaviours (Table 15). There was, though, a stronger positive relationship with bird durations (Table 15), suggesting that ecological value can influence the time spend on the green wall and still can play a part of importance for birds to express behaviours (Bolhuis Casas, 2016).

5.3. Green Infrastructure Comparison

Throughout this study, street trees were more used by urban birds than green walls: more species, more behaviours and birds were found to be active for longer durations (Figure 18), though there was no significant difference between the time spent between the two green infrastructures (Table 9). There were also strong positive relationships for both green infrastructures with respect to bird behaviours and duration, as well as behaviour and durations for species richness and abundance of the green infrastructures, meaning the variables were correlated (Table 11). The relationships with bird behaviours was stronger for green walls, while bird duration was stronger for street trees (Table 11). Street trees, though, may be a more suitable convention for birds than green walls: they have a better potential for birds, as they offer more variety of resources (i.e., food) as well as being a habitat for both feeding and nesting (Fernández-Juricic, 2000). This allowed a larger bird richness and abundance (Table 7) with a larger ability to support greater bird diversity and the attributes to allow birds to express more behaviours (Table 8) (Pena, et al., 2017; Wood & Esaian, 2020). As a conservation point of view, street trees are well known to support more urban birds and guilds, important for reducing the negative effects of urbanisation – particularly biotic homogenisation (Pena, et al., 2017).

Street trees are seen as an alternative suitable habitat for the urban environment (Fernández-Juricic, 2000). However, when comparing street trees to other larger green infrastructures (e.g., urban parks) they were seen as an intermediate habitat (Fernández-Juricic, 2000; Barth, FitzGibbon, & Wilson, 2015). Fernández-Juricic (2000) described that bird species increased from least suitable (e.g., control streets) to the most suitable (e.g., urban parks). Barth, FitzGibbon, & Wilson (2015) found the species composition of a vegetated street (i.e., full of street trees) was similar to that of parks and significantly different from non-vegetated streets. Though, Fernández-Juricic (2000) only found around half of the reported species richness in parks in the vegetated streets studied. They stress the lack of species due to habitat requirements, for example, that breeding substrates were not provided or that larger areas for foraging or breeding were needed. This included species such as robin and long-tailed tit that were not recorded. In this study, both these species were observed on street trees (Table 7) suggesting that such species will still use street trees (e.g., for feeding and shelter) regardless of possible habitat constraints.

Street trees still have their limitations, but they are associated with an increase in bird diversity (Pena, et al., 2017), but higher densities of birds are also associated with increased street tree density and size (Wood & Esaian, 2020). Tree coverage is important and was found to be positively correlated with higher numbers of bird species (Barth, FitzGibbon, & Wilson, 2015), but street trees can be spread out and more isolated from other vegetation (Long & Frank, 2020). This limits specific birds, for example, specialists and insectivores (Long & Frank, 2020). These species require greater heterogeneity across larger spatial extents to meet foraging and nesting needs (Long & Frank, 2020). The general sparseness and separation of street trees can mean that they offer fewer resources needed by birds and are less attractive (Long & Frank, 2020). More tree density, as well as an increase in tree diversity, can contribute to a greater resource availability due to increased diversity of food and microhabitats, key to supporting a larger bird activity (Barth, FitzGibbon, & Wilson, 2015). The inclusion of an understorey to the trees is also important for smaller bodied and preferable ground species (e.g., wren and dunnock) (Barth, FitzGibbon, & Wilson, 2015). Vegetation cover can be key (Wood & Esaian, 2020; Leveau & Leveau, 2020), the reason that Fernández-Juricic (2000) and Barth, FitzGibbon, & Wilson (2015) found that larger green infrastructures were better for birds as they offer more vegetation options.

Though not as complex as urban parks and gardens, both scattered and aggregated street trees contribute to supporting urban birds (Villaseñor, Escobar, & Hernández, 2021). Barth, FitzGibbon, & Wilson (2015) expressed that they sampled a low number of trees, but still observed a positive pattern of more species. This is similar to this study, where a relatively small sample of street trees were surveyed, and still found a positive trend in both bird richness and abundance. Street trees are a positive element in the urban setting, as valuable green infrastructure for the environment and people, along with being a suitable resource for urban birds. Especially compared to non-vegetated streets (Barth, FitzGibbon, & Wilson, 2015). The same goes for green walls are better for birds when compared to non-vegetated walls (Chiquet, Dover, & Mitchell, 2012; Belcher, et al., 2019). It could be implied that both green infrastructures are equal in means of a solution to improve the urban environment, replacing concrete impervious surfaces to incorporating more vegetation, improving the area and urban bird activity.

It can be highlighted that green walls do have potential benefits for birds: a finding supported by this and other studies, with several examples of species using them for nesting but mainly for feeding and resting. However, it still seems there are more limitations for green walls, particularly for habitat potential, with the lack of roosting, breeding and nesting behaviours. Belcher, et al. (2019) stress the fact that green walls may not be able to replace the natural habitat for some bird species. The low bird richness and abundance at green walls suggests that there are a limited number of species that can exploit them. It is suggested green walls are better as food resources, through the wide acknowledgement of bird foraging behaviours and the various feeding guilds, from a presumable good source of vegetation. It can, therefore, be suggested that future green wall planting should focus on providing food for bird food specialists over habitats specialists.

Nonetheless, there was low bird activity on the green walls observed in Manchester and Salford cities. The absence of bird behaviours, along with the low bird species richness and abundance, can appear contradictory as a total of 18 species were observed at the green wall sites (Table 2). Realistically meaning 14 bird species choose not to or are incapable of using the green walls, whereas 11 species were found using the comparable street tree counterparts. The bird species that were not present on street trees included species that generally prefer other available features. This included herring gull and black-headed gulls normally found in flight or on buildings instead, dunnock and wren preferring ground understory, and grey wagtail and mallard active near water sources. Examples of species that would have used trees, such as carrion crow and great tit, were observed using other street trees on site, that were not selected to be observed as part of the study comparing green walls and street trees. There was not an expectation for all bird species to use green walls, but it leaves questions as to why only a limited number of species were exploiting the green walls when there was a substantial amount of bird activity around them.

