Initially for Matthew,

now to share with Éowyn and Rowan

Abstract

Rural hedges are ubiquitous features in the British landscape and are recognised for their biological, cultural and aesthetic importance. Hedges are also present in urban settings; as relicts of previously farmed landscapes and as planted boundaries. Relatively little is known about their composition, spatial distribution nor their biodiversity value to our cities. This thesis responds to this knowledge gap by evaluating the ecological value of urban hedges in the UK with a focus on their use by birds, small mammals and insects. The research involved habitat surveys undertaken in the city of Stoke-on-Trent (2015 – 2017) to collect data including: hedge species and physical structure, surrounding land-use and floral composition of verges. Associated field surveys of birds, insects and small mammals were also completed. In addition to the ecological assessment, a photographic perception study was conducted to investigate the public perceptions of Stoke-on-Trent's hedges. This sought to identify which type of hedge species, management style and appearance was most valued in the urban context.

Results indicated that birds, insects and small mammals all preferred wide hedges with verges, associated with woody habitats. Significant preference was shown by birds and mammals for hawthorn hedges over beech, privet or non-hedged controls. For the first time, arboreal use of urban hedges by small mammals was also demonstrated. The visual and aesthetic characteristics of hedges favoured by the public were in-line with those that enhanced biodiversity. Hedges provide a range of ecosystem services as well as opportunities for contact with nature and their continued existence in cities should be supported. As such, this thesis concludes with a set of management guidelines for local authority staff to use in order to maximise their benefit to the people who live alongside them and the wildlife that lives within them.

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Table of Contents

Table of Figures

List of Tables

1 Rationale

This introductory chapter will outline the general, underpinning, concepts relevant to the thesis as a whole, whilst subsequent chapters will include literature reviews of specific themes. Introductions to the urban environment, green infrastructure, hedges in both rural and urban areas and how they are important to both wildlife and people are followed by an explanation of the aims and objectives of the project and a description of the flow of the thesis.

1.1 *Urbanising populations*

Human populations are increasing and becoming more urban (Rees, 1997; Marzluff, 2001; Ahern, 2011; Andersson *et al.*, 2014). Since 1950 the human population living in cities has increased dramatically (Yuen and Hien, 2005; Fuller *et al.*, 2007; United Nations, 2014b, 2014a) from 30% (746 million people) of the then world's population to 54% (3.9 billion people) in 2014 and it is predicted that by 2050 66% (6.4 billion people) will be urban (United Nations, 2014b). Based on the 2014 Mid-year estimates official statistics, in England, 83% of people live in urban areas (Anon., no date b), 82% of Americans live in cities, 70% of Europeans, (United Nations, 2014b) and these numbers are rising with the population of Europe is expected to be over 80% urban by 2050 (United Nations, 2014b). Land utilised for transport or settlement covers about 2.3 million ha; almost 10% of the total land surface of Great Britain is urbanised (Haines-Young *et al.*, 2000; Evans, Newson and Gaston, 2009). Urban areas were considered as a replacement to the previously existing natural habitats but this is now changing and urban areas are now becoming considered as ecosystems in their own right, as a result, there is increasing interest in urban ecology (McIntyre *et al.*, 2001; Evans, Newson and Gaston, 2009; Brenner, 2013). The impacts of urbanisation can create distinct changes to: the landscape through the loss and fragmentation of habitats and creation of the built structures (Marzluff, 2001; McIntyre *et al.*, 2001; Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013), species assemblages to a more urban specialised community and recombinant communities, (Evans, Newson and Gaston, 2009; Concepción *et al.*, 2016), and the human populations in terms of human health and wellbeing (Rees, 1997), but, as yet, our understanding of these effects is limited (Chace and Walsh, 2006).

There is no standard definition of urban and definitions vary from country to country. This becomes problematic with global urban population estimates based on incomparable, sometimes conflicting data (Uchida and Nelson, 2010; Deuskar, 2015). Definitions of urban are based on population size, population density, type of economic activity, physical characteristics, level of infrastructure, or a combination of some, or all of these (Deuskar, 2015).

One hundred and one of 232 countries use minimum population as one or the only criteria. Thresholds vary, the most frequently used being 2,000 but almost as frequently 5,000 (Deuskar, 2015). The UK definition of an urban area requires a population of over 10,000 (Anon., no date c; Jones and Leather, 2012). Population density thresholds are much less frequently used and vary from 150 per square km used in Germany to 1,500 used in China and the Seychelles (Deuskar, 2015). The problem with this method alone, is that it does not consider how far this dense population extends (Deuskar, 2015). The Office for National Statistics' urban area definition, as used for the urban areas in 2001 census products, uses a 'bricks and mortar approach' which also includes the area of land required to be covered by 'urban' land uses: where urban areas are 20 hectares or more with 1,500 or more residents (Anon., no date d).

Attempts have been made to create a standard urban definition including: The World Development Report (WDR) 2009 approach and the Organisation for Economic Co-Operation and Development (OECD) methodology (Deuskar, 2015). The WDR approach is an agglomeration index based on: minimum population density, the population of a 'large' city centre (population density), and time to travel to that large city centre by road (Uchida and Nelson, 2010; Deuskar, 2015). The OECD methodology identifies urban cores - connected highly populated areas based on population size and population density and then identifies 'hinterlands' or commuter areas within which 15% of the population commute towards the urban core area (Deuskar, 2015). Both of these methods however, require the use of commuting data that is not readily available in many countries (Deuskar, 2015). There is also research into using satellite imagery as the viability of highly sophisticated, high resolution images is increasing. Similar data including minimum core size, core density, hinterland density, total population, and maximum distance between pixels is used, with pixels used as the units of analysis (Deuskar, 2015).

Producing a common description of an urban area can be important for comparisons, however, there is more to cities than just their physical form (Deuskar, 2015). Traditionally, a town or city would be a built-up area with a service core with enough shops and services to make it appear 'urban'. i.e. it would offer educational, administrational, entertainment, social, and commercial services and usually have been well established historically, with a network of roads and infrastructure leading into an out of the area. However, this is no longer the case for many UK towns as they have grown into each other, there has been the development of suburbs and satellite towns and others have lost their commercial centres (Anon., no date c).

Urbanisation has been a driver in improving economies and societies bringing increased movement of goods and people, lower fertility, and longer life expectancy (United Nations, 2014b). Towns and cities are important as drivers of development, for commerce, economic activity, transport, communication, education, the arts and culture, and provision of national and international links (United Nations, 2014b) and urban dwellers usually enjoy a reduction in poverty (Rees, 1997; United Nations, 2014b), higher levels of literacy and education, better health care, greater access to social services and an increase in the opportunities for cultural and political participation (United Nations, 2014b). Planning theory suggests that the benefits of living in cities rises to a point, after which crowding begins to outweigh the benefits (Sarkar and Webster, 2017), and urban populations may also be subject to increased pollution, congestion, and urban decay that negatively impact on human life (Rees, 1997).

1.2 *Impacts of urban life*

In modern cities humans are the main influencer on the physical environment (Galea and Vlahov, 2005), but the urban environment also exerts impacts on the health and wellbeing of its residents. It is difficult for most people to comprehend a city as a functioning ecosystem (Rees, 1997). Not only does increased urbanisation have profound impacts upon land use and sustainability (Ahern, 2011), with its influences stretching out to impact areas often over 200 times its size (Rees, 1997), but the urban environment can even be deemed detrimental to the health of humans (Ahern, 2011; Panagopoulos, Duque and Dan, 2016). Urbanisation delivers a stark change to how the population of the cities of the world are living to that of the more natural or semi-natural environments in which they have lived for the previous several thousand years (Rees, 1997; Galea and Vlahov, 2005) and concern is growing about the impacts on people's wellbeing as they interact less and less with nature (Miller, 2005; Fuller *et al.*, 2007; Dallimer *et al.*, 2012; Cox, Hudson, *et al.*, 2017; Jennings *et al.*, 2017). Health benefits of the countryside include more likely access to fresh air and green and blue spaces. In the city there are many aspects that would promote healthier lifestyles such as access to jobs, walkable distances, and access to activity spaces. There are however, a high proportion of people in sedentary jobs and there are increasing mental health problems, obesity, and cardiovascular disease (Sarkar and Webster, 2017) plus health conditions associated with the impacts of urban life including asthma & respiratory conditions, psychological distress, and child development problems (Andersson *et al.*, 2014).

The impacts of an urban area on health may be categorised into three themes: the physical environment, the social environment, and access to health and social services (Galea and Vlahov, 2005). In the physical environment pollution is an issue which can come in many forms. Air pollution is predominantly from the combustion of fossil fuels (Cohen *et al.*, 2005) and is a particular problem in urban areas as this is where most combustion occurs and the reduced air flows result in higher concentrations. Higher concentrations of fine and ultrafine particles may also be found adjacent to roads from exhaust fumes as well as other particles resulting from tyre and engine wear (Dover, 2015). Air pollution from sources such as exhaust fumes, industrial emissions, waste incineration and power generation (WHO, 2018) results in exposure of people to toxic substances including ozone, nitrogen dioxide, and sulphur dioxide as well as particulate matter (PM), VOCs and CO (Cohen *et al.*, 2005; Curtis *et al.*, 2006; Weerakkody *et al.*, 2017; WHO, 2018). These have been linked to increases in hospital admissions and acute and chronic health effects including lung cancer and cardiopulmonary mortality (Seaton *et al.*, 1995; Brunekreef and Holgate, 2002; Cohen *et al.*, 2005), an increased risk of stroke, heart disease, lung cancer and chronic and acute respiratory diseases (WHO, 2018) and over 800,000 premature deaths annually throughout the world (Cohen *et al.*, 2005; Curtis *et al.*, 2006). $PM_{2.5}$ was associated with 467,000 deaths in Europe in 2013 including 29,000 within the UK (Weerakkody *et al.*, 2017). Over 80% of people living in urban regions, where the levels of air pollution are recorded, were exposed to limits of pollution that exceeded recommendations by the World Health Organisation (WHO). Although most of these areas are in low-income cities there are still 56% of cities (containing over 100,000 inhabitants) in high-income countries which do not meet WHO guidelines (WHO, 2018). This pollution can be a problem for entire regions and is not restricted to areas adjacent to the source due to regional transport of pollutants (Frumkin, 2002). Noise pollution is a major problem in urban areas (Enderle and

Weihjr, 2005), due to population growth and urbanisation with associated increases in noises produced including increases in road, rail and air transportation. The impacts of this increased pollution have economic costs as well as being detrimental to health and wellbeing (Goines and Hagler, 2007). These non-auditory impacts include cardiovascular disease, annoyance, sleep disturbance, and cognitive performance (Basner *et al.*, 2014) and there is much research to suggest the compounding impacts of both noise and air pollution on health (e.g. Stansfeld, 2015). There are also frequent reports of the negative health impacts of artificial light which has been linked to breast cancer and sleep disorders e.g. (Cho *et al.*, 2015).

1.3 *Urban areas and biodiversity*

Urbanisation is also creating urban ecosystems by converting indigenous habitats to land of anthropogenic use such as domestic dwellings, commercial and industrial centres with patches of relict indigenous habitat which become more fragmented and isolated. The ecosystems created are 'spatially heterogeneous and temporally dynamic' (McIntyre *et al.*, 2001).

Urban ecology is often taken to mean the ecology of non-human species within cities (Rees, 1997) and urban areas can be seen to have great potential for biodiversity (Alvey, 2006). At a coarse scale, areas of increased urbanisation tend to also be areas of high biodiversity (Evans and Gaston, 2005; Vergnes, Kerbiriou and Clergeau, 2013) because many other species perceive the same environments as humans to be beneficial as many other species. i.e. highly biodiverse areas tend to be on areas of productive land. However, a high human population density adversely affects the richness and diversity of other species via increased species extinction rates (Evans and Gaston, 2005; Bonier, 2012).

Biotic and abiotic consequences of urbanisation include changes to climate, species interactions, and community composition (Bonier, 2012), the replacement of natural features with artificial structures (Vergnes, Kerbiriou and Clergeau, 2013), and reduced connectivity (increased fragmentation) through the dissection of habitats by roads and rail networks (Dover, 2015). This often results in small patches of ecological habitat interspersed within a hostile matrix (Vergnes, Kerbiriou and Clergeau, 2013; Dover, 2015) and may be considered as a mosaic of hot (built) and cold (vegetated) patches within an urban area (Buyantuyev and Wu, 2010). Patches may be fragments of cultural landscapes which were present prior to urbanisation (Andersson *et al.*, 2014). The main factors reducing urban biodiversity are loss of habitat, reduction in areas for forage, fragmentation of the remaining habitats, (Evans, Newson and Gaston, 2009; Chiquet, Dover and Mitchell, 2012), increased non-native vegetation, unfavourable management practices, decreased vegetation complexity, increased predation (Marzluff, 2001), and human disturbance (Baker *et al.*, 2003; Baker and Harris, 2007; Evans, Newson and Gaston, 2009). Not all species are affected in the same way by urbanisation as there is variation in their ability to tolerate disturbance and habitat fragmentation (Bolger, Scott and Rottenberry, 2001). Urban species assemblages may be a result of recombinant ecosystems which are created by people, not necessarily intentionally, and comprise a mix of both locally occurring and exotic species (Meurk, 2010).

Invertebrates are found in great diversity in urban areas including some rare and important species, but some species are showing a large decrease in numbers due to urban expansion (Whitmore, Crouch and Slotow, 2002; Kadas, 2006; Jones and Leather, 2012; Gosling *et al.*, 2016; Kadas and Gedge, 2016). The same is true of birds (Marzluff, 2001; Evans and Gaston, 2005; Sandström, Angelstam and Mikusiński, 2006; Chiquet, Dover and Mitchell, 2012; Węgrzynowicz, 2013), and small mammals (Dickman and Doncaster, 1987; Baker *et al.*, 2003; Michel, Burel and Butet, 2006; Baker and Harris, 2007; Buesching *et al.*, 2008).

The ability to support species also varies with the quality of the green spaces within the city or urban area (Bolger, Scott and Rottenberry, 2001; Sandström, Angelstam and Mikusiński, 2006). Urban areas are now being recognised as potentially important for conservation (Evans, Newson and Gaston, 2009), particularly if they contain natural structures such as trees, deadwood and holes (Sandström, Angelstam and Mikusiński, 2006). Urban semi-natural habitat patches often offer habitats that are rare in the surrounding area; examples include: ponds, and uncultivated areas. Many of these are high in biodiversity (Andersson *et al.*, 2014), and offer wide ranging ecosystem services (Andersson *et al.*, 2014). Ecological corridors within urban areas may offer some mitigation to the effects of habitat fragmentation by linking between urban habitat patches and to habitats outside the town or city. Bolger *et al*., (2001) suggest that suitability of corridors for wildlife varies with species. Some species are fragmentation-sensitive and have more stringent requirements for their corridors than do more fragmentation-tolerant species. The most important requirement appeared to be the percentage cover of native shrub species and less importance was found with the length or width of the corridor. Even fragmentation-sensitive species have been found to benefit from the inclusion of urban ecological corridors. As the influence on hedge ecology of adjacent urban matrixes may differ from the influences of rural areas, caution should be used when applying knowledge about the functioning and management of corridor habitats of other landscapes and further study in urban areas is required (Vergnes, Kerbiriou and Clergeau, 2013).

It is important to take into consideration the heterogeneity of the urban environment which is not captured by one single variable and many have to be considered. These include vegetation cover of surrounding areas, tree cover and vegetation density (herbaceous, scrub and tree density total vegetation density) amongst others. Almost all of these factors are shown to significantly affect species richness (Beninde, Veith and Hochkirch, 2015).

1.4 *Green Infrastructure*

As there is no nationally accepted definition of Green Infrastructure of the UK (Forest Research, 2010), so a definition for this study will be given following a review of some of the definitions by relevant organisations or important works on Green Infrastructure.

There are definitions of Green Infrastructure which include phrases such as “strategically planned”, “network”, “high quality” areas that are “designed and managed” “capable of providing a range of ecosystem services” (Natural England, 2009). Although I believe that this latter is the goal, in this report I also consider unmanaged or spontaneous elements of nature to be components of green infrastructure. Could an element be considered as a Green Infrastructure asset simply when natural or semi-natural and offering at least one ecosystem service?

“GI is the network of natural and seminatural features, green spaces, rivers and lakes that intersperse and connect villages, towns and cities. Individually, these elements are GI assets, and the roles that these assets play are GI functions. When appropriately planned, designed and managed, the assets and functions have the potential to deliver a wide range of benefits – from providing sustainable transport links to mitigating and adapting the effects of climate change”(Landscape Institute, 2013 pp3).

This definition suggests that natural and semi natural elements can be assets offering small benefits, but when included together and appropriately managed become a network offering many services and greater benefits.

The Town and Country Planning authority's definition incorporates all features of the landscape which are important for wildlife corridors and suggests the requirement for connectivity facilitating movement across a range of scales.

"Green Infrastructure is the sub-regional network of protected sites, nature reserves, greenspaces, and greenway linkages. The linkages include river corridors and flood plains, migration routes and features of the landscape, which are of importance as wildlife corridors. Green infrastructure should provide for multi-functional uses i.e., wildlife, recreational and cultural experience, as well as delivering ecological services, such as flood protection and microclimate control. It should also operate at all spatial scales from urban centres through to open countryside." (TCPA, 2004 p6)

The US EPA defines GI as an approach to managing surface water following rainfall events which offer other benefits or ecosystem services (United States Environmental Protection Agency, 2017).

Although most (if not all) green infrastructure offers something in the way of flood alleviation there are many other services that may take priority especially in areas where flooding is not the major concern.

"…the combined structure, position, connectivity and types of green spaces which together enable delivery of multiple benefits as goods and services. It is important to consider green infrastructure holistically and at landscape as well as individual site scale." (Forest Research, 2010)

This definition suggests that only green spaces are considered to be part of green infrastructure and may therefore exclude street trees, rain gardens, or green walls.

"Rain gardens are vegetated, permeable areas designed to retain rainwater following a rainfall event." (Atkins, 2018 p253).

Green infrastructure as a term appears to refer to the collective pieces of natural, semi natural, or man-made structures that include vegetation and/or water that when added together produce multiple benefits.

These individual pieces may or may not be perceived as offering great benefit individually but need to be protected due to the cumulative benefits offered when these are all added together. For this report, these pieces will be termed elements and the definition of green infrastructure will be:

The collective resource of large and small naturalistic elements and the cumulative benefits they offer

Where naturalistic means: derived from, or closely resembling nature.

These elements could, as described by Dover (2015), include plants, vegetation or microbes (e.g. the fauna inhabiting the area below or within permeable pavements which can remove pollutants from infiltrating water). These elements can be semi-natural e.g. a woodland, a park or garden, or part of an engineered structure such as a green wall or green roof. The infrastructure part of the term refers to the provision of ecosystem services.

Examples of elements of urban green infrastructure include: country parks, nature reserves, private and public gardens, cemeteries, allotments, golf courses, old brown-field sites, woodlands, or interventions such as green roofs or street trees and these offer a diversity of ecosystem services (Natural England, 2009; Landscape Institute, 2013; Andersson *et al.*, 2014; Dover, 2015); however, we have limited understanding of the generation of ecosystem services (Andersson *et al.*, 2014).

Ecosystem services offer the promotion of both biological, physical, economic and social diversity (Ahern, 2011) and are categorised differently by many institutions and authors, however, there is general consensus on the services offered. There are services that assist in ecosystem functioning such as nutrient and water cycling and soil formation and development and pollination (Andersson *et al.*, 2014; Dover, 2015) and those that offer benefits to biodiversity such as habitat provision and food production (Alvey, 2006; Andersson *et al.*, 2014; Dover, 2015). There are benefits to human health and wellbeing such as provision of places for recreation (Fuller *et al.*, 2007; Forest Research, 2010; Andersson *et al.*, 2014; Dover, 2015), improvement in air and water quality (Andersson *et al.*, 2014; Dover, 2015) as well as aesthetic appeal and evoking positive states of mood (Kuo and Sullivan, 2001; Todorova, Asakawa and Aikoh, 2004; Matsuoka and Kaplan, 2008; Brown and Grant, 2016; Snep *et al.*, 2016). Community-based benefits include bringing people together in a shared space, and economic benefits including flood prevention, higher land and building values, and increased business investment (Forest Research, 2010; Dover, 2015; Vivid Economics, 2017) reduced heating and cooling costs (Dover, 2015), and reduced healthcare costs. Climate control benefits include heat island mitigation, wind interception, (Forest Research, 2010; Dover, 2015) and carbon capture. Forest Research, (2010) have the aim of developing systems that will cope with extreme events; futureproofing our cities for climate change.

Small patch sizes mean that it is unlikely that a full range of ecosystem services can be offered from individual patches (Andersson *et al.*, 2014); however, even small elements may offer many of these benefits and this is known as multifunctionality (Landscape Institute, 2013). The most commonly used example of this is street trees which offer habitat for biodiversity, aesthetic appeal, shade from sun and wind, air pollution mitigation and, to some extent, flood mitigation (Landscape Institute, 2013). To achieve multiple benefits over a larger area there is a requirement for functional connectivity (Andersson *et al.*, 2014), this is where the benefits of cumulative elements offer more than can be achieved by all of the elements individually. An example of this could be where all elements required for a species to survive may not be available from one place i.e. the food plants for a butterfly may not be in the same habitat patch as the nectar plants (Begon, Harper and Townsend, 1996). Flood water would not be mitigated to a large extent by simply including a pond but buffer strips alongside a road, connected to swales and then to an attenuation pool would be much more effective in combination than would be the sum of their parts (Atkins, 2018). To reach the highest potential benefit, the green spaces should be appropriately managed and new elements planned to become a network of interconnected elements (Sandström, Angelstam and Mikusiński, 2006). It may also be true that communities (human populations) of urban areas are not properly functional without an interconnected network or green space.

There is much evidence to support the benefits of green infrastructure but there are still barriers to its implementation. Within our now compact towns and cities, space is at a premium and green infrastructure needs to offer provision of ecosystem services without taking up too much horizontal space (Ahern, 2011). Small patches could have high heterogeneity (Andersson *et al.*, 2014; Dover, 2015) or there could be multiple interconnected patches of varying habitat types offering a diverse heterogeneous mosaic. Maximising the potential of our small habitat patches would make the best use of these space limited areas to offer maximum functionality, biodiversity, and ecosystem service provision.

1.5 *Benefits of urban biodiversity*

Ecosystem services potentially offered by urban hedges are varied but include aesthetic appeal, (Kuo and Sullivan, 2001; Todorova, Asakawa and Aikoh, 2004; Matsuoka and Kaplan, 2008; Brown and Grant, 2016; Snep *et al.*, 2016), privacy (Oreszczyn and Lane, 2001; Gosling *et al.*, 2016), noise and light barriers (Renterghem, 2014; Gosling *et al.*, 2016) and may assist in air pollution mitigation (Varshney and Mitra, 1993; Tiwary, Reff and Colls, 2008; Dover, 2015; Gosling *et al.*, 2016; Weerakkody *et al.*, 2017) as well as increasing urban provision of habitats for biodiversity (e.g. Dover, 2015; Gosling *et al.*, 2016) particularly for birds. There is mounting evidence of the wider benefits of human contact with the natural environment (Barr and Gillespie, 2000; Jackson, 2003; Miller, 2005; Dallimer *et al.*, 2012; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Jennings *et al.*, 2017), particularly with respect to: sensory contact with plants within urban areas, the aesthetic appeal of, and interaction with outdoor environments; including the opportunity for proximity with wildlife (Jackson, 2003; Todorova, Asakawa and Aikoh, 2004; Matsuoka and Kaplan, 2008; Brown and Grant, 2016; Snep *et al.*, 2016). These passive experiences are often the most common experience of nature that people have (Kaplan, 2001; Kaplan and Austin, 2004; Clucas *et al.*, 2011; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Cox, Shanahan, *et al.*, 2017) and most occur within streets and residential areas (Cox, Hudson *et al.*, 2017). With more people living in cities conservation action is becoming more dependent on people's experiences of nature (Snep *et al.*, 2016). People enjoy seeing birds and hearing birdsong (Brown and Grant, 2016) which has been shown to induce positive changes in mood (Kaplan, 2001; Kaplan and Austin, 2004; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Cox, Shanahan, *et al.*, 2017).

Although it is not a marketable commodity and the services provided vary considerably , biodiversity is important as an essential component of sustainable ecosystems and, as such, important in preserving our future (Blignaut and Aronson, 2008). Neighbourhood satisfaction was found to be increased by the ability to see natural elements from windows (Fuller *et al.*, 2001) and people are willing to pay more for houses in, pay more for products from, and spend more time in, areas with trees (Morales, 1980; Anderson and Cordel, 1988; Wolf, 2003; CABE Space, 2005). Positive associations have been measured between the species richness of plants and birds within an urban greenspace and the mental health and wellbeing benefits to people and communities who experience them (Angold *et al.*, 2006; Fuller *et al.*, 2007; Jones and Leather, 2012; Goodwin, Keep and Leather, 2017).

There is a large body of literature suggesting that there may be conflict between the goals of designing and managing landscapes for wildlife and for aesthetics (e.g. Fuller et al., 2007; Hull IV, 1992; Jorgensen et al., 2002; Parsons, 1995; Qiu et al., 2013). The benefit to wellbeing from exposure to green elements increases when people perceive the biodiversity value to be higher; but, participants' levels of understanding means that areas they believe to be better for wildlife may not actually be better (Dallimer *et al.*, 2012). For example, an area of parkland with regularly mown grass may be perceived as good for wildlife whereas a diverse meadow with standard trees would offer more benefit to wildlife. Landscapes and habitats that offer greatest benefits to biodiversity often look untidy, and if people can correctly identify areas of high biodiversity it may not correlate with the areas that they find aesthetically pleasing (Nassauer, 1995; Fuller *et al.*, 2007; Qiu, Lindberg and Nielsen, 2013). Even when people appreciate the benefit of improving ecological quality they may not wish to do so at the expense of the attractiveness of their neighbourhoods (Nassauer, 1995). Hedgerows that are not managed appropriately have the potential to look untidy (Oreszczyn and Lane, 2000). Many studies have found that when people understand the benefits to biodiversity they welcome more natural looking green elements into their city areas such as meadows in parks, residential areas and along roadsides (Jiang and Yuan, 2017; Southon *et al.*, 2017) and these meadows were preferred to amenity grassland or formal planting schemes as were meadows with higher structural heterogeneity (Southon *et al.*, 2017).

The British Government and many non-governmental organisations are increasingly highlighting the importance of urban wildlife (Baker and Harris, 2007) and have become more aware of the detrimental impacts to human health of poor quality urban environments (Evans, Newson and Gaston, 2009; Brenner, 2013). To function effectively and to retain wildlife, urban environments require an interconnected network of appropriately-managed, suitable green space (Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009; Dover, 2015).

1.6 *Hedges – a history and current status*

It is important to define what is meant in this study by the term "hedge" because this has a different meaning to the term "hedgerow". A hedge is the woody component while a hedgerow encompasses the woody structure plus the herbaceous element and other features such as banks and ditches but the terms are often used interchangeably (Forman and Baudry, 1984). Even the term hedge has different meanings and in some instances can include turf banks and stone walls (Greaves and Marshall, 1986; Dover, 2019a), may or may not include trees, and can be as simple as ‘a structure that defines the limits of a field’ (Greaves and Marshall, 1986 p4). The managed nature of the woody component is sometimes key to the definition of a hedge e.g. that of Baudry, Bunce and Burel (2000) and Maskell *et al.*, (2008) distinguish between linear woody features by management; those without management are called a line of trees or scrub, and those recently managed are categorised as hedges. In urban environments the term hedge is likely to be more accurate as many will not have the associated adjacent herbaceous element and even though it is not a criteria of this study most will have undergone some form of management. Much of the published research is based on the study of hedgerows in rural landscapes and this term will therefore also feature heavily in this thesis.

Hedges have been associated with agriculture for a very long time (Forman and Baudry, 1984). They were used by the Romans to delineate boundaries (Nozedar, 2012) and it is likely that prior to the Roman invasion of England hedges were already part of the landscape (Rackham, 1990). They were familiar in Anglo-Saxon times (410-1066 AD) (Rackham, 1976, 1986, 1990; Nozedar, 2012) to mark boundaries and were described as ‘old’ hedges in sources from as early as 816 AD (Rackham, 1986); some Anglo-Saxon hedges still exist today (Nozedar, 2012). Hedge numbers steadily increased during the Middle-Ages (500-1500 AD) (Rackham, 1976) and by the 15th century hedges existed in all parts of England (Rackham, 1990) and were present around most villages and along parish boundaries (Rackham, 1986, 1990). During Tudor (1485-1603 AD) and Stuart (1603-1714 AD) times hedges were very valuable especially due to the mini ice age with the provision of fuel wood and food (1300 – 1870 AD), and severe punishments were imposed to protect them (Rackham, 1986, 1990). There was very little hedge destruction between 1870 and 1950 except for those destroyed by wartime activities (Rackham, 1986, 1990). After this time, it became more practical to grub out hedges due to the use of larger machinery, and over concerns about hedges being a source of pests and weeds. Farmers were even encouraged to do so by the Ministry of Agriculture to increase food production (Sharman, 1988). Those hedges that remained were heavily managed meaning many were damaged or destroyed (Rackham, 1990).

The distribution, and the type (e.g. species make up, morphology due to management, associated features such as ditches or trees), of hedgerow is influenced by many factors both environmental, temporal and cultural. Hedgerows in locations of similar situation are likely to be similar in character. Ancient hedges alongside roadways in North and West Britain consist of a combination of woody species whilst those demarking the field boundaries in these regions are more likely to be hawthorn (*Crataegus monogyna*) suggesting that they were planted during the major period of enclosure of open land in the 1700s (Rackham, 1986). Gorse hedging is found both in areas of poor soils and areas that suffer the force of the Atlantic gales. Hedges in some areas differ in their species composition due to the inclusion of exotic species in local planting schemes e.g. fuschia (*Fuschia magellanica*) hedges in Ireland and beech (F*agus sylvatica*) in South-West England (Baudry, Bunce and Burel, 2000).

In Britain, hedges are usually composed of species such as hawthorn and blackthorn (*Prunus spinosa*) that are less likely to be eaten by livestock. Trees that do well as hedges also include amongst others, field maple (*Acer campestre*), hazel (*Corylus avellana*), oak (*Quercus robur*), sycamore (*Acer pseudoplatanus*) or of other species which, like blackthorn and hawthorn are traditionally managed by laying (Baudry, Bunce and Burel, 2000; Woodlands Investment Management, 2019). Hedges were typically planted when farming became individualised rather than collective to prevent the mixing of stock (Baudry, Bunce and Burel, 2000). The new fields created during the Parliamentary Enclosure Acts were planted using hawthorn (Hoskins, 1955; Rackham, 1976, 1986, 1990). In 1790 hedges in the counties of the East Midlands had ash (*Fraxinus*) trees (sometimes elm (*Ulmus*)) planted widely spaced alongside (Hoskins, 1955). Hedge species in Europe are more commonly blackthorn, hawthorn (*Crataegus Spp.*), hazel, dog rose (*Rosa canina*) and elder (*Sambucus nigra*) (Gosling *et al.*, 2016; Graham *et al.*, 2018).

It is estimated that in England there are around half a million miles of hedgerow, but this is decreasing despite government protection (Nozedar, 2012). Hedges have been important in the English landscape (Faiers and Bailey, 2005; Defra, 2007a) for centuries (Barr and Gillespie, 2000; Oreszczyn and Lane, 2000; Nozedar, 2012) in both our towns and cities, and in our countryside and this importance is reflected in many countries throughout the world (Rackham, 1986; Baudry, Bunce and Burel, 2000; Baudry and Bunce, 2001), but studies for countries outside Europe are scarce (Baudry, Bunce and Burel, 2000). Within Europe, particularly in France, hedgerows can form a network thorough the landscape which is often termed ‘bocage’ and is an important landscape component at this connected scale (Baudry, Bunce and Burel, 2000). Despite their importance it is often the case that we know very little about how many hedges we have or about their composition, structure, or condition. Data generated by the Countryside Survey however, provides information on changes in their extent and condition (Barr and Gillespie, 2000).

A hedge is not a natural landscape feature but is a human-made element to provide a variety of functions such as crop and stock shelter, boundary delineation, or sources of products (Rackham, 1986; Baudry, Bunce and Burel, 2000; Oreszczyn and Lane, 2000). More recently, their importance is turning towards their ecological values, such as an ecological refuge in otherwise inhospitable environments, and cultural benefits (Oreszczyn and Lane, 2001). The reduction in their importance for past functions (Rackham, 1986; Baudry, Bunce and Burel, 2000) has led to a decline in their quality and abundance (Baudry, Bunce and Burel, 2000).

Baudry *et al*. (2000) note the requirement of management as a component of the definition of a hedge and highlight the importance of the humanised nature of hedges such as the prevention of their expansion onto land required for another use. This will be key especially in urban environments due to the increased ‘control’ humans place on the urban environment.

1.7 *Hedges and biodiversity*

Rural hedges or hedgerows are well studied in terms of their importance for biodiversity (e.g. Dover and Sparks, 2000; Maudsley, 2000; Dainese *et al.*, 2015) and are key to the biodiversity of our intensively managed farmland (Boughey *et al.*, 2011; Staley *et al.*, 2016; Lecq *et al.*, 2017). Well managed hedges offer habitats in their own right for a range of vertebrate, and invertebrate species (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017), act as corridors (Baudry, Bunce and Burel, 2000; Boughey *et al.*, 2011), provide cover from predators, access to food on either side (Forman and Baudry, 1984), and increase landscape structural heterogeneity (Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Boughey *et al.*, 2011). Hedges also act as a ‘genetic’ store (a place in which rare species can survive to later move to favourable habitats) (Faiers and Bailey, 2005). The functions of hedges (ecosystem services) are affected by their species composition, history, and management (Baudry, Bunce and Burel, 2000), and adjacent landuse (Forman and Baudry, 1984).

Hedges can be species rich wildlife habitats (Faiers and Bailey, 2005), 80% of woodland wildlife is estimated to breed in hedgerows, 66% of lowland terrestrial birds and 66% of lowland mammals use hedgerows. Hedges offer habitat to different species throughout the year (Forman and Baudry, 1984). Habitat quality affects species abundance (Dover and Sparks, 2000) and the quality of a hedge to support wildlife can vary with a number of factors (PTES, 1993) including: planted species, surrounding landuse, design and management, and environmental conditions (PTES, 1993; Dover and Sparks, 2000)**.**

Species offering food in the form of flowers e.g. hawthorn, blackthorn and wild privet (*Ligustrum vulgare*), or berries e.g. hawthorn, blackthorn and Rose (Rosa) offer food sources to biodiversity (PTES, 1993; Barr and Gillespie, 2000; Dover and Sparks, 2000; Staley *et al.*, 2016) as do soft fruit producing species such as Bramble (*Rubus fruticosus*) and management to allow a constant supply of food throughout the year offers obvious advantages (PTES, 1993; RSPB, 2017).

Hedges are also important on a landscape scale and can act as corridor habitat for birds providing a comparatively safe route between patches of woodland and other habitats in search of food and other resources. The connectivity of hedges in landscapes must be carefully considered as there needs to be a destination into which a hedge terminates as birds moving along a hedgerow to an inhospitable environment may be detrimental to the population as a whole (Hinsley and Bellamy, 2019).

1.8 *Managing hedges for biodiversity*

The composition, management and structure of hedges influences their suitability to support wildlife (Kotzageorgis and Mason, 1997; Bellamy *et al.*, 2000; Hinsley and Bellamy, 2000; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007). There is provision under agri-environment schemes to protect and enhance hedgerows in rural areas (Croxton and Sparks, 2002; Pocock, Evans and Memmott, 2010; Amy *et al.*, 2015) and hedgerows were designated as a priority habitat in the 1994 UK Biodiversity Action Plan (Biodiversity Reporting and Information Group, 2007), but this protection does not extend to urban areas.