5.4. Green Infrastructure Overview

Green walls and street trees, along with other greening interventions (e.g., green roofs and rain gardens), are important techniques for improving urban biodiversity within the concept of reconciliation ecology (Francis & Lorimer, 2011). However, there are still ecological and societal limitations to their use (Francis &

Lorimer, 2011). The main problem is that they are generally not designed for wildlife. Local climate control is becoming an essential application for green infrastructures as nature-based solutions to improve local air quality and reduce temperature (Manso & Castro-Gomes, 2015; Urban Green-Blue Grids, 2019). For example, for green walls, addressing issues of climatic impacts, air pollution is one factor directing the design (Treebox, 2014; Ansglobal, 2019a; Inleaf, 2019). Another design criterion is aesthetics (EFB, 2019a). Green walls have a visual appeal making them 'beautiful focal points' (HYVERT, 2020). A biophilic design can be beneficial for the wellbeing of urban residents and visitors outweighing the usually 'grey' built environment (Biotecture, 2018; Morelli, et al., 2018; Manchester City Council, 2019a). However, both design intentions have led to green infrastructure, such as green walls, not designed with wildlife in mind: filled with plants that are not suitable for wildlife.

Plant selection is central when it comes to green infrastructure design and realistic expectations should be taken into account related to plant growth, diversity and aesthetic (Sheweka & Magdy, 2011; Barth, FitzGibbon, & Wilson, 2015). Being suitable for wildlife means taking into consideration their natural supporting mechanism and adaptability to harsh environments (Sheweka & Magdy, 2012). It is thought that plant species diversity is significant, especially for invertebrates, as well as native plants, which is essential for native wildlife (Madre, et al., 2013; Partridge & Clark, 2018). However, this study, together with Bolhuis Casas (2016), found plant diversity on a green wall was not as influential for bird activity, whereas the presence of appropriate plant species was. Overall, the biodiversity value of a green wall depends on the age, type and composition of vegetation used (Bolhuis Casas, 2016; EFB, 2019a; Grant & Gedge, 2019; Urban Green-Blue Grids, 2019). A varied heterogeneous design and a landscape-scale approach can both help to maximise the biodiversity potential of green infrastructures, improving their urban ecological success (Francis & Lorimer, 2011).

Biodiversity value of green walls has been found to be dependent on the green walls' size and surroundings (Elgizawy, 2016). Species richness has been found to be influenced by patch size (James, Norman, & Clarke, 2010; Strohbach, Lerman, & Warren, 2013; Grafius, et al., 2017), and for green walls this means height and area (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). It was found that height and area was important as the taller and larger the green wall saw more bird activity (Edwards, 1994; Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Surya, 2016; Belcher, et al., 2019). While there were strong positive relationships between bird activity and the size of the green wall, there was none for the distance of the green wall to other green spaces. Isolation, limiting their connectivity, can affect the 'stepping stone' functionality of nature-based solutions and affect the level of biodiversity (Madre, et al., 2014; Elgizawy, 2016; Grafius, et al., 2017). However, Madre, et al. (2014) also explains that the surrounding environment and other local variables can exhibit minor influences on species richness and abundance. Nature-based solutions, such as green walls and roofs, can provide for wild biodiversity, including many arthropods and bird species (Madre, et al., 2013; EFB, 2019a), despite their isolation in an urban landscape in three dimensions (Madre, et al., 2014).

It is becoming imperative that evaluations and assessments are needed to improve the biodiversity contribution of green infrastructures. At the moment, the impacts of the various green infrastructures on local bird communities are not well understood (Partridge & Clark, 2018). From the limited available studies, including this one, it is possible to conclude that, for green walls, height, area and plant suitability is influential on bird usage (Chiquet, Dover, & Mitchell, 2012; Bolhuis Casas, 2016; Belcher, et al., 2019). All viable recommendations for improvement. This study also found that the surrounding noise levels can be a negative influence, acting as a limitation to biodiversity usage of green walls. Noise can be negative on urban bird activity, increasing vigilance and avoidance (Fernández-Juricic, 2000; Pena, et al., 2017; Leveau & Leveau, 2020), a factor that is deemed difficult to counteract, consequentially from the lack of research.

There was a greater bird species richness, abundance and behaviour association with street trees than with green walls, suggesting that this green infrastructure is better to serve birds in the intensity of the urban environment. Especially as street trees have been seen to help reduce the negative effects of noise, and seeing more birds using the street trees regardless of noise of area (Pena, et al., 2017). For birds, street trees are higher and safer, have more resources and affordances, and are exploited by a range of bird species. Whereas, green walls are small and apprehensive, man-made and with less affordances, and becoming evident that limited species can exploited them. As trees are a more natural feature, they are more accepted by birds (Davis, Major, & Taylor, 2016; Pena, et al., 2017; Wood & Esaian, 2020) and perceptibly the best choice compared to green walls in the demanding environment. Street trees are more common and recognised in the urban environment, and are a well-known solution to the urban climate issues as well (Dover, 2015). For example, their cooling effect averting urban heat stress, while also simultaneously offering amenity and aesthetic value (Dover, 2015; Salmond, 2016; Rivkin, et al., 2019).

Despite these biological evaluations and findings, it is evident that delivering social, economic and environmental benefits to the public is becoming a priority for green infrastructures (Jackson, 2019). For instance, there are still contested issues with tree-based green infrastructures and their health and safety implications (Braverman, 2008; Dover, 2015; Bartlett & Jain, 2019). Putting public benefits first often leads to compromising green infrastructure planning, and leaving biodiversity conservation left to be retrofit (Jackson, 2019). Green infrastructure initiatives, for both street trees and green walls, should not direct efforts away from biodiversity priorities which tend to be diluted, prioritising humans rather than biodiversity interests (Jackson, 2019). Their climate change mitigation properties have become a major led drive for research, and a powerful driver to support the promotion to policy and decision-makers (Bartlett & Jain, 2019). For example, large-scale research projects such as IGNITION, which are invested in green infrastructures as climate change adaptation features (Greater Manchester Combined Authority, 2019; Urban Innovative Actions, 2019). It is a case of learning to accept the multi-functional use of green infrastructures that can benefit both people and wildlife.

5.5. Recommendations

In the future, surveying bird activity in the cities could be extended further into the year to study mating, nesting and fledgling behaviours on green walls and street trees to establish further evaluation on the two green infrastructures.

This study also enthuses further studies carried out in the cities of Manchester and Salford, UK. These two cities are great examples of how UK cities are developing and exercising green infrastructures, with continuous growth in street trees, green walls and green roofs, and as the forefront of innovative European research. Such locations have great potential to expand biodiversity and urban conservation inquiries for the UK. Yet, these are two of many Greater Manchester districts, which should also be investigated, occupied with substantial urban areas and the drive to advance the biodiversity policies.

More green infrastructure studies should be carried out in more UK cities. Urban greening policies are growing in the UK, not just Greater Manchester, from London, Birmingham, Sheffield, Leeds, Liverpool, Belfast and Cardiff. All that will have their urban bird communities too. Further studies on each cities' green infrastructures and urban biodiversity will help further develop urban bird usage and understanding. Especially for green walls, which are becoming more available in various cities. This study used one UK-based green wall study, which was significant. More UK-based green wall studies would be beneficial to create a larger database of the different UK green walls and to fully evaluate their pros and cons towards bird biodiversity. More studies specifically on living walls too, as Chiquet, Dover, & Mitchell (2012) only used green facades. Living walls are becoming the go-to green wall for cities, irrespective that they seem to face the most limitation due to scale, plants and maintenance.

As a whole, further evidence-based research is necessary to make urban greening more compelling, which is required for policy and decision-makers to implement policies, plans and projects (EFB, 2019a). It is particularly necessary, as there are issues around their capital maintenance costs and economic value as they still are deemed to have no direct revenue (Bartlett & Jain, 2019; EFB, 2019a; Grant & Gedge, 2019). This is becoming exceptionally common for green walls, as they are known to face costs for construction, installation and maintenance (Loh, 2008; EFB, 2019a; Grant & Gedge, 2019; Urban Green-Blue Grids, 2019). The overall costs of green infrastructures can discourage their uses, particularly for habitat improvement and biodiversity conservation strategies (Francis & Lorimer, 2011; Bolhuis Casas, 2016). Environmental benefits from urban greening can produce a convincing economic argument, especially through storm water management and pollution reduction (Loh, 2008; Francis & Lorimer, 2011; Sheweka & Magdy, 2011; EFB, 2019a; Grant & Gedge, 2019). Though there is a need for them to be seen less from the perspective of energy conservation, as well as ornamental gardening, and more from a regional perspective on the landscape and ecological planning (Brenneisen, 2006).

It is imperative to ensure their wide range of benefits are not detrimental to biodiversity priorities (Jackson, 2019). Their multifunctionality presents an opportunity to increase funding and investment in natural spaces and biodiversity conservation (Jackson, 2019). Biological diversity and richness are essential to the ecosystem process including productivity, carbon storage, water and nutrient cycling, and decomposition (Jackson, 2019). One of the many needs of urban residents (Dearborn & Kark, 2010; Madre, et al., 2013), it favours the wellbeing of citizens justifying their additional cost (Madre, et al., 2013; Madre, et al., 2014). Biodiversity conservation arguably represents a more fundamental public benefits planning priority, from the quality of life benefits derived from natural capital and healthy ecosystem services (e.g., Biodiversity Net Gain) (Jackson, 2019; Wainhouse, Wansbury, & Hicks, 2019).

Though, as green infrastructures are constantly evolving, ongoing research is required for collecting technical data to fully understand their biodiversity potential (Brenneisen, 2006; Loh, 2008). Green infrastructures can be a tool for preserving and restoring biodiversity in urban areas, but more research is needed to improve their design for urban wildlife (Brenneisen, 2006). Especially as there is still an issue of whether that they can function as ecosystems and how the urban landscape can foster them (Madre, et al., 2013). The increase of green technologies has also led to the need for research on a wide range of topics. It is becoming more imperative than ever, though, to be more biodiversity and conservation focused (Brenneisen, 2004). Particularly as studies are becoming subjective and many biodiversity topics have not been investigated in depth (Köhler, 2008; Weinmaster, 2009; Francis & Lorimer, 2011).

For green walls, as green infrastructures, they have the potential to promote and support a positive outcome for biodiversity conservation. Over a decade of research they have been shown to be a successful part of the urban conservation strategy (rancis & Lorimer, 2011; Jackson, 2019). Green walls are often overlooked and in need of further evaluation and assessment to be appropriately refined, particularly as a technique for reconciliation ecology (Francis & Lorimer, 2011). Exploring both benefits and disadvantages of green walls through assessments can provide an evidence base support, necessary for them to be used with increased confidence by designers and developers (Loh, 2008; Bartlett & Jain, 2019; Jackson, 2019).

6. REFERENCES

Ansglobal. (2019a). Living Walls Benefits. Retrieved 5 February, 2019, from https://www.ansgroupglobal.com/living-wall/benefits

Ansglobal. (2019b). The Principles and Benefits of Biophilic Design. Retrieved 8 February, 2019, from https://www.ansgroupglobal.com/news/principles-and-benefits-biophilic-design

Ansglobal. (2020). Case Studies. Retrieved 5 February, 2020, from https://www.ansgroupglobal.com/learn/case-studies

Ardley, N. (1980). *Illustrated guide to birds and birdwatching.* London: Kingfisher

Armson, D., Stringer, P., & Ennos, A. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. *Urban Forestry & Urban Greening*, *12*(3), pp. 282–286. doi: 10.1016/j.ufug.2013.04.001

Barth, B. J, FitzGibbon, S. I., & Wilson, R. S. (2015). New urban developments that retain more remnant trees have greater bird diversity. *Landscape and Urban Planning*, *136*, pp. 122–129. doi: 10.1016/j.landurbplan.2014.11.003

Bartlett, D., & Jain, S. (2019). The 'Cool Towns' Project: Using Green/Blue Infrastructure to Reduce Heat Stress in Public Open Spaces. *inpractice*, (105), pp. 12-15

Basile, M., Russo, L. F., Russo, V. G., Senese, A., & Bernardo, N. (2021). Birds seen and not seen during the COVID-19 pandemic: The impact of lockdown measures on citizen science bird observations. *Biological Conservation*, *256*, 109079–. doi: doi.org/10.1016/j.biocon.2021.109079