Hedgerow management greatly impacts the provision the hedge offers to wildlife. The management of hedgerows impacts their physical structure (Hinsley and Bellamy, 2000; Amy *et al.*, 2015; Staley *et al.*, 2016; Graham *et al.*, 2018), in particular size and structural diversity of hedges (Croxton and Sparks, 2002; Bates and Harris, 2009). Management that produces larger taller and denser hedgerows and greater diversity of growth stages on organic farms has been shown to be beneficial (Whittingham and Evans, 2004; Bates and Harris, 2009). Greater hedge volume is usually associated with greater species biomass (Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Newton, 2017) and thus a greater prey abundance for predators (Michel, Burel and Butet, 2006). Wider hedges have a larger area in which to provide shelter at ground level thus increasing opportunity for foraging and shelter (from predators and weather)(Forman and Baudry, 1984; PTES, 1993) particularly at the base (RSPB, 2017) because wide hedges can act as corridors for movement of plant and animal species' through a landscape (Forman and Baudry, 1984), and provide a larger surface area for seed and fruit production (Croxton and Sparks, 2002; Bates and Harris, 2009). However, where hedge bases are wide they may reduce the space available for basal ground flora (Dover *pers comm* November 2018). Hedge length is important as this provides a greater habitat area (Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018) but condition is unlikely to be uniform along the entire length of the hedge (Burel and Baudry, 1995; Graham *et al.*, 2018).

Heterogeneity of the structure provides a wider range of niches to exploit and thus supports a wider biodiversity (Whittingham and Evans, 2004). Large scale hedge cutting or synchronised cutting regimes, which reduces structural heterogeneity of the hedgerow, should be avoided (Batáry, Matthiesen and Tscharntke, 2010). Hedges should be managed on a three year rotation via cutting, coppicing, or laying to facilitate provision of diversity of structure and a constant supply of food throughout the year (PTES, 1993; Dover and Sparks, 2000; Barr *et al.*, 2010; Staley *et al.*, 2016). Hedge laying is considred to have many wildlife benefits (PTES, 1993; Dover and Sparks, 2000) via either modern or traditional methods (Amy *et al.*, 2015) and gaps should be planted up (PTES, 1993; Hedgelink, 2017; RSPB, 2017). A whole hedge should not all be cut in one year (RSPB, 2017)

Ideally cutting should be undertaken every 3 or 5 years, and to allow birds and small mammal species to access berries cutting should be undertaken during late winter not autumn (Staley *et al.*, 2012). It is recommended that less than one third of a hedge be cut at one time to increase structural diversity (Hedgelink, 2017), or where this is unachieveable one side of a hedge in one year and the other a year or two later (PTES, 1993). Where even this is impractivcal due to intensive use on either side of the hedge, incremental increases in the height of cutting should provide fruit each season and permit the hedge to develop each year, whilst still maintaining a 'neat' hedge appearance (PTES, 1993; Staley, Amy and Pywell, 2014).

Appropriate management of hawthorn hedges to facilitate haw production due to the abundance of hawthorn hedges in the urban green infrastructure resource would greatly increase the sources of food available for urban birds during the winter months (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002)

Sensitive management on either side of a hedge (sometimes known as a buffer zone) is also key to the biodiversity provision (Barr and Gillespie, 2000; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Todd, Tew and Macdonald, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018). When vegetation is sparse some species can be found less frequently and some species will only stray from the hedge bottom if adjacent vegetation is dense (Pollard and Relton, 1970) or tall (Todd, Tew and Macdonald, 2000).

Biodiversity can be increased with the inclusion of wide diverse boundary features e.g. grassy verges or ditches (Merckx *et al.*, 2009; Newton, 2017). Shorter vegetation encourages foraging but increases the vulnerability of species to predators, longer vegetation increases food resources and offers increased protection thus a matrix is often beneficial for biodiversity (Whittingham and Evans, 2004). This should be an area of less intensely managed land e.g. rough grassland, or a diverse perrenial border including a variety of plants at least 1 m wide and cut infrequently; ideally every three years on rotation (PTES, 1993; Dover and Sparks, 2000; Barr *et al.*, 2010; Staley *et al.*, 2016). The seasonality of cuttting impacts the suitability of a hedge to support biodiversity. Cutting during summer can reduce some species abundances but increase others and auturmn/winter cutting can destroy overwintering stages. The highest diversity of flower assmeblages could be produced with sypathetic management for pollinators by cutting being staggered to avoid widespread resource depletion possibly mowing one side of the road at a time and mowing should be avoided altogether during peak foraging activity in late summer (Cole *et al.*, 2017). Cutting different sections in different seasons where cut and uncut areas are in close proximity to allow species to seek refuge when an area is cut is thought to be the best method (Dover & Sparks, 2000). It has been found that the structural complexity of the hedge base positively influences biodiversity which can be achieved by the inclusion of roots, holes, stones and logs (Lecq *et al.*, 2017). In urban areas there may be conflict with the inclusion of these elements because they may not be deemed appropriate for urban areas by some members of the public (Qiu, Lindberg and Nielsen, 2013).

More and taller hedgerow trees are beneficial to many species (Graham *et al.*, 2015; Newton, 2017) e.g. invertebrates (Peng, Sutton and Fletcher, 1992; Maudsley, 2000; Merckx *et al.*, 2009; Garratt *et al.*, 2017; Goodwin, Keep and Leather, 2017), bats (Boughey *et al.*, 2011), small mammals (Todd, Tew and Macdonald, 2000), and birds (Newton, 2017) through food production and forage for insects, and the providsion of shelter (Merckx *et al.*, 2009). Tree seed was thought to provide a major food resource for wood mice during the winter and may provide a reason for some species to move from the hedges to use the resources in the surrounding landscape (Todd, Tew and Macdonald, 2000). Management should increase the density and variation of age structure of hedgerow trees (Merckx *et al.*, 2009).

The species of a hedge may affect the biodiversity it supports**.** Hedge species that offer food or flowers such as hawthorn, blackthorn, and wild privet (*Ligustrum vulgare*) offer benefit to biodiversity and support a wide range of species (PTES, 1993). However, management of the hedges to permit the fruiting and flowering of hedges is important if this benefit to biodiversity is to be realised with the provision of a constant supply of food throughout the year (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017). For example, hedgerow berries provide a winter food resource for many species including small mammals and birds (Croxton and Sparks, 2002). Hawthorn hedges produce an important food resource in the autumn and winter but due to the lack of other food sources is particularly important in winter for mammal species due to their production of haws (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Staley *et al.*, 2012). Due to the dominance of hawthorn in agricultural landscapes this fruit production is a significant source of food (Croxton and Sparks, 2002). The production of haws is strongly influenced by management practices and the quantity of haws of appropriately managed hedges can be 50 to 150 times greater compared to those cut annually (Croxton and Sparks, 2002). The less frequently a hedge is cut the more fruit is produced.

Privet is a semi-evergreen shrub with flowers and berries (RHS, 2018; The WildlifeTrusts, 2018) with a bushy habit (RHS, 2018) that is widespread in England and Wales. The berries are often eaten by birds, privet provides good cover for birds and other animals and is the main food plant of the Privet Hawk-moth (RHS, 2018) but there seems to be little research on the benefits of privet to wildlife.

Beech based hedges are inherently poor in species (Baudry, Bunce and Burel, 2000) but small mammals consume beechnuts in forest areas (Jensen, 1985; Suchomel and Urban, 2011) and many bird species including black birds and siskin feed on beechnuts and beechnuts provide a considerable proportion of the winter food supply of great tits (Packham *et al.*, 2012). However, it is unlikely that the beech in the hedges of this study are managed in such a way that production of beechnuts is facilitated, and in Britain the late frosts also diminish fruiting (Packham *et al.*, 2012). The leaves of beech hedges remain much longer than those of other species and are often present throughout the winter (Packham *et al.*, 2012). This may offer increased protection during winter months; thus cutting which removes these leaves would eliminate this benefit.

Areas with an abundance of hedgerows have a high biomass of species and increased fragmentation and a decrease in the resources of hedges over a landscape generally causes a reduction in biodiversity but can cause small scale increase in abundance in the remaining hedges due to a lack of other available habitat (Michel, Burel and Butet, 2006). Providing more hedgerows and carefully managing them has been demonstrated to have a significant impact on preserving species particularly in landscapes that lack other habitats that provide good opportunities for species such as woodlands, copses, bushes and trees (Batáry, Matthiesen and Tscharntke, 2010). Such habitats are rare in some urban environments and it is likely to follow that adding hedges with carefully managed adjacent vegetation to our towns and cities may have a large impact on richness and diversity of urban birds. Connectivity to other hedges or wooded areas is important for hedgerow biodiversity as edges with direct connection with woodland would be expected to have an increased number of woodland species habiting them (Pollard and Relton, 1970). Protecting existing hedgerows is very important as replacement hedgerows, no mater how biodiverse the planting, often fail to replace the unique microhabitas that form over time in the hedge bases. These include stones, logs and roots. It has been found that the structural complexity of the hedge base positively influences biodiversity (Lecq *et al.*, 2017).

Producing networks of farmland hedges has been found to promote bidiversity, ecosystem functioning and ecosytem services (Dover and Sparks, 2000; Barr *et al.*, 2010; Staley *et al.*, 2016; Lecq *et al.*, 2017). This could be achieved by linking up pre-existing hedges. If planting new hedges consideration of the inclusion of abundant ground refuges using logs and stones should be made to increase value to biodiversity (Lecq *et al.*, 2017), although as previously mentioned this may be controvertial.

The diversity of species making hedges their home means that selected management may be beneficial for some whilst deterring to others (Whittingham and Evans, 2004) and management for groups of animal will be discussed in more detail in subsequent chapters.

1.9 *Urban hedges*

There is little research published on the composition and history of urban hedges which, as a result, appear to be a somewhat neglected and underappreciated resource despite their potential as ecosystem delivery vehicles as components of urban green infrastructure. Due to the lack of current literature on urban hedges the review that follows in this section combines published information on rural and urban hedges together with personal observations.

The species of a hedge in urban areas may be quite different to those found in rural environments. Hedges of urban areas are likely to result from one of two methods, either from encapsulated remnants of boundary hedges present before the expansion of the urban area, or those planted to delineate boundaries of domestic dwellings or industrial enterprises created during urbanisation and which will be more modern in origin. The hedges of more ancient origin are likely to consist of hawthorn and blackthorn (Gosling *et al.*, 2016) created during the enclosure period (Baudry, Bunce and Burel, 2000). Although many of the hedges with more ancient origins may still contain hawthorn or balckthorn (Gosling *et al.*, 2016), more recently planted hedges may reflect the trend for privet (*Ligustrum spp.*) hedging during the 1950s, the introduction of Laylandii (*Cupressocyparis laylandii*) hedges during the 1980s and the current 'preference' for the use of beech hedging in towns and cities (visible in Stoke-on-Trent). The more recent hedge species selection is possibly due to the preference for non-spiny species in public areas or school grounds (Gosling *et al.*, 2016), or those which have a dense habit and foliage for increased privacy (Oreszczyn and Lane, 2001; Gosling *et al.*, 2016), or are quick growing – but with subsequent issues relating to height management. In many office and industrial parks shrubs are often planted and may form hedges. In a recent study by Gosling *et* *al.*, (2016) beech, holly (*Ilex aquifolium*), ivy (*Hedera Spp*.), laurel (*Laurus Spp*.), privet and yew (*Taxus baccata*) are more commonly found in urban areas (Gosling *et al.*, 2016).

The structure of urban hedges tends to be less beneficial for wildlife than that of rural hedges or those hedges on the edge of towns and cities (Faiers and Bailey, 2005; Gosling *et al.*, 2016). Urban hedges are more likely to undergo management practices that reduce their ability to offer food as they are less likely to have fruits, flowers or seeds and generally have a lower animal biodiversity (Gosling *et al.*, 2016). Urban hedges may suffer from the impacts of high footfall and damage by people and, as a result, require management to prevent this damage reducing their biodiversity value (Faiers and Bailey, 2005). Over-management in also more commonplace in urban environments (Oreszczyn and Lane, 2001; Faiers and Bailey, 2005; Gosling *et al.*, 2016). The landuse on either side of urban hedges is likely to be different to that in rural locations with more intensive uses (Faiers and Bailey, 2005; Gosling *et al.*, 2016) and are more likely to have hard surfaces immediately adjacent. Whilst this has a detrimental effect on the biodiversity in rural areas the presence of a hard surface on one side was not shown to have a major impact on the biodiversity value of urban hedges but the management of the immediately adjacent land did have a large impact on the biodiversity value of an urban hedge (Gosling *et al.*, 2016). The tidying and 'over-management' of many urban hedges, and the demands on the adjacent landuse, means that they are, in most cases, not a hedgerow in the sense that they have a hedge base with a perennial flora. As a result, any herbaceous seeds deposited by birds (or small mammals) fail to develop and 'weeds' are removed or cannot germinate where hard (sealed) surfaces are present. Some hedges, however, do have an area analogous to a hedge base (e.g. grass strip or amenity planting) on at least one side. It has been suggested that changes to management of urban hedges to that which improves hedgerow structure (Faiers and Bailey, 2005) and improvements the adjacent land would lead to improvements in the biodiversity value of urban hedges (Gosling *et al.*, 2016). In urban environments, hedges tend to be shorter in length than rural hedges as they often delineate borders to property which, in urban settings, is much more likely to be shorter than field or estate boundaries.

1.10 *Hedges and people*

Hedges as hedgerows, evoke emotions in people and have been part of our cultural heritage for centuries (Baudry, Bunce and Burel, 2000; Oreszczyn and Lane, 2001). Initially hedges were important for their function in stock-proofing farmed landscapes. They have also become valued for their provision to wildlife, their action as refuges for beneficial species, but also for their aesthetics, specifically in terms of colours, scents, and patterns (Oreszczyn and Lane, 1999, 2001; Gosling *et al.*, 2016) if hedges are planted within our cities they have the potential to offer these benefits to large numbers of people. Findings from a study by Oreszczyn and Lane (2001), which used interviews of people from both the UK and Canada, suggest that people felt that hedges brought the countryside into towns and diversity was seen as important. Most hedges were seen to function primarily to provide privacy and barriers against noise, but they were particularly valued for the improvements that they made to how the area looked. It was shown that taller hedges were valued for their contribution to birdlife but some thought that they may act as a hazard to traffic. Hedges that are 'well maintained' to look neat and tidy were found to be preferred but those cut at the 'wrong time' so that they turned brown were particularly disliked (Oreszczyn and Lane, 2001). This suggests that aesthetics, i.e. a neat tidy hedge, was most important in how people perceived hedges to be well or badly managed.

" Hedges are part of the wonder of the escape from the city" (Nozedar, 2012)

Due to the high density of people living in cities, hedges must be perceived as a benefit to their human neighbours if we are expecting them to accept and appreciate them. The view of people in planting and managing this green commodity must be considered if maximum benefit, both to wildlife, and human health and wellbeing is to be achieved. Where public amenity is to be considered such as along canals or within parks conflict may arise on how hedgerow management should be addressed (Faiers and Bailey, 2005).

1.11 *Aims and objectives of the study*

There is a paucity of data on the importance of linear strips of vegetation adjacent to roads to biodiversity (Carthew, Garrett and Ruykys, 2013) and road verges are often not considered for their contribution to green infrastructure even though they make up a considerable amount of the semi-natural habitat (Jones and Leather, 2012). This study looks at how hedges, as an element of green infrastructure, can be included as a positive influence on both biodiversity and human health and wellbeing in urban areas. The social aspects are also integrated into this study due to the impacts that biodiversity has on mental wellbeing and community relationships.

The study aims to:

1. To assess the biodiversity value of urban hedges

But also, as the preservation of hedges in urban areas requires the support of people, it was deemed necessary to:

2. To assess peoples' perception of urban hedges and other types of urban boundaries

3. The findings of these studies will then be used to ascertain what makes a hedge more valuable to wildlife and which hedge types and management regimes are preferred by people of urban areas. This information can then be used alongside published research and personal observations to inform planners and city managers to ensure that the provision of urban green infrastructure is accepted and appreciated by its neighbours whilst maximising its potential benefit to urban wildlife

1.11.1 Biodiversity study objectives

1. To use field survey to assess the use of urban hedges by:
    a. Birds
    b. Small mammals
    c. Invertebrates

2. To identify the characteristics of the hedges and surrounding areas using field surveys and Geographical Information Systems (GIS) and use multivariate analysis to identify relationships between the characteristics and variations in species richness and abundance.

1.11.2 Perception study objectives

To use a questionnaire to gather evidence to assist in answering the following questions.

1. Is there any preference for a type of boundary in an urban environment?
2. Do members of the public perceive wildlife, aesthetics, or ease of maintenance to be more important when selecting a boundary?
3. Do people perceive, correctly, which type of a hedgerow offers better provision for wildlife?

1.12 *Flow of the thesis*

The chosen layout has been displayed as a flowchart (Figure 1-1)

1. The rationale offers a brief introduction to the general themes behind the ideas investigated in the research and outlines the aims and objectives for the whole study. The themes will be introduced more thoroughly in the chapters to which they more specifically relate.

2. The general methodology describes the processes common to other chapters and specific methods used for individual areas of study are given a detailed explanation in their relevant chapters.

3. ,4., 5. The biodiversity section is divided into studies undertaken on the use of hedges by different taxonomic group. Each chapter will draw conclusions for that organism type.

6. The perceptions of urban hedges chapter reports on a study undertaken to assess the views held by people who live or work in Stoke-on-Trent and surrounding areas of their preference for different boundary types and their management.

7. Both value to wildlife and appeal to people of urban environments are key components to consider when selecting the elements to include in urban green infrastructure. This chapter combines the two areas studied to try and identify if there is commonality in the types of hedges and management that offers greatest benefit to urban wildlife and urban dwellers and discusses where possible conflicts may arise. This chapter also contains management recommendations for urban hedges and makes recommendations for further study.

8. The main findings of the research are highlighted here.

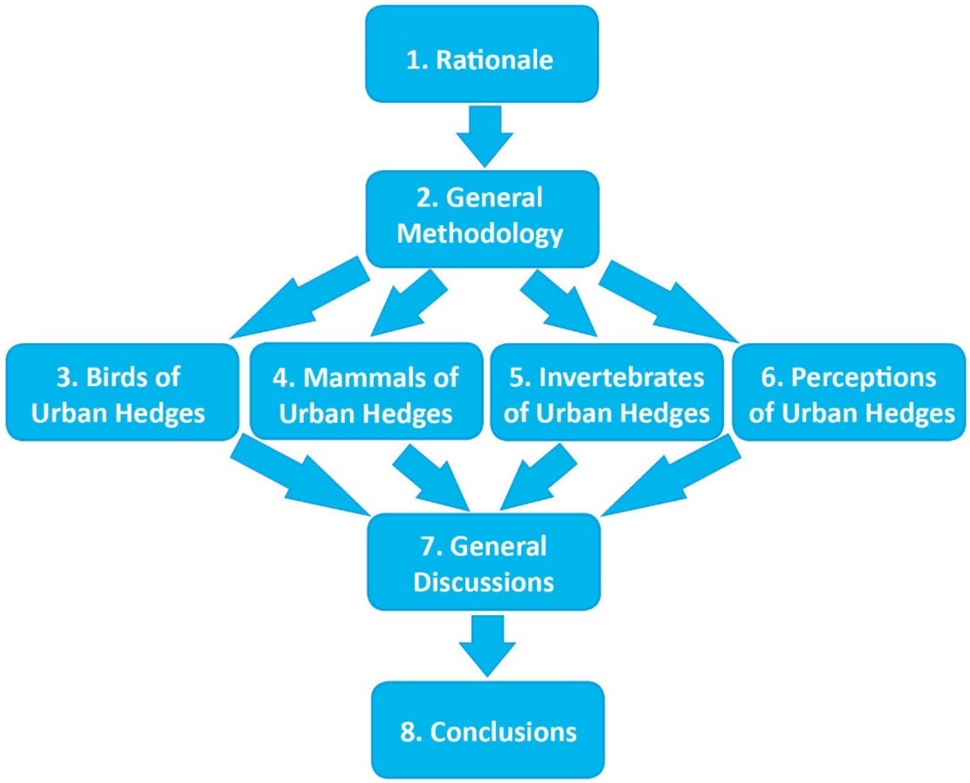

Figure 1-1 Flow diagram of the thesis

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2 General Methods

2.1 *Introduction to study area*

Stoke-on-Trent (SoT) is an interesting city in the west midlands of England (Figure 2-1) as it is composed of 6 initially separate towns which were aggregated to create a city (Jayne, 2004). For this study the adjacent area of urban Newcastle-under-Lyme (Figure 2-2) is also included within the study area. The total conurbation of Stoke-on-Trent and Newcastle-Under-Lyme has a population of 377,079 based on mid-year estimates of the Office of National Statistics (ONS, 2017) making it the 11th largest in the UK. It is also interesting due to its industrial past including steel works, coal mining and the potteries industry leaving vast areas of damaged land (Ball, 1989). By the end of the 1950s around 10% of Stoke-on-Trent was derelict (Taylor, 2008) and in 1967 it had the most derelict area, by district, (Tandy, 1974; City of Stoke-on-Trent, 1993) in the UK, which led in the 1970s to large scale reclamation and regeneration through the inclusion of playing fields, lakes and nature reserves to create natural looking spaces which permeate the city (Tandy, 1974). Although there are still some 350 hectares of derelict land it is now one of the greenest cities in the UK (Staffs University GIS Archive). Thirty-nine % of the land area of Stoke-on-Trent is green space with 657 areas of green space totalling 3,674 hectares (Figure 2-3) (Staffs Uni GIS data archive).

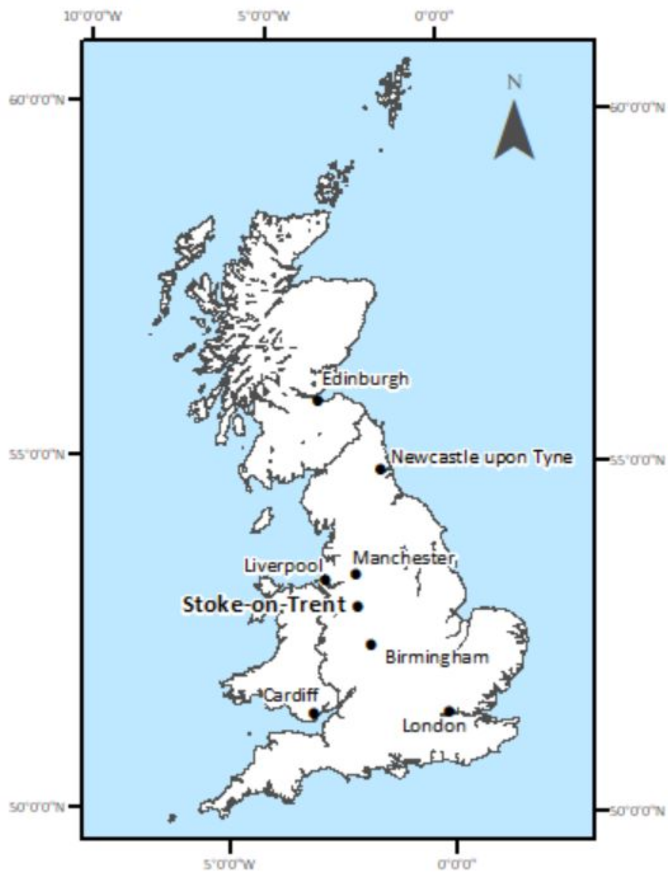

Figure 2-1 Location map of Stoke-on-Trent within the UK ©ESRI digital data, 2018 Staffordshire University Licence

Figure 2-2 Extent and proximity of Stoke-on-Trent and Newcastle-under-Lyme, UK ©ESRI digital data, 2018 Staffordshire University Licence

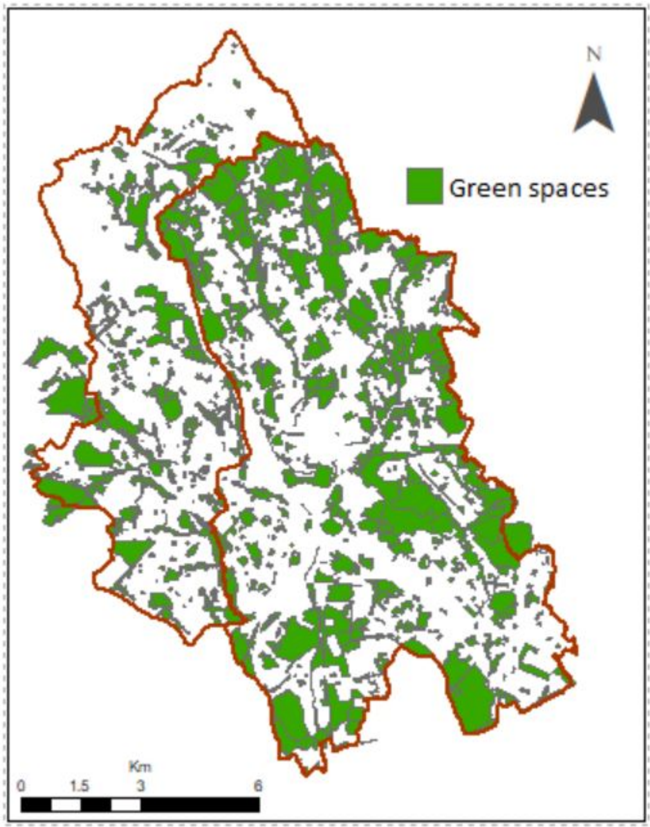

Figure 2-1 The green spaces of Stoke-on-Trent and Newcastle-Under-Lyme ©ESRI digital data, 2018 Staffordshire University Licence

2.2 *Study site selection (Hedges and Controls)*

Hedges of all species and quality were initially identified through driving tours around the city. Driving routes were targeted in advance using Google Maps and Google StreetView (accessed March to May 2015). As with the National Hedgerow Survey (Defra, 2007a), hedges were selected based on the following criteria:

- At least 30m in length
- At least 95% continuous with minimal gaps within the selected hedge.
- At least 1.2 metres in height.

In addition, for the purposes of this study, urban hedges needed to:

- Have at least one long edge adjacent to some form of urban land-use for example a road, track, or car park.
- Composed of at least 95% of its woody species throughout the site length.

Although many urban hedges are shorter than 30 m, this selection criterion was retained to ensure that comparisons could be made with existing rural hedge studies. In addition, a 30 m stretch allowed the placement of multiple mammal tubes at each sample site (See Chapter 4 Mammals of Urban Hedgerows) The hedges included in this study were mainly located along roadsides bounding local-authority maintained areas such as car parks or allotments but also included some alongside residential gardens.

Using the above criteria a total of 82 potential hedges were identified as possible survey sites from the driving tours of the city, with almost all roads being surveyed using either Google Maps or driving tours. In some cases, hedges along the same road were considered to be separate for survey purposes, in such cases there was either a significant break (over 5 m) between the adjacent hedge or the landuse changed significantly in the area behind, for example, from residential properties to open green space, or the management of that section was different to the adjoining section or there was a change in woody hedge species. The 30 m survey section would be selected from within these identified hedge sections and the gap between the 30 m survey locations was maximised to avoid pseudoreplication. The most abundant woody hedge species in the city were hawthorn, Japanese privet (*Ligustrum ovalifolium*) and beech (*Fagus sylvatica*) and these three species formed the basis of the sampling strategy (Figure 2-4 and Appendix A). Only 13 beech hedges in the survey area met the criteria. Choices of which hawthorn and privet hedges to eliminate, in order to match the number of available beech hedges, were made based on consideration of similar land use behind the hedges to those of the beech hedges, where possible. As there were many more beech hedges in the city centre than other species, and no beech hedge was found adjacent to allotments, this resulted in some differences in the distribution of these three species throughout the city with a lower number of beech hedges found in the residential areas compared to the centre. Another consideration was to include both large and small hedges of each species in the samples. Due to access issues, sample hedge numbers were reduced to 12 beech, 11 hawthorn and 10 privet for the invertebrate surveys. Some hedges were not considered suitable or access/permission was not granted for small mammal surveys and this limited the number of beech and hawthorn hedges to 10 but only 8 for privet. As more privet hedges were identified in the study area , two other privet hedges were substituted giving 10 hedges of each species for the mammal surveys. The survey section of each hedge was located within the centre of the length of the hedge or hedge section.

Controls were identified once the hedges to be surveyed were selected. These were areas where no hedge was present and could include: a gap in a hedge, railings, fence panels and brick walls. Examples included where a large section of hedge had been removed, where a hedge section has been replaced by a fence, or on the opposite side of the road to a study hedge where no hedge was present. These were deemed suitable providing similar land use existed behind the control and were not more than 150 m away (although most were much closer) from a survey hedge.

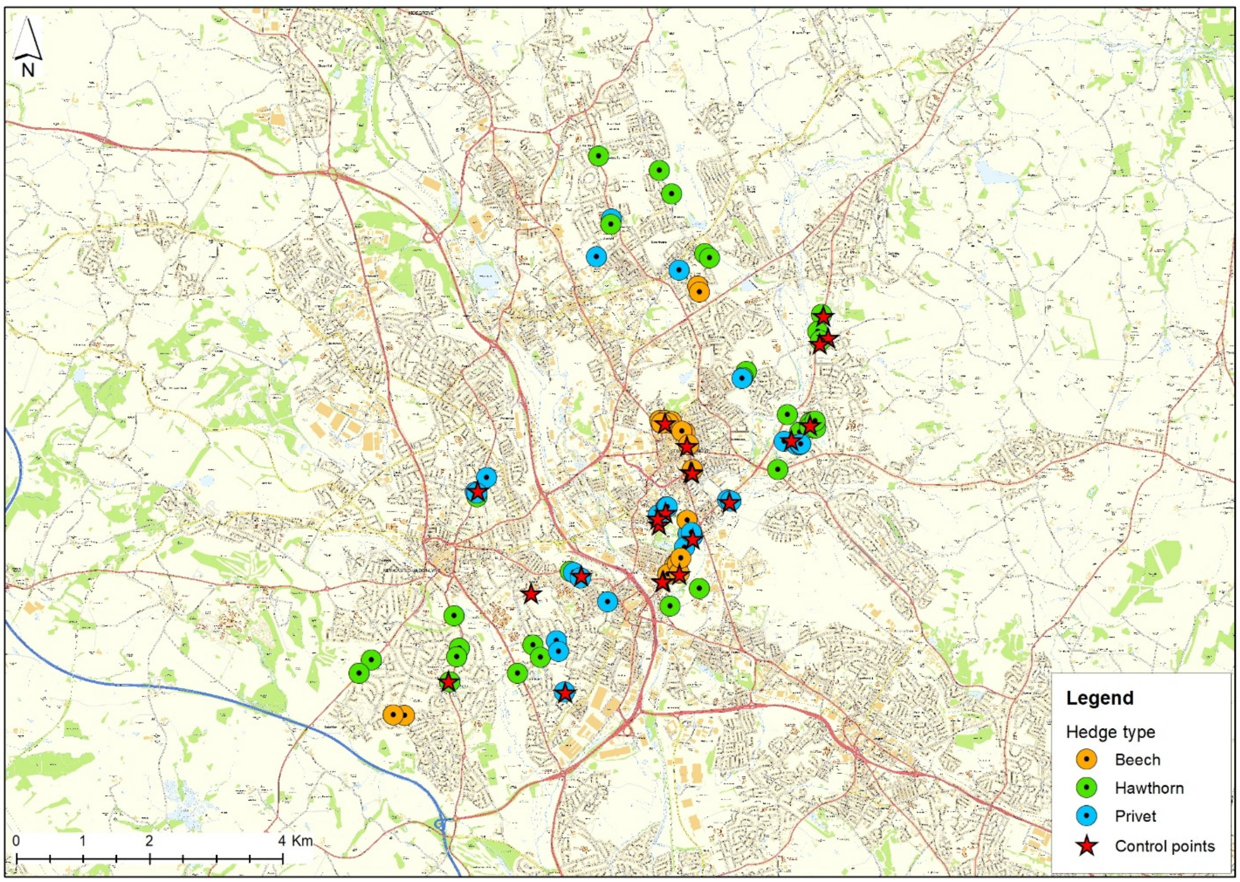

Figure 2-2. Location map of suitable beech, hawthorn & privet hedges to use in the biodiversity surveys and identified control locations. From these hedges survey hedges were selected for the biodiversity surveys. ©ESRI digital data, 2018 Staffordshire University Licence

2.3 Hedge and surrounding landuse surveys

2.3.1 Hedge surveys

A detailed study of each selected hedge's physical characteristics was undertaken (Appendix B). This was based on that used for the UK National Hedgerow Survey (Defra, 2007a). Data collected included hedge dimensions and two annotated sketches of the environment immediately surrounding the hedge, one of which was transverse, one in cross section. Any gaps present were measured and recorded.

Measurements showed variation in hedge structure along its length, identified the shape of the cross section and highlighted the presence of features such as a banks, ditches, fences or railing within the hedge or any other features (a full list of these can be seen in the proforma (Appendix C). Hedge features measured included: height, width (volume was calculated - height cm x width cm x 30 m) and the total length of hedge (some 30 m sections encompassed almost the entire hedge length others only a small part of the total). Any obvious management practices relating to cutting regimes were also recorded.

Floral components of the hedge were recorded (including woody species and climbing species such as ivy or bramble) and the percentage of the hedge which these contributed was estimated. If trees were present within the hedgerow or adjacent to it, they were added to the sketch and identified to species. The distance from the hedge and the diameter at breast height (DBH = 1.2 m) of up to four trees within the 5 m either side of the hedge were measured. The percentage of cover from trees of the hedge was also recorded by estimating the percentage of the hedge that was beneath the canopy of trees.

2.3.2 Adjacent landuse and vegetation characteristics

Landuse adjacent to the hedge and adjacent vegetation was sketched where access was feasible. Notes were made about the presence of, location, and distance from the hedge of roads, pavements, shrubs, trees, buildings and any other notable features based on direct observations with use of supplementary information from Google maps and OS maps.

Details of the landuse within 5 m of either side of the hedge were recorded, including:

- Type of land cover. The use of that area was recorded and features measured. If landuse varied these different areas were sketched and annotated. E.g. if a pavement was adjacent this would be sketched and the width measured and recorded, the verge on the other side of the pavement would also be included if it fell within the 5 m buffer.
- Vegetation Height (cm). Vegetation height was measured at three locations (10 m apart) along the length of the hedge and the average calculated. If there was significant variation in height of adjacent vegetation along the hedge length then 3 measurements were taken at each of the different heights and an average (mean) was recorded for each section on the sketch and an overall mean calculated to be used in the subsequent analyses.
- Floristic composition of the basal vegetation. This was assessed by identifying the 10 most abundant plant species and the % cover of the 30 m x 5 m section they occupied was estimated. However, floristic composition on most of the areas in front of the hedge was mown amenity grassland which was difficult to ID to species with little variation in flowering plant composition. Due to access issues to the side behind the hedge, there was an incomplete dataset .Thus these data were not included in subsequent analysis.
- Whether there was vegetation adjacent on one, both or neither side of the hedge was recorded.

2.3.3 Surrounding land cover – image analysis

The percentage cover of different land cover types surrounding each hedge within 50 m, 100 m and 250 m of either side of the hedge was calculated from high-resolution aerial photography (©ESRI digital data, 2018 Staffordshire University Licence) which was classified using the mapping software ArcGIS v10.5. These high resolution, false colour, images of Stoke-on-Trent and urban Newcastle-under-Lyme were used as a base from which to classify the landuse of the urban conurbation. The imagery consisted of 3 colour bands: red, green and blue.

Supervised classification was undertaken where training areas were used (see paragraph below) to exemplify the main categories of landuse (Enderle, 2005). The categories used were: woody vegetation (areas covered by trees or shrubs), rough grass (thick, tussocky grassland, allowed to grow tall), smooth grass (frequently mown grassland sometimes referred to as amenity grassland e.g. playing fields), shadows on grass (darker areas where shadows alter the colour of the land in the image), and impervious surfaces (concrete, tarmac or rooftops, for example which represent built up areas) .

Fifteen representative training areas across the image were identified for each class. A supervised classification was carried out using these training areas and the results checked visually for accuracy against the original image and against topographic maps of the city. Errors were identified as some sections within areas of woody vegetation were incorrectly classified as smooth grassland. To rectify this Nearest Neighbour analysis (Ebdon, 1985; Andy, 2005) was used, where adjacent pixels were compared and areas where there was more variation between pixels were classified as woodland.

Each 30 m hedge location was mapped as an arc (a 2-dimensional line) and a 50 m buffer polygon was created from each hedge. The new buffer polygon was overlaid on the categorised image and used to clip out the classified land cover data surrounding each hedge. The percentage of that area that was categorised into each landuse could then be calculated. This was repeated for 100 m and 250 m buffers. This method was a modified version of that used by Lancaster and Rees (1979).

2.4 *Statistical analysis*

2.4.1 Normality and significance testing

Statistical analysis was undertaken using SPSS versions 21 to 25®. Normality tests were carried out using Shapiro-Wilk tests. For comparisons of means where data were parametric ANOVA tests followed by Tukey's post-hoc tests (Ennos, 2012) were used, non-parametric data were compared using Kruskal-Wallis (a non-parametric equivalent of 1-way ANOVA) followed by Dunn's tests; in both cases Bonferroni corrections were applied (Dunn, 1964; Napierala, 2012).

2.4.2 Dimension reduction

Data describing hedge parameters and surrounding land use which were related to variations in species richness and abundance resulted in 34 variables. Some were expected to be related to each other. Dimension reduction using Principal Component Analysis (PCA) (Fodor, 2002) was undertaken in SPSS to identify colinearity between these variables.

2.4.3 Multivariate analysis

2.4.3.1 Generalized linear mixed models (GLMMs)

Generalized linear mixed models (GLMMs) are the best method for analysing non-normal data that have random effects (Bolker *et al.*, 2009). They combine two statistical methods 1. Linear mixed models that incorporate random effects and 2. generalized linear models which can handle non-normal data (Bolker *et al.*, 2009). The variation in fixed effects is of interest to the test e.g. does the abundance of birds vary with change in the fixed effect of height? (Graften and Hails, 2002; Bolker *et al.*, 2009). Here random effects are categorical variables where the variation within the categories is of interest rather than the impact of the category itself (Graften and Hails, 2002; Bolker *et al.*, 2009) i.e. does bird abundance in hawthorn hedges vary with height of the hedge? Here, hedge species is the random effect and many samples were taken from within the species of hawthorn.

In this study GLMMs were used to identify the variables which most strongly correlated with the variation in bird abundance and richness and abundance of mammals. GLMM are suitable for use with nonparametric data by linking them to another distribution family (Bolker *et al.*, 2009). The data for bird richness and abundance and mammal detections were nonparametric, and consequently data were converted (square-rooted, or log transformed) to a Poisson distribution family where necessary. The GLMM with Laplace approximation was used as this methodology was suitable when the mean of the response variable was less than 5 (as was the case for some of the richness data from the bird study and the mammal data), and suitable for use with only one random effect variable (Anon., no date a; Bolker *et al.*, 2009) and the software package Glmer (Bolker *et al.*, 2009) was used in R (R Development Core Team, 2008).

2.4.3.2 Random Forest analysis

Random Forest (RF) is an algorithmic model which ‘learns’ the relationships between variables and is suitable for use with many variables and a low number of repeats and the method is not affected by collinearity, as it can automatically manage interactions (Oppel and Huettmann, 2010). Random Forest analysis generates decision trees using a boot-strapped sample (selection) of the data where it selects the best predictor variable at each branch. Many decision trees are produced based on a different boot strapped selection of data, thus creating a forest where the accuracy increases by building on the results from the previous trees (Liaw and Wiener, 2002; Oppel and Huettmann, 2010).

The importance scores for each variable are generated by calculating the percentage increase in the mean squared error resulting from removing that variable from the model (i.e. how much less effective the model becomes without that variable). As a sample subset is used each time a tree is generated then the importance of each variable can change with each run although the relative importance is fairly stable between runs, the specific values can vary (Liaw and Wiener, 2002). Therefore the process was run 500 times and the median and range of importance scores for each variable is represented as a boxplot. The Random Forest R-code was adapted from Liaw and Wiener (2002) and run in the RStudio package version 3.4.1 (R Development Core Team, 2008) using the package randomForest. Significance tests (ANOVA) were carried out on the importance scores given to each variable over the default 500 runs to establish if there was a significant difference in the importance of the factors in explaining the variation of the comparison factor (e.g. abundance of birds in the area). Where significant differences were found Tukey's post-hoc tests were used.

Extra variables selected were the proportions of rough grass, smooth grass and woody vegetation within a 50 m buffer. 50 m was selected as the buffer size to include as this roughly coincides with the size of home ranges for mice and voles on good quality habitat (Attuquayefio, Gorman and Wolton, 1986; Erlinge *et al.*, 1990) and with the reduced home range during nesting season of the house sparrow (Shaw *et al.*, 2011). The proportion of woody vegetation in 250 m was also included as Jones and Leather's, (2012) work reports that the amount of woody vegetation in a wide area around a survey site influences the numbers and diversity of invertebrates found and the work of Hinsley *et al.*, (2002) highlights the importance for birds. The percentage of impervious surfaces within 250 m were also included as this not only indicates the level of urbanness but also is the inverse of percentage green space thus accounting for the amount of grassy vegetation too. (Appendix B)

2.4.4 Discriminant analysis

Discriminant Analysis of Principal Components (DAPC) was used to identify if the differences between the richness and abundance of birds found using hedges of different species was attributable to variation of the other assessed variables (e.g. hedge volume, percentage of vegetative cover on the side in front of the hedge) rather than characteristics provided by the hedge species itself. DA tries to identify differentiation between groups by partitioning variation into a 'between group' and 'within group' component and synthesises its own variables (components) on which to align these predefined groups (Jombart and Devillard, 2010). It is able, therefore, to partition-out the within group variation to more adequately discriminate individuals between groups when compared to PCA methodologies (Jombart and Devillard, 2010).

3 Birds of Urban Hedges

3.1 *Introduction*

3.1.1 Birds in urban environments

As the human population increases and our urban areas expand, the habitats that would have previously been inhabited by birds are becoming smaller, more fragmented and more altered, both in the UK and globally (Marzluff, 2001; Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013). Urbanisation is one of the main causes of biotic homogenisation due to making the area suitable for one species, humans. This homogenisation may be on a global scale as many cities are similar throughout the world and as cities are modernising this is becoming more pronounced (Mckinney, 2006). In many UK cities, the streets have become cleaner (Robinson, 2005; Laet and Summers-Smith, 2007) and recently, there has been an increase in the density of buildings within city areas due to urban infilling, redevelopment of brownfield sites, and infilling of gardens. This further reduces open spaces (Robinson, 2005; Evans, Newson and Gaston, 2009) and reduces the abundance of 'weedy' species available which are important for seed production. Increasingly tidy gardens with the inclusion of more built features such as patios, decking and more formal planting reduce the vegetative cover and complexity and reduce the number of weed seeds and insect availability (Robinson, 2005). This densification and infilling within city areas, results in decreased habitat availability, reduced patch size, increased edge, increased non-native vegetation, and decreased vegetation complexity resulting in isolated, degraded patches (Marzluff, 2001; Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013). Urbanisation is widely considered to be a cause of loss of bird species (Lancaster and Rees, 1979; Marzluff, 2001; Chace and Walsh, 2006; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009; Lepczyk *et al.*, 2017) as bird species richness in cities is often lower than that of surrounding areas (Lancaster and Rees, 1979; Lepczyk *et al.*, 2017). The same may not be the case for bird density (Marzluff, 2001; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009) and total abundance and biomass may be higher in urban areas than surrounding more natural areas (Lancaster and Rees, 1979). Human population density is strongly associated with areas of high energy availability (high inputs of sunshine, good water supply) and, as such, with areas in which richness of other species would be high; but, as human population increases the rate at which other species diversity increases with increased energy availability is reduced (Araújo, 2003; Gaston and Evans, 2004; Evans and Gaston, 2005; Bonier, 2012).

Birds and vascular plants are heavily impacted by urban sprawl (Concepción *et al.*, 2016). Bird species diversity is lowest in city centre areas - characteristically having higher proportions of sealed surface, and is commonly found to be highest at moderate levels of urban development such as suburbs (Evans, Newson and Gaston, 2009; Beninde, Veith and Hochkirch, 2015) as there is often high habitat heterogeneity in such areas (Evans, Newson and Gaston, 2009). Not all species of bird are affected similarly by levels of urbanisation and the higher bird abundance is often a result of an increase in common species adapted to urban conditions whilst specialist species still hang on (Concepción *et al.*, 2016). Total bird density usually peaks in highly developed regions but the community is usually dominated by a few synanthropic (associated with man) species (Evans, Newson and Gaston, 2009).

Species decline could be predominately due to the loss of suitable habitats and habitat fragmentation (Marzluff, 2001; Evans, Newson and Gaston, 2009). Smaller habitat patches are widely accepted to be able to support fewer species (MacArthur and Wilson, 1967)

Patches of natural or semi-natural habitats within urban areas are often small with high edge ratios, increased non-native vegetation and low structural diversity (Vergnes, Kerbiriou and Clergeau, 2013; Dover, 2015). Fragmentation frequently influences avian assemblages and patch size has been identified as an influential factor affecting species richness as was the level of isolation of a patch (Evans, Newson and Gaston, 2009). There are also issues including increased nest predation (Marzluff, 2001; Chace and Walsh, 2006; Arroyo-Solís *et al.*, 2013), nest parasitism (Chace and Walsh, 2006), supplementary feeding e.g. bird feeders in people's gardens (Lancaster and Rees, 1979; Fuller *et al.*, 2008; Evans, Newson and Gaston, 2009), physical disturbance (Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013) and disturbance in the form of traffic noise and the effects of artificial light (Arroyo-Solís *et al.*, 2013). There is also the increased rick of collision with man-made objects and infrastructure (Klem 1989 in Chace and Walsh, 2006). Modern buildings have more sealed surfaces with fewer opportunities for nest building (Arroyo-Solís *et al.*, 2013; Snep *et al.*, 2016). These changes are occurring both locally and globally (Marzluff, 2001). The reduced bird species diversity in highly urbanised areas may also be due to a lack of time for species to adapt to the relatively new urban environment (Emlen (1974) in Lancaster and Rees, 1979).

Not all bird species are affected by urbanisation in the same way. There is often thought to be an increase in non-native species (Marzluff, 2001) at the expense of specialist species (Concepción *et al.*, 2016), but this is not always the case (Bonier, 2012). More recent research suggests that urban bird assemblages are more native-rich and that cities are not homogenised at a global level (Lepczyk *et al.*, 2017). It is widely accepted however, that certain species do survive better in urban areas than others (Marzluff, 2001; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009; Clucas *et al.*, 2011) and that highly urbanised habitats are dominated by a few bird species (Lancaster and Rees, 1979). Species composition changes as environments become more urbanised (Marzluff, 2001; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009) and birds of urban areas are generally categorised into three groups: urban avoider e.g.tree pipet (*Anthus trivialis*), urban adapter e.g. common swift (*Apus apus*) (Bhattacharya, Primack and Gerwein, 2002)(Shwartz, Shirley and Kark, 2008) and red kite (*Milvus milvus)* (Orros and Fellowes, 2015), and urban exploiter e.g. the house sparrow (*Passer domesticus*) (Sandström, Angelstam and Mikusiński, 2006; Bonier, 2012; Lepczyk *et al.*, 2017). Urban avoiders are usually absent in highly urbanised areas but may be present in more natural areas within a city, urban adapters or urban users can survive in urban areas but populations require immigration from non-urbanised areas to persist, (Lepczyk *et al.*, 2017) for such populations urban habitats may be population sinks (Chace and Walsh, 2006), urban exploiters or dwellers can survive and persist, even thrive, in urban areas (Sandström, Angelstam and Mikusiński, 2006; Lepczyk *et al.*, 2017).

Fragmentation results in the loss of ground (e.g. woodlark (*Lullula arborea*)) or hole nesters (e.g. common redstart (*Phoenicurus phoenicurus*)), forest birds (e.g. marsh tit (*Parus* palustris) (Dorp and Opdam, 1987)) and species which require larger areas of intact habitat (Marzluff, 2001; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009). Increased levels of nest predation (Marzluff, 2001) e.g. from cats (Churcher and Lawton, 1987) and avian predators such as sparrow hawks (*Accipiter nisus*) (Robinson, 2005), leads to decreases in birds who nest in interior habitats - preferring to nest in areas away from the edge of a habitat in an area of more stable continuous (core) habitat, and ground nesters with increased levels of urbanisation (Marzluff, 2001). These types of bird are found in lower numbers and found at lower species diversity in city centre areas and higher numbers towards the periphery (Sandström, Angelstam and Mikusiński, 2006). These differences in relative abundance of types of bird may not be stable throughout the year e.g. insectivore abundance decreased in all types of urban habitats during winter months; probably due to a decrease in abundance of insects for food (Lancaster and Rees, 1979). Studies have noticed a reduction in migratory species in urban areas (Reale and Blair, 2005) but the causes of this are not fully understood. Hypotheses include smaller individuals being forced into urban areas due to being out competed in rural habitats, different composition of plant species (Ohio State University, 2008), or an inability of migratory birds, with their reduced number of broods per year, to compensate for nesting losses in urban areas where nesting success tends to be lower (Reale and Blair, 2005). In urban areas migratory birds also arrive later (Tryjanowski *et al.*, 2013) and begin nesting later, reducing time available for rearing broods, fewer re-nesting attempts were made by migratory birds and fewer birds returned in subsequent years (Ohio State University, 2008).

Raptors have home ranges that extend beyond the urban boundary and therefore the urban area does not necessarily account for all its habitat requirements. Some species of raptor often favour urban environments where they can experience reduced persecution by humans, which is more commonplace in rural areas, and a good food supply of smaller birds. Not all species of raptor are affected in the same way by urban environments and not all species can find suitable nesting sites or abundant prey (Chace and Walsh, 2006). Urban nesting sites in bridges and overpasses, and buildings were found to be important for the Peregrine Falcon (*Falco perigrinus*) particularly in the Midwest of USA where urban birds were found to make up 58% of its regional population in a study of 60 urban areas (Cade *et al.*, 1996; Chace and Walsh, 2006). The Mississippi Kite (*Ictinia mississippiensis*) was also found to be abundant in urban areas of North America with large populations in towns and cities. They nest in wooded areas and have shown to have greater breeding success and denser populations in urban areas than in rural areas and their major prey is large insects and in some areas a large number of vertebrates and this change to a more varied diet may have helped them to expand into urban areas (Parker, 1996).

There is an increase in species able to nest on buildings (e.g. swifts and swallows) (Lancaster and Rees, 1979; Marzluff, 2001), however, some buildings are more suitable to facilitate nesting than others. Older buildings tend to have more cavities and ledges than the more modern housing stock with energy efficient windows and soffits and an increased use of PVC, offering fewer cervices for nesting and perching. More nesting sites are found in buildings in more socially deprived areas where houses are often less frequently repaired (Summers-smith, 2003; Robinson, 2005).

The majority of built modern structures are closed with barren surfaces and offer very little opportunity for nesting or even song or resting perches. Structural heterogeneity of the built environment may provide holes, crevices and ledges for nesting and in highly urbanised areas but, as these may be the only available spaces for nesting, the species present would be restricted to those able to nest in such habitats. Therefore there is decreased species diversity with an increase in built structures as these offer much less ecological benefit than would trees or bushes (Lancaster and Rees, 1979).

The ability of an avian species to do well in urban environments reflects its ability to adapt to the urban environment and to levels of nest predation and parasitism, changes in predator assemblages, food supply and disease (Chace and Walsh, 2006). Urban-breeding birds tend to be common, generalists (Bonier, 2012; Concepción et al., 2016), granivorous or omnivorous, cavity nesters (Lancaster and Rees, 1979; Chace and Walsh, 2006; Lepczyk et al., 2017), or ledge nesters and ground feeders (Lancaster and Rees, 1979). Such species, often termed urban birds (Sandström, Angelstam and Mikusiński, 2006), are used as urban indicators (Sandström, Angelstam and Mikusiński, 2006) as their populations are higher in urban areas than in other areas (Evans, Newson and Gaston, 2009) and often dominate bird communities of the more industrial or urbanised city areas. Examples of urban birds include house sparrow (*Passer domesticus*), common starling (*Sturnus vulgaris*) and rock dove (*Columba livia*) which are common in cities all over the world (Lancaster and Rees, 1979; Bonier, 2012). Twenty seven species have been identified as urban dwellers of UK cities some of which are red list species e.g. house sparrow, common starling and song thrush (*Turdus philomelos*) and some are amber listed including the mistle thrush (*Turdus viscivorus*) and the dunnock (*Prunella modularis*) (Evans, Newson and Gaston, 2009) (Table 3-1) It is likely, however, that even urban indicator species are dependant upon the woody vegetation cover in such areas as the abundance of even these species is likely to increase a urban gardens and green spaces mature and become more leafy (Henderson *et al.*, 2007).

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Table 3-1 Bird species commonly found in urban areas (Urban Indicators (Henderson *et al.*, 2007)*) adapted from* Evans, Newson and Gaston (2009)*. Data from the NBN gateway accessed November 2018. Information on their specialisms and concern status were obtained from* Orłowski (2008), Evans, Newson and Gaston (2009) and Hinsley and Bellamy (2019)*. Species ordered by number of recordings in the area (NBN data).*

Common Name	Scientific Name	Urban Dweller	Urban specialist	Species of conservation concern	Species known to use Hedgerows	Number of NBN Gateway (record within 5km radius ST4 2DE)
Blackbird	*Turdus merula*	✔			✔	9955
Woodpigeon	*Columba palumbus*	✔				8238
Blue Tit	*Cyanistes caeruleus*	✔			✔	9188
House Sparrow	*Passer domesticus*	✔	✔	✔		7791
Robin	*Erithacus rubecula*	✔			✔	8387
Common Starling	*Sturnus vulgaris*	✔		✔		5944
Eurasian Magpie	*Pica pica*	✔			✔	8316
Carrion Crow	*Corvus corone*	✔				4236
Great Tit	*Parus major*	✔			✔	7240
Greenfinch	*Carduelis chloris*	✔			✔	4780
Wren	*Troglodytes troglodytes*	✔			✔	4789
Collared Dove	*Streptopelia decaocto*	✔	✔			6631

Chaffinch	*Fringilla coelebs*	✔			✔	4263
Dunnock	*Prunella modularis*	✔		✔	✔	7415
Song Thrush	*Turdus philomelos*	✔		✔	✔	1996
Goldfinch	*Carduelis carduelis*	✔			✔	4048
Mistle Thrush	*Turdus viscivorus*	✔		✔		2231
Blackcap	*Sylvia atricapilla*	✔				1433
Mallard	*Anas platyrhynchos*	✔				1043
Eurasian Jay	*Garrulus glandarius*	✔				641
Long-tailed Tit	*Aegithalos caudatus*	✔			✔	2874
Jackdaw	*Corvus monedula*	✔				2912
Pied Wagtail	*Motacilla alba*	✔				595
Green Woodpecker	*Picus viridis*	✔		✔		142
Common Swift	*Apus apus*	✔	✔	✔		844
Eurasian House Martin	*Delichon urbicum*	✔	✔	✔		606
Sparrowhawk	*Accipiter nisus*	✔				1259

Different urban settlements present similar opportunities and challenges meaning that urban bird assemblages may be more similar to those of other urban areas than to those of the surrounding less disturbed habitats (Chace and Walsh, 2006). However, cities do vary considerably and the habitats and areas within a city can also vary considerably (Lancaster and Rees, 1979; Snep *et al.*, 2016), and these variations are reflected in the bird assemblages (Evans, Newson and Gaston, 2009; Beninde, Veith and Hochkirch, 2015). There is a lack of research to help us to fully understand the patterns of distribution and the drivers of these variations (Evans, Newson and Gaston, 2009) but it is thought to be influenced by the cities' landcover, intact vegetation and age of the city (Aronson *et al.*, 2014; Beninde, Veith and Hochkirch, 2015). Urban bird assemblages are found to respond positively to increased structural complexity, species richness of woody vegetation and to supplementary feeding and negatively to human disturbance (Lancaster and Rees, 1979; Evans, Newson and Gaston, 2009). Fragmentation frequently influences avian assemblages as patch size was found to be important (Evans, Newson and Gaston, 2009; Beninde, Veith and Hochkirch, 2015) as were corridors, but vegetation composition and structure were found to have the greatest impact on avian biodiversity (Chace and Walsh, 2006; Beninde, Veith and Hochkirch, 2015) and were found to be more influential than the level of isolation (Evans, Newson and Gaston, 2009). Birds prefer urban areas that retain more native species and 'natural' vegetative structure (Chace and Walsh, 2006). So it is important that corridors and urban habitats are wide and complex enough to act as a habitat.

Local factors were found to be more influential to conservation and to species richness than regional factors which highlights the importance of improving habitats within towns and cities to support bird species (Evans, Newson and Gaston, 2009) and many studies e.g. Sandström, Angelstam and Mikusiński, (2006) use birds as an indicator of the health of urban green spaces. Biodiversity-friendly management has a positive impact, alongside improving patch quality, focus needs to be on remedying fragmentation, ensuring larger patch sizes and greater connectivity via the creation of a network of corridors (Concepción *et al.*, 2016; Snep *et al.*, 2016). This challenge for implementing effective green infrastructure requires collaboration with landscape architects to place more importance on the inclusion of green habitats whilst maintaining compact urban growth yet avoiding the formation of very dense urban areas lacking in important green elements (Concepción *et al.*, 2016).

Vegetation is very important in provision of habitat for urban birds (Lancaster and Rees, 1979) and is more beneficial if the vegetation is native as exotic plants tend to have fewer insects than native plant species (Southwood, 1961; Chace and Walsh, 2006; Helden, Stamp and Leather, 2012; Snep *et al.*, 2016). Urban bird species diversity, richness and abundance increase with foliage height, diversity and total vegetation cover. Trees and woodland are particularly important; it has been found that the presence of a tree layer may be the most important factor in the increase of bird species richness and urban woodland is important to the abundance of insectivores. If these woody habitats are woody species rich and managed for increased structural diversity and complexity of foliage, bird species diversity is likely to increase (Lancaster and Rees, 1979; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009). A complex vegetation structure is usually associated with the provision of a range of accessible niches, foraging areas and food supplies, a range of suitable nesting sites, and therefore the ability to support a wide range of species (Lancaster and Rees, 1979; Snep *et al.*, 2016).

As birds respond differently to different habitats and management regimes it needs to be considered whether to focus on specific species or biodiversity as a whole (Evans, Newson and Gaston, 2009). For example, starlings were found most commonly in areas where vegetation cover was between 35 and 85% with grassy vegetation predominating. House sparrows were not found in areas where vegetation cover was 60% or higher and were not found in woodland areas (Lancaster and Rees, 1979). As species of conservation concern were only found in low numbers, if at all, and found only in few urban habitats perhaps conservation should be targeted to increase their numbers (Evans, Newson and Gaston, 2009). With the house sparrow being red listed (Commission, 2018) some recent research has been undertaken to investigate how to manage urban habitats for their benefit (e.g. Churcher and Lawton, 1987; Summers-smith, 2003; Robinson, 2005; Laet and Summers-Smith, 2007; Shaw *et al.*, 2011; Węgrzynowicz, 2013). There is a requirement for some urban structures to facilitate the house sparrow which may be deterred by increased woody vegetation cover. Improving conditions for one species, in most cases, however, may also improve conditions for others.

3.1.2 Birds in hedges

Hedges are the woody component predominantly planted as field boundaries, with or without trees, which may or may not undergo management (Greaves and Marshall, 1986; Baudry, Bunce and Burel, 2000; Dover, 2019a) (See Rationale section 1.6) which support rural biodiversity (e.g. Forman & Baudry, 1984; Dover & Sparks, 2000; Groot et al., 2010). Hedges are well established features of the British landscape, existing for many centuries in both rural areas and in our towns and cities (e.g. Rackham, 1986; Barr and Gillespie, 2000; Baudry, Bunce and Burel, 2000; Oreszczyn and Lane, 2000; Faiers and Bailey, 2005; Nozedar, 2012). Their original function was to: delineate boundaries, mark ownership, contain stock, act as wind breaks and act as a source of wood and wild food. Their ecological value is now well recognised (Rackham, 1986; Baudry, Bunce and Burel, 2000; Oreszczyn and Lane, 2000). Hedges can be aesthetically pleasing features of urban environments (Faiers and Bailey, 2005; Gosling *et al.*, 2016) but little is known about the ecological value of our urban hedgerows and without this knowledge we do not know how to protect, expand or future proof these valuable elements of our green infrastructure (Defra, 2007a).

Rural hedges are well known for their importance to biodiversity (Boughey *et al.*, 2011; Dainese *et al.*, 2015; Staley *et al.*, 2016; Lecq *et al.*, 2017; Newton, 2017; Hinsley and Bellamy, 2019), due to their complex structure and large volume support more birds than other field boundary types (Hinsley and Bellamy, 2019) and are now protected in the UK as priority habitat (JNCC and Defra, 2012). Well managed hedges offer habitats in their own right for a range of vertebrate, and invertebrate species (PTES, 1993; Amy *et al.*, 2015; Anderson, 2002; Dover & Sparks, 2000; Hedgelink, n.d.; RSPB, n.d.; Staley *et al.*, 2016). They are important for food provision, nesting and shelter for farmland birds (Vickery, Feber and Fuller, 2009; Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018). In farmland areas most birds are found on or near to hedges (Batáry, Matthiesen and Tscharntke, 2010) and birds can be found in very high densities within hedges during the breeding season (Newton, 2017). Hedges may offer the only place where plant and animal species can find resources in some areas (Garratt *et al.*, 2017). In the UK, Hedgerows are associated with 65 bird species (UK Biodiversity Steering Group, 1995; Graham *et al.*, 2018) with 66% of lowland terrestrial birds estimated to breed within hedgerows (Forman and Baudry, 1984). Seven species are considered to be hedgerow specialists: dunnock (*Prunella modularis*), whitethroat (*Sylvia communis*), lesser whitethroat (*Sylvia curruca*), linnet (*Linaria cannabina*), goldfinch (*Carduelis carduelis*), greenfinch (*Chloris*

chloris) and yellow hammer (*Emberiza citrinella*) (Fuller *et al.*, 2001; Graham *et al.*, 2018). Other species are known to use hedgerows for other purposes including: foraging, shelter, and protection from predators when foraging in local areas (Forman and Baudry, 1984; Whittingham and Evans, 2004; Graham *et al.*, 2018) e.g. woodpigeon (*Columba palumbus*), reed bunting (*Emberiza schoeniclus*), stock dove (*Columba oenas*), tree sparrow (*Passer montanus*) (Whittingham and Evans, 2004), and management should also consider these (Graham *et al.*, 2018).

The ecological functions of hedges are affected by their species composition, history, and past and present management (Baudry, Bunce and Burel, 2000; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Gosling *et al.*, 2016; Graham *et al.*, 2018) and adjacent landuse (Forman and Baudry, 1984; Faiers and Bailey, 2005; Gosling *et al.*, 2016) (See Rationale Section 1.8).

A hedge provides a habitat unlike any that would be found elsewhere in rural (Graham *et al.*, 2018) or urban habitats and this impacts the abundance and diversity of birds (Benton, Vickery and Wilson, 2003). The management of hedgerows impacts their physical structure (Hinsley and Bellamy, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018). Birds are more abundant in long (Burel and Baudry, 1995; Graham *et al.*, 2018), wide, tall hedges (Newton, 2017) with a heterogenous hedge structure (Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018; Hinsley and Bellamy, 2019), however there are exceptions e.g. the Common Linnet (*Carduelis cannabina*) prefers shorter hedges (Whittingham and Evans, 2004). There are more birds in hedges with more, taller, trees and when associated with wide diverse boundary features e.g. grassy verges or ditches (Newton, 2017). Trees are beneficial in hedges to many species through the provision of forage, singing posts and nesting sites for some, however trees may provide a vantage point for avian predators. Nesting may be more successful in hedges with a denser structure as nests are more difficult for predators to see and may be a barrier to their entering the hedge (Hinsley and Bellamy, 2019).

Sensitive management on either side of a hedge is also key to increasing its value to biodiversity (Barr and Gillespie, 2000; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018). Some birds prefer taller vegetation particularly at some times of year, shorter vegetation is likely to encourage foraging efficiency yet longer vegetation is known to increase food supplies. Habitat heterogeneity from a matrix of short and long vegetation is associated with higher biodiversity in farmland landscapes (Benton, Vickery and Wilson, 2003; Whittingham and Evans, 2004; Hinsley and Bellamy, 2019).

Providing more hedgerows and carefully manging them has been demonstrated to have a significant effect on preserving farmland birds particularly in landscapes that did not have many habitats that provide good opportunities for nesting such as woodlands, copses, bushes and trees (Batáry, Matthiesen and Tscharntke, 2010). Such habitats are rare in some urban environments and it is likely to follow that adding hedges with carefully managed adjacent vegetation to our towns and cities may have a large impact on richness and diversity of urban birds. (For more information on hedgerow management see rationale section 1.8).

3.1.3 Hedges in urban environments

Hedges in urban environments often have a different woody species composition and management regime to those of rural hedges (See Rationale section 1.9). This, alongside their adjacent landuse may strongly influence their suitability to support wildlife and the communities which they support. There is little published information on the use of urban hedgerows by birds.

3.1.4 Benefits of nature within our cities

Although urbanisation creates a potentially hostile environment for many bird species the unique environment also creates niches to exploit. Many urban habitats accommodate a rich, diverse bird fauna (including some endangered species), offer prime habitat for some species (Clucas *et al.*, 2011; Snep *et al.*, 2016) and play a part in metapopulation dynamics. With improved green infrastructure and sensitive management of our urban green spaces, urban areas have potential to offer much more to breeding birds (Clucas *et al.*, 2011; Snep *et al.*, 2016). Such sensitive management not only benefitting biodiversity but humans as well through experiences of nature (Snep *et al.*, 2016) as there is mounting evidence of the health benefits to humans of urban birds (e.g. Bhatti and Church, 2001; Fuller *et al.*, 2008; Snep *et al.*, 2016) (See Rationale section 1.5 and chapter 6).

Management of urban green spaces has, for a long time, been aimed to create a ‘tidy’ aesthetic (e.g. Hull, 1992; Parsons, 1995; Fuller *et al.*, 2007; Hoyle, Hitchmough and Jorgensen, 2017; Southon *et al.*, 2017) and this has been reflected in the management of urban hedges (Oreszczyn, 2000; Oreszczyn and Lane, 2000; Faiers and Bailey, 2005; Gosling *et al.*, 2016).

Conflict between managing hedges for wildlife, the constraints imposed by the urban environment, and the acceptability of the aesthetics of wildlife hedges to people living or working in their vicinity must be considered (see chapter 6 Perceptions of urban hedges).

3.1.5 Research gap

There is extensive research on the use of rural hedges by birds. Research into urban birds has identified great potential for improvements to be made to urban areas through improving or increasing the semi-natural habitats. There is a lack of knowledge of the use of specific habitats including hedges by birds within urban environments to explain the variation in their richness and abundance. With continued urban expansion and an increased understanding of the importance of green infrastructure, developing our understanding is essential to inform planners and developers of the importance of protecting or enhancing these green resources within our growing towns and cities. As urban hedges differ in species composition, management regimes and adjacent landuse to rural hedgerows (Faiers and Bailey, 2005; Gosling *et al.*, 2016) research is required to help to develop appropriate management recommendations which consider these differences. We need to assess the current status of the hedges in terms of their species composition, physical structure and the adjacent landuse and investigate the use of these hedges by birds. Findings can then be interrogated to identify which characteristics affect the abundance and richness of bird species using the hedges. This study aims to develop our understanding of the use of urban hedges by birds and to assess the parameters which influence their use through answering the following questions.

3.1.6 Research questions

1. Are there more birds found in areas with hedges than areas without?
2. Does the woody hedge species affect the richness and abundance of birds found to be using the hedge and the surrounding area?
3. Which other characteristics of the hedge and surrounding area affect the richness and abundance of birds?

3.2 Method

3.2.1 Hedgerow selection criteria

3.2.2 Hedgerow selection

Of the hedges identified through driving tours around the city, 13 hedges of each of beech, hawthorn and privet species were selected to be surveyed for bird use and 13 no-hedged control locations were also selected (as described in methods chapter section 2.2). Example hedges can be seen in Appendix A.

Controls were areas where no hedge was present and could include: a large gap in a hedge, railings, fence panels and brick walls. Examples included where a large section of hedge had been removed, where a hedge section has been replaced by a fence, or on the opposite side of the road to a study hedge where no hedge is present. These were deemed suitable providing similar land use existed behind the control and were not more than 150 m away from (although most were much closer) a survey hedge (Figure 3-1).

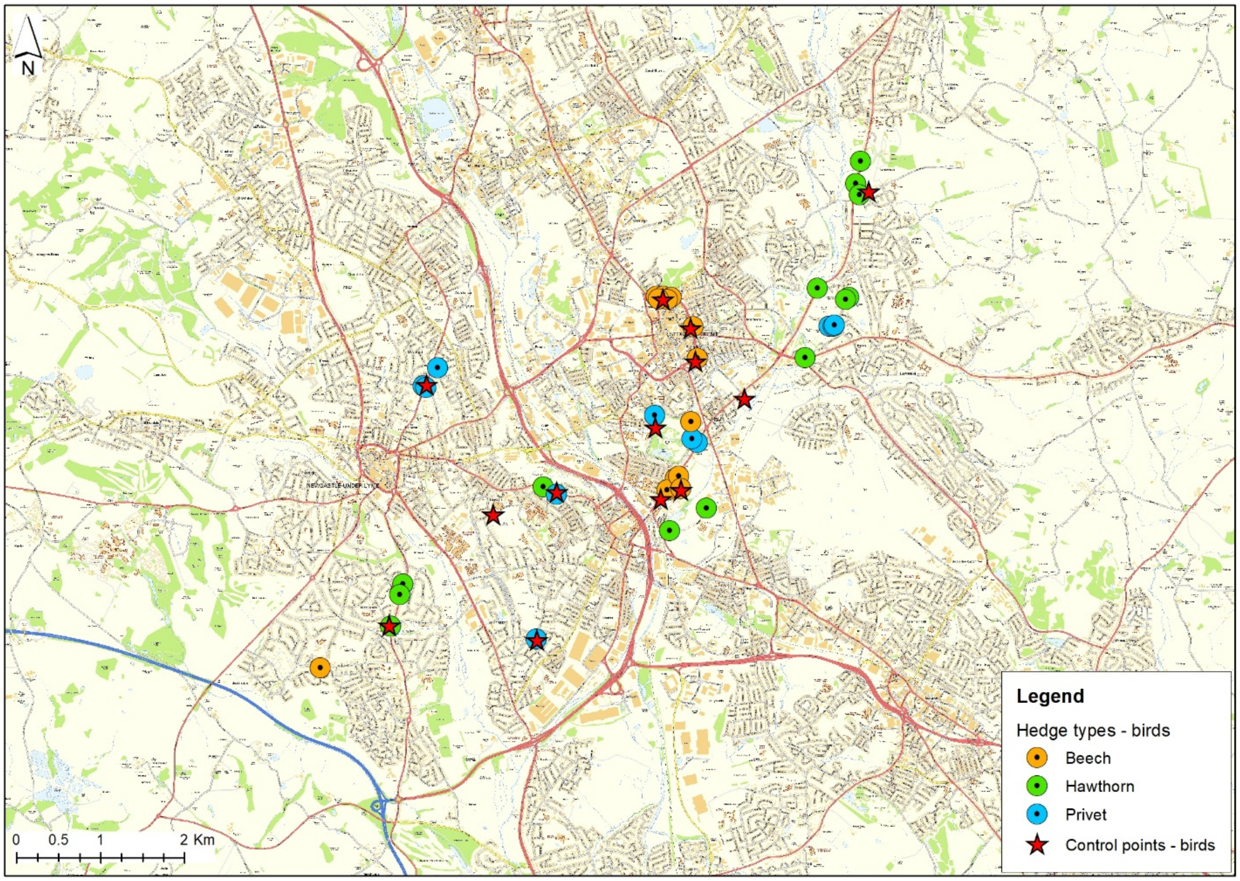


Figure 3-1 Locations of study hedges and control sites used for bird surveys within Stoke-on-Trent. ©ESRI digital data, 2018 Staffordshire University Licence

3.2.3 Hedge and adjacent landuse surveys

The data on the physical properties of the hedge and adjacent landuse were surveyed (for a full list of parameters see methods section 2.3). Variation in the use of the surrounding landscape was measured using classified aerial photography in ArcGIS (see methods section 2.3.3).

3.2.4 Bird surveys introduction

Bird survey methodologies commonly include point counting where a survey plot or location is entered, a set time of waiting is observed and all birds (except those just flying over) seen in the survey plot in a set time are recorded with the surveyor remaining in the same position (Hamel *et al.*, 1996; Sisk, Haddad and Ehrlich, 1997; Saab, 1999; Melles, Glenn and Martin, 2003; Batáry, Matthiesen and Tscharntke, 2010). Walking a survey route is a commonly used method where a surveyor walks a set route and maps the location and number of all birds (except those just flying over) (e.g. Fischer et al., 2011). These methodologies produce bird inventories – a list of all species observed on a particular piece of land (Hamel et al., 1996) this is useful for presence/absence surveys and if repeated annually then the data can be used to provide information on numbers and trends (Hamel et al., 1996). Direct strip methodologies involve walking a set route through a survey plot and recording the activities, species location and activities of all birds seen or heard (Lancaster and Rees, 1979)

Sounds of birds were not included in this survey as it was not possible to accurately identify whether the bird was in the hedge, behind the hedge or in the trees above. Also, the volume of traffic in the areas made it difficult to hear the birdsong at times during the surveys.