Belcher, R. N., Sadanandan, K. R., Goh, E. R., Chan, J. Y., Menz, S., & Schroepfer, T. (2019). Vegetation on and around large-scale buildings positively influences native tropical bird abundance and bird species richness. *Urban Ecosystems*, *22*(2), pp. 213–225. doi: 10.1007/s11252-018-0808-0

Biotecture. (2018). What motivates us? Retrieved 5 February, 2019, from https://www.biotecture.uk.com/about-us/what-motivates-us/

Bolhuis Casas, E. (2016). Bird use of living walls in the city of Bogotá, Colombia (Bachelor thesis, The University of Applied and Environmental Sciences, Bogotá, Colombia). Retrieved from https://repository.udca.edu.co/handle/11158/494

Braverman, I. (2008). “Everybody loves trees”: policing American cities through street trees. *Duke Environmental Law & Policy Forum*, *19*(1), pp. 81-118. Retrieved from heinonline.org

BREEAM. (2011). Migitating Ecological Impact. Retrieved 5 May, 2021, from https://www.breeam.com/BREEAM2011SchemeDocument/Content/11_landuse/le03_general.htm

Brenneisen, S. (2004). Green Roofs – How Nature Returns to the City. *Acta Horticulturae*, *643*(37), pp. 289-293. doi: 10.17660/actahortic.2004.643.37

Brenneisen, S. (2006). Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland. *Urban Habitats*, *4*(1), pp. 27-36. Retrieved from www.urbanhabitats.org

British Ornithologists' Union. (2017). The British List: A Checklist of Birds of Britain (9th edition). *Ibis*, *160*, pp. 190-240. Retrieved from https://bou.org.uk/british-list/

BTO. (2020a). Lesser Redpoll: our 'new' garden finch. Retrieved 1 October, 2020, from https://www.bto.org/our-science/projects/gbw/about/news/latest/2013/redpoll-rise

BTO. (2020b). Mistle Thrush. Retrieved 15 November, 2020, from https://www.bto.org/our-science/projects/gbw/gardens-wildlife/garden-birds/a-z-garden-birds/mistle-thrush

BTO. (2021a). Breeding and Survival. Retrieved 23 July, 2021, from https://www.bto.org/understanding-birds/birdfacts/about-birdfacts/demography

BTO. (2021b). How to monitor nests. Retrieved 23 July, 2021, from https://www.bto.org/our-science/projects/nesting-neighbours/how-monitor-nests

Carbó-Ramírez, P., & Zuria, I. (2011). The value of small urban greenspaces for birds in a Mexican city. *Landscape and Urban Planning*, *100*(3), pp. 213–222. doi: 10.1016/j.landurbplan.2010.12.008

Catchpole, D. E., & Slater, P. (2008). *Bird Song: Biological Themes and Variations.* Cambridge: Cambridge University Press

Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: A review. *Landscape and Urban Planning*, *74*(1), pp. 46–69. doi: 10.1016/ j.landurbplan.2004.08.007

Chiquet, C., Dover, J. W., & Mitchell, P. (2012). Birds and the urban environment: the value of green walls. *Urban Ecosystem*, *16*(3), pp. 453-462. doi: 10.1007/s11252-012-0277-9

Clergeau, P., Croci, S., Jokimäki, J., Kaisanlahti-Jokimäki, M. L., & Dinetti, M. (2006). Avifauna homogenisation by urbanisation: Analysis at different European latitudes. *Biological Conservation*, *127*(3), pp. 336–344. doi: 10.1016/j.biocon.2005.06.035

Clergeau, P., Jokimäki, J., & Savard, J. L. (2001). Are Urban Bird Communities Influenced by the Bird Diversity of Adjacent Landscapes? *The Journal of Applied Ecology*, *38*(5), pp. 1122–1134. doi: 10.1046/j.1365-2664.2001.00666.x

Collins, R., Schaafsma, M., & Hudson, M. D. (2017). The value of green walls to urban biodiversity. *Land Use Policy*, *64*, pp. 114–123. doi: 10.1016/j.landusepol.2017.02.025

Coma, J., Pérez, G., de Gracia, A., Burés., Urrestarazu, M., & Cabeza, L. F. (2017). Vertical greenery systems for energy savings in building: A comparative study between green walls and green facades. *Building and Environment*, *111*, pp. 228-237. doi: 10.1016/j.buildenv.2016.11.014

Cornelis, J., & Hermy, M. (2004). Biodiversity relationships in urban and suburban parks in Flanders. *Landscape and Urban Planning*, *69*(4), pp. 385–401. doi: 10.1016/j.landurbplan.2003.10.038

Cox, D. T. C., & Gaston, K. J. (2015). Likeability of Garden Birds: Importance of Species Knowledge & Richness in Connecting People to Nature. *PLoS ONE*, *10*(11), pp. 1-14. doi: 10.1371/journal.pone.0141505

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of Nearby Nature Simultaneously Associated with Multiple Health Benefits. *International Journal of Environmental Research and Public Health*, *14*(2), pp. 172-. doi: 10.3390/ijerph14020172

Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-Being and Species Richness. *BioScience*, *62*(1), pp. 47–55. doi: 10.1525/bio.2012.62.1.9

Davis, A., Major, R. E., & Taylor, C. E. (2016). Do trees flower longer in the city? A comparison of flowering eucalyptus trees in streets, remnants and continuous forest and their association with nectarivorous birds. *Urban Ecosystems*, *19*(2), pp. 735–747. doi: 10.1007/s11252-015-0515-z

Dearborn, D.C., & Kark, S. (2010). Motivations for conserving urban biodiversity. *Conservation Biology*, *24*(2), pp. 432–440. doi: 10.1111/j.1523-1739.2009.01328.x

DEFRA. (2018). Wild bird populations in the UK, 1970 to 2017. Retrieved 30 March, 2019, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/754432/UK_Wild_birds_1970-2017_FINAL__002_.pdf

Donnelly, R., & Marzluff, J. M. (2004). Importance of reserve size and landscape context to urban bird conservation. *Conservation Biology*, *18*(3), pp. 733–745. doi: 10.1111/j.1523-1739.2004.00032.x