A point count methodology was the basis for the survey techniques adopted, but bird behaviours were also recorded as these would help to ascertain what the birds were using the hedge for (e.g. shelter, breeding, a source of food). Predominantly, behaviours were used to indicate the likelihood of a species using the hedge for breeding purposes, as in the BTO/JNCC/RSPB Breeding Bird Survey (Risely *et al.*, 2013)

A multispecies survey was appropriate for this study as the bird populations using urban hedges is relatively poorly known; this methodology, is suitable for estimating the impacts factors or habitat variations have on the distribution and diversity of birds (Bibby, 2004). For this study the factors being hedge species, hedge physical properties and surrounding landuse.

To identify what the birds were using the hedge for (e.g. were they using it as a food source, roosting, or as habitat in which to breed), behaviours of the birds needed to be recorded rather than just count data. A pilot field study was undertaken to ascertain the behaviours exhibited by birds (what the birds were doing) and to evaluate the survey methodology in such urban environments. An ethogram (list of observed behaviours) (Table 3-2) adapted from those in the Breeding Status codes of the British Trust for Ornithology used in the Breeding Evidence Survey (BTO, 2011) was produced. The breeding bird survey ethogram categorised behaviours which suggest the level of likelihood of the observed bird using the area for breeding purposes. Similar categories were utilised for this study. The study ethogram also included: Associated Perching - where birds were perched, for example on a lamppost or tree which was also in the study area (5 m either side of the hedge and the air above), was included to incorporate the information on birds using the area adjacent to the hedge as well. Behaviours that indicated use for shelter and feeding were also recorded. These included flying into the hedge and also moving along the hedge and feeding on insects or berries.

Table 3-2 Ethogram of bird behaviours. Adapted from the Breeding Evidence Survey (BTO, 2011) *with additional behaviours observed during pilot studies.*

Using area	
F	Flying over
AP	Associated Perching – using a structure or tree in the adjacent areas
GF	Feeding on the ground within 5 m in front of the hedge
Using hedge	
Feeding	
FB	On **B**erries
FS	On **S**eeds
FI	On **I**nsects
FP	Using hedge to scout **P**rey
Shelter	
SH	Flying into the hedge – not necessarily for nesting purposes
SO	Flying out of hedge
SC	Traveling along the hedge – corridor use
SP	Perching on top of hedge
BC	Bouncing along the base of the hedge
Breeding	
Possible Breeder	
H	Species observed in breeding season for which hedge is suitable nesting **H**abitat
S	**S**inging male present (or breeding calls heard) in breeding season in hedge if hedge is suitable breeding habitat
Probable Breeder	
P	**P**air observed in hedge if hedge is suitable breeding habitat
D	Courtship and **D**isplay in hedge if hedge is suitable breeding habitat
N	Visiting probable **N**est site within hedge
A	**A**gitated behaviour or anxiety calls from adults, suggesting probable presence of nest or young nearby
NB	**N**est **B**uilding
Confirmed Breeding	
DD	**D**istraction **D**isplay or Injury Feigning
UN	**U**sed **N**est or eggshells found
FY	Recently **F**ledged **Y**oung or downy young – providing young are not capable of significant geographic movement (still dependant on adults)
ON	Adults entering or leaving nest site indicating that it is **O**ccupied or seen on a **N**est
FF	Adults carrying **F**aecal sack or **F**ood for young
NE	**N**est Containing **E**ggs

NY	**N**est seen containing **Y**oung

3.2.5 Bird surveys

Hedges and control locations were surveyed using multispecies (Bibby, 2004) observational surveys following a point count methodology (Hamel *et al.*, 1996; Sisk, Haddad and Ehrlich, 1997; Saab, 1999; Melles, Glenn and Martin, 2003; Batáry, Matthiesen and Tscharntke, 2010). An observation point was chosen for each hedge; this was approximately 10-15 m away depending on the width of adjacent roads. The same observation point was used for all subsequent surveys on that hedge/control location. The observer stood facing the survey hedge/control and information on the weather and traffic conditions and any notable observations were recorded during a 7-minute acclimatisation period to allow birds to become accustomed to the observer's presence (Chiquet, Dover and Mitchell, 2012). Any changes in weather or traffic intensity were noted down throughout the survey.

A stationary observation of the hedge, area 5 m in front, in the associated trees, and sky above was undertaken for 20 minutes. The size of the area is based on the study by Chiquet, Dover and Mitchell, (2012) who surveyed the 10 m area surrounding urban green walls. As this study is only examining the area in front of the hedge then 5 m was adopted. Bird species were identified (in one hedge dunnocks were present and were difficult to distinguish from house sparrows so the two species were combined) and behaviours were recorded for each bird occurrence (this may be multiple visits by the same individual or by different birds). If an occurrence continued without stopping (e.g. an alarm call or singing from on top of the hedge) it was counted as a new occurrence every 2 minutes. This, however, occurred infrequently but may have led to some pseudoreplication of birds. A behaviour was only recorded if there was visual observation of the individual. Hearing a bird alone was not sufficient as in periods of heavy traffic it was not possible to clearly identify the birdsong to a specific species and quieter birds species' calls may have been missed. Also, it is exceptionally difficult to pinpoint the source of the sound sufficiently to be sure if the sound was from within the hedge or from behind.

Bird behaviours were recorded, as in the breeding birds survey (Risely *et al.*, 2013), and categorised to indicate whether these were indicative of possible, probable or confirmed breeding (Table 3-2).

Each hedge/control location was surveyed 4 times as recommended by Mason and Macdonald (2000) and Fernández-Juricic (2004) on a rolling cycle to allow observations to be undertaken throughout the summer as different birds breed at different times of the year and also to mitigate the impacts of varying weather conditions. As it is known that bird activity and traffic volumes vary throughout the day each hedge was survey at different times within periods of peak activity and low activity. Surveys were undertaken in the 5 hours after dawn (30 mins before sunrise) on days of suitable weather conditions. Conditions were deemed unsuitable if winds were stronger than Beaufort scale 5 (Tennekes, 2009) or rain was particularly heavy (BTO, 2015). The 4 surveys of each hedge were spread over the summers (April to September) of 2014 and 2015.

A nest survey was undertaken during the post-nesting season of autumn 2016 following methodologies similar to that of Furguson-Lees, Castell and Leech (2011). This involved walking along the length each of the hedges and manipulating the vegetation by hand to allow the interior to be seen. The presence of a nest which looked like it had been used during the recent breeding season was recorded. It was assumed that a nest had been recently used if the nest appeared intact and not heavily damaged with some evidence of nest lining material.

3.2.6 Data analysis

Data were categorised to identify which birds were using the area i.e. including the ground immediately in front of the hedge and associated trees, which were using the hedge specifically, and those birds in the skies above (Table 3-3).

Table 3-3 Descriptions used to distinguish between the categories of area into which the data were collated.

Category	**Description**
Total abundance in area	The total counts of bird occurrences including those in the sky above and in the 5 m wide area in-front of the hedge/control location
Total abundance using area	The total counts of bird occurrences in the hedge, the 5 m wide area in-front of the hedge and those perched in associated trees or structures (e.g. fence posts or railings). This does not include birds flying through or over the area.
Total abundance using hedge	The total counts of bird occurrences in the hedge only
Total richness in area	The total number of different species occurrences including those in the sky above and in the 5 m wide area in-front of the hedge/control location
Total richness using area	The total number of different species of bird in the hedge, the 5 m wide area in front of the hedge and those perched in associated trees or structures (e.g. fence posts or railings). This does not include birds flying through or over the area
Total richness using hedge	The total counts of bird occurrences in the hedge only

Initial data analysis was undertaken using SPSS version 25. Unless otherwise stated, normality was tested using Shapiro-Wilk tests. For comparisons of means where data were parametric ANOVA tests followed by Tukey's post-hoc tests were used, non-parametric data were compared using Kruskal-Wallis followed by Dunn's tests; in both cases Bonferroni corrections were applied. Dimension reduction using Principal Component Analysis (PCA) was undertaken to identify colinearity between variables. (See Table 3-4 for variables included and selected following the procedure).

Multivariate analysis was undertaken using R (see section 2.4.3). This involved Generalised Linear Mixed-effect Modelling using the GLMmer with Laplace approximation to (see section 2.4.3.1). Random Forest Regression (RFR) analysis was used to identify the importance of the physical hedge and surrounding landuse variables in explaining the variations in bird richness and abundance (See section 2.4.3.2). Discriminant analysis of Principal Components (DAPC) was used to identify if the differences between the richness and abundance of birds found using hedges of different species was attributable to variation of the other assessed variables (see section 2.4.4).

Table 3-4 The environmental and hedge variables and which analyses they have been included in. ✔ indicates that the variable was included in the analysis. Side A and in-front of hedge mean the side of the hedge closest to the road where the surveyor was positioned. Side B or behind hedge means the side of the hedge facing away from the road and the observer.

Variables	**Inputted to PCA**	**Out of PCA**	**Included in GLMM**	**Included in DAPC**	**Included in RFR**
% Smooth Grass within 250 m	✔				
% Smooth Grass within 100 m	✔				
% Smooth Grass within 50 m	✔				
% Green Space within 250 m	✔				✔
% Impervious surfaces within 250 m	✔				
% Impervious surfaces within 100 m	✔				
% Green Space within 100 m	✔				
% Woody Vegetation within 100 m	✔				
% Woody Vegetation within 250 m	✔				
% Woody Vegetation within 50 m	✔				✔
% Green Space within 5 m	✔				✔
% Impervious surfaces within 5 m	✔				
% Woody Vegetation within 5 m	✔				
% Impervious surfaces within 50 m	✔	✔	✔	✔	✔
% Green Space within 50 m	✔				
Hedge Species	✔				
% Rough Grass within 100 m	✔				
% Rough Grass within 250 m	✔				
Total Length of Hedge	✔	✔	✔	✔	✔
% Rough Grass within 50 m	✔				✔
Hedge Volume	✔	✔	✔	✔	
Hedge Width	✔				
Hedge Height	✔				✔
Vegetation Height in 5 m A	✔				✔
Average Tree DBH	✔	✔	✔	✔	✔
Average Tree Distance	✔				
% Rough Grass within 5 m	✔				
% Canopy Cover	✔				✔
% Vegetation Cover in 5m A	✔	✔	✔	✔	✔
% Smooth Grass within 5 m	✔				
% Vegetation Cover in 5 m B	✔	✔	✔	✔	✔
Vegetation Height in 5 m B		✔	✔	✔	✔
Distance to road			✔	✔	✔

Table 3-5 Variable and the representative contraction used in the RF analysis. Side A and in-front of hedge mean the side of the hedge closest to the road where the surveyor was positioned. Side B or behind hedge means the side of the hedge facing away from the road and the observer.

Variable	**Contraction used in RF**
Adjacent vegetation	Adjacent _V
% Canopy Cover	Canopy cover
Average Tree DBH	DBH
% Rough Grass within 50 m	Grass_R50
% Smooth Grass within 50 m	Grass_S50
Hedge Height	Height
% Impervious surfaces within 250 m	Impervious_250
% Impervious surfaces within 50 m	Impervious_50
Inverse proximity to road	Inverse Proximity
Total Length of Hedge	Total_Length
Vegetation Height in 5 m A	V_Height_A
% Vegetation Cover in 5m A	V_Percent_A
Vegetation Height in 5 m B	Veg_HeightB
% Vegetation Cover in 5 m B	Vegetation B
% Impervious surfaces within 250 m	Woody_250
% Woody Vegetation within 50 m	Woody50
Hedge Volume	WxHx3000

3.3 *Results*

A total of 39 hedges (13 of each species) and 13 non-hedged areas were surveyed on a rolling cycle during the summer months of 2013 and 2014. Each hedge and non-hedged area was surveyed four times with a total of 208 surveys. Two thousand, six hundred and sixty three birds were surveyed, comprising 26 species and 34 hedges (87%) were seen to be used by birds.

In total, 18 species of bird were found to be using the hedges and immediate surrounding area, a total of 16 species were observed to be using the hedge and area immediately surrounding all hawthorn hedges, a total of 12 using beech and 12 using privet hedges and surrounding area and 11 species using control locations. There were 15 species observed using hedges alone. Species richness of all hawthorn hedges combined was 15, privet 9 and beech 8 (Table 3.6). The average number of each bird species found for all four surveys of each hedge was averaged by species and is given in Table 3-6 and Table 3-8. The most commonly found birds were sparrows (due to difficulties in to distinguishing between hedge sparrows (dunnock) and house sparrows in one hedge, they have been combined. In the vast majority of hedges only house sparrows were observed) and blackbirds and they were found in all species of hedge but in varying numbers. Sparrows were most abundant in hawthorn hedges, and blackbirds were most abundant in beech hedges.

Table 3-6 Total number of species using the hedge and surrounding area, and total numbers of species observed using the hedges. Data include the total richness for all hawthorn hedges, all beech hedges, all privet hedges and the total richness of all hedges. See Table 3-3 for explanations of categories

	Total species using area	Total species using hedge
Total (all locations)	**18**	**15**
Beech	12	8
No-hedge control	11	-
Hawthorn	16	15
Privet	12	9

*Table 3-7 Number of each species of bird observed to be using the areas immediately surrounding all the hedges or control locations and total number of each bird species using the hedges alone - see Table 3-3 for definitions of categories. * Total richness for all hedges of that species or for all control location plus the surrounding area on the left. Total richness of all hedges only of that species on the right hand side of the table. **Total richness of all birds using all of the areas and hedges and total richness of all species using all hedges only. Bold figures represent the highest abundance of that species/total.*

	Beech Areas	Control Areas	Hawthorn Areas	Privet Areas	Beech Hedges	Hawthorn Hedges	Privet Hedges
House sparrow/ Dunnock.	19	19	**275**	74	43	**268**	66
Blackbird	24	7	**37**	26	**46**	36	13
Wren	6	3	5	**35**	6	8	**21**
Wood Pigeon	**26**	15	10	**26**	1	**3**	
Goldfinch	**21**	2	18	8	3	**11**	1
Blue Tit	5	2	8	**11**		**10**	9
Magpie	8	**10**	**10**	6	**2**	**2**	
Chaffinch			**7**	4	4	**6**	4
Robin	2	1	**3**	1	2	**3**	
Great Tit			3	**4**		2	**3**
Mistle Thrush			**5**			**4**	
Carrion Crow	**3**	2	2				
Pied Wagtail		**7**					
Song Thrush	**2**		1	1		**1**	**1**
Greenfinch				**5**			
Starling			**1**			**1**	

Collard Dove	**2**						
Kestrel			1			**1**	
Long- tailed Tit			1			**1**	
Total Richness per hedge spp. or control*	12	11	**16**	12	8	**15**	8
Total Richness**		**18**				**15**	

Table 3-8 The mean number of each species of bird observed, by hedge type. distinguishing between house sparrows (predominantly) and dunnocks was difficult in one hedge were both were present so the two were collated. House sparrows and dunnocks (almost entirely house sparrows) and blackbirds were the most commonly observed species. There are on average 4.9 house sparrows observed to be using a hawthorn hedge, 0.71 for beech, and 1.17 for privet. There were, on average, 0.66 blackbirds observed to be using a hawthorn hedge, 0.77 for beech, and 0.02 for privet. Grey areas indicate where no birds of this species were observed.

	Beech	Hawthorn	Privet
Goldfinch	0.05	0.20	0.02
Blackbird	0.77	0.66	0.02
House sparrow/ Dunnock	0.72	4.92	1.17
Pigeon	0.07	0.05	0.00
Magpie	0.03	0.09	0.02
Robin	0.03	0.05	0.00
Song Thrush	0.00	0.02	0.02
Mistle Thrush	0.00	0.07	0.00
Blue Tit	0.05	0.05	0.27
Great Tit	0.00	0.18	0.06
Chaffinch	0.07	0.04	0.00
Wren	0.10	0.14	0.44
Starling	0.00	0.02	0.00
Kestrel	0.00	0.02	0.00
Long Tailed Tit	0.00	0.02	0.00
Total Richness	**9**	**15**	**6**

3.3.1 Comparison of woody hedge species

The mean number of birds found in the areas surrounding and including the hedges over the 4 surveys for each hedge was analysed using a Kruskal-Wallis test and no significant differences were found (*H= 4.667, p= 0.198, n= 53 hedges/control locations*). It is visible from Figure 3-2 that there was a greater range and higher number of birds in areas with a hawthorn hedge (although not significantly).

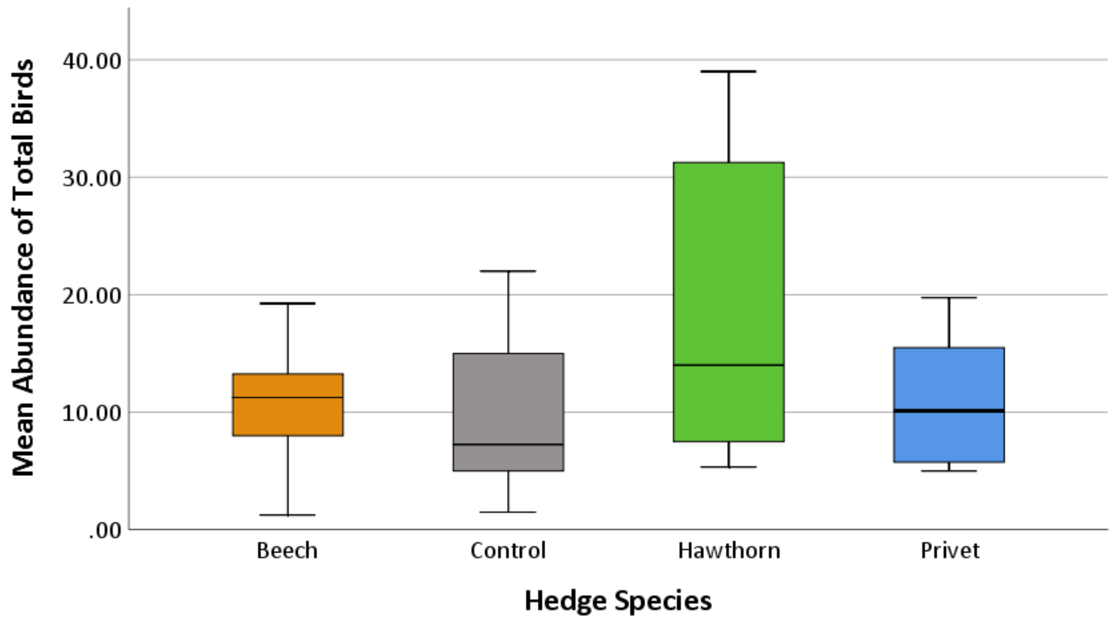


Figure 3-2 Box plot of mean (average over the 4 surveys) number of total birds in the area (5 m in front of the hedge and in the skies above). There were no significant differences between the mean number of total birds found in the area using a Kruskal-Wallis test

The results indicate that there is a significant difference in the number of birds using the hedge and areas immediately around hedges of different species and control locations (Figure 3-3) (*H= 28.822, p= 0.000, n= 52*). Data includes all birds in the area but excludes those just flying through. Areas with any of the three species of hedge were found to have significantly more birds than those without a hedge (*beech T= -2.762, p= 0.035; hawthorn T= -5.299, p=< 0.001; privet T= -3.381, p= 0.004*).

As there was not necessarily a structure in control locations, comparisons of use of the hedge itself was made only between hedges not controls, as if there was only a gap then this was not able to be used by birds. Analysis of the use of the hedge excludes using the ground in front or perching on any surrounding trees or lamp posts; it only includes activity on or within the hedge. As expected from looking at the previous results the distribution of birds was not the same between the hedge species (*H= 9.920, p=0.007, n= 40*). Post-hoc analysis identified that the significant differences were between hawthorn and privet (*T= 2.503, p=0.037*) and between hawthorn and beech (*T= -2.920, p=0.011*) (Figure 3-4).

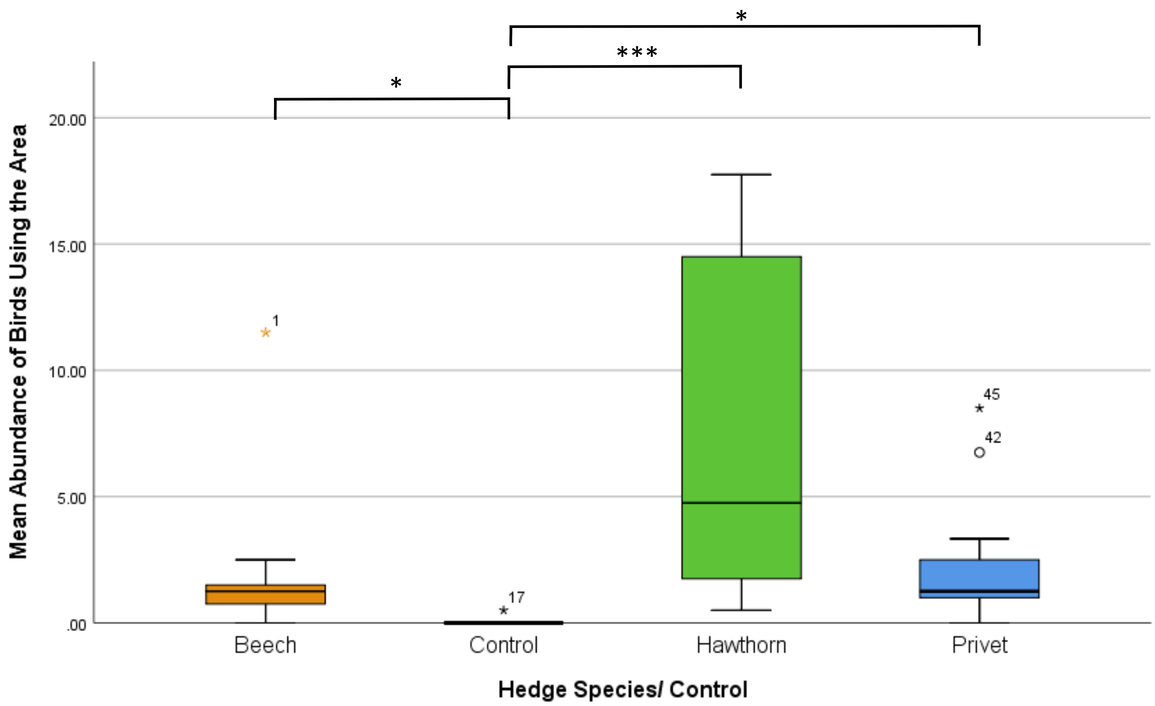


*Figure 3-3–Box plot of mean (of the 4 repeated surveys per hedge) number of birds using the area (the hedge, 5 m in front of the hedge and any associated trees or features). Dunn-Bonferroni test scores for significance between the mean number of birds in the area compared by hedge species/control identified that significantly more birds were observed to be using locations containing a hedge than control locations. No significant differences were found between areas containing a hedge of beech, hawthorn or privet. Brackets above indicate significant differences; *= p< 0.5, *** = p<0.001.*

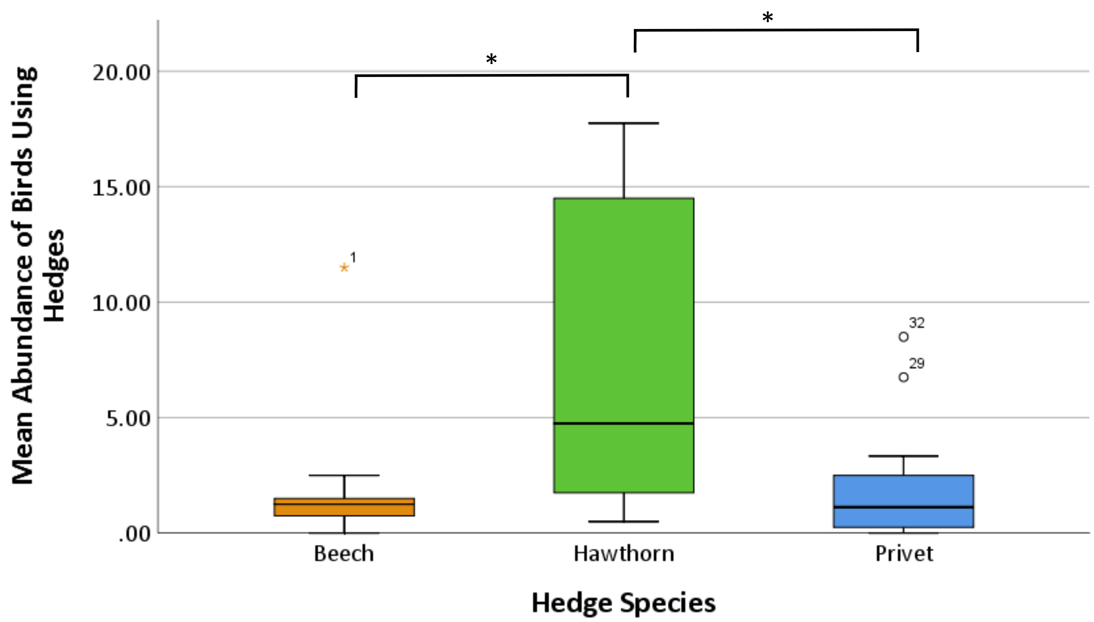


*Figure 3-4 Box plot of mean (of the 4 repeated surveys per hedge) number of birds using the hedge. Dunn-Bonferroni test scores for significance between the mean number of birds using the hedge, compared by species identified that hawthorn hedges had a significantly higher abundance of birds than beech or privet. Brackets above identify significant differences; *= p< 0.5.*

The richness of bids using the area was calculated by the total over the 4 surveys of the number of species observed in the hedge, the area 5 m in front of the hedge and in the trees above. Comparisons by hedge species used a one-way ANOVA. This indicated there was no significant difference in the richness of birds ($F= 1.778, p=0.163, n= 44$) when compared by species or control (Figure 3-5).

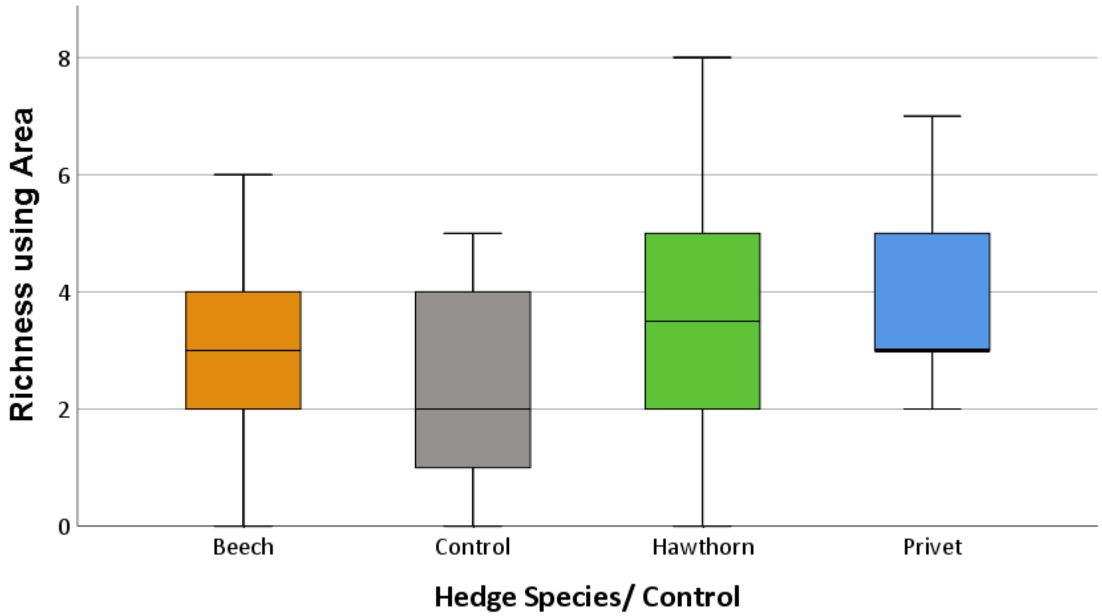


Figure 3-5– Box plot of the total richness of the birds using the hedge, 5 m in front of the hedge and the associated trees. No significant differences were identified.

The richness of the bird species using the hedges alone showed no significant difference when compared by species (*H = 4.143, p=0.126, n= 41*) (Figure 3-6).

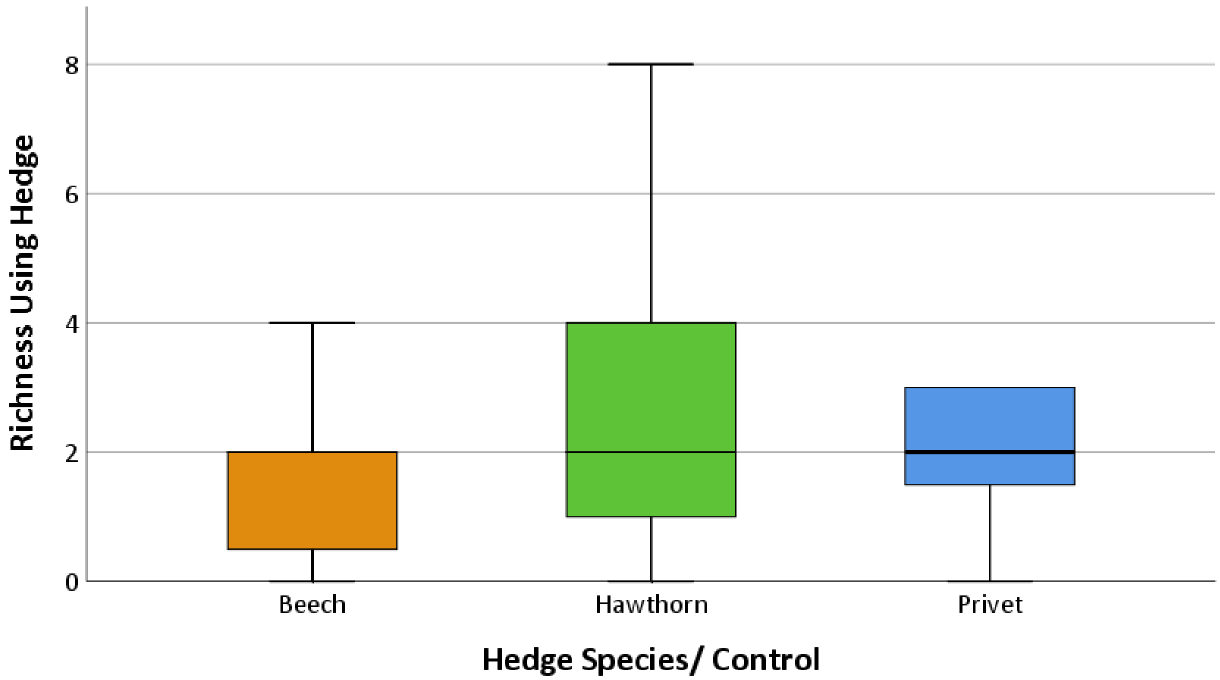


Figure 3-6 Box plot of total richness of birds using the hedge, measured over the 4 surveys per hedge. No significant differences were identified between hedge species.

3.3.2 Possible, probable or confirmed breeding

The abundance of behaviours indicating possible, probable or confirmed breeding (Table 3-9) of birds in the hedge was compared by hedge species (Table 3-10). Significance tests of these data was not attempted due to low numbers of observations in each category. Hawthorn hedges had a higher mean number of species however this is unlikely to be significant.

Table 3-9 Breeding category definitions

Breeding Category	Data Included
Possible breeding	Observations indicative of possible, probable and confirmed breeding
Probable breeding	Observed behaviours indicative of probable and possible
Confirmed breeding	Only behaviours indicative of confirmed breeding

Table 3-10 Mean number of bird species with behaviours (±1SE) indicating possible, probable or confirmed breeding by hedge species.

	Beech	Control	Hawthorn	Privet
Possible	1.29 ±0.29	0.15 ±0.12	1.77 ±0.26	1.15 ±0.34
Probable	0.64 ±0.20	0.08 ±0.08	1 ±0.23	0.69 ±0.26
Confirmed	0.14 ±0.10	0 ±0	0.38 ±0.18	0.08 ±0.08

3.3.3 Nest surveys

The number of nests found in each hedge was compared by hedge species and there was a significant difference in the number of nests found using a Kruskal-Wallis test with Dunn Bonferroni post-hoc. (*$n=39$, $H=7.209$, $p=0.027$*); there were significantly more nests found in privet hedges than beech (*$T=-2.591$, $p=0.029$*). However, numbers were low (Figure 3-7).

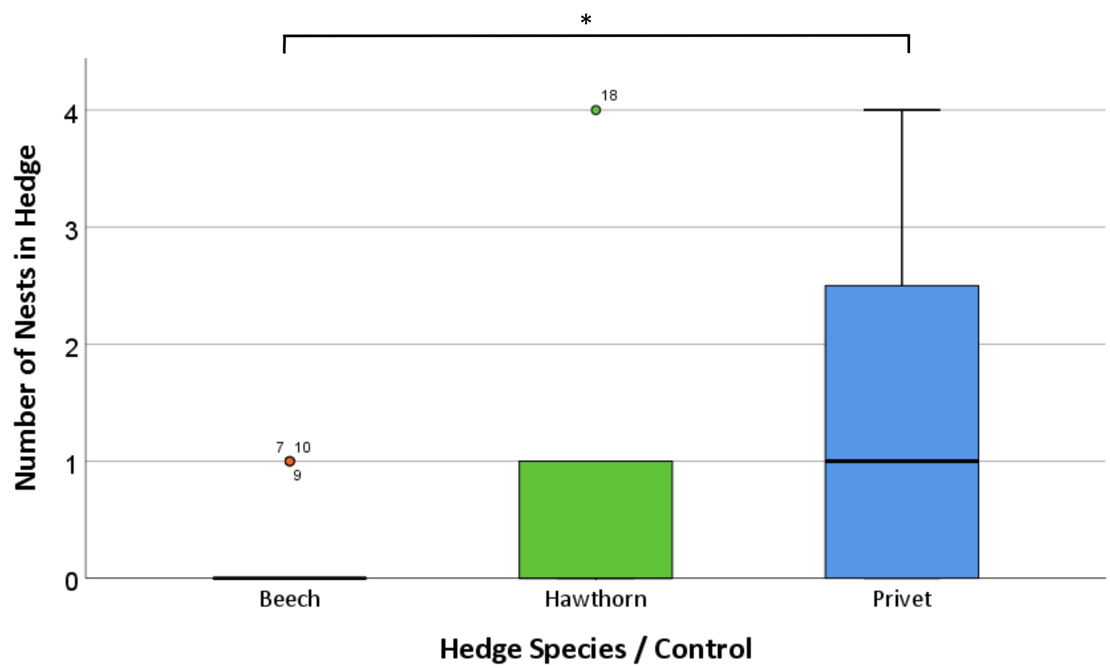


*Figure 3-7 Boxplot of the numbers of nest found by hedge species. Kruskall-Wallis significance test identified significant differences. Post-hoc Dunn-Bonferroni identified significantly more nest found in privet hedges than beech. Brackets above identify significant differences; * = p< 0.05*

3.3.4 Comparing impacts of other variables

3.3.5 PCA analysis

Dimension reduction was undertaken using PCA analysis which identified many correlations between the environmental variables and grouped them into components. The first seven components were responsible for 84.64% of the variance and are shown in Table 3-11. A number of variables were identified as corelated. A representative variable of each component was selected to be included in the multivariate analysis, simplified justifications are also shown. The selected 7 variables and inverse proximity to the road were included in subsequent analysis. With studying roadside hedges it is likely that the proximity to the road is going to have an impact on the biodiversity in the hedges (Bhattacharya, Primack and Gerwein, 2002; Angold *et al.*, 2006; Jones and Leather, 2012). Table 3-12 identifies which variables are included in each subsequent analysis.

Table 3-11 Results of the PCA. Selected variables are listed in column 1, the correlating variables in column 2, and the % of variance explained by these variables in bold. + indicates a positive correlation to the correlating variables, and – indicates a negative correlation.

Selected Variable	Correlates with		Reason for choice
- % Impervious surfaces within 50 m	+ % Smooth Grass within 250 m + % Smooth Grass within 100m + % Green Space within 250 m - % Impervious surfaces within 250 m - % Impervious surfaces within 100 m + % Green Space within 100 m + % Woody Vegetation within 100 m + % Woody Vegetation within 250 m + % Woody Vegetation within 50 m + % Green Space within 5 m - % Impervious surfaces within 5 m + % Woody Vegetation within 5 m - % Impervious surfaces within 50 m +% Green Space within 50 m + Hedge Species	**47%**	Impervious represents a proxy for the likelihood of buildings for nesting and is the inverse of % of green space in the area. 50 m chosen as this represents the reduced home range size of the house sparrow (Shaw *et al.*, 2011)
+ Total Length of Hedge	+ % Rough Grass within 100 m + % Rough Grass within 250 m + % Rough Grass within 50 m	**9.8%**	This correlation is likely due to longer hedges being found in areas of open green space. Hedge length was selected as impacts on bird richness and abundance.(Batáry, Matthiesen and Tscharntke, 2010) Longer hedges are likely to be found in areas of open green space and so this may also be linked to amount of green space.
+ Hedge Volume	+ Hedge Width + Hedge height + % Rough Grass within 50 m	**7.8%**	Volume encompasses both width and height
+ Average Tree DBH	- Average Tree Distance	**5.8%**	DBH gives some indication of tree size as well as presence of trees
+ % Vegetation Cover in 5m A	+ % Smooth Grass within 5 m	**5.6%**	Most vegetation cover within 5 m of the front of the hedge is smooth grass but not exclusively.
+ % Vegetation Cover in 5 m B	None	**4.7%**	A component on its own
- Vegetation Height in 5 m B	- % Woody Vegetation within 50 m	**3.6%**	If vegetation is very tall it is likely to be woody but not all woody vegetation in 50 m will be directly behind the hedge.

3.3.5.1 GLMM (using GLMmer)

Table 3-12 Table 3 12 Variables included in each subsequent analysis (PCA, GLMM DPCA and RF) to be compared against bird richness and abundance. ✔indicates that this variable was included in the named analysis.

	Inputted to PCA	**Out of PCA**	**Included in GLMM**	**Included in DPCA**	**Included in RFR**
% Smooth Grass within 250 m	✔				
% Smooth Grass within 100 m	✔				
% Smooth Grass within 50 m	✔				✔
% Green Space within 250 m	✔				
% Impervious surfaces within 250 m	✔				✔
% Impervious surfaces within 100 m	✔				
% Green Space within 100 m	✔				
% Woody Vegetation within 100 m	✔				
% Woody Vegetation within 250 m	✔				✔
% Woody Vegetation within 50 m	✔				✔
% Green Space within 5 m	✔				
% Impervious surfaces within 5 m	✔				
% Woody Vegetation within 5 m	✔				
% Impervious surfaces within 50 m	✔	✔	✔	✔	✔
% Green Space within 50 m	✔				
Hedge Species	✔				
% Rough Grass within 100 m	✔				
% Rough Grass within 250 m	✔				
Total Length of Hedge	✔	✔	✔	✔	✔
% Rough Grass within 50 m	✔				✔
Hedge Volume	✔	✔	✔	✔	
Hedge Width	✔				
Hedge Height	✔				✔
Vegetation Height in 5 m A	✔				✔
Average Tree DBH	✔	✔	✔	✔	✔
Average Tree Distance	✔				
% Rough Grass within 5 m	✔				
% Canopy Cover	✔				✔
% Vegetation Cover in 5m A	✔	✔	✔	✔	✔
% Smooth Grass within 5 m	✔				
% Vegetation Cover in 5 m B	✔	✔	✔	✔	✔
Vegetation Height in 5 m B	✔	✔	✔	✔	✔
Inverse proximity to road			✔	✔	✔
Adjacent vegetation					✔

GLMM was used to examine the relationships between the 8 selected variables in explaining the variance in bird richness and abundance. The mean bird abundance over the 4 surveys per hedge was averaged and used in the comparisons and total bird species richness over the 4 surveys per hedge was used. Hedge species was used as a random effect in each survey as this has previously been shown to affect richness and abundance in these data

The GLMM results (Table 3-13) indicate that: hedge volume, inverse proximity to road, the percentage of impervious surfaces within a 50 m buffer and the percentage of vegetation behind the hedge are significantly positively associated with bird abundance using the area. No factors were significantly negatively associated. However, the model failed to converge after 99 iterations. The number of iterations was not increased to force the model to converge.

The factors identified by the GLMM to be significantly positively associated with bird abundance using the hedge alone (Table 3-14) were hedge volume, and percentage of vegetation behind. The DBH of trees shows a significant negative association with bird abundance in the hedge. Again, this model failed to converge after 99 iterations.

As variation in richness between hedge species was low, it was unsurprising that no factors were found to significantly affect the richness of birds using the area around a hedge or with richness of birds using the hedge itself (Tables 3-15 & 3-16). These results are summarised in Table 3-18.

Table 3-13 GLMM results for variables compared to bird abundance using each area per survey (n=39), Random effect = hedge species. Hedge volume, inverse proximity to road, percentage of impervious surfaces within 50 m of the hedge, and percentage of vegetation behind the hedge show significant positive associations

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	-0.954	0.340	*ns*
Hedge Volume	2.017	0.044	*
Percentage of Vegetation in front of hedge (5 m)	0.691	0.490	*ns*
Total Length of hedge	0.349	0.727	*ns*
Inverse Proximity to Road	2.144	0.032	*
% impervious within 50m buffer	2.089	0.037	*
% vegetation behind the hedge within 5 m	3.823	0.000	***
Vegetation height behind hedge	-1.144	0.253	*ns*

*** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

Table 3-14 GLMM results for variables compared to bird abundance per survey per hedge (n=39), Random effect = hedge species. Average DBH of trees in the area shows a significant negative association with bird abundance in the hedge. Hedge volume, and percentage of vegetation behind the hedge show a significant positive association with bird abundance in the hedge

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	-2.854	0.004	**
Hedge Volume	2.743	0.006	**
Percentage of Vegetation in front of hedge (5 m)	1.692	0.091	†
Total Length of hedge	1.162	0.245	*ns*
Inverse Proximity to Road	0.709	0.479	*ns*
% impervious within 50m buffer	0.397	0.691	*ns*
% vegetation behind the hedge within 5 m	3.479	0.001	***
Vegetation height behind hedge	-0.381	0.703	*ns*

*** = p< 0.001, ** = p < 0.01, * = p< 0.05, †= p< 0.1, ns = p> 0. 1

Table 3-15 GLMM results for variables compared to bird richness per survey per area (n=39), Random effect = hedge species. None of the variables were shown to be significantly associated with bird richness within the hedges

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	0.972	0.331	*ns*
Hedge Volume	1.110	0.267	*ns*
Percentage of vegetation in front of hedge (5 m)	-0.520	0.603	*ns*
Total Length of hedge	0.796	0.426	*ns*
Inverse Proximity to Road	0.697	0.486	*ns*
% impervious within 50m buffer	-0.151	0.880	*ns*
% vegetation behind the hedge within 5 m	0.997	0.319	*ns*
Vegetation height behind hedge	0.540	0.590	*ns*

ns = p> 0. 1

Table 3-16 GLMM results for variables compared to richness of birds using the hedges (n=39), Random effect = hedge species. None of the variables were shown to be significantly associated with bird richness within the hedges

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	-0.552	0.581	*ns*
Hedge Volume	0.940	0.347	*ns*
Percentage of vegetation in front of hedge (5 m)	1.169	0.243	*ns*
Total Length of hedge	1.088	0.277	*ns*
Inverse Proximity to Road	-0.411	0.681	*ns*
% impervious within 50m buffer	-1.303	0.193	*ns*
% vegetation behind the hedge within 5 m	0.029	0.977	*ns*
Vegetation height behind hedge	1.266	0.206	*ns*

ns = p> 0. 1

The Random Forest results (Figures 3-8, 3-9, 3-10 and 3-11) (Table 3-17 for contractions used) indicate that the percentage of woody vegetation in 250 m and 50 m of the hedge, the percentage of vegetation in front of the hedge, the distance (inverse proximity) from the road and the % of impervious surfaces within 50 m are important in explaining the variations in the bird abundance using the area. DBH and height of vegetation in front of the hedge and hedge volume are the most important in explaining the variations in bird richness using the area; however, importance scores are low. The percentage of woody vegetation in 250 m and 50 m of the hedge, and the percentage of vegetation in front of the hedge are important in explaining variation in bird abundance using the hedge. Variations in richness of birds in the hedge was found to be best explained by % vegetation in front, % Rough grass 50 m, and distance to the road, but importance scores were low. These results are summarised in table 3-18

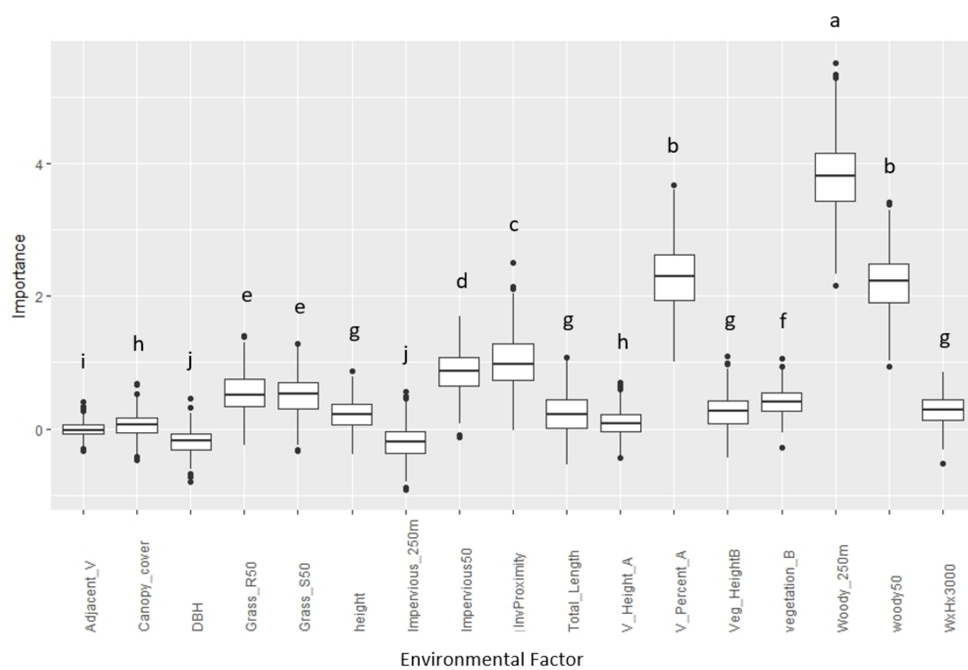


Figure 3-8 Boxplot of importance of impact the environmental factor has on explaining the variation in bird abundance per run of the random forest algorithm. Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are % of woody vegetation within 250 m of the hedge, % of woody vegetation within 50 m of the hedge, % of vegetation in 5 m in front of the hedge, inverse proximity to the road and % of impervious surfaces within 50 m..

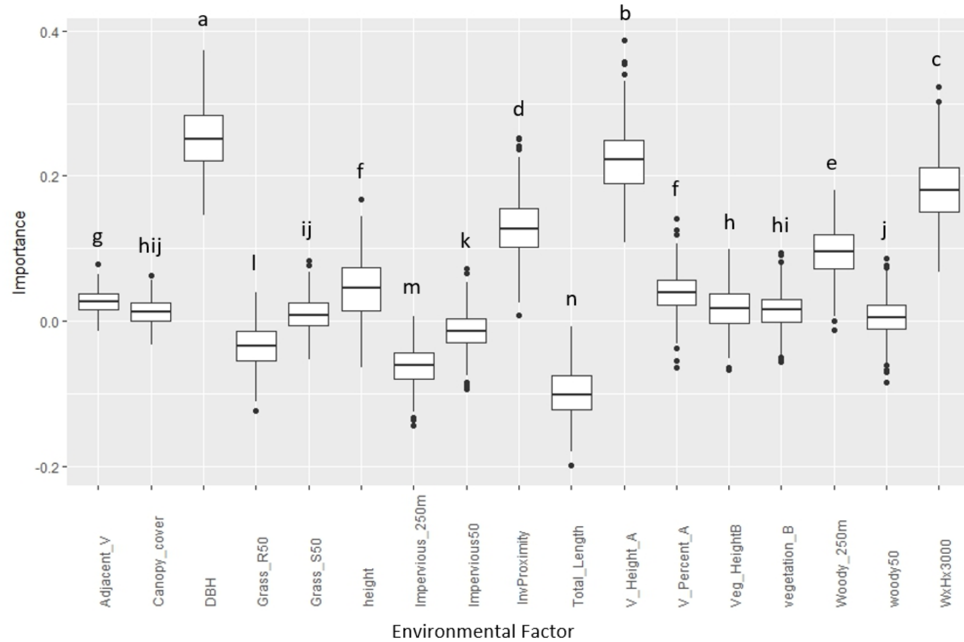


Figure 3-9 Boxplot of importance of impact the environmental factor has on explaining the variation in bird richness per run of the random forest algorithm. Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are: DBH of trees, % of vegetation in 5 m in front of the hedge, hedge volume (WxHx300), and inverse proximity to the road. Importance scores are low.

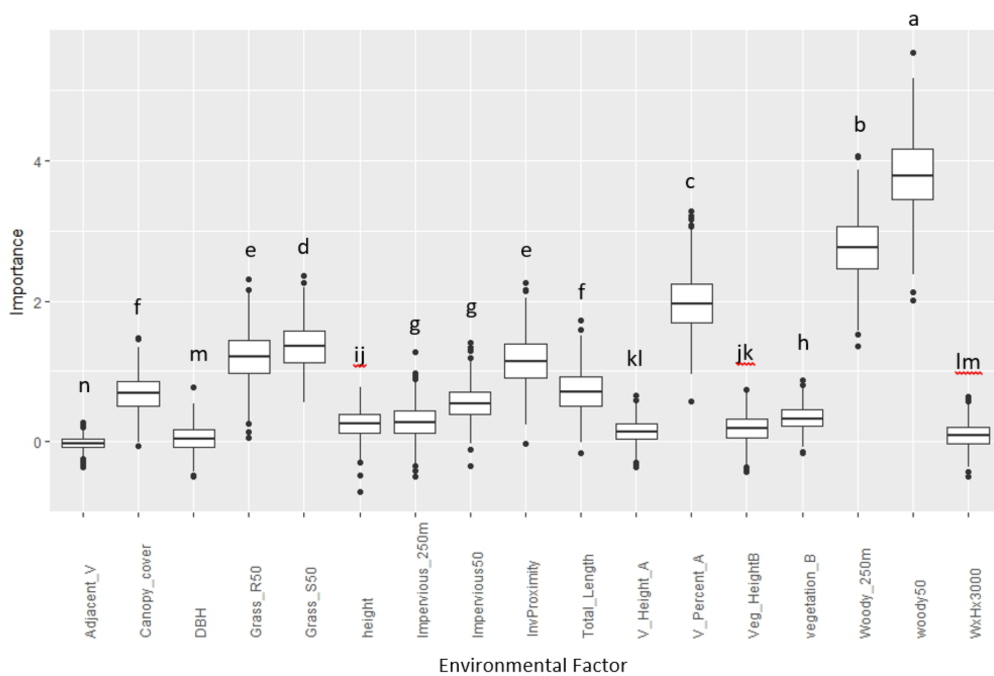


Figure 3-10 Boxplot of importance of impact the environmental factor has on explaining the variation in bird richness per run of the random forest algorithm. Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are: % of woody vegetation within 50 m of the hedge, % of woody vegetation within 250 m of the hedge, % of vegetation in 5 m in front of the hedge, % of smooth grass within 50 m of the hedge.

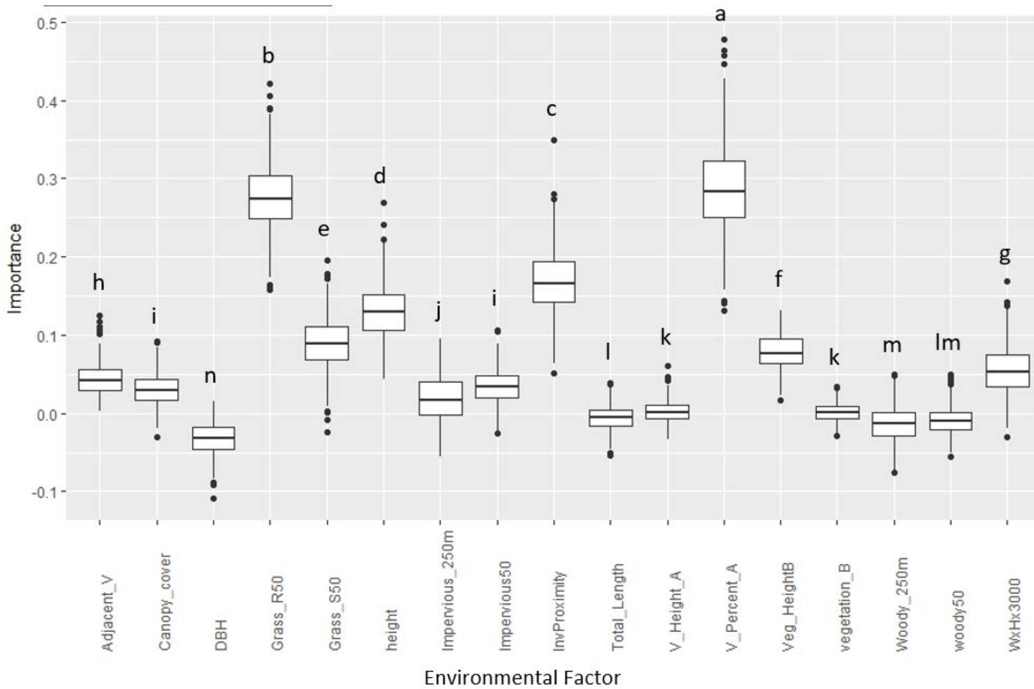


Figure 3-11 Boxplot of importance of impact the environmental factor has on explaining the variation in bird richness using the hedge per run of the random forest algorithm. Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are: % of rough grassland within 50 m of the hedge, % of vegetation in 5 m in front of the hedge, and inverse proximity to the road. Importance scores are low.

Table 3-17 Contractions used in RF. Variables in the left column are represented in the RF graphs by the contractions shown in the right hand column.

Variable	Contraction used in RF
Adjacent vegetation	Adjacent _V
% Canopy Cover	Canopy cover
Average Tree DBH	DBH
% Rough Grass within 50 m	Grass_R50
% Smooth Grass within 50 m	Grass_S50
Hedge Height	Height
% Impervious surfaces within 250 m	Impervious_250
% Impervious surfaces within 50 m	Impervious50
Inverse proximity to road	Inverse Proximity
Total Length of Hedge	Total_Length
Vegetation Height in 5 m A	V_Height_A
% Vegetation Cover in 5m A	V_Percent_A
Vegetation Height in 5 m B	Veg_HeightB
% Vegetation Cover in 5 m B	Vegetation B
% Woody Vegetation within 250 m	Woody_250
% Woody Vegetation within 50 m	Woody50
Hedge Volume	WxHx3000

*Table 3-18 Summary table of GLMM and Random Forest results. Significant factors are included for GLM and significance levels are shown using the asterisks *** = p< 0.001, ** = p < 0.01, * = p< 0.05 . Median importance scores for the random forest results are included in parentheses*

Variable	**GLM +ve**	**GLM -ve**	**Random Forest Importance**
Bird Abundance Area	Hedge Volume* Inverse Proximity to road* % Impervious surfaces within 50 m* % Vegetation Cover in 5 m B ***		% Woody within 250 m (3.80) % Vegetation Cover in 5m A (2.29) % Woody Vegetation within 50 m (2.20) Inverse Proximity to road (1.00) % Impervious within 50 m (0.85)
Bird Richness Area	-	-	Average Tree DBH (0.25) Vegetation Height in 5 m A (0.22) Hedge Volume (0.18)
Bird Abundance Hedge	Hedge Volume** % Vegetation Cover in 5 m B ***	Average Tree DBH**	% Woody within 50 m (3.79) % Woody within 250 m (2.76) % Vegetation Cover in 5m A (1.97)
Bird Richness Hedge	-	-	% Vegetation Cover in 5m A (0.29) % Rough grass within 50 m (0.28) Inverse Proximity to Road (0.17)

3.3.5.2 The impact of adjacent vegetation

The presence of adjacent vegetation on either or both sides of a hedge was also considered to be a possible factor to influence the abundance and richness of birds in an area as studied for invertebrates by Gosling *et al.*, (2016). In this study due to only one hedge having no adjacent vegetation this was excluded from the analysis and only comparisons of hedges where vegetation was present on one or both sides were included. Following normality tests Mann

Whitney U tests were undetaken on non parametric data and independent samples t-tests were used where data were normally distributed.

No significant differences were found in the mean (of the 4 surveys per hedge) abundance of birds in the area (*n= 38, U=176.5. p=0.95*) or in the hedge (*n= 38, U=200.5. p=0.52*). No significant difference was found in bird richness in the area (*n= 38, F=.615. p=0.546*) however bird richness was significanly higher in hedges with adjacent vegetation on both sides compared to hedges with adjacnet vegetation on one side only (*n= 38, U=247.5. p=0.04*) (Figure 3-12).

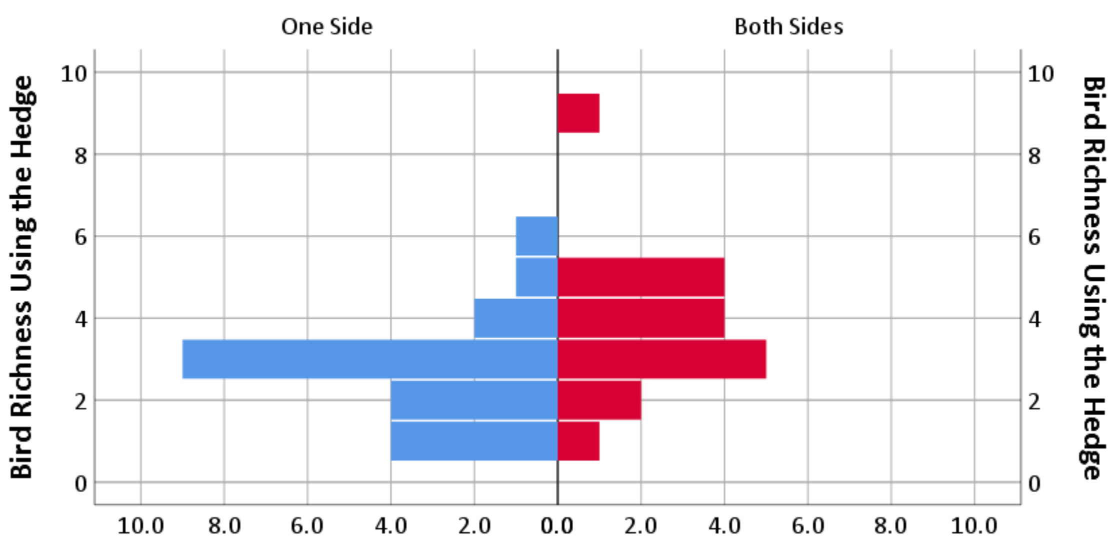


Figure 3-12 Paired histogram of bird richness compared by the presence of adjacent vegetation on one or both sides. Richness is significantly higher in hedges where there is adjacent vegetation on both sides.

3.3.6 Assessing variation between hedge species

DAPC (see section 2.4.4) was used to assess the variation between hedges of the three woody species. The same 8 variables that were included in the GLMM (Table 3-12) were inputted into the DAPC to assess if there were differences in these variables within hedges in the predefined woody species groups. E.g. were beech hedges smaller with less associated vegetation than the other species?

The DAPC was only able to identify one component on which to align the hedges (Figure 3-13) suggesting that there is little variation between the groups on any other component inputted or synthesised. There is considerable overlap between the distributions of each species along the only component identified, therefore, groups are not discriminated between based on the inputted 8 variables.

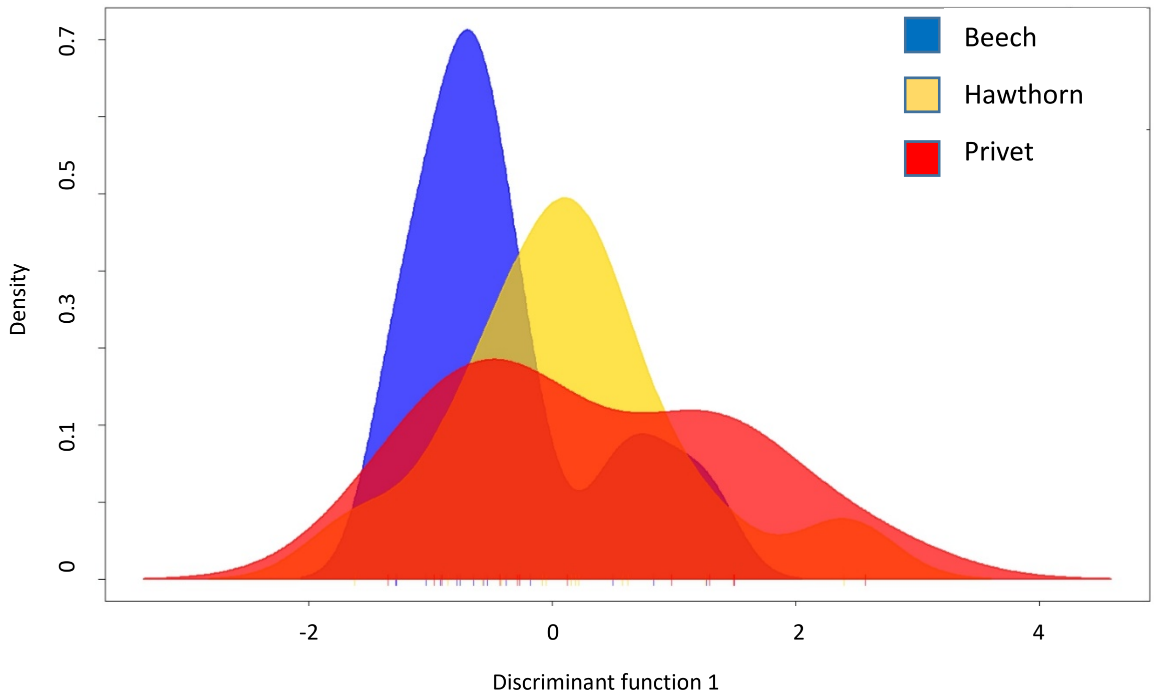


Figure 3-13 Alignment of hedges by predefined species groups along the first principal component synthesised using DAPC (the only component identified). 1= beech, 3 = hawthorn, 4 = privet. There is considerable overlap between hedges of each woody species. DAPC is unable to discriminate between hedges of different species by the variables inputted.

3.4 Discussion

Bird surveys of 39 hedges (13 each of the three most common species) and 13 control locations were carried out in urban areas of Stoke-on-Trent and urban Newcastle-under-Lyme during the summers of 2015 and 2016. Eighty seven percent of the hedges were seen to be used by birds and many factors of the hedges and surrounding areas were found to significantly affect the richness and abundance of birds using the hedge.

Fifteen species of birds were found to use urban hedges (Table 3-7) including some species which are red list species e.g. house sparrow, common starling and song thrush *Turdus* *philomelos* and some are amber listed including the mistle thrush *Turdus viscivorus* and the dunnock *Prunella modularis* (Evans, Newson and Gaston, 2009).

The following sections will seek to answer the research questions by discussing the results relevant to those areas of study.

3.4.1 Are there more birds found in areas with hedges?

The total number of all birds observed in the areas (including those observed using the hedge, the area in front of the hedge, using trees or structures within the area and those flying over or through) (Table 3-3)showed that there was no significant difference in the abundance of birds in areas containing a hedge compared with those in areas without a hedge; however, when birds that were only flying through the area were removed leaving only birds that were using the hedge or surrounding areas the abundance was significantly less in areas without a hedge than in areas containing any of the three hedge species. In farmland areas the presence of a hedge increases bird abundance in areas adjacent to the hedge compared with the areas adjacent to a non-hedged field boundary particularly in the breeding season (Batáry, Matthiesen and Tscharntke, 2010; Newton, 2017) and this would appear, from these results, to be the case in urban areas. It may be also be the case that in urban areas that a hedge offers one of very few places for protection from predators as is often the case in some rural areas (Newton, 2017). As the presence of a hedge significantly increases the abundance of birds in the area in both rural locations (Batáry, Matthiesen and Tscharntke, 2010; Newton, 2017) and in the results of this study, it may be associated with the idea of ecological contrasts where the surrounding areas offer little suitable semi-natural habitat (Garratt *et al.*, 2017). Control locations were in similar areas and in close proximity to the hedges, with similar landuse behind, therefore, the presence of a hedge is likely to be the major difference between the survey areas. As woodland copses, bushes and trees are likely to be less abundant in urban areas the provision of hedgerows, as in rural areas where these alternative habitats are scarce, seem to have a significant effect on the abundance birds in the area (Batáry, Matthiesen and Tscharntke, 2010).

There was, however, no significant difference in the species richness of birds using the hedges or areas immediately surrounding them compared to control locations. Eighteen species of bird were found to be using the hedges and immediate surrounding areas; 17 of these are species associated with urban areas as described by Evans, Newson and Gaston (2009) plus a kestrel (raptors are also known to do well in urban environments (Chace and Walsh, 2006)). The study hedges were situated in highly urbanised areas so rare or less synanthropic species were unlikely to be found (Marzluff, 2001; Evans, Newson and Gaston, 2009).

3.4.2 Does the woody hedge species affect the richness and abundance of birds found to be using the hedge and the surrounding area?

There was no significant difference found in the abundance of birds using the area immediately surrounding the hedge when each hedge species and control locations were compared, however, when birds using the hedges were compared significantly more birds were found to be using hawthorn hedges than hedges of other species. There was no significant difference between the abundance of birds using privet hedges compared to beech hedges. Hawthorn hedges and privet hedges, if appropriately managed, can offer food or flowers (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017); and it is possible that the provision of food is greatest in hawthorn hedges as privet is rarely managed to permit flowering and there is little research describing the importance of privet in providing food for species. As the surveys were conducted in summer there were no flowers or haws on the hawthorn so the likely food available would be insects; this is investigated in Chapter 5 Invertebrates of Urban Hedges. Hawthorn is a native species and is associated with many more species of invertebrate than beech (Southwood, 1961) but there is little research into invertebrates associated with Japanese privet. Hedge density may also play a part. Observations made during this study revealed that beech had a sparse but more regimented internal branching structure providing an open hedge interior with a fairly complete curtain of leaves on the exterior of the hedge. Hawthorn hedges were observed to be much more heterogeneous with branches of varying lengths and a less regimented pattern of branching, typically having a less continuous curtain of leaves at the edge due to the heterogeneity of the lengths of the branches and at much less regular intervals producing heterogeneity of microhabitats. Privet hedges had a dense structure, as noted by Oreszczyn and Lane (2001), of many more and thinner branches with a more upright habit producing a very densely branched interior.

Although there was not a significant difference in the richness of birds using areas containing different hedge species, when comparing the individual hedges, 16 of the 18 bird species found were observed to be using areas that contained hawthorn hedges. Again, there was no significant difference in the richness between individual hedges compared by species, but the total richness of bird species found to be using the hedge itself for all hawthorn hedges was almost double the total for the other two hedge species (15 species found to use hawthorn hedges compared to 8 using beech or privet). Sparrows (predominantly house sparrows) were abundant in all three hedge species but most abundant in hawthorn hedges. Blackbirds were commonly found in beech and hawthorn hedges and were more abundant in beech hedges than sparrows.

Behaviours indicating whether breeding was possible, probable, or confirmed to be taking place in the hedge showed no significant difference with hedge species although numbers were low. There were significantly more nests found in privet hedges than beech hedges. The denser nature of privet hedges (Oreszczyn and Lane, 2001) may make them suitable nesting locations (Hinsley and Bellamy, 2019) in light of the increased nest predation in urban areas (Marzluff, 2001; Chace and Walsh, 2006; Shaw *et al.*, 2011; Arroyo-Solís *et al.*, 2013). The low numbers of nests or associated behaviours suggesting probable and confirmed breeding within the hedges suggests that the hedges offer many other benefits to birds in urban areas, as they do in rural areas, such as food provision and shelter (Vickery, Feber and Fuller, 2009; Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018). A more heterogenous planting regime may make hedges more attractive to animals for the provision of food and shelter (Gosling *et al.*, 2016)

The survey only considered single species hedges as these were the most common within the study area and thus most representative and only surveyed during summer months. Further study may consider mixed species hedges as a comparison however these were not present in sufficient number without expanding the survey area as most planted hedges within urban environments are single species (Oreszczyn and Lane, 2000; Faiers and Bailey, 2005; Gosling *et al.*, 2016). Undertaking surveys during other times of year would help to build a more complete picture of the use of urban hedges by birds.

3.4.3 *Which other characteristics of the hedge and surrounding area affect the richness and abundance of birds?*

Both hedge volume, and the percentage of vegetation behind the hedge, were found to significantly positively affect the abundance of birds using both the hedge itself or the hedge and the surrounding area. The distance from the road and the percentage of impervious surface was also found to be positively associated with the abundance of birds using the area around the hedge. It is difficult to explain why impervious surfaces were positively related to bird abundance. This may be due to the large numbers of sparrows present who require buildings for nesting skewing the results. However when data were reanalysed with sparrows data removed woody vegetation and impervious surfaces were the most important factors, although importance scores were low. It may also be due to a higher ratio of bird feeders in domestic gardens. So, in accordance with other published material, the larger the volume of the hedge the more birds you are likely to find using the hedge and its surrounding area, (Hinsley and Bellamy, 2019), and the more vegetation behind the hedge the more abundant birds are likely to be (e.g. Dover and Sparks, 2000; Hinsley and Bellamy, 2000). Hedge volume was also found to be important to bird richness in the area, and moderately important for bird richness using the hedge being the fourth most important factor of those included in both the GLMM and Random Forest analyses, however importance scores were low. A greater hedge volume is associated with higher bird species richness and abundance in rural areas (Hinsley and Bellamy, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018). Hedge volume was used in the GLMM study to encompass hedge height and hedge depth, so it may also be either of these factors that affect the abundance of birds and both are known to individually affect the abundance of birds in rural environments (Newton, 2017). Hedge height was suggested to be of greater importance to the richness of birds using the hedges than hedge volume but less important for richness is the surrounding area; however, importance scores for all factors were low for bird richness. It was shown to be of equal importance to hedge volume for bird abundance within the area and height was suggested to be slightly more important when explaining the variation in bird abundance within a hedge. Higher importance scores for bird abundance and the more factors implied by the results to be significantly related may be explained by the smaller variation in the richness of birds found at each site.

Vegetation on either side is shown to impact the biodiversity value of hedges in both rural (Barr and Gillespie, 2000; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Faiers and Bailey, 2005; Gosling *et al.*, 2016; Staley *et al.*, 2016; Graham *et al.*, 2018) and urban hedges (Faiers and Bailey, 2005; Gosling *et al.*, 2016). The quality of the vegetation and structural diversity of the vegetation was not tested in this study and much of the vegetation found in proximity to the urban study hedges is not highly diverse vegetation. However, even the 'lower quality' vegetation that currently is present in the areas adjacent to the study areas is influencing the abundance of birds and even mown grassland may be useful foraging areas (Whittingham and Evans, 2004). Further study that seeks to explore the impact of vegetation quality on either side of the hedges in terms of its management for biodiversity and assesses the impact would be beneficial in answering this question. However, in the urban environments included in this study there was very little variation in height of the vegetation on either side of the study hedges as most of the areas were amenity (frequently mown) grassland which generally varied between about 4 and 6 cm in height depending on how recently they had been mown.

The inverse proximity to the road showing a negative relationship in the GLMM suggests that the further a hedge is from a road the more birds there are likely to be. The Random Forest analysis also indicates that the distance from the road is important in explaining the variation in both bird richness and abundance using the hedge and using the surrounding areas. This is likely to be due to the levels of disturbance associated with busy roads (Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013). Also, if a hedge is close to a road this limits the area in front of the road that could be greenspace.