Dover, J. W. (2015). *Green infrastructure: Incorporating plants and enhancing biodiversity in buildings and urban environments*. London: Routledge

Dunnett, N., Nagase, A., & Hallam, A. (2008). The dynamics of planted and colonising species on a green roof over six growing seasons 2001–2006: influence of substrate depth. *Urban Ecosystems*, *11*(4), pp. 373–384. doi: 10.1007/s11252-007-0042-7

Edwards, B. (1994). Biodiversity and Building Design (Encouraging wildlife to live in buildings). *Architect Journal, 199*(23), p. 36

EFB (2019a). Living Roofs and Walls from policy to practice: 10 years of urban greening in London and beyond. Retrieved 27 October, 2019, from https://livingroofs.org/wp-content/uploads/2019/04/LONDON-LIVING-ROOFS-WALLS-REPORT-2019.pdf

EFB. (2019b). Green Walls Basics. Retrieved 8 February, 2019, from https://efb-greenroof.eu/green-wall-basics/

Elgizawy, E. M. (2016). The Effect of Green Facades in Landscape Ecology. *Procedia Environmental Sciences*, *34*, pp. 119-130. doi: 10.1016/j.proenv.2016.04.012

European Commission. (2019). European Green Infrastructure and Ecosystem Services Strategy. Retrieved 8 February, 2019, from https://ec.europa.eu/environment/nature/index_en.htm

European Environment Agency. (2019). What is green infrastructure? Retrieved 28 January, 2020, from https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/what-is-green-infrastructure

Evans, K. L., Chamberlain, D. E., Hatchwell, B. J., Gregory, R. D., & Gaston, K. J. (2011). What makes an urban bird? *Global Change Biology*, *17*(1), pp. 32–44. doi: 10.1111/j.1365-2486.2010.02247.x

Fernandez-Canero, R., & Gonzalez-Redondo, P. (2010). Green roofs as a habitat for birds: a review. *Journal of Animal and Veterinary Advances*, *9*(15), pp. 2041-2052. doi: 10.3923/javaa.2010.2041.2052

Fernández-Juricic, E. (2000). Avifuanal Use of Wooded Streets in a Urban Landscape. *Conservation Biology*, *14*(2), pp. 513-521. doi: 10.1046/j.1523-1739.2000.98600.x

Fernández-Juricic, E., & Jokimäki, J. (2001). A habitat island approach to conserving birds in urban landscapes: Case studies from southern and northern Europe. *Biodiversity and Conservation*, *10*(12), pp. 2023–2043. doi: 10.1111/j.1523-1739.2004.00032.x

Francis, R. A. (2009). Perspectives on the potential for reconciliation ecology in urban riverscapes. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *4*(73), pp. 1-20. doi: 10.1079/PAVSNNR20094073

Francis, R. A. (2011). Wall ecology: A frontier for urban biodiversity and ecological engineering. *Progress in Physical Geography*, *35*(1), pp. 43–63. doi: 10.1177/0309133310385166

Francis, R. A., & Lorimer, J. (2011). Urban reconciliation ecology: The potential of living roofs and walls. *Journal of Environmental Management*, *92*(6), pp. 1429-1437. doi: 10.1016/j.jenvman.2011.01.012

Frietjes. (2019). Greater Mancheter with former districts [image]. Retrieved 10 January, 2019, from https://commons.wikimedia.org/wiki/File:Greater_Manchester_with_former_di distric.png

Goddard, M. A., Dougill, A. J., & Benton, T. J. (2012). Why garden for wildlife? Social and ecological drivers, motivations and barriers for biodiversity management in residential landscapes. *Ecological Economics*, *86*, pp. 258-273. doi: 10.1016/j.ecolecon.2012.07.016

Grafius, D. R., Corstanje, R., Siriwardena, G. M., Plummer, K. E., & Harris, J. A. (2017). A bird's eye view: using circuit theory to study urban landscape connectivity for birds. *Landscape Ecology*, *32*(9), pp. 1771-1787. doi: 10.1007/s10980-017-0548-1

Grant, G. (2006). Extensive green roofs in London. *Urban Habitats*, *4*(1), pp.51-65. Retrieved from www.urbanhabitats.org

Grant, G., & Gedge, D. (2019). A Decade of Green Roofs and Green Walls in London. *inpractice*, (105), pp. 8-11

Greater Manchester Biodiversity Project. (2011). The Greater Manchester Biodiversity Project. Retrieved 31 May, 2019, from http://www.gmbp.org.uk/site/index.php?option=com_frontpage&Itemid=1

Greater Manchester Combined Authority. (2019). Ground breaking IGNITION project gets under way in Greater Manchester. Retrieved 31 May, 2019, from https://www.greatermanchester-ca.gov.uk/news/ground-breaking-ignition-project-gets-under-way-in-greater-manchester/

Groffman, P. M., Cavender-Bares, J., Bettez, N. D., Grove, J. M., Hall, S. J., Heffernan, J. B., Hobbie, S. E., Larson, K. L., Morse, J. L., Neill, C., Nelson, K., O'Neil-Dunne, J., Ogden, L., Pataki, D. E., Polsky, C., Chowdhury, R. R., & Steele, M. K. (2014). Ecological homogenization of urban USA. *Frontiers in Ecology and the Environment*, *12*(1), pp. 74–81. doi:10.1890/120374

Growing Green Guide. (2014). A guide green roofs, walls and facades in Melbourne and Victoria, Australia. Retrieved 18 August, 2019, from https://www.melbourne.vic.gov.au/SiteCollectionDocuments/growing-green-guide.pdf

Halfwerk, W., & Slabbekoorn, H. (2009). A behavioural mechanism explaining noise dependent frequency use in urban birdsong. *Animal Behaviour*, *78*(6), pp. 1301-1307. doi: 10.1016/j.anbehav.2009.09.015

Halfwerk, W., Bot, S., Buikx, J., van der Velde, M., Komdeur, J., ten Cate, C., & Slabbekoorn, H. (2011). Low-frequency songs lose their potency in noisy urban conditions. *Proceedings of the National Academy of Sciences, USA*, *108*(35), pp. 14549-14554. doi: 10.1073/pnas.1109091108

Hayman, P., & Burton, P. (1982). *The birdlife of Britain: a dramatic new way of identifying and understanding the birds of Britain and Europe.* London: Emblem in association with The Royal Society for the Protection of Birds

Hollyman, G. (2018). Salford campus to be 'living laboratory' for green infrastructure. Retrieved 5 February, 2019, from https://www.salford.ac.uk/news/articles/2018/salford-campus-to-be-living-laboratory-for-green-infrastucture

HYVERT. (2020). HYVERT Previous Work. Retrieved 5 February, 2020, from https://hyvert.co.uk/applied/

Illman, S. (2019). Integrating Green and Blue. *inpractice*, (105), pp. 6-7

Inleaf. (2019). Green Walls. Retrieved 5 February, 2019, from https://inleaf.co.uk/green-walls/

Inleaf. (2020). Inleaf Installs Manchester University's First Living Wall. Retrieved 5 February, 2020, from https://inleaf.co.uk/manchester-universitys-first-living-wall/

IUCN. (2017). Grow green: new partnership to demonstrate benefits of nature-based solutions in cities. Retrieved 31 May, 2019, from https://www.iucn.org/news/europe/201706/grow-green-new-partnership-demonstrate-benefits-nature-based-solutions-cities

Jackson, M. (2019). Green Infrastructure: A Biodiversity or Pubic Benefit Agenda? *inpractice*, (105), pp. 19-21

James, P., Norman, D., & Clarke, J. (2010). Avian population dynamics and human induced change in an urban environment. *Urban Ecosystems*, *13*(4), pp. 499-515. doi: 10.1007/s11252-010-0132-9

Morton, J. (2011). What to Expect with Green Walls. *Buildings*, *105*(6), p. 24. Retrieved from www-proquest-com.salford.idm.oclc.org/docview/874547237?pq-origsite=primo

Johnston, R. F., & Janiga, M. (1995). *Feral Pigeons* (Vol. 4). Oxford: Oxford University Press

Kadas, G. (2006). Rare invertebrates colonizing green roofs in London. *Urban Habitats*, *4*(1), pp. 66-86. Retrieved from www.urbanhabitats.org

Kane, B., Warren, P. S., & Lerman, S. B. (2015). A broad scale analysis of tree risk, mitigation and potential habitat for cavity-nesting birds. *Urban Forestry & Urban Greening*, *14*(4), pp. 1137–1146. doi: 10.1016/j.ufug.2015.10.012

Kempenaers, B., Borgström, P., Loës, P., Schlicht, E., & Valcu, M. (2010). Artifical night lighting affects dawn song, extra-pair siring success, and lay date in songbirds. *Currently Biology*, *20*(19), pp. 1735-1739. doi: 10.1016/j.cub.2010.08.028

Köhler, M. (2008). Green facades – a view back and some visions. *Urban Ecosystem*, *11*(4), pp. 423-436. doi: 10.1007/s11252-008-0063-x

Kowarik, I. (2011). Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution*, *159*(8), pp. 1974-1983. doi: 10.1016/j.envpol.2011.02.022

Lepczk, C., & Warren, P. (Eds.). (2012). *Urban Bird Ecology and Conservation*. University of California Press. Retrieved September 19, 2019, from http://www.jstor.org/stable/10.1525/j.ctt1ppvkj

Leveau, L. M., & Leveau, C. M. (2020). Street design in suburban areas and its impact on bird communities: Considering different diversity facets over the year. *Urban Forestry & Urban Greening*, *48*, 126578–. doi: 10.1016/j.ufug.2019.126578

Li, L., Tietze, D., Fritz, A., Lü, Z., Bürgi, M., & Storch, I. (2018). Rewilding cultural landscape potentially puts both avian diversity and endemism at risk: A Tibetan Plateau case study. *Biological Conservation*, *224*, pp. 75–86. doi: 10.1016/j.biocon.2018.05.008

Lindo, D. (2018). *How to be an Urban Birder*. New Jersey: Princeton University Press

Liu, K. K. Y. (2002). Energy efficiency and environmental benefits of rooftop gardens. *Construction Canada*, *44*, pp. 20–23. Retrieved from https://nrc.canada.ca/en

Living Roofs. (2019). Green and Living Walls – Planting the walls of buildings with vegetation. Retrieved 31 May, 2019, from https://livingroofs.org/green-walls/

Loh, S. (2008). Living Walls – A Way to Green the Built Environment. *BEDP Environment Design Guide*, *1*(TEC 26), pp. 1-7. Retrieved from http://www.jstor.org/stable/26149051

Long, L. C., & Frank, S. D. (2020). Risk of bird predation and defoliating insect abundance are greater in urban forest fragments than street trees. *Urban Ecosystems*, *23*(3), pp. 519–531. doi: 10.1007/s11252-020-00939-x

Lorimer, J. (2008). Living roofs and brownfield wildlife: towards a fluid biogeography of UK nature conservation. *Environment and Planning A: Economy and Space*, *40*(9), pp. 2042–2060. doi: 10.1068/a39261

Lundholm, J. T., & Marlin, A. (2006). Habitat origins and microhabitat preferences of urban plant species. *Urban Ecosystems*, *9*, pp. 139–159. doi: 10.1007/s11252-006-8587-4

Lutz, A., Simpson-Housley, P., & Deman, A. (1999). Wilderness: Rural and Urban Attitudes and Perceptions. *Environment and Behavior*, *31*(2), pp. 259-266. doi: 10.1177/00139169921972092

Madre, F., Clergeau, P., Machon, N., & Vergnes, A. (2015). Building biodiversity: Vegetated façades as habitats for spider and beetle assemblages. *Global Ecology and Conservation*, *3*(C), pp. 222–233. doi: 10.1016/j.gecco.2014.11.016

Madre, F., Vergnes, A., Machon, N., & Clergeau, P. (2013). A comparison of 3 types of green roof as habitats for arthropods. *Ecological Engineering*, *57*, pp. 109–117. doi: 10.1016/j.ecoleng.2013.04.029