The data also suggest that the more impervious areas there are within a 50 m buffer circling the hedge the more birds that are likely to be using the hedge. This could be due to the high numbers of house sparrows recorded. House sparrows were found to be abundant in most hedges and are known to require both woody vegetation e.g. a hedge and buildings for nesting within their reduced home ranges during nesting season (Shaw *et al.*, 2011) and sparrows are not found in areas with more than 60% vegetation cover (Lancaster and Rees, 1979). The measure of percentage of impervious surfaces was also used to represent the abundance of green space in the buffers around the study areas as there are obvious inverse relationships so the significance of a greater percentage of impervious surfaces also suggests that there is likely to be a significant negative relationship between bird abundance in the area and amount of green space. This may be unexpected as you would expect more birds to be found in areas with more vegetation (Lancaster and Rees, 1979) but could be explained in that if there were many green habitats in the area then birds may be using these areas instead of areas close to roads. However, the Random Forest analysis suggests that the proportion of woody and grassy vegetation is more important than the proportion of impervious surfaces but does not indicate whether there is a positive or negative relationship. The proportion of woody vegetation within the locality of a hedge was suggested by Hinsley and Bellamy, (2019) to positively influence the number of birds using hedges. The concept of ecological contrasts (Garratt *et al.*, 2017) may apply here. The proportion of woody vegetation in the surrounding areas was indicated to be the most important factors for bird abundance using the hedge and two of the three most important for bird abundance using the area but to be of less importance for bird richness using both hedge and the surrounding area. In areas with high levels of impervious surfaces there are likely to be fewer green habitats (as implied by the negative colinearity of these in PCA results) and therefore there may be fewer suitable habitats for birds to use and, as such, there is an increased number of birds using the available hedges. Woody vegetation in the surrounding areas was described by e.g. Hinsley *et al.*, (2002) to affect bird numbers in hedges. The presence of woody habitats adjacent to the hedge could offer alternative habitat to the birds and they are likely to remain in more protected habitats especially if the trees were behind the hedge and therefore further from the road and footpath areas where disturbance levels are likely to be much higher. If the trees or other areas of semi-natural vegetation were behind the hedge, then birds are more likely to fly out of the back of the hedge and not be seen by the observer but it is beyond the scope of this paper to answer this, and further study to assess whether birds were preferentially using the trees or other semi-natural habitats is required. In rural locations the presence of a hedgerow offers most benefit in areas that offer less in the way of alternative habitat and thus have higher abundance of birds (McIntyre, 2000; Batáry, Matthiesen and Tscharntke, 2010; Garratt *et al.*, 2017). Having more trees in an area means that there are alternative habitats to roadside hedges and thus even if the hedges in this area are of a higher quality than some in areas with a higher proportion of sealed surfaces with little alternative habitat, then due to more choice of habitats there may be fewer birds within the roadside hedges.

The mean DBH of trees was used to indicate the influence of the number of trees in proximity to the hedge due to colinearity between these 2 variables. DBH was suggested by the GLMM to be the most important factor in explaining the variation in bird richness using the area, least important in explaining the bird abundance using the area, and to have little importance in explaining bird abundance or richness using the hedge using the Random Forest analysis. It was, however, shown to negatively affect the abundance of birds using the hedge by the GLMM. DBH was used as it combines tree presence and some indication of tree age which is often linked to their likely increased complexity and associated increased importance for biodiversity. Because the percentage canopy cover was not highlighted as important in the Random Forest analysis it is thought that some other benefit such that the presence of, age of trees, or how close to the hedge these trees were might have had an influence. It is likely however, that a combination of many of these factors would have an influence. Trees associated with hedges are positive factors influencing birds in hedges (Hinsley and Bellamy, 2019) with tree number and height usually accepted to increase the number of birds in the hedges in rural areas (Newton, 2017). Trees are beneficial to increasing the abundance of birds in urban areas (Lancaster and Rees, 1979), particularly if these trees were diverse in structure and species (Lancaster and Rees, 1979; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009); so my findings were surprising. One factor suggested to explain a detriment of the presence of trees is that they may offer a vantage point to avian predators of smaller birds (Hinsley and Bellamy, 2019). The factors suggested by the Random Forest analysis to be most important in explaining the variations in both richness and abundance of birds appear to be describing the proportions of vegetation in front of the hedge or in the vicinity of the hedge, in particular, woody habitats but both smooth and rough grassland also.

It is likely, however, that the count of birds in areas with a woody or shrubby area or tall ruderal vegetation behind would be an under recording as birds are likely to have been using the other side of the hedge more frequently and would not have been seen by the observer. This could be rectified by surveying both sides of the hedge at the same time, this would require two surveyors and could only be undertaken where access was granted and may be investigated in future survey work.

The importance scores of both grassland and woodland being high may also suggest that heterogeneity of surrounding habitat may be important to urban birds as well as rural. This may provide more of the attributes required for a bird's activities as some species nest in hedges, sing in trees and forage in grassland (Hinsley and Bellamy, 2019) and house sparrows nest in buildings and forage in woody vegetation such as hedges and trees (Shaw *et al.*, 2011). Research into identifying the threshold proportion of impervious surface after which the hedges are used less frequently due to the availability of other habitats in urban areas would be useful; as would the identification of the proportion of greenspace which provides the maximum area to species abundance and richness within urban areas.

The presence of hard surfaces immediately adjacent to hedgerows has been shown to have a major impact on the biodiversity value of rural hedges but having impervious surfaces on just one side may exert much less of an impact on urban hedges (Gosling *et al.*, 2016). The findings of this study tend to show no significant impact of the presence of adjacent vegetation (i.e. not a hard surface) on one side on bird abundance using the area or hedge but richness was higher when vegetation was present on both sides. The percentage of vegetation cover within 5 m behind was shown to be significantly related to bird abundance and important for richness. Management of these areas immediately adjacent to the hedge is likely to have impacts on the biodiversity of the hedge and surrounding area, as found by Gosling *et al.*, (2016). The results from this study also suggest that the habitats slightly further from the hedge but in the surrounding areas greatly impact the richness and abundance of birds in hedges with woody vegetation and grassy vegetation in the locality of the hedges being most important.

It appears that combinations of many factors will have an effect on bird abundance as is the established understanding for rural hedgerows. It appears that similar factors influence rural and urban hedges, so it would follow that management recommendations for rural hedgerows would benefit the biodiversity value of urban hedges. It is likely, therefore, that management to produce a tall, dense, wide, hedgerow with a complex structure and a diverse ground flora adjacent on one, or both sides (Dover and Sparks, 2000; Whittingham and Evans, 2004; Batáry, Matthiesen and Tscharntke, 2010; Staley *et al.*, 2016; Newton, 2017; Graham *et al.*, 2018; Hinsley and Bellamy, 2019) where possible, and hedgerow trees (Hinsley and Bellamy, 2019) would be beneficial to birds in the urban environment too. A heterogeneous mix of different hedge types and management regimes in urban environments would likely benefit urban bird diversity due to some species preferring different hedge characteristics to others including the dunnock which prefers lower hedges (Hinsley and Bellamy, 2019). Management should not be synchronised, as is often the case in urban areas, to allow for heterogeneity of hedgerow structure and of the buffer strips on either side (Whittingham and Evans, 2004; Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018). Obviously in urban environments there are a number of limitations and different pressures on the hedges and adjacent landuse such as sealed surfaces (Faiers and Bailey, 2005) and the ability to manage these habitats in a way that facilitates biodiversity may be more challenging (Oreszczyn and Lane, 2001; Faiers and Bailey, 2005; Gosling *et al.*, 2016).

Ultimately, the success of green elements in areas depends on public support (Miller and Hobbs, 2002). Therefore, we need to consider the viewpoint of many different people when planning our urban landscape to ensure benefit to both ecology and human health and wellbeing (Burel and Baudry, 1995; Jorgensen, Hitchmough and Calvert, 2002) and if we are going to continue the trend of moving towards more naturalistic vegetation within towns and cities, understanding how the public feel about natural vegetation is important (Jorgensen, Hitchmough and Calvert, 2002; Derkzen, van Teeffelen and Verburg, 2017). People are becoming more accepting of natural looking elements within our towns and cities (Jiang and Yuan, 2017; Southon *et al.*, 2017) but these elements must be located in the most appropriate places. If these habitats are to benefit both people and birds they should be located in areas where a larger number of people can access them to get the experiences of nature such as along routes to work or school (Todorova, Asakawa and Aikoh, 2004; Miller, 2005; Barton and Pretty, 2010). In urban environments due to the demands on space carefully managed hedgerows may offer a way to incorporate biodiversity and other ecosystem services into the city without the expense of a green wall and also not taking up too much valuable horizontal space. The cost and demand for space is greater in urban environments and this pressure is increasing (Robinson, 2005; Evans, Newson and Gaston, 2009) and the flexibility to allow hedges to be wider and taller may conflict with other demands on the area. For example, encroachment of pavements by hedges may not be feasible, and the conversion of hard surfaces to facilitate buffers or verges on either side may not be economically viable. There are however, many locations where biodiversity friendly management could be incorporated such as adjacent to areas of open green space, parks, alongside canals, or surrounding school fields or football fields. Some roadside verges also have hedges with mown grasslands on either side. Bird friendly management in these areas, where visibility is not impacted may not only be beneficial for wildlife but could mean a reduction in maintenance costs (Jorgensen, Hitchmough and Calvert, 2002).

3.5 *Conclusion*

Urban hedges were shown to be used by 15 species of bird and were used for a range of activities including breeding, foraging and shelter and should be protected and increased in urban areas to increase the abundance of birds. The woody hedge species should be an important consideration when planning green infrastructure and selecting which hedges to plant, as hawthorn hedges were found to be used by significantly more birds than beech or privet hedges; however, significantly more nests were found in privet hedges than beech hedges. Management of hedges for biodiversity should reflect biodiversity-friendly management of rural hedges as similar factors were found to significantly affect the abundance of birds. Urban hedgerows should be protected, preserved and sympathetically managed and the number of hedges increased as they provide habitat, forage and shelter for urban bird species including the red listed house sparrow, common starling and song thrush and some amber listed including the mistle thrush and the dunnock. The survey hedges were adjacent to roads, many with a high footfall and the abundance of birds shown to use them suggests that they are important for providing opportunities for experiences of nature thus benefitting the health and wellbeing of our urban population.

4 Mammals of Urban Hedgerows

4.1 *Introduction*

4.1.1 Mammals in urban environments

Urban areas throughout the world are set to grow significantly in the not too distant future (Rees, 1997; Marzluff, 2001; Ahern, 2011; Andersson *et al.*, 2014). Although it is sometimes argued that species richness increases with human population size (Gaston and Evans, 2004), most suggest urban areas have a reduced biodiversity (Bonier, 2012) and it is generally assumed that urban environments are less attractive to native wildlife and less beneficial to human health than rural areas (Button, no date; Rees, 1997; Chace and Walsh, 2006; United Nations, 2014a).

The environments of large cities can be very different from that of natural areas (Rees, 1997). Urbanisation dramatically alters the landscape (McCleery, 2010; Bonier, 2012). Areas become more complex (Angold *et al.*, 2006), highly fragmented by roads, and the small patches of remaining natural and semi-natural habitats are squeezed between homes, shops, factories, car parks, schools etc. (Baker *et al.*, 2003; Baker and Harris, 2007; Dover, 2015) with little connectivity to other habitats (Baker *et al.*, 2003). Fragmentation is an important impact of urbanisation (Dickman and Doncaster, 1987). Urban habitats also suffer dramatically increased levels of human disturbance (Baker *et al.*, 2003; Baker and Harris, 2007; Evans, Newson and Gaston, 2009). Urbanisation has had a marked effect on small mammal populations over the last 50 years (Baker and Harris, 2007), and as the human population becomes more urbanised the extent and impact of our urban environments are set to increase (Rees, 1997; Marzluff, 2001; Baker and Harris, 2007; United Nations, 2014b).

Much research has been undertaken on small mammal distribution in many rural areas but little on their distribution and abundance patterns in urban environments (Baker *et al.*, 2003; Baker, Bentley and Ansell, 2005). Generally, as urbanisation increases mammal diversity decreases (McCleery, 2010).The changes to a landscape associated with urban expansion are likely to impact small mammal species; especially as they appear to be negatively impacted by increased fragmentation, increased distance from natural or semi-natural habitat (Baker *et al.*, 2003; Baker and Harris, 2007; McCleery, 2010), introduced species (McCleery, 2010). Mammals are also impacted by increased populations of specific predators of small mammals including cats (*Felidae*) (Borkenhagen 1979 in Dickman and Doncaster, 1987), and foxes (Vulpes vulpes (L.)) (Harris 1977; Doncaster 1985 in Dickman and Doncaster, 1987) and dogs which can reduce the local populations of small mammals (Dickman and Doncaster, 1987). E.g. Wood mouse population size is negatively impacted by the presence of cats (Baker *et al.*, 2003).

However, there are both positives and negatives to small mammals of urbanisation (Dickman and Doncaster, 1987). Some small mammals are likely to be found in higher densities in areas with moderate levels of development, (Racey and Euler, 1982; McCleery, 2010) with access to anthropogenic food sources and structures for shelter (McCleery, 2010). Therefore, low population sizes of small mammals in urban areas are likely to be due to habitat modification by humans and predation by rather than lack of food (Dickman and Doncaster, 1989).

Some mammal species are tolerant to urban development whilst others are indifferent, and others intolerant (Racey and Euler, 1982). Species that respond poorly to urbanisation (Toms and Newson, 2006) or development characteristically have large body sizes, large habitat movements (Dickman and Doncaster, 1989; McCleery, 2010) or are habitat specialists (McCleery, 2010). Small mammals which are less than 10 kg are more likely to survive in urban environments as they are less obtrusive and can utilise smaller patches of natural or semi-natural habitat that more closely resemble the habitat present before urbanisation (Dickman and Doncaster, 1987; Baker and Harris, 2007). Urban mammal species also tend to be omnivores and more generalist in terms of food or habitat preferences (Baker and Harris, 2007; McCleery, 2010) and are able to move through a matrix of habitats such as those found in urban environments (Baker and Harris, 2007). Some species can find suitable habitat in gardens, parks and cemeteries, etc. (McCleery, 2010). Species able to scavenge can benefit greatly from the abundance of food and shelter in areas such as rubbish dumps (Courtney & Fenton 1976; in Dickman and Doncaster 1987) and some species including the house mouse (*Mus musculus*) and brown rat (*Rattus norvegicus*) are found in their highest abundance in areas such as storm sewers and domestic dwellings (Brooks 1973 in Dickman and Doncaster, 1987). A study in South-eastern South Australia found roadside vegetation to be an important habitat for small mammals, and some species including the house mouse were more commonly found in roadside habitats than fragmented remnant habitat patches (Carthew, Garrett and Ruykys, 2013).

Many of the small mammals found in urban areas are restricted to fragments that most closely resemble the landscape present prior to urbanisation and those that they exploit in rural/agricultural areas (Dickman and Doncaster, 1987). In rural areas, wood mice (*Apodemus sylvaticus*) are more commonly found in deciduous woodland, hedgerows, field and grasslands (Dickman and Doncaster, 1987). The bank vole (*Myodes glareolus*) is largely restricted to hedgerows and other non-crop areas in agricultural landscapes (Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009) with little movement into surrounding areas in farmed landscapes (Michel, Burel and Butet, 2006). Small mammals are unlikely to risk exposure of tarmac (Oxley, Fenton & Carmody 1974 in Dickman and Doncaster, 1987) but may disperse along railways and canal vegetation (Goriup 1976; Yalden 1980 in Dickman and Doncaster, 1987).

Small mammal communities are largely affected by the character of the habitat (Suchomel and Urban, 2011) and as species remain in one habitat patch for most of their lives due to their small size, resultantly, impacts upon their patch exert a major impact on their population (Dickman and Doncaster, 1987). Vegetation is a strong influencer of small mammal density specifically vegetation density at specific heights (Dickman and Doncaster, 1987). Mammals respond positively to vegetative composition, edge effect and habitat heterogeneity (Racey and Euler, 1982). Vegetation cover between 50 and 100 cm above the ground was positively correlated with wood mouse population density (Dickman and Doncaster, 1987). In urban areas there are high levels of habitat degradation via the loss of vegetation structure (McCleery, 2010). Many of the habitats in urban areas occupied by small mammals are associated with habitat modification and high levels of disturbance e.g. lawns, parks & golf courses (Dickman and Doncaster, 1987; Baker *et al.*, 2003; McCleery, 2010). Small mammals were also found to be most abundant in Oxford in remnant patches of semi-natural vegetation, such as urban woodlands which can support very high populations of small mammals, particularly if these areas have restricted dispersal opportunities, fruiting trees and little in the way of predators (Dickman and Doncaster, 1987). Wood mice and bank voles, however, were commonly found in gardens, parks, and allotments and did not show much movement from their home patch. In addition, building debris and rubbish can be used as shelter by small mammals from weather and predators (Dickman and Doncaster, 1987).

High quality gardens in urban areas may mitigate for the lack of semi-natural habitats and high habitat fragmentation for mammal populations in urban areas (Baker *et al.*, 2003). Populations of small mammals in urban areas can be positively influenced by practices of householders in their gardens as they can offer many microhabitats and food sources. The planting of fruiting and seed-bearing plants, constructing compost heaps, and the reduction in the use of pesticides and herbicides has also benefited small mammals (Good, 2000; Baker *et al.*, 2003). However, these practices are not commonplace and levels of disturbance, vegetation removal and predation by cats are often high (Baker *et al.*, 2003).

Wood mice were found to be the most common species in urban patches and this is likely to be due to its varied diet and ability to survive in a number of different habitat types (Dickman and Doncaster, 1987; Baker *et al.*, 2003). Wood mice were found by Dickman & Doncaster (1987) to be present in all urban habitat types and in 84% of all patches in their study of habitats in Oxford. Wood mice flourish in domestic gardens but other species do not (Baker *et al.*, 2003). Only two species: wood mice and bank voles were found in urban gardens and bank voles were rare (Dickman and Doncaster, 1987; Baker *et al.*, 2003). Domestic garden populations of wood mice may act as source populations for other areas and may buffer the effects of fragmentation on this species (Baker *et al.*, 2003). Both bank voles and field voles (*Microtus agrestis*) are rare in urban habitats and if they are found it is in areas of dense rough grassland (Dickman and Doncaster, 1987). Bank voles, although rarely found, were widely distributed in Bristol. Areas where they were present include woodland, cemeteries or churchyards, and domestic gardens (Baker *et al.*, 2003). Rat species were not included in these studies.

Dispersal distances of wood mice are larger than those of voles and may influence their ability to reach habitat patches to colonise new areas (Baker *et al.*, 2003). Wood mice can make long distance movements of between 100-500 m periodically. Both wood mice and bank voles were able to move between habitat patches and recolonised recently cleared habitat patches within six months but closer habitat patches were colonised more quickly and wood mice were able to colonise areas more quickly than voles (Dickman and Doncaster, 1987, 1989). Wood mouse populations were found to be unrelated to the availability of food sources or vegetation cover or human disturbance (Baker *et al.*, 2003).

Small mammals are an interesting biodiversity element due to their ecological importance, as most terrestrial carnivores depend upon them as a food source to some degree (Michel, Burel and Butet, 2006; Buesching *et al.*, 2008; Bates and Harris, 2009). They are also good indicators of habitat quality (Buesching *et al.*, 2008) and are important as consumers and as prey for other species (Suchomel and Urban, 2011).

4.1.2 Mammals in rural hedges

Hedges are managed rows of trees or shrubs (Baudry, Bunce and Burel, 2000) which support biodiversity through the provision of food, shelter and habitat (Forman and Baudry, 1984; Kotzageorgis and Mason, 1997; Dover and Sparks, 2000; Bates and Harris, 2009; Groot, Jellema and Rossing, 2010; Staley *et al.*, 2012; Amy *et al.*, 2015). Their composition, management and structure influence their suitability to support wildlife (Kotzageorgis and Mason, 1997; Bellamy *et al.*, 2000; Hinsley and Bellamy, 2000; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007). Small mammals, for example, are well known to use rural hedges (Sutton, 1992; Benton, Vickery and Wilson, 2003; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009; Amy *et al.*, 2015; Staley *et al.*, 2016). There is provision under the agri-environment schemes to protect and enhance hedgerows in rural areas (Croxton and Sparks, 2002; Pocock, Evans and Memmott, 2010; Amy *et al.*, 2015) and hedgerows were designated as a priority habitat in the 1994 UK Biodiversity Action Plan (Biodiversity Reporting and Information Group, 2007), but this protection does not extend to urban areas.

A hedge's structural condition has a strong effect on its value to wildlife (Staley *et al.*, 2015), but there have been fewer studies into the effects of hedgerow structure on small mammal populations than bird populations (Bates and Harris, 2009). Cutting regimes influence the size and structural diversity of hedges (Croxton and Sparks, 2002; Bates and Harris, 2009); management that produces larger hedgerows and greater diversity of structure on organic farms has been shown to be beneficial to small mammal populations (Bates and Harris, 2009). Higher hedge volume is usually associated with higher small mammal biomass (Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007) and thus a higher prey abundance for predators (Michel, Burel and Butet, 2006). Wider hedges have a larger area in which to provide shelter at ground level thus increasing opportunity for foraging and shelter (from predators and weather) (Croxton and Sparks, 2002; Bates and Harris, 2009). Mature hedgerows offer a greater food resource then younger hedgerows (Kotzageorgis and Mason, 1997). With appropriate trimming frequency larger hedges will provide larger surface area for seed and fruit production (Croxton and Sparks, 2002; Bates and Harris, 2009).

However, work carried out by Bates and Harris (2009) showed that a difference in hedgerow size did not have a significant effect on the abundance and diversity of small mammal populations on organic farms. So, although differences in hedgerow structure are important for biodiversity, these do not necessarily benefit all species. For example, hedgerow connectivity may be important for wood mice (Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009) and yellow-necked mice (*Apodemus flavicollis*) which prefer well established hedges with few gaps (Kotzageorgis and Mason, 1997; Bates and Harris, 2009; Staley *et al.*, 2015) as do dormice (Bright, 1998) and bank voles which are negatively associated with hedgerow gappiness.

Increased fragmentation and a decrease in the resources of hedges reduce small mammal richness and small mammal diversity but can cause a local small scale increase in abundance (Michel, Burel and Butet, 2006). Areas with a higher hedgerow density have a higher biomass of small mammals (Michel, Burel and Butet, 2006). Insectivorous mammals are extremely sensitive to hedgerow habitat loss (Croxton and Sparks, 2002; Bates and Harris, 2009), this is particularly detrimental to shrews, and so replanting to replace lost hedges and increase connectivity would greatly benefit these species (Pocock and Jennings, 2006; Bates and Harris, 2009).

It is thought that wood mice colonise hedges with direct connection with woodland and numbers decrease in hedges with distance from areas of woodland, however this was not found in the study by Pollard and Relton (1970). Surrounding vegetation also impacts the abundance and diversity of species within a hedge, when vegetation is sparse wood mice can be found less frequently (Todd, Tew and Macdonald, 2000) even though wood mice move freely into vegetation on either side of hedges. Bank voles, however, will only stray from the hedge bottom if adjacent vegetation is dense and are probably more reliant on woody vegetation for survival (Pollard and Relton, 1970). Tree seed was thought to provide a major food resource for wood mice during the winter and collecting these seeds may provide a reason for some species to move from the hedges. Mice and other small mammals suffer greatly from aerial predators in open habitats and would therefore be less likely to stray from the protection of hedges if vegetation on either side of the hedge is not dense or tall (Todd, Tew and Macdonald, 2000). However, there is research by Tew (1994) which shows that hedges may also be prime habitat or hunting grounds for weasels who predate small mammals.

Hedgerows in agricultural landscapes were shown to be the preferred habitats for wood mice in both winter and summer: in winter there was significantly more use of hedges than crop vegetation, but there was a more random use of vegetation cover types in summer. Hedges are thought to be used during the summer months as they are a good source of invertebrate prey and provide bolt holes for shelter (Todd, Tew and Macdonald, 2000). Positive influences on small mammal populations may come from an increase in the area covered by hedgerows as this is demonstrated by many studies to positively affect small mammal populations more significantly than improved management alone, leading to significant increases in mammal abundance. Increasing hedge coverage could be achieved via hedge planting, hedge repair and should be accompanied by careful management and the inclusion, where possible, of woodland habitats (Bates and Harris, 2009; Pocock, Evans and Memmott, 2010).

Hawthorn (*Crataegus monogyna*) hedges produce an important food resource in the autumn and winter for mammal species due to their production of haws (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Staley *et al.*, 2012). Due to the dominance of hawthorn in agricultural landscapes this fruit production is a significant source of food (Croxton and Sparks, 2002). The production of haws is strongly influenced by management practices and the quantity of haws of appropriately managed hedges can be 50 to 150 times greater compared to those cut annually (Croxton and Sparks, 2002). The less frequently a hedge is cut the more fruit is produced. Ideally cutting should be undertaken every 3 or 5 years, and, to allow small mammal species to access these berries, cutting should be undertaken during late winter not autumn (Staley *et al.*, 2012). Hawthorn is also beneficial in providing a source of insect prey for small mammals as it is associated with a much larger number of invertebrates than beech (Southwood, 1961).There seems to be little research on the benefits of hedging privet (*Ligustrum ovalifolium*) to wildlife.

Beech (*Fagus sylvatica*) based hedges are inherently poor in species but are of considerable ecological interest (Garbutt and Sparks (1999) in Baudry, Bunce and Burel, 2000). Small mammals consume beechnuts in forest areas (Suchomel and Urban, 2011) and these, alongside oak (Quercus) and hazel (Corylus) seeds, are often preferred as they are large rich in energy and nitrogen (Jensen, 1985). However, it is unlikely that the beech in the hedges of this study are managed in such a way that production of beechnuts is facilitated, and in Britain the late frosts also diminish fruiting (Packham *et al.*, 2012). Yellow necked mice were found to be abundant in areas with abundant seed-bearing beech trees but dense stands of beech show low food diversity (Suchomel and Urban, 2011). The provision of such seeds can lead to prolonged reproductive periods in small mammals including voles (Jensen, 1985). The leaves of beech hedges remain much longer than those of other deciduous species and are often present throughout the winter (Packham *et al.*, 2012). This may offer increased protection during winter months and may make beech hedges more appealing to small mammals.

The wood mouse is widespread throughout the UK and is characteristically found in woodlands but is also found in most habitats (Attuquayefio, Gorman and Wolton, 1986). It is a generalist making it less sensitive to changes in habitat than specialist species (Michel, Burel and Butet, 2006), an omnivore with a varied diet of seeds, buds, fruits, fungi, snails and arthropods (Attuquayefio, Gorman and Wolton, 1986). Wood mice can exploit areas outside the hedgerow network due to its high dispersal capacity (Halle, 1993; Michel, Burel and Butet, 2006) including an ability to rapidly colonise (Michel, Burel and Butet, 2006) newly created habitats with pioneer vegetation species (Halle, 1993). The wood mouse benefits from habitat heterogeneity to find a diverse range of food but uses hedgerows as a predominant overwintering habitat (Michel, Burel and Butet, 2006).

Wood mice move more from the hedge than voles (Brown and Twigg, 1970). The bank vole is largely restricted to hedgerows and other non-crop areas in agricultural landscapes and are negatively affected by features such as gaps in the hedgerows (Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009). They remain in the hedgerows with little movement into surrounding areas in farmed landscapes (Pollard and Relton, 1970; Michel, Burel and Butet, 2006) unless in areas of dense grassy vegetation as they prefer a lot of ground cover and are more sensitive to a lack of vegetation than wood mice (Pollard and Relton, 1970). Voles are more abundant in, and make up a larger proportion of the small mammals, in a hedge with a dense varied undergrowth (Brown and Twigg, 1970).

Both mice and voles were found to move along hedgerows. Average movements of mice along a hedge is 21 m with a range of between 5-60 m and 19 m for bank voles with a range of 5-50 m. Bank voles moved along hedges but were not captured away from the hedge, mice were caught in small numbers away from the hedge. Bank voles were found in higher numbers in hedges with a dense, varied ground layer (Brown and Twigg, 1970).

Common shrews (*Sorex araneus*) and pigmy shrew (*S. minutus*) have high activity rates (Genoud, 1984) and huge daily energy requirements. Hedgerows are a permanent habitat as they represent habitats with high food abundance (Wang and Grimm, 2007) for common shrews which are rarely found outside field boundary habitats (Pollard, Hooper and Moore, 1974; Tew 1994 in Kotzageorgis and Mason, 1997) only for some foraging activity. Common shrews were more abundant in hedges with adjacent permanent water possibly due to increased invertebrate numbers and diversity (Stoate, 2019). Common shrews were less frequently found in more recently planted hedges and were found in greatest number in older, hedges in 'good' condition. Hedgerows may act as corridors for common shrews as well as other small mammals species between woodland fragments (Kotzageorgis and Mason, 1997). Hedgerow size was found not to affect shrew abundance, but shrews were more abundant in hedges with wide, diverse hedge margins in autumn (Bates and Harris, 2009). To increase shrew numbers planting schemes on either side of hedges to encourage a dense varied ground flora may be beneficial.

4.1.3 Arboreality in hedges

Wood mice demonstrate arboreal behaviour, especially in males, whereas arboreality was only demonstrated by bank voles where food was scarce and population density was high (Buesching *et al.*, 2008). Wood mice were shown to demonstrate arboreality in roadside hedges during autumn and winter. This is thought to be for searching for food (Pollard and Relton, 1970; Montgomery, 1980) as evidence was found for the taking of rosehips (Pollard and Relton, 1970) and the predation of birds' nests (Walankiewicz, 2002). Arboreality may also result from intraspecific competition particularly between wood mice and yellow-necked mice (Montgomery, 1980; Buesching *et al.*, 2008). During the breeding season females appear to be territorial with respect to other females but males overlap with other males and female ranges (Attuquayefio, Gorman and Wolton, 1986). Bank voles climbed much less frequently than wood mice and were restricted to hedge bottoms unless adjacent cover was dense and it is likely that they would return to the hedge bottom rather than remain in the adjacent vegetation (Pollard and Relton, 1970).

One in 5 wood mice and 1 in 5 bank voles were caught in trees in a study by Buesching *et al.*, (2008) and 20% of the wood mouse activity was concluded to take place arboreally compared to 10% of bank vole activity. The likelihood of a small mammal entering a ground trap was higher as it could be accessed from any angle whereas arboreal traps could only be accessed by climbing up a specific branch. More arboreality was demonstrated in areas of high population density. Dense shrubby vegetation facilitated arboreality due to a good branch network. Benefits of this arboreality may be predator avoidance as shrubby vegetation may offer cover from aerial predators and a more silent movement due to not disturbing leaf litter (Buesching *et al.*, 2008). Where there are populations of different species of small mammals coexistence is facilitated by the more agile becoming more arboreal (Montgomery, 1980; Buesching *et al.*, 2008) and in areas of dense population of individual species then this overcrowding may result in more arboreal activity. The search for food may also drive individuals to be more arboreal as at times of year when food is plentiful these behaviours are less common. However, this seasonal variation was not shown in wood mice which could be explained due to the pursuit of insect prey. This search for insect prey may also explain why they are more arboreal than bank voles (Buesching *et al.*, 2008).

4.1.4 Hedges in urban environments

Although associated with the UK countryside, hedges occur within urban areas – either as relicts from previous land use or subsequently planted. Little is known about urban hedges in terms of their species composition, distribution, or value to wildlife and consequently we are ill-informed to protect, preserve, expand or future-proof this green commodity (Defra, 2007a) (See Chapter 1 Rationale Section 1.9).

4.1.5 Focus of the study

The study was conducted in Stoke-on-Trent and the adjoining town of Newcastle-under-Lyme in the north Midlands of England. This city region has a combined population of 381,693 (ONS, 2017) making it the 11th largest conurbation in the UK. Study hedges were located throughout the study area in both urban centres and residential areas (Figure 4-1).

Intensification of agriculture appears to affect species richness less than abundance of small mammals (Michel, Burel and Butet, 2006); generally, intensification leads to a loss of abundance of more specialist species as more common species (e.g. the wood mouse) become more dominant at the expense of the rarer, more specialist species (Michel, Burel and Butet, 2006), it is expected that urbanisation would have similar but more severe impacts than intensification of agriculture. Preserving linear habitats and the associated surrounding habitats may offer support for small mammal species (Gelling, Macdonald and Mathews, 2007).

My aim was to carry out a survey of urban hedges to see whether they provide suitable habitat for mice, voles and shrews, and whether this was affected by the main hedgerow plant species and the adjacent landuse. Baker et al. (2003) found mammal traps within public areas were frequently moved or stolen. Since our study hedges were located in areas with high footfall, live trapping was not an option and simple presence/absence survey methods (Mills, Godley and Hodgson, 2016), robust enough to cope with busy urban environments were used. Most mammal surveys are conducted at ground level but as many small mammal species are known to be arboreal (Montgomery, 1980; Bright, 1998; Juškaitis, 1999; Buesching *et al.*, 2008), I also investigated small mammal arboreality within the study hedges. The National Biodiversity Network Gateway (NBN Gateway) was interrogated in 2016 and the species of mammal found in a 5 km radius from postcode ST4 2DE, the centre of the study area, to see which small mammal species were likely to be present (Table 4-1).

Table 4-1 Species recoded within a 5 km square centred on the study area. Source - (NBN Gateway, 2016)

Species	Number of records
Grey squirrel *Sciurus carolinensis*	908
Fox *Vulpes vulpes*	565
Hedgehog *Erinaceus europaeus*	320
Wood mouse, *Apodemus sylvaticus*	155
Brown rat *Rattus norvegicus*	90
Weasel *Mustela nivalis*	24
Common shrew *Sorex araneus*	20
Stoat *Mustela erminea*	17
Field vole *Microtus agrestis*	16
Pygmy shrew *S. minutus*	10
Bank vole *Myodes glareolus*	9
Harvest mouse, *Micromys minutus*	3
Water shrew *Neomys fodiens*	3
House mouse *Mus musculus*	1
Black rat *Rattus rattus*	1

4.1.6 Research questions

The aim of this study was to answer the following questions:

1. Are mammals found to use urban hedges?
2. Are more mammal detections recorded in areas with hedges than control locations?
3. Do the number of detections of small mammals vary with hedge species?
4. Which other properties of the hedge and surrounding area affect the number of detections?

4.2 Method

4.2.1 Hedgerow selection criteria

A subset of the hedges identified through driving tours around the city (See section 2.2) used for the bird surveys were used. Two privet hedges which were not used for bird surveys were surveyed for small mammals as, due to access/permission problems (permission needed to be given and the hedges needed to be suitable for placing tubes within them), only 8 of the privet hedges used in the bird surveys were suitable. 10 hedges of each of these species were selected to be surveyed for mammal use based on their accessibility, and to encompass a range of hedge characteristics, i.e. a few large, medium and small hedges of each species, as far as possible, were chosen. It was aimed to select hedges with a range of different landuses behind, however, species tended to have characteristic landuses behind them. E.g. most allotments were bounded by privet hedges and hedges in the city centre areas were more commonly beech hedges, so this was only achievable to a certain degree (Examples of hedges and control locations are available in Appendix A). 10 control locations were also selected based on similar criteria. Controls were areas where there was no hedge was but where a linear structure was present, e.g. railings, fences and brick walls. These were deemed suitable providing similar land use existed behind the control and were not more than 150 m away from (although most were much closer to) a survey hedge (Figure 4-1).

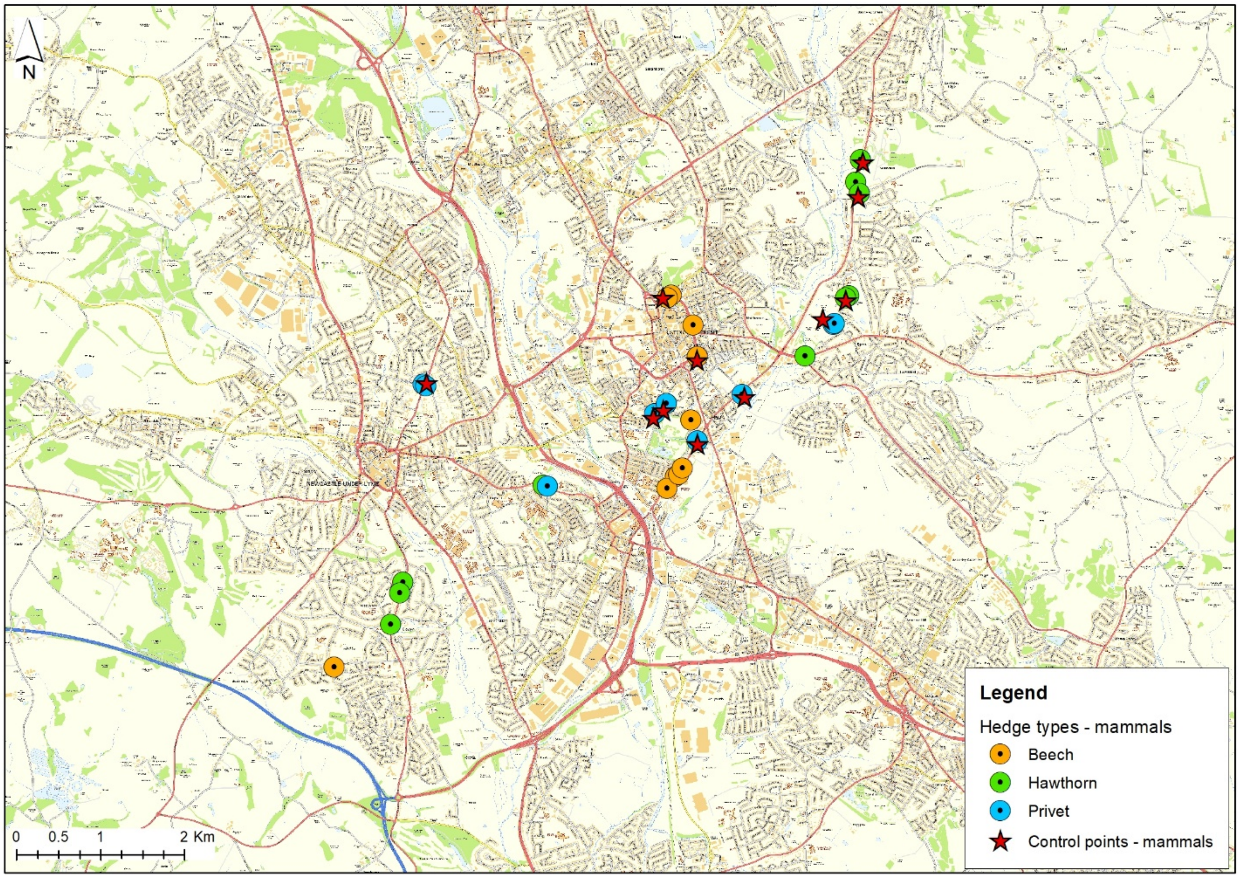


Figure 4-1 Locations of study hedges and control sites used for mammal surveys within Stoke-on-Trent. ©ESRI digital data, 2018 Staffordshire University Licence.