Madre, F., Vergnes, A., Machon, N., & Clergeau, P. (2014). Green roofs as habitats for wild plant species in urban landscapes: First insights from a large-scale sampling. *Landscape and Urban Planning*, *122*, pp. 100–107. doi: 10.1016/j.landurbplan.2013.11.012

Manchester City Council. (2019a). Biodiversity and Wildlife. Retrieved 31 May, 2019, from https://secure.manchester.gov.uk/info/500002/council_policies_and_strategies/1668/biodiversity_and_wildlife

Manchester City Council. (2019b). Green and Blue Infrastructure. Retrieved 31 May, 2019, from https://secure.manchester.gov.uk/info/500002/council_policies_and_strategies/7061/green_and_blue_infrastructure

Manchester Institute for Collaborative Research on Ageing. (2016). Green infrastructure and the health and wellbeing influences on an aging population (GHIA). Retrieved 31 May, 2019, from https://www.micra.manchester.ac.uk/research/projects-and-groups/ghia/

Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, *41*, pp. 863-871. doi: 10.1016/j.rser.2014.07.203

Marzluff, J. M., Bowman, R., & Donnelly, R. (2001). A historical perspective on urban bird research: trends, terms, and approaches. In: Marzluff J.M., Bowman R., Donnelly R. (eds) *Avian Ecology and Conservation in an Urbanizing World*. Boston, MA: Springer

Mayrand, F., & Clergeau, P. (2018). Green Roofs and Green Walls for Biodiversity Conservation: A Contribution to Urban Connectivity? *Sustainability (Basel, Switzerland)*, *10*(4), pp. 985-. doi: 10.3390/su10040985

Miller, M. W. (2006). Apparent effects of light pollution on singing behavior of American robins. *Condor*, *180*(1), pp. 130-139. doi: 10.1650/0010-5422(2006)108[0130:AEOLPO]2.0.CO;2

Mitsch, W. J. (2012). What is ecological engineering? *Ecological Engineering*, *45*, pp. 5–12. doi: doi.org/10.1016/j.ecoleng.2012.04.013

Møller, A. P. (2012). Urban areas as refuges from predators and flight distance of prey. *Behavioral Ecology*, *23*, pp. 1030–1035. doi: 10.1093/beheco/ars067

Morelli, F., Mikula, P., Benedetti, Y., Bussière, R., Jerzak, L., & Tryjanowski, P. (2018). Escape behaviour of birds in urban parks and cemeteries across Europe: Evidence of behavioural adaptation to human activity. *Science of the Total Environment*, *631-632*, pp. 803-810. doi: 10.1016/j.scitotenv.2018.03.118

National Biodiversity Network Trust. (2020). Explore Your Area. Retrieved 15 November, 2020, from https://records.nbnatlas.org/explore/your-area#53.4807593|-2.2426305000000184|12|ALL_SPECIES

Natural History Museum. (2020). Nature: liberated by lockdown? Retrieved 23 July, 2021, from https://www.nhm.ac.uk/discover/nature-liberated-by-lockdown.html

Nature Greater Manchester. (2019). Urban Pioneer. Retrieved 31 May, 2019, from https://naturegreatermanchester.co.uk/project/urban-pioneer/

Office for National Statistics. (2020). Population Estimates. Retrieved 20 June, 2020, from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populatpopulationes

Ong, B. L. (2003). Green plot ratio: an ecological measure for architecture and urban planning. *Landscape and Urban Planning*, *63*(4), pp. 197–211. doi: 10.1016/S0169-2046(02)00191-3

Oppla. (2019). About: Nature-Based Solutions. Retrieved 5 February, 2019, from https://oppla.eu/about

Oscar, G., Lluís, B., Sergi, H., & Gabriel, G. (2021). Rapid behavioural response of urban birds to COVID-19 lockdown. *Proceedings of the Royal Society of B, 288*(1946), pp. 20202513-202025123. doi: 10.1098/rspb.2020.2513

Partridge, D. R., & Clark, J. A. (2018). Urban green roofs provide habitat for migrating and breeding birds and their arthropod prey. *PloS One*, *13*(8), pp. e0202298–e0202298. doi: 10.1371/journal.pone.0202298

Pećarević, M., Danoff-Burg, J., & Dunn, R. R. (2010). Biodiversity on Broadway--enigmatic diversity of the societies of ants (*Formicidae*) on the streets of New York City. *PloS One*, *5*(10), e13222–. doi: 10.1371/journal.pone.0013222

Pena, J. C. de C., Martello, F., Ribeiro, M. C., Armitage, R. A., Young, R. J., & Rodrigues, M. (2017). Street trees reduce the negative effects of urbanization on birds. *PloS One*, *12*(3), pp. e0174484–e0174484. doi: 10.1371/journal.pone.0174484

Price, J. W. (2010). Green Façade Energetics (Master's thesis, University of Maryland, Maryland, USA). Retrieved from https://drum.lib.umd.edu/handle/1903/11291

Radford, K. G., & James, P. (2012). Changes in the value of ecosystem services along a rural–urban gradient: A case study of Greater Manchester, UK. *Landscape and Urban Planning*, *109*(1), pp. 117-127. doi: 10.1016/j.landurbplan.2012.10.007

Reid, J., Jones-Morris, S., & Snell, L. (2019). Parish Green Infrastructure Strategies. *inpractice*, (105), pp. 26-28

Rewilding Britain. (2019). Rewilding. Retrieved 24 January, 2019, from https://www.rewildingbritain.org.uk/rewilding/

Rivkin, L. R., Santangelo, J. S., Alberti, M., Aronson, M. F. J., de Keyzer, C. W., Diamond, S. E., Fortin, M., Frazee, L. J., Gorton, A. J., Hendry, A. P., Liu, Y., Losos, J. B., MacIvor, J. S., Martin, R. A., McDonnell, M. J., Miles, L. S., Munshi-South, J., Ness, R. W., Newman, A. E. M., … Johnson, M. T. J. (2019). A roadmap for urban evolutionary ecology. *Evolutionary Applications*, *12*(3), pp. 384–398. doi: 10.1111/eva.12734

Roehr, D., & Laurenz, J. (2008). Living skins : environmental benefits of green envelopes in the city context. *Transactions on Ecology and the Environment*, *113*, pp. 149–158. doi: 10.2495/ARC080151