4.2.2 Small mammal surveys

The small mammal surveys methodology of hair and footprint tubes in urban hedges has been published as (Atkins *et al.*, 2018) and is attached as an appendix to this document (Appendix K).

The hedges and controls were surveyed for the presence of mammals during September and October 2015 and 2016. Two methods were employed: hair tubes (Figure 4-2) in 2015, and footprint tubes in 2016 (Figure 4-3 Small footprint tube. a) 65 mm wide downpipe cut to 250 mm length, both ends open. b) Insert – corrugated plastic. Inkpad, formed from painted masking tape, at each end a piece of tracing paper secured in the centre. & Figure 4-4). Hair tubes were baited with one level 5 ml spoonful of fly pupae and one heaped 5 ml spoonful of wild-bird seed. A fold of forensic lifting tape (sticky side out) was secured inside the tubes with double-sided sticky tape to hang low enough into the tube to brush against the back of a shrew entering or exiting the tube. The flexibility of the tape meant that it did not pose a barrier to mice or voles. Two sizes of footprint tube were used to collect footprints. Paint pads were constructed by painting masking tape with a mixture of non-toxic powder paint and sunflower oil. Two sheets of tracing paper to record footprints were positioned in the larger tubes and one in each of the smaller tubes. During pilot studies, tracing paper was found to be less palatable to slugs and snails, and the ability to overlay this on example footprints made identification more accurate. Cut-up hotdogs were put into an open Petri dish in the larger tubes to attract hedgehogs, but the smaller tubes were not baited as small mammals are sufficiently inquisitive and have been demonstrated to enter traps without the requirement for baiting and baiting is not used in the surveys conducted by The Staffordshire Mammal Group (D. Crawley, 2015, personal communication 3rd December 2014).

The larger footprint tube followed a similar construction to that used in the PTES hedgerow survey and as it was hoped that any hedgehog data collected within our urban hedges would be sent to them.

Small footprint tunnels were constructed so that they could be positioned along the branches of frequently trimmed (and therefore narrow) hedges. Inkpads were placed at either end of each tube with the collection paper between them. This arrangement allowed for the collection of an animal's full gait (front and back paws) in the relatively short length of tube.

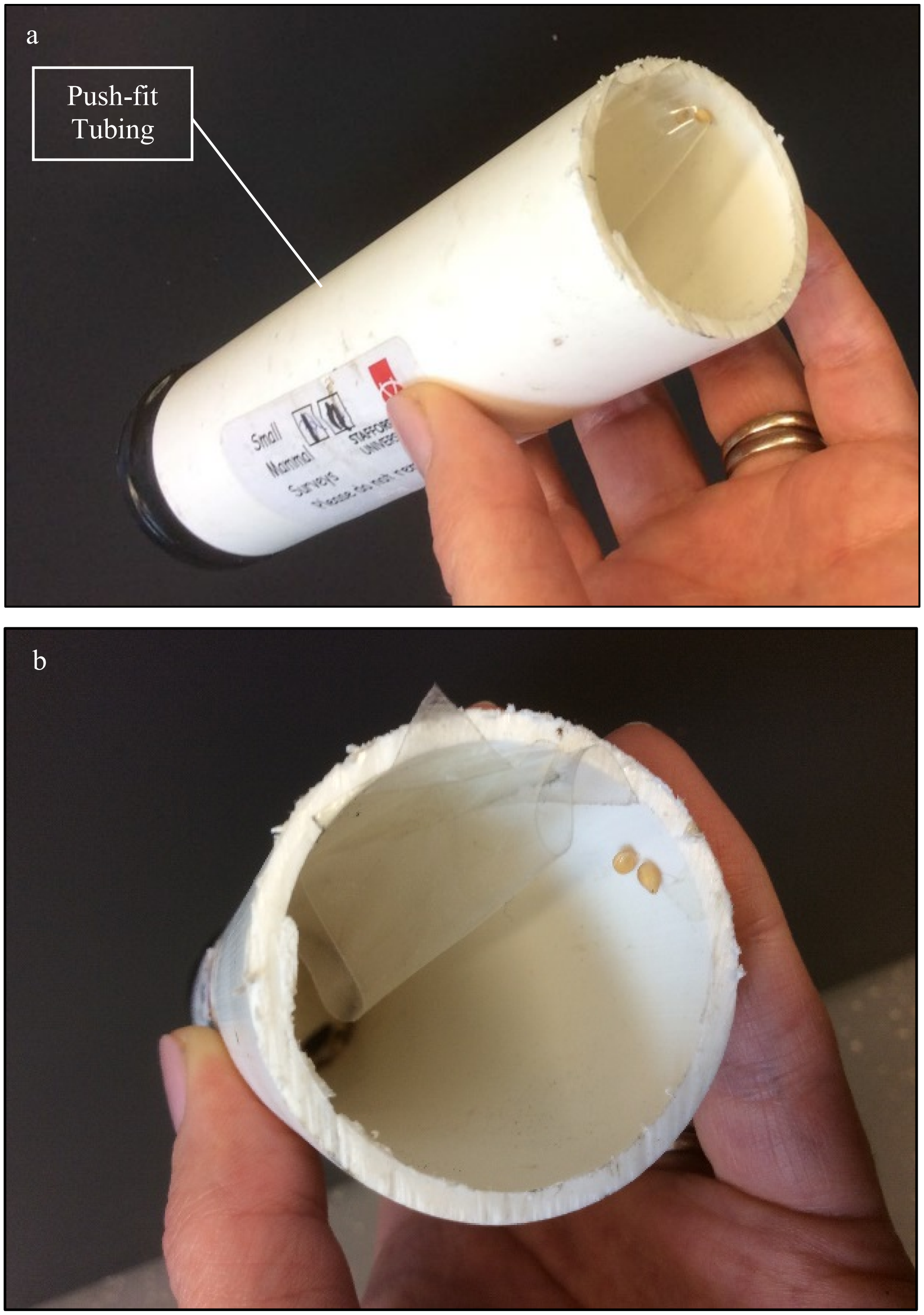


Figure 4-2. Hair tube. a) Design using 65 mm push fit tubing and b) forensic lifting tape folded (sticky side out) to hang low enough to be brushed against by a shrew. Other end of the tube is sealed. Baited with fly pupae and wild bird seed.

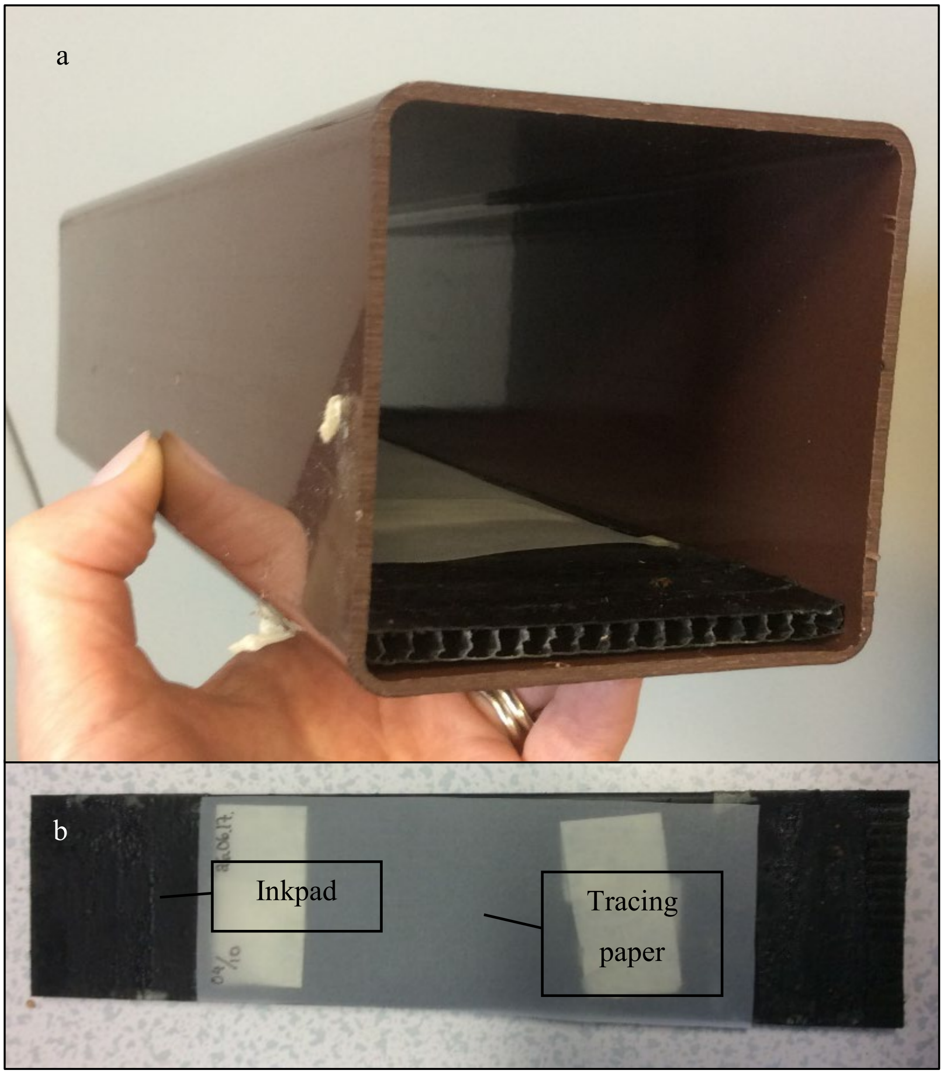


Figure 4-3 Small footprint tube. a) 65 mm wide downpipe cut to 250 mm length, both ends open. b) Insert – corrugated plastic. Inkpad, formed from painted masking tape, at each end a piece of tracing paper secured in the centre.

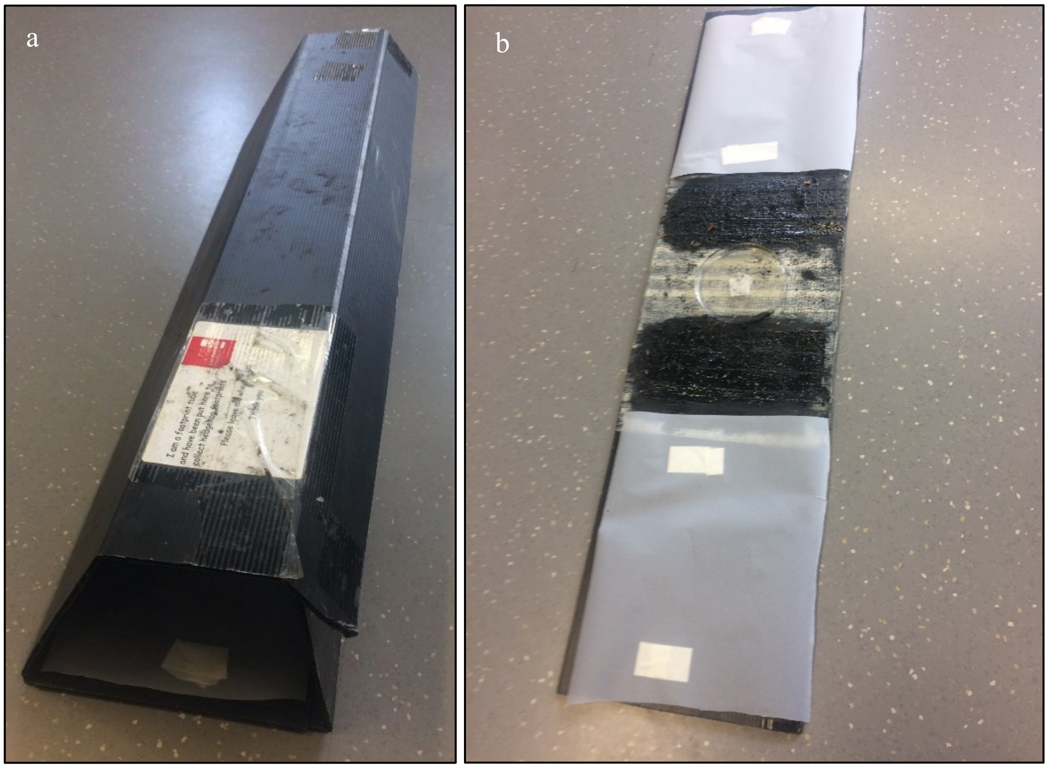


Figure 4-4 Large footprint tube. a) Corrugated plastic folded to form a tube; width 200 mm height 195 mm depth 800 mm. b) Insert – corrugated plastic with inkpad (painted masking tape) either side pf a Petri dish containing cut up hotdogs. Tracing paper secured to both ends.

Hair tubes were positioned at 5 metres (m) apart (horizontally) and 5 m in from the edge of the 30 m survey lines at 3 heights: at ground level, and at one third and at two thirds of the hedge height (Figure 4-5) giving a total of 15 tubes per hedge. Footprint tubes were placed 7.5 m in and 7.5 m apart. Large tubes were placed at ground level and smaller tubes at one third and at two thirds of the hedge height on a branch, secured in place using cable ties. The size of the larger tunnels reduced the practicality of including 5 along the base and 9 footprint tubes in total were placed in each hedge. All tubes remained in the hedges for four nights and were visited at the end of this period, after which they were removed.

Once collected, hair tubes were examined for droppings and other evidence such as caches or nesting materials to indicate use by small mammals. The tapes were removed from the hair tubes and examined for hair; if present, the tape was sealed in a Petri dish and labelled. Attempts were made to ID hair to species level using methods suggested by Teerink (1991) but with limited success. Sheets from the footprint tubes were collected and footprints identified by comparing to reference prints.

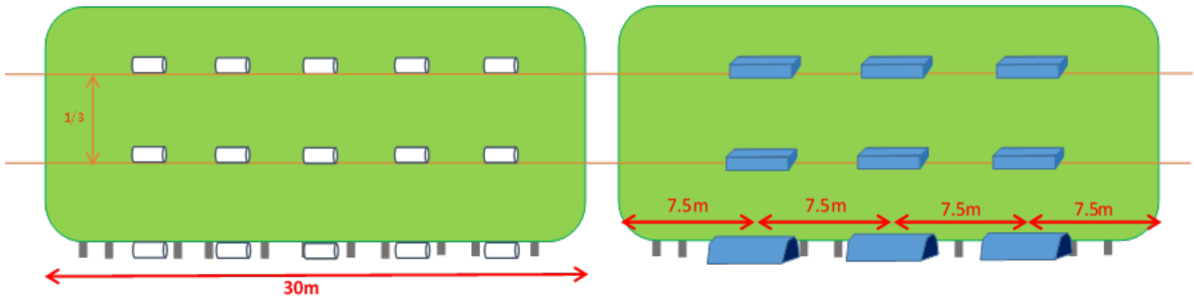


Figure 4-5 Tube positioning strategy. a) Baited hair tubes (white) positioned 5 m apart and 5 m in from the edge of the 30 m survey area at ground level, one third and two thirds of the height of the hedge. b) Footprint tubes were placed 7.5 m apart and 5 m in at the same three heights.

4.2.3 Hedgerow & surrounding area surveys

Many factors other than hedge species may impact on the number of mammals found in an area (Kotzageorgis and Mason, 1997; Bellamy *et al.*, 2000; Hinsley and Bellamy, 2000; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007). To establish the importance of these influences on the number of detections in the survey areas, data on the physical parameters of the hedge were collected alongside data on the surrounding landscape (See methods section 2.3).

4.2.3.1 Hedge physical properties

A detailed study of each hedge's physical characteristic was undertaken (Appendix B). Data collected included measurements and annotated sketches and photographs of the environment immediately surrounding the hedge (See methods section 2.3.1).

4.2.3.2 Adjacent vegetation & surrounding landuse

A hedge alone is unlikely to encompass the whole of a home range for a mammal and therefore the surrounding landuse will have an important influence on the number and diversity of mammals using the hedge (see section 4.1.2). Range sizes of wood mice in less productive habitats are significantly larger than those living in more suitable areas such as woodland (Attuquayefio, Gorman and Wolton, 1986). Range sizes of male wood mice in less productive habitats are approximately circular with a radius of about 100 m whilst range sizes in woodland habitats are more linear with the long axis about 80 m in length and 20 – 50 m for the short axis. Female ranges are smaller on a ratio of approximately 1:1.4 (Attuquayefio, Gorman and Wolton, 1986). Home ranges of bank voles overlapped and their size varied with season being much smaller during winter (Erlinge *et al.*, 1990) range sizes could be up to 200 m (Andrzejewski and Babinskawerka, 1986). However, if adjacent landuse is not suitable then a vole in particular would be less likely to stray from the hedge (Pollard and Relton, 1970).

It is important to take into consideration the heterogeneity of the urban environment which is not captured by one single variable (Beninde, Veith and Hochkirch, 2015). Factors that affect the biodiversity of an area include vegetation cover of surrounding areas, tree cover, and vegetation density (herbaceous, scrub and tree density total vegetation density); almost all of these factors are shown to significantly affect small mammal species richness (Croxton and Sparks, 2002; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009).

Landuse immediately on either side of the hedge was recorded and sketched where access was feasible (See section 2.3.2).

The percentage cover of different landcovers surrounding the hedges were calculated by categorising high-resolution aerial photography of Stoke-on-Trent (©ESRI digital data, 2018 Staffordshire University Licence) using ArcGIS (See section 2.3.3).

4.2.4 Data analysis

Please see chapter 2 General Methods

4.2.4.1 Comparing impacts of woody hedge species

As tubes were not positioned above ground in control locations, significance testing was undertaken using ground level data only for both footprint and hair tube generated data when control locations were included. When comparing between hedges only, data from all levels were used.

Due to two sizes of footprint tube being used data were categorised into ‘all small mammals’, and ‘mice/voles and shrews’ as mice, voles and shrews were small enough to fit into the smaller tubes whereas species such as squirrels, rats, cats and dogs could not. Prints of all mammals were compared separately to prints of mice/voles and shrews. When comparing data for all small mammals only ground level data were used.

To compare the number of detections between the three species of hedge, which had tubes at different levels (ground level plus two heights above ground within each hedge), for both footprint tubes and hair tubes, Schierer-Ray-Hare tests were used to identify differences between height, hedge species and interactions between the two. This method was only used on prints of species small enough to fit into the smaller of the footprint tubes (i.e. mice, voles and shrews) and on all detections in the hair tubes. Where significant differences were identified Dunn-Bonferroni tests were used to identify where these differences lay.

4.2.4.2 Comparing impacts of other variables

Dimension reduction was undertaken using PCA (See section 2.4.2) Generalised Linear Mixed-effect Model (GLMM) with Laplace approximation (GLMmer) (Anon., no date a; Bolker *et al.*, 2009) and Random Forest analysis (Liaw and Wiener, 2002) were used to identify which of these selected variables may be responsible for the variation of number of detections of small mammals within a hedge (See section 2.4.3). (Table 3-4 for variables included in analysis).

The impact of presence of adjacent vegetation is assessed using either ANOVA or Kruskal-Wallis tests with associated post-hoc analysis.

4.2.4.3 Comparing differences in the groups of hedges by species

To ascertain whether there were differences in the hedge species based on the variables measured (e.g. were beech hedges shorter, or did hawthorn hedges have a greater volume, or were privet hedges in areas with less impervious surfaces?) a Discriminant Analysis of Principal Components was undertaken (DAPC).

4.3 Results

Overall, 450 hair tubes and 270 footprint tubes were placed within 30 hedges, and 50 hair tubes and 30 footprint tubes were placed within control locations. Signs of mice/voles, shrews, cats, dogs, rats and squirrels were found (Table 4-2); 63% of all hedges surveyed showed evidence of small mammal activity compared with just 10% of control boundaries.

Table 4-2 Number of tubes with species' footprints collected at all heights within all hedges and NHL boundaries. Some tubes contained footprints of more than one species.

Mice/vole	Shrew	Rat	Squirrel	Cat	Dog	Total	Spoilt or removed	No. with no prints
44	14	10	4	2	1	56	8	206

Rat prints were not evenly distributed with boundary type (H=14.061, p= 0.002, n=40); they were found significantly more frequently in control locations than in locations with privet (Dunn-Bonferroni T=3.026, p= 0.015) or hawthorn hedges (Dunn-Bonferroni T=3.026, p= 0.015), although overall numbers were low. There was also footprint evidence of larger mammal species including squirrels, cats and a dog.

4.3.1 Comparison of woody hedge species

4.3.1.1 Hair tubes

There was a significant difference in the likelihood of finding evidence of small mammal activity when comparing the three hedge species and control boundaries (*H=9.854, p=0.020, n=40*) (ground level data only). Hawthorn hedges were significantly more likely to have evidence of small mammals than control boundaries (*T =-2.792, p=0.031, n=40*) (Figure 4-6a). When the impact of hedge species and tube height were investigated, the Scheirer-Ray-Hare test indicated a significant difference between the number of detections with hedge species ($\chi 2_2$ = *12.899, p<0.01*), but not with tube height ($\chi 2_3$ = *1.922*), and there was no interaction between tube height and hedge species ($\chi 2_4$ = *0.300*). Post-hoc analysis showed that hawthorn (*T = -3.294, p=0.003*) and privet (*T =-2.462, p=0.041*) hedges had significantly more detections than beech hedges (Figure 4-6 b).

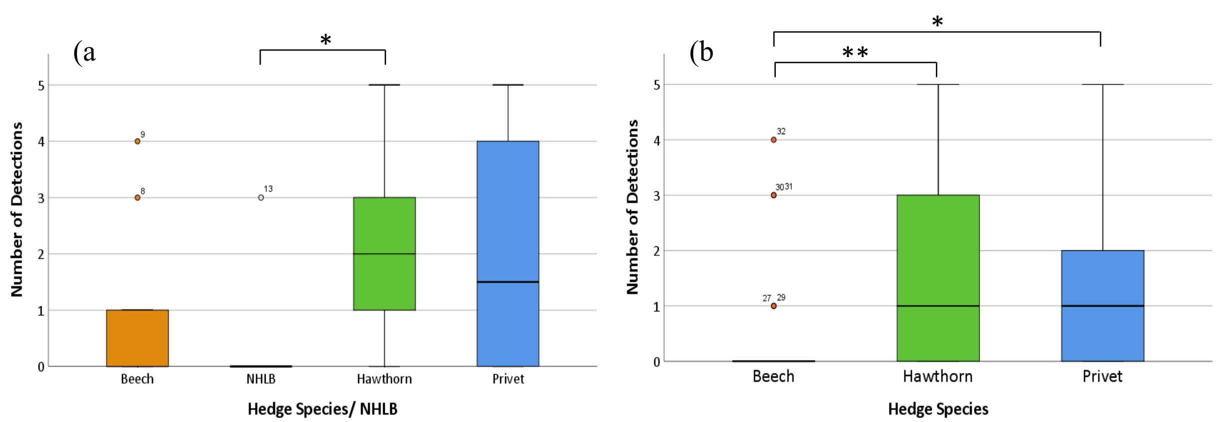


*Figure 4-6. Box plots illustrating signs of mice/voles and shrews from hair tubes by hedge species/control. Outliers are represented by dots. Dunn-Bonferroni test scores for significance between the mean number of small mammals in the area compared by hedge species/no-hedge. Lines join hedge species showing significant differences, *p< 0.05, ** p= <0.01 (a) Ground level data only. Significantly more detections were found in hawthorn hedges than in control locations (NHLBs) (T =-2.792, p=0.031, n=40). (b) data from all levels. Hawthorn (T = -3.294, p=0.003) and privet (T =-2.462, p=0.041) hedges had significantly more detections than beech hedges.*

4.3.1.2 Footprint tubes

The number of signs of all small mammals at ground level did not vary significantly (H=5.501, p=0.139, n=40) with hedge species/control; however, when I compared data for mice/vole and shrew prints the distribution was significantly different (H=10.201, p=0.017, n=40). Prints were more likely to be found in hawthorn hedges than control boundaries (T=-2.823, p=0.029) or beech hedges (T=-2.705, p= 0.041) (Figure 4-7 a). When hedge species and tube height were investigated a Scheirer-Ray-Hare test showed a significant difference between the number of detections with hedge species ($\chi2_1$ =14.510, p<0.001) but not tube height ($\chi2_2$ = 0.151), and there was no interaction between tube height and species ($\chi2_3$ = 0.148). Post-hoc analysis identified that hawthorn (T =-3.567, p=0.001) and privet (T =-2.582, p=0.029) hedges had significantly more detections than beech hedges (Figure 4-7 b).

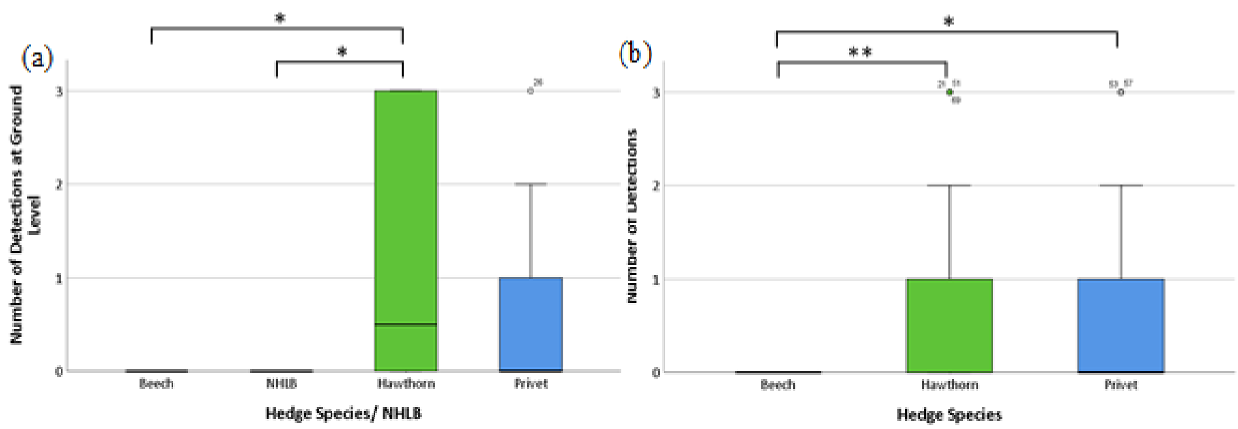


*Figure 4-7 Box plots illustrating signs of mice/voles and shrews from footprint tubes by hedge species/control (NHLB). Outliers are represented by dots. Dunn-Bonferroni test scores for significance between the mean number of mammals in the area compared by hedge species/no-hedge. Lines join hedge species showing significant differences, *p< 0.05, ** p= <0.01. (a) Footprint occurrence at ground level only. Significantly more detections were found in hawthorn hedges than in control locations (T=-2.823, p=0.029) or beech hedges (T=-2.705, p= 0.041). (b) Data from all levels. Hawthorn (T =-3.567, p=0.001) and privet (T =-2.582, p=0.029) hedges had significantly more detections than beech hedges.*

4.3.2 Arboreality in Urban Hedges

Arboreality of small mammals was demonstrated in all three of the hedge species using both hair and footprint tubes (Table 4-3). A Sheirer-Ray-Hare test was undertaken which compared both species and height. There was no significant difference between the number of detections at the ground and upper level of hedges, but fewer were found in the middle level of hawthorn when using footprint tubes (H = 8.808, p = 0.012 post-hoc T = 2.964 p = 0.009). Shrew prints, though infrequent, and mice/vole prints were found at all levels of hedges. Forty five % of mice/vole and shrew prints were found above ground and 58% of detections in the baited hair tubes (Table 4-4).

*Table 4-3 (a) Number and per cent of tubes with mice, vole, or shrew prints or tubes with signs at each level for each type of hedge. (b) Test statistics comparing the median number of signs in each type of hedgerow according to survey method There were fewer signs of mice, voles, or shrews in the middle (above-ground) level of hedges compared with the ground for hawthorn using footprint tubes: * (Dunn-Bonferoni T = 2.964 p=0.009)*

(a) Method		Position				(b) Test statistic	
Footprint Tubes	Hedge	Ground	Mid	Upper	Total	Kruskal Wallis	*p value*
	Beech	0 (0%)	0 (0%)	0 (0%)	0	-	-
	Hawthorn	16 (64%)	1 (5%)	8 (32%)	26	8.808*	0.012
	Privet	6 (40%)	4 (26.7%)	5 (33.3%)	15	0.457	0.789
Hair Tubes	Hedge	Ground	Mid	Upper		Kruskal Wallis	*p value*
	Beech	8 (57%)	2 (14%)	4 (29%)	14	1.589	0.452
	Hawthorn	21 (38%)	15 (27%)	20 (36%)	56	1.8	0.416
	Privet	19 (42%)	13 (29%)	13 (29%)	45	2.3	0.321

Table 4-4 Numbers (and %) of sheets with prints of mice/voles or shrews at each level. Prints of mice/voles and shrews were found at all levels within the hedges.

	Level			
Small Mammal	Ground	Mid	Upper	Total
Mice/vole	26 (61%)	5 (11%)	11 (26%)	42
Shrew	4 (29%)	4 (29%)	6 (43%)	14

4.3.3 Comparing the impacts of other variables

To identify the relationships between the measured variables and to identify any likely collinearity which may affect the reliability of the GLMmer analysis, PCA was used. PCA analysis identified that three components explained 58.3% and seven components explained 85.0% (Table 3-11). Suggesting that 7 would be the number of variables to include to give the greatest representation for the fewest variables in subsequent analysis. Inverse proximity to the road was also included as this may impact on mammal abundance (Carthew, Garrett and Ruykys, 2013).

There was correlation between the % cover of landuses within the different sized buffers because larger buffer areas encompassed the smaller buffer areas. The greatest impact of landuse would probably be felt within the 50 m around the hedgerow due to range sizes of small mammals (See section 4.2.3.2), as a result landuse within a 50 m radius of the hedge was selected for inclusion rather than the larger buffers. % impervious surfaces was selected to represent the types of landuse as it is an inverse of % green space and represents the degree to which urbanisation has dominated the landscape Table 3-13).

Total length of the hedge and the amount of rough grass in the area showed a correlation, possibly due to the longer hedges being found in areas of open green space which is where rough grass would be more common. Total hedge length was included within the GLMM, however, as both of these variables are likely to affect the likelihood of finding small mammals in the area. Relationships between hedge volume, height and width are well documented in the literature to affect small mammals and hedge volume were included to represent hedge structural characteristics in the GLMM. Tree proximity and average DBH were shown to have a relationship and DBH was selected to be included in the GLMM as this indicated both the presence of trees and gives some indication of their size. Vegetation cover adjacent to the hedge was been suggested in many studies to have an effect on small mammal abundance and percent of vegetation behind the hedge did not show strong correlations with other variables and was included in the GLMM. Woody vegetation and hedge height were shown to have a relationship, hedge volume was included in the GLM but consideration of woody vegetation was considered when interpreting the results for hedge volume. Percentage of vegetation in front of the hedge was included in the GLMM to also represent % smooth grass in 5 m.

Following the dimension reduction from the PCA 8 variables were compared against mammal survey data. The variables included were average DBH of trees in the area, hedge volume, percentage of vegetation in front of the hedge, total length of the hedge, inverse proximity to road, percentage of impervious land cover within a 50 m buffer of the hedge, percentage vegetation cover within 5 m strip behind the hedge, and the height of the vegetation behind the hedge with the random effect variable of hedge species as this has been shown in the initial data analysis to have a significant effect on the number of detections of small mammals. These variables were compared against the count data for the number of detections using the hair tubes per hedge and then again for the number of tubes with mice, vole or shrew prints per hedge.

The GLMM results for frequency of detections per hedge when using hair tubes suggest that the average DBH of trees in the area is negatively associated with number of detections and hedge volume is positively associated (Table 4-5). The frequency data from the footprint tubes did not generate any significant associations with any variables (Table 4-6) but numbers of detections were lower.

Table 4-5 GLMM results for variables compared to mice/vole and shrew abundance using hair tubes (n=29), Random effect = hedge species. There is a significant negative association with DBH of trees and a significant positive association with hedge volume

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	-3.365	<0.001	***
Hedge Volume	3.089	0.002	**
Percentage of Vegetation in front of hedge (5 m)	-1.615	0.106	ns
Total Length of hedge	1.129	0.259	ns
Inverse Proximity to Road	1.227	0.220	ns
% impervious within 50m buffer	-0.846	0.398	ns
% vegetation behind the hedge within 5 m	1.286	0.199	ns
Vegetation height behind hedge	0.988	0.323	ns
Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, † = p< 0.1, ns = p> 0. 1			

Table 4-6 GLMM results for variables compared to mammal abundance using footprint tubes (n=30), Random effect = hedge species. No variables showed a significant association at the 5% level.

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	0.171	0.864	ns
Hedge Volume	1.286	0.198	ns
Percentage of Vegetation in front of hedge (5 m)	-0.311	0.756	ns
Total Length of hedge	0.761	0.447	ns
Inverse Proximity to Road	1.719	0.086	†
% impervious within 50m buffer	-1.832	0.067	†
% vegetation behind the hedge within 5 m	1.107	0.268	ns
Vegetation height behind hedge	-1.769	0.077	†
Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, † = p< 0.1, ns = p> 0. 1			

Adjacent vegetation was assessed using independent samples Mann-Whitney U tests following normality tests and there was no significant difference found in the abundance of prints (*U=105.0, p= 0.668, n= 29*) or evidence from the baited hair tubes (*U=84.0, p= 0.636, n= 29*) with adjacent vegetation on one or both sides of the hedge. Adjacent vegetation was also shown to be less important than many other variables in explaining the variation in number of detections in hair tubes within the study hedges when using Random Forest analysis.

16 variables were included in the Random Forest analysis and following 500 iterations of the algorithm the importance scores for each variable are shown in the box and whisker plots (Figure 4-8 and Figure 4-9).

The % of grass in 50 m, was shown to be significantly more important than the other variables in explaining the variation in the number of detections from hair tubes and number of tubes with footprints. Rough grass in 50 m and % woody vegetation in 50 m were also shown to be important in explaining the variation in number of detections in hair tubes followed by DBH of trees and the distance from the road.

% grass within 50 m, the % of rough grass and the %impervious surfaces within 50 m followed by % woody vegetation in 50 m, and vegetation height behind the hedge were important in explaining the variation in number of tubes found with footprints. Suggesting that parameters of the surrounding landscape are more important than characteristics of the hedge itself. The results are summarised in Table 4-7).