Root-Bernstein, M., Gooden, J., & Boyes, A. (2018). Rewilding in practice: Projects and policy. *Geoforum*, *97*, pp. 292-304. doi: 10.1016/j.geoforum.2018.09.017

RSPB. (2015). Birds of Conservation Concern: the population status of birds in the UK, Channel Islands and Isle of Man. Retrieved 24 January, 2019 from https://www.rspb.org.uk/globalassets/downloads/documents/conservation-projects/bocc4-report.pdf

RSPB. (2019a). Where have all the birds gone? Retrieved 24 January, 2019, from https://www.rspb.org.uk/birds-and-wildlife/advice/how-you-can-help-birds/where-have-all-the-birds-gone/

RSPB. (2019b). UK conservation status explained. Retrieved 24 January, 2019, from https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/uk-conservation-status-explained/

RSPB. (2019c). How to take part in the Big Garden Birdwatch. Retrieved 20 June, 2019, from https://www.rspb.org.uk/get-involved/activities/birdwatch/everything-you-need-to-know-about-big-garden-birdwatch/

RSPB. (2020a). Grey Wagtail. Retrieved 15 November, 2020, from https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/grey-wagtail/

RSPB. (2020b). Jay. Retrieved 15 November, 2020, from https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/jay/

Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., Dirks, K. N., Heaviside, C., Lim, S., Macintyre, H., McInnes, R. N., & Wheeler, B. W. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, *15*(Suppl 1), pp. 95–171. doi: 10.1186/s12940-016-0103-6

Sheweka, S., & Magdy, N. (2011). The Living walls as an Approach for a Healthy Urban Environment. *Energy Procedia*, *6*, pp. 592-599. doi: 10.1016/j.egypro.2011.05.068

Sheweka, S., & Magdy, N. (2012). Green Facades as a New Sustainable Approach Towards Climate Change. *Energy Procedia*, *18*, pp. 507-520. doi: 10.1016/j.egypro.2012.05.062

Slabbekoorn, H. (2013). Songs of the city: noise-dependent spectral plasticity in the acoustic phenotype of urban birds. *Animal Behaviour*, *85*(5), pp. 1089-1099. doi: 10.1016/j.anbehav.2013.01.021

Slabbekoorn, H., & den Boer-Visser, A. (2006). Cities change the songs of birds. *Current Biology*, *16*(23), pp. 2326-2331. doi: 10.1016/j.cub.2006.10.008

Sol, D., Lapiedra, O., & González-Lagos, C. (2013). Behavioural adjustments for a life in the city. *Animal Behaviour*, *85*(5), pp. 1101–1112. doi: 10.1016/j.anbehav.2013.01.023

Sternberg, T., Viles, H., & Cathersides, A. (2011). Evaluating the role of ivy (*Hedera helix*) in moderating wall surface microclimates and contributing to the bioprotection of historic buildings. *Building and Environment*, *46*(2), pp, 293-297. doi: 10.1016/j.buildenv.2010.07.017

Strohbach, M. W., Haase, D., & Kabisch, N. (2009). Birds and the City: Urban Biodiversity, Land Use, and Socioeconomics. *Ecology and Society*, *14*(2), pp. 31–. doi: 10.5751/ES-03141-140231

Strohbach, M. W., Lerman, S. B., & Warren, P. S. (2013). Are small greening areas enhancing bird diversity? Insights from community-driven greening projects in Boston. *Landscape and Urban Planning*, *114*, pp. 69–79. doi: 10.1016/j.landurbplan.2013.02.007

Surya, S. (2016). Biodiversity and Bird Friendly Design in Urban Areas for Sustainable Living. *Indian Journal of Science and Technology*, *9*(5), pp. 1-7. doi: 10.17485/ijst/2016/v9i5/87224

Treebox. (2014). Environmental Benefits. Retrieved 5 February, 2019, from http://www.treebox.co.uk/environmental-benefits.html

Urban Green-Blue Grids. (2019). Green Facades. Retrieved 18 August, 2019, from https://www.urbangreenbluegrids.com/measures/green-facades/

Urban Innovative Actions. (2019). IGNITION – Innovative financing and delivery of natural climate solutions in Greater Manchester. Retrieved 31 May, 2019, from https://www.uia-initiative.eu/en/uia-cities/greater-manchester

Urban Pioneer. (2018). Strategic Plan – Greater Manchester. Retrieved 31 May, 2019, from https://www.greatermanchester-ca.gov.uk/media/1291/urban-pioneer-strategic-plan-jan-2018.pdf

Viles, H. A., & Wood, C. (2007). Green walls?: integrated laboratory and field testing of the effectiveness of soft wall capping in conserving ruins. *Geological Society*, *271*, pp. 309-322. doi: 10.1144/GSL.SP.2007.271.01.29

Villaseñor, N. R., Escobar, M. A., & Hernández, H. J. (2021). Can aggregated patterns of urban woody vegetation cover promote greater species diversity, richness and abundance of native birds? *Urban Forestry & Urban Greening*, *61*, pp. 127102-. doi: 10.1016/j.ufug.2021.127102

Wainhouse, M., Wansbury, C., & Hicks, J. (2019). One Policy, Many Metrics: Comparing Different Metrics Because the Maths Matters. *inpractice*, (104), pp. 17-20

Weinmaster, M. (2009). Are green walls as "green" as they look? An introduction to the various technologies and ecological benefits of green walls. *Journal of Green Building*, *4*(4), 3e18. doi: 10.3992/jgb.4.4.3

Wheater, C. P., Bell, J. R., & Cook, P. A. (2011). *Practical Field Ecology: A Project Guide*. West Sussex: Wiley-Blackwell

Wheelwright, J., & Walker, L. (2019). Leaves on the Line Please: Using Green Infrastructure to Unlock the Potential of Linear Assets. *inpractice*, (105), pp. 23-25

Wonderwall. (2019). About Wonderwall. Retrieved 5 February, 2019, from http://www.wonderwall.direct/about-us/

Wood, E. M., & Esaian, S. (2020). The importance of street trees to urban avifauna. *Ecological Applications*, *30*(7), pp. e02149-. doi: 10.1002/eap.2149