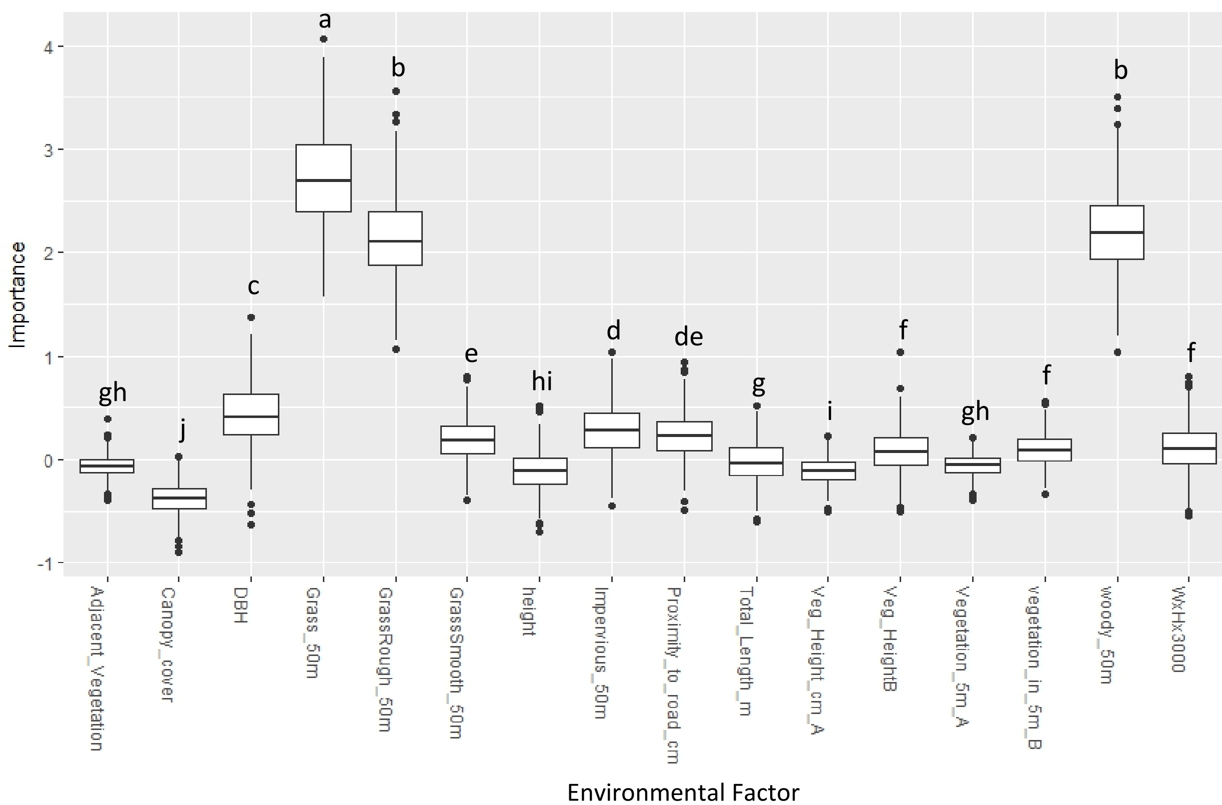


Figure 4-8 Boxplot indicating the importance that each environmental factor has in explaining the variation in number of detections found using hair tubes per run of the random forest algorithm. Scores for variables with different lower case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are % of grass within 50 m of the hedge, % of rough grass and % of woody vegetation within 50 m of the hedge.

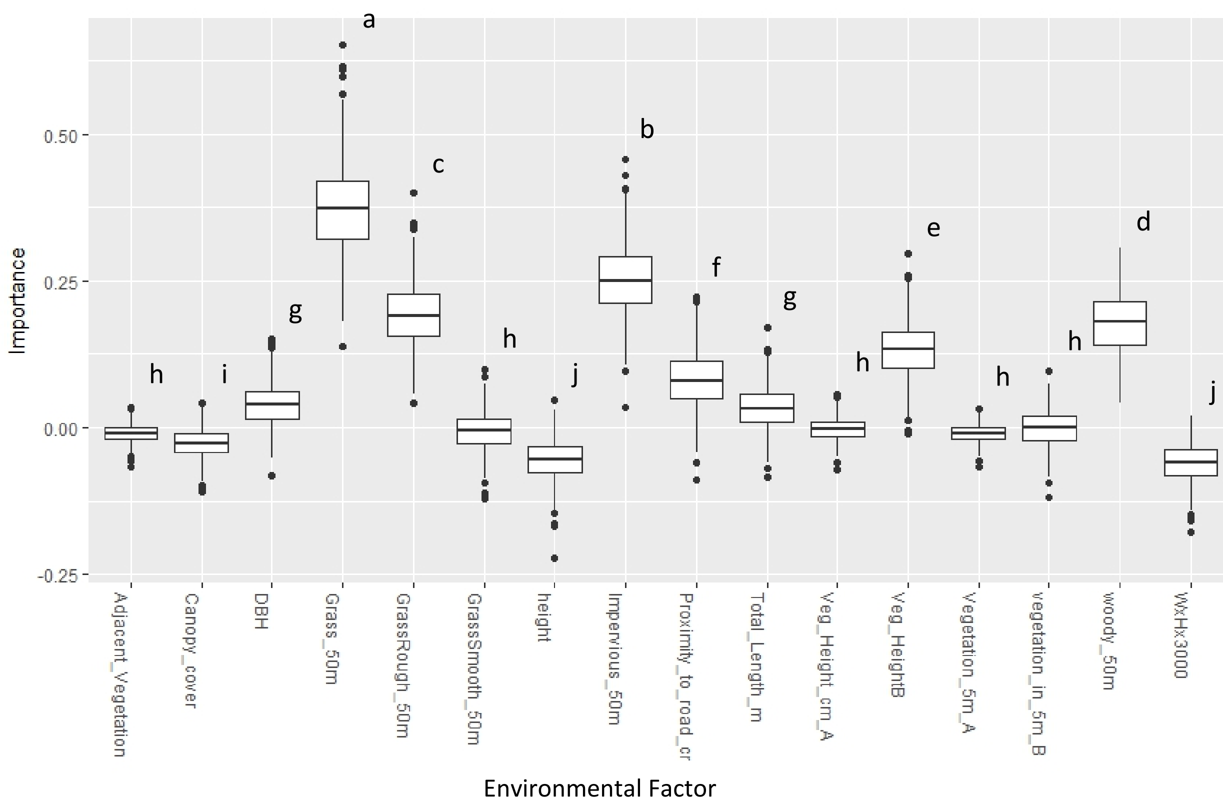


Figure 4-9 Boxplot of importance of impact the environmental factor has on explaining the variation in number of detections found using footprint tubes per run of the random forest algorithm. Scores for variables with different lower case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are % of grass within 50 m of the hedge, % impervious surface within 50 m buffer of the hedge, % of rough grass and % of woody vegetation within 50 m of the hedge

*Table 4-7 Summary table of GLMM and Random Forest results. Significant factors are included for GLM and significance levels are shown using the asterisks *** = p< 0.001, ** = p < 0.01, * = p< 0.05 . Median importance scores for the random forest results are included in parentheses*

Variable (new)	**GLM +ve**	**GLM-ve**	**Random Forest Importance**
Mice/vole, & Shrew abundance hair tubes	Hedge Volume**	DBH***	Grass 50 m (2.71) Woody (2.19) Rough Grass 50 m (2.14)
Mammal abundance footprint tubes			Grass 50 m (0.37) Impervious 50 m (0.25) Rough Grass 50 m (0.19)

The results indicate that, in addition to hedge species and other physical properties of the hedge, properties of the surrounding land impact the number of detections of mammals within the hedges. To assess whether the variation in number of detections of small mammals in the hedges was attributable to variations in the physical properties of the hedge or due to the hedge species itself Discriminant Analysis of Principal Components (DAPC) was used (Figure 4-10). This would establish whether the hawthorn hedges had different physical and surrounding features than that of beech or privet hedges which would identify whether the hedge species could be differentiated from each other by other physical properties measured. The variables included were average DBH of trees in the area, hedge volume, percentage of vegetation in front of the hedge, total length of the hedge, inverse proximity to road, percentage of impervious land cover within a 50 m buffer of the hedge, percentage vegetation cover within 5 m strip behind the hedge, and the height of the vegetation behind the hedge. The DAPC identified only one principal component on which differences could be identified. (Figure 4-10). The significant overlap between the hedge parameters measured suggests that a diverse mix of hedges of each species was included as specified in the selection process as the hedge species could not be separated by any variable. For example, beech hedges did not characteristically have a higher volume, more or larger associated trees, more vegetation in front of the hedge, or more impervious surface within a 50 m buffer than the other hedge species.

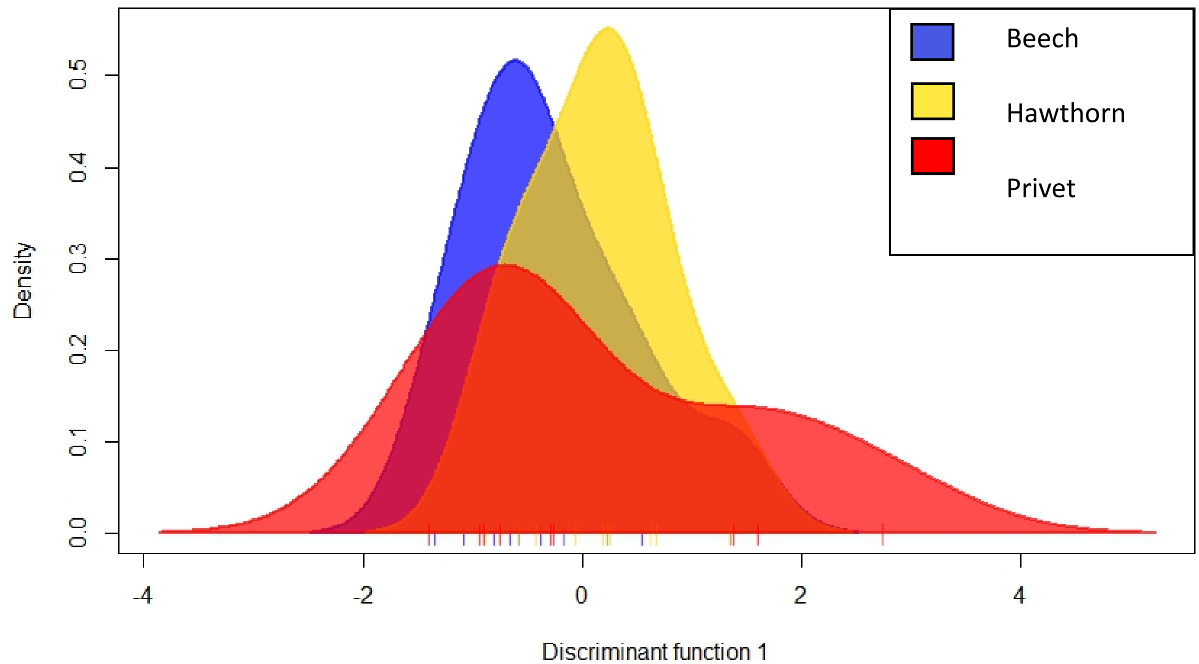


Figure 4-10 Alignment of hedges by woody hedge species along the first principal component (the only component identified). in the variation of hedge species in the variables representing hedge and surrounding landscape characteristics. There is considerable overlap between hedges of each woody species. DAPC is unable to discriminate between hedges of different species by the variables inputted.

4.4 Discussion

Mammal surveys of 30 hedges (10 each of the three most common species) using baited hair tubes and footprint tubes were undertaken in the urban areas of Stoke-on-Trent and Newcastle-under-Lyme in the autumn of 2015 and 2016. This is a proof-of-concept that both hair tubes and footprint tubes can be used to provide evidence of small mammal activity in hedges in urban environments. Small mammals were found to use almost two thirds (63%) of the hedges surveyed, a finding that agrees with the view of Baker & Harris (2007) and Dickman and Doncaster (1987) that small mammals were suited to urban habitats and are usually found in habitats similar to those inhabited within rural areas. Small mammals are well known to use hedges in agricultural landscapes (Sutton, 1992; Benton, Vickery and Wilson, 2003; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009; Amy *et al.*, 2015; Staley *et al.*, 2016) and our result suggest that they are commonly used within urban areas.

4.4.1 Are there more mammals found in areas with hedges?

Control locations were selected in areas in close proximity to hedges and many of which may have been within the home ranges of the mammals found to be using the urban hedges. Detections of small mammals within control locations, even though they contained a linear feature were found in just 10% of controls. This suggests that mammals use hedges significantly more frequently than the other types of boundary included in this study.

Rat prints were not evenly distributed between study areas and were found significantly more frequently in areas that did not contain a hedge than in areas with a beech or hawthorn hedge, however numbers of rat prints found were very low. It may be that, rather than the presence of a hedge, access to anthropogenic food sources may be more important in the distribution of rat populations but it is beyond the scope of this research to provide evidence for this.

4.4.2 Does the woody hedge species affect the likelihood of finding small mammal species?

It is suggested by the results that hedge species does influence the likelihood of finding mammals in an area. Significantly more detections of mammals were found at ground level in areas that contained a hawthorn hedge compared to areas that did not contain a hedge, and significantly more prints were found at ground level in hawthorn hedges than in beech hedges or areas without a hedge.

The difference in numbers of detections and prints found in hawthorn hedged areas than control locations could be due to the protection offered by having a hedge present, the provision of food, and/or even provision of habitat (Forman and Baudry, 1984; Kotzageorgis and Mason, 1997; Dover and Sparks, 2000; Bates and Harris, 2009; Groot, Jellema and Rossing, 2010; Staley *et al.*, 2012; Amy *et al.*, 2015).

As there were significantly more detections and prints of mice/voles and shrews in both hawthorn and privet hedges than beech hedges and as there was not a difference in other parameters between the hedge species then this difference is likely to be due to a difference in the provision offered by the woody species itself. There is little published information on the benefits of privet to small mammals but it is likely to provide good protection from predators due to its dense bushy habit, flowers and fruits (RHS, 2018), if management permits flowering and fruiting, and may provide a source of insects. Hawthorn also provides cover and protection from predators but also an important food source in the form of berries, when managed appropriately (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Staley *et al.*, 2012), and insects (Southwood, 1961). Beech mast may provide a food source for small mammals (Jensen, 1985; Suchomel and Urban, 2011; Packham *et al.*, 2012), however it is unlikely that managed beech hedges would fruit as beech does not produce fruit until it reaches maturity (Ian Hoskins, pers comm, 19th November 2018).

4.4.3 Which other characteristics of the hedge and surrounding area affect the abundance of mammals?

Factors shown in the analysis of hedge parameters and adjacent land indicate that the size and number of trees in the area may mean that fewer small mammals are using the hedges. This could be due to possible preferential use of areas of woody vegetation behind the hedges than the hedges which are closer to the disturbance of the road. It has been found in previous studies of rural areas that hedges in close proximity to woodland have a higher number of small mammals, this was however not found to be the case in this study, or in a study by Pollard and Relton (1970). It was also suggested by the results that hedges with a larger volume would be more likely to support small mammals as found in many studies of rural areas (Kotzageorgis and Mason, 1997; Croxton and Sparks, 2002; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009). A large hedge volume is often associated with a lower cutting frequency which is also well documented as beneficial for small mammal populations (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Bates and Harris, 2009; Staley *et al.*, 2016).

The DBH being negatively related to mice/vole and shrew abundance when using the baited hair tube method, is more difficult to explain especially as two of the top three hedges that had a high score for DBH had evidence of small mammals from both methods. However, also a number of the hedges that did not have trees also showed a lot of evidence of small mammals. Almost one third of hedges that showed evidence in hair tubes of small mammals had no trees present including the three hedges that had the highest number of tubes with mammal evidence. Further research into this phenomenon is required. Trees in rural hedges are associated with increased use by mammals due to the provision of forage and food in the form of invertebrates and fruits and seeds (Jensen, 1985).

It has been suggested that management of vegetation adjacent to a hedge is important for biodiversity within the hedge (Pollard and Relton, 1970; Michel, Burel and Butet, 2006). Gosling *et al.* (2016) found that the presence of a hard surface on one side of the hedge did not have a major effect on the biodiversity value of the hedge, although this research did not study mammal species. Similar conclusions could also be drawn from the results of this study as no significant difference was found in the number of detections of mammals found in hedges with adjacent green space on one side or two sides. So long as forage is accessible, maybe it does not need to be on both sides. The small number of hedges surveyed in this study with hard surfaces on neither side means that the impact of this is not adequately evidenced and would require further research. Management and landuse within 50 m of the hedge was suggested to impact on the number of detections and prints found within a hedge, and the percent of grass and woody vegetation was most important. This is likely to be due to access to foraging in the surrounding areas. The percent of vegetation immediately behind the hedge was not shown to be important. There was, however, little variation as the hedge selection criteria meant that selected hedges would have some green landuse behind or in close proximity and 77% of hedges had at least 75% vegetation cover in the 5 m behind the hedge. The percent of impervious land cover which represented the amount of green space, percentage of grass in total, % of rough grass, % of smooth grass and woody vegetation was not shown to be significant. However, when the constituents were included individually in the Random Forest analysis the percent of grass, the percent of rough grass and the percent of woody vegetation were significantly more important than impervious surfaces and DBH which were shown to be significant in the GLMmer.

This study suggests that urban hedges, even though they may be less sympathetically managed for wildlife than rural hedgerows (Faiers and Bailey, 2005; Gosling *et al.*, 2016), provide valuable wildlife habitat and may be used as corridors for animals to move between larger green infrastructure elements and, as such, should be protected and expanded. Mammals have been found to use the hedge as a three-dimensional habitat and therefore offer a space-effective way to provide habitats for mammals in urban areas.

There is literature suggesting that providing diversely managed rough grass or scrubby areas adjacent to rural hedges facilitates foraging (Pollard and Relton, 1970; Faiers and Bailey, 2005; Michel, Burel and Butet, 2006; Gosling *et al.*, 2016) and offers protection from predators

(Pollard and Relton, 1970; Dickman and Doncaster, 1987, 1989) and as such increases mammal populations; and the findings in this study indicate that the same management methods would be beneficial to small mammal communities in urban areas. The inclusion and sensitive management of the hedge to produce a larger hedge volume and greater diversity of growth stages (Croxton and Sparks, 2002; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009) would be beneficial. As would incorporating foraging areas such as rough grass (Pollard and Relton, 1970) and sources of food including fructiferous trees into surrounding vegetation (Todd, Tew and Macdonald, 2000). Greater mammal diversity is likely to be provided for should there be more food available within the hedge itself. This may be achieved by more sympathetic management with a cutting regime that permits flowering and fruiting as is recommended in rural landscapes (Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Staley *et al.*, 2012). Greater connectivity could be created by expanding existing hedges or planting new ones that link those already in place which is likely to increase mice, vole and shrew abundance (Bates and Harris, 2009). The woody species of a hedge is suggested to play a role in the use of a hedge by small mammals and hawthorn and privet are likely to provide a more favourable habitat than beech hedges and should therefore be considered for recommended species to plant. Further studies investigating a wider set of hedge species and mixed hedges and studying small mammal use at other times of the year would provide useful information. The use of species such as beech and privet as hedges in urban areas is common; however, there is little research on how to manage these hedges to benefit small mammals but it is likely that allowing privet to flower would increase invertebrate abundance and thus provide insectivorous prey for small mammals but permitting sufficient growth for beech to permit mast production would be impractical and may be best achieved by allowing some hedge plants to grow into trees.

The provision of larger, more dense hedges with abundant adjacent vegetation in urban areas may not always be obtainable due to pressures of space or management requirements such as keeping pavements free from overhanging branches. Some areas, however, possibly in hedges surrounding football pitches, public gardens, industrial and office estates, or school grounds and those alongside, canals and riversides may be suitable locations for biodiversity friendly management. The benefits of nature to people suggest that efforts should be made to incorporate hedges and opportunities for contact with nature where people would receive the most benefit such as routes to work or schools. Previously, there has been conflict between the management methods that people expect e.g. neat, tidy hedges and management that benefits wildlife and the resultant ecosystem services (See section 11). There appears to be a change in attitudes towards nature in our cities and perceptions are beginning to become more appreciative of wilder more natural looking environments and the benefits these bring (Jorgensen, Hitchmough and Calvert, 2002; Jiang and Yuan, 2017; Southon *et al.*, 2017) (See Chapter 6).

4.4.4 Arboreality in urban hedges

Small mammals were found to be not only using the base of the hedges but also using the upper levels as frequently as the base, suggesting that the hedges provide a three-dimensional habitat. Arboreality has been demonstrated in woody environments for both wood mice (Pollard and Relton, 1970; Montgomery, 1980; Buesching *et al.*, 2008) and bank voles (Montgomery, 1980; Buesching *et al.*, 2008) and this arboreality is likely to be more frequently demonstrated in areas of high population density or food scarcity and is facilitated by dense branching vegetation (Buesching *et al.*, 2008). Any of these could be the drivers of the arboreality demonstrated by small mammals in this study. Most of the hedges were frequently trimmed so that the production of berries or mast was reduced or prevented but there will still be insects present which may increase their benefit to insect eating species (Buesching *et al.*, 2008).

Fifty-eight % of hair tube detections and 44% of footprints were found above ground. As access to the tubes being more difficult in arboreal locations (Buesching *et al.*, 2008), the arboreal behaviour of small mammals in urban hedges is suggested to be substantial. As manoeuvring within the internal structure of hedges, and at height, presumably requires more energy expenditure than activity at ground level, there must some advantage provided by the hedge canopy. Being active above the ground may help small mammals avoid predators such as cats (*Felis catus*) (Baker, Bentley and Ansell, 2005), birds (Buesching *et al.*, 2008), and foxes (*Vulpes vulpes*) (Scott *et al.*, 2014). Canopy use may also reflect the influences of intra- and inter-specific competition and food availability (Buesching *et al.*, 2008). A higher percentage (72%) of shrew prints were found above ground than those of mice/voles (37%) maybe this benefit is due to the proportion of insects that make up their diet (Buesching *et al.*, 2008).

4.4.5 *Survey methodologies*

Although the two survey methods were not undertaken at the same time, both hair tubes and footprint tubes provided similar evidence of the presence of small mammals; 66% of hedges where small mammals were detected showed evidence from both methods, 94% had evidence from hair tubes, and 72% for footprint tubes. Small footprint tubes were not baited in any way, and future studies may show whether baiting influences tube efficiency. Whilst the hanging tape approach may have deterred some individuals from entering tubes, the abundance of footprints suggests that deterrence, if any, is likely to be minimal. An improvement to future studies using hair tubes would be to identify hairs to species and to include both small and large tubes at the base of the hedge and in control boundaries.

4.5 *Conclusions*

Small mammals were found to use the majority of urban hedges surveyed and hawthorn and privet hedges were more likely to support small mammals than beech or boundaries without a hedge during autumn surveys. Hedges also provided a three-dimensional habitat for small mammals. The use of hedges by small mammals may be improved with sympathetic management of the hedge itself but maybe more importantly the surrounding areas with rough grassland and woody vegetation being key factors. Both the hair tubes and the footprint tubes were effective methods for sampling in these challenging urban environments. Hair tubes provided information on presence-absence but identifying hairs to species should be a focus for future studies. In contrast, it was more straightforward to identify species or type with the footprint tubes. My data suggests that hedges are a valuable component of urban habitats and should be protected and the resource increased with sympathetic management for wildlife.

5 Invertebrates in Urban Hedges

5.1 *Introduction*

5.1.1 Invertebrates in urban areas

To be able to conserve biodiversity as urbanisation continues we need to understand how urbanisation affects wildlife (Helden and Leather, 2004; Jones and Leather, 2012). Cities provide for a wide range of plants and animals, sometimes in unusual recombinant communities (Angold *et al.*, 2006). Some studies have found no change in the number or diversity of invertebrates with proximity to urban areas but some species, however, have shown declines or are not present in urban areas (Helden and Leather, 2004). As urbanisation occurs, habitats are changed; some are lost altogether, some are reduced in size whilst others are created (Jones and Leather, 2012).

Urbanisation generally leads to reduced species richness due to fragmentation (Faeth and Kane, 1978; Evans, Newson and Gaston, 2009; Goodwin, Keep and Leather, 2017), habitat loss and the destruction of habitats that are beneficial to invertebrates via pollution, drainage and diversion of watercourses, or simply by the removal of host plant species (McIntyre, 2000). Urbanisation has been considered a major cause of loss of arthropod species (McIntyre, 2000) and the general consensus between authors is that urbanisation is detrimental to invertebrate diversity and abundance (Helden and Leather, 2004). Invertebrates are found in great diversity within urban areas which can even support some rare and important species (McIntyre, 2000; Helden and Leather, 2004; Angold *et al.*, 2006; Jones and Leather, 2012; Goodwin, Keep and Leather, 2017). Twelve -15% of the UK nationally scare and rare invertebrates have been found in brownfield sites (Open Mosaic Habitats on Previously Developed Land) (Small, Sadler and Telfer, 2003). Never the less, the biodiversity of invertebrates in urban areas is relatively little studied (McIntyre, 2000; McIntyre *et al.*, 2001; Helden and Leather, 2004) and the loss of some species exemplifies why continued monitoring of urban invertebrates is important (Jones and Leather, 2012). As cities are rapidly expanding and infilling, knowledge of how ecology integrates with social science is urgently needed (Small, Sadler and Telfer, 2003; Breuste, Niemelä and Snep, 2008).

As species respond differently to urbanisation, the composition of invertebrate communities is likely to be different in urban areas to non-urban areas. Species found within urban areas are likely to be generalists and opportunistic species which are able to cope with high levels of fragmentation, smaller habitat patch sizes, and higher levels of disturbance than would be found in some (many rural habitats are also small and fragmented) less urbanised environments. Urban invertebrates tend to be smaller species types (Jones and Leather, 2012) and individuals within a species may also be smaller and flying species with higher dispersal rates (Sadler *et al.*, 2006). Species would tend to be those with larger wings (macropterous), as brachypterous (short winged) species would have difficulties moving between patches and flightless species may not be able to escape their habitat fragments in times of disturbance (Sadler *et al.*, 2006). Dimorphic winged species have an advantage in urban areas as the larger winged forms can disperse and colonise new areas and the smaller winged forms have higher reproductive success (Sadler *et al.*, 2006; Jones and Leather, 2012). Exotic species may be more abundant in urban settings due to an increased likelihood of introduction and these species may displace native arthropods (McIntyre, 2000), whereas native woodland invertebrates are found in much lower abundance in urban areas (Sadler *et al.*, 2006). Individual changes may be in response to habitat structures rather than types of habitat (McIntyre *et al.*, 2001) and many authors suggests that urban semi-natural habitats often have a reduced structural diversity (Vergnes, Kerbiriou and Clergeau, 2013; Dover, 2015).

Urban green spaces come in many forms including parks, hedges, gardens, recreational areas as well as unplanned remnants of less altered habitats more similar to what was there prior to urbanisation and also derelict land, ruderal sites and wilder gardens (Breuste, Niemelä and Snep, 2008; Jones and Leather, 2012; Dover, 2015). These semi-natural habitats typically have high levels of disturbance (Jones and Leather, 2012) and are often landscaped and contain exotic flora (McIntyre, 2000). Urban green spaces are dissected and interspersed within a mosaic of different landuses including highly anthropogenic habitats such as residential and commercial areas, and infrastructure such as roads and railways (Breuste, Niemelä and Snep, 2008; Jones and Leather, 2012; Dover, 2015). The built land is a barrier to some species (Sadler *et al.*, 2006; Croci *et al.*, 2008; Jones and Leather, 2012) but the semi-natural patches in urban areas may have benefits as habitats corridors or stepping stones (McIntyre, 2000; Small, Sadler and Telfer, 2003; Angold *et al.*, 2006).

Green spaces in the city centre would be further from sources of colonisation than those towards the edge of a city or those closer to more natural vegetation (McIntyre, 2000).

Isolation may be an important influencer on urban habitat richness and diversity (Breuste, Niemelä and Snep, 2008). Reduced site area, isolation and fragmentation were found to have significant negative impacts on carabids (Jones and Leather, 2012), particularly woodland beetle assemblages (Angold *et al.*, 2006). This was also found to be true in Diptera, Coleoptera (Faeth and Kane, 1978), and Lepidoptera which were found in reduced numbers in smaller parks and greater abundance in larger the parks (Giuliano, Accamando and Mcadams, 2004). Patch size, specifically, is expected to impact total invertebrate species richness and abundance (Breuste, Niemelä and Snep, 2008; Bolger *et al*, 2000 in Jones and Leather, 2012), Hemiptera richness (Helden and Leather, 2004), carabid composition (Sadler *et al.*, 2006; Jones and Leather, 2012), particularly woodland specialists (Angold *et al.*, 2006), spider richness (Miyashita et al., 1998 in Jones and Leather, 2012), Lepidoptera (Giuliano, Accamando and Mcadams, 2004; Saarinen *et al.*, 2005; Jones and Leather, 2012), Agromyzidae (Diptera) richness (Keep, 2006 in Jones and Leather, 2012), and on extinction rates including Diptera & Coleoptera (Faeth and Kane, 1978). Butterflies may not be affected by proximity to other sites and are more able to move freely throughout the city and can have relatively distant source populations (Angold *et al.*, 2006) but were found in greater abundance on road verges with proximity to woodlands (Saarinen *et al.*, 2005).

Angold *et al.*, (2006) suggests that dispersal is not usually a limiting factor for urban invertebrates and that influences of the patch itself and the surrounding landscape may exert greater influences on invertebrate species including butterflies and carabids. The quality of the patch itself was found to be more important to urban invertebrates than the surrounding landscapes with high levels of early successional stage vegetation with high seed production and substrate variability being particularly beneficial (Angold *et al.*, 2006; Small, Sadler and Telfer, 2006). The abundance of carabids is related to the abundance of taller herbs (Angold *et al.*, 2006). Habitat heterogeneity and associated increased niche availability has been demonstrated to positively impact on invertebrate communities and species richness; this heterogeneity can come with age of a habitat (Helden and Leather, 2004; Angold *et al.*, 2006; Jones and Leather, 2012) or the progress of succession following disturbance (Small, Sadler and Telfer, 2003). Recently disturbed or cleared sites in early stages of succession are dominated by predatory species, and those which are good dispersers (including many rare species), or those present in local undisturbed habitats. Frequent disturbance of sites limits the succession into older habitats which tend to be richer in invertebrate species (McIntyre, 2000) which is a reason why brownfield sites are so important. There is a change in invertebrate species as the successional process takes place (Small, Sadler and Telfer, 2003). In brownfields in the West Midlands of the UK, carabid richness reduced as brown field sites aged due to vegetation succession leading to decreased habitat heterogeneity (Small et al., 2006 in Jones and Leather, 2012). Species who thrive in older sites are Lepidoptera, leaf hoppers and spiders. However, many arthropods were found to be negatively influenced by age of London gardens. In general, it is assumed that richness increases with site age (Jones and Leather, 2012); however, the highest plant diversity is found in sites that are relatively young (Angold *et al.*, 2006) and the increased richness and abundance of Lepidoptera was also associated with plant species richness (Giuliano, Accamando and Mcadams, 2004), therefore it appears that lepidoptera benefit from both site age and increased plant species richness. Carabids in brownfield sites prefer vegetation in earlier successional stages (Small, Sadler and Telfer, 2003). The abundance and richness of native tree species on urban roundabouts was associated with general invertebrate species richness (Helden, Stamp and Leather, 2012), and caterpillar numbers and thus butterfly and moth abundance (Goodwin, Keep and Leather, 2017), as was Hemiptera abundance (Helden and Leather, 2004) on urban roundabouts. The maintenance, restoration and creation of good quality habitats are essential to the survival of invertebrates in urban areas and should be prioritised over increasing the connectivity of habitats (Angold *et al.*, 2006).

The quantity of semi-natural habitats in the landscape surrounding urban habitat patches is also considered to impact on invertebrate abundance within an urban habitat. Particularly the amount of green space within 1km or 5 km (Angold *et al.*, 2006; Jones and Leather, 2012), as these habitats in close proximity are likely to assist in providing sufficient suitable environment to sustain a population (Davies, 1979 in Jones and Leather, 2012). Butterfly diversity, for example, in south west Manchester UK decreased with increased urban cover which is probably due to fewer host plants and nectar sources (Jones and Leather, 2012).

As with most urban habitats, urban hedges are usually adjacent to roads, paths and railways (Jones and Leather, 2012), which can be barriers to invertebrates whether flying (e.g. bees) or crawling (e.g. carabids) and are only very rarely crossed unless an individual or population is displaced or food was removed from their habitat (Bhattacharya, Primack and Gerwein, 2002). Large roads in a study in a Swiss forest were found to be absolute barriers to gene flow in ground beetles (*Carabus violaceus*) (Keller and Largiade, 2003; Baudry and Burel, 2019). However, increased road density is not always shown to reduce short-winged species as species survive in the habitat fragments as roadsides can act as open habitats, refugia or corridors to movement (Jones and Leather, 2012). Roads with adjacent pavements are likely to experience high footfall and recreational use affects the number of carabids found in areas leading to a decline in woodland specialists with increase in the proportion of urban generalists (Angold *et al.*, 2006; Sadler *et al.*, 2006). The high light levels due to reduced canopy cover, and increased levels of nitrogen adjacent to roads can affect invertebrate species composition, richness and diversity (Jones and Leather, 2012), but there are also the influences of other factors including, pollution, higher temperatures, less moisture, high levels of emissions, high turbulence, noise, dust, night lights (headlights), high salinity (pH) and a different composition of plant species (Jones and Leather, 2012). Butterfly diversity is affected by verge width due to increased food source and breeding habitat (Saarinen *et al.*, 2005; Jones and Leather, 2012). A study of bumble bee abundance on roadside and arable field side of hedges found almost twice as many bumble bees in margins on the roadside than the crop-facing side of hedges probably due to the more abundant floral resources present on the road-facing side (Hanley and Wilkins, 2015).

The impact of disturbance is related to the body size of the invertebrate species. Larger species have larger range requirements, smaller population sizes, lower reproductive output, slower responses to environmental change and longer life cycles than smaller species. In some instances, intermediate levels of disturbance can lead to increased invertebrate diversity, but disturbance is generally considered harmful especially if it reduces habitat heterogeneity (Jones and Leather, 2012). An example of this could be frequent hedge cutting to create a uniform shape (Batáry, Matthiesen and Tscharntke, 2010). Some species have been shown to move away from areas following disturbance and highly disturbed areas are often dominated by a few species (Jones and Leather, 2012). Undermanagement is better for invertebrates due to increased protection from predators and increased heterogeneity leading to a greater diversity of niches (Jones and Leather, 2012). This leads to increased food for herbivores and thus to increased prey for predators and parasites, more oviposition sites and variation in microclimates (Helden and Leather, 2004; Helden, Stamp and Leather, 2012; Jones and Leather, 2012). However if management such as cutting is undertaken at the correct times of year and is used to create habitat heterogeneity such as cutting a hedge in sections

(Whittingham and Evans, 2004; Bates and Harris, 2009) or creating a patchwork or strips of different heights in herbaceous vegetation then this sort of management may be beneficial to wildlife (Dover and Sparks, 2000; Defra, 2007b; Schofield, 2016; Cole *et al.*, 2017). There are also the aforementioned benefits of disturbance and the creation of early successional stages (McIntyre *et al.*, 2001)

5.1.2 Urban hedges

There is much more research conducted on rural hedges than on urban hedges (Gosling *et al.*, 2016), meaning there is little information on their distribution, quantity, quality and species composition. A study by Faiers and Bailey (2005) noted that the canalside hedges of urban areas were of a lower structural quality and offered less to biodiversity than their rural counterparts. There is also limited understanding by people living in urban areas of the importance of hedges for wildlife (Gosling *et al.*, 2016).

Gosling *et al.*, (2016) found that the woody species of urban hedges differ significantly from those of rural locations with beech, privet and holly being amongst those more prominent in urban areas. The groups of invertebrates within the hedges also differed to those found in hedges in rural locations with ants, earwigs and shieldbugs being more commonly found in urban areas and fewer blowflies, caterpillars, harvestmen, other beetles, spiders and weevils than in their rural counterparts (See Rationale section 1.9).

5.1.3 Invertebrates in hedges (and trees)

Hedges are important for invertebrates in rural landscapes as they offer relatively stable microclimates, habitat, overwintering sites and early season refuge, act as refuges from disturbance (such as crop cutting, mowing and pesticide application) and are particularly important refuge when crops are removed. They may act as a corridor for the movement of pollinators (Frouz and Paoletti, 2000; Maudsley *et al.*, 2000; Varchola and Dunn, 2001; Garratt *et al.*, 2017; Holland, 2019), provide food resources in the form of invertebrate prey, pollen, nectar, seeds and fruits (Holland, in press), and are important for maintenance of populations in the surrounding landscape (Frouz and Paoletti, 2000). Hedges provide a sheltered area on the leeward side and this has been shown to be an area for congregation of a large number of invertebrates (Maudsley, 2000).

There is some evidence that hedges within landscapes increase the richness and abundance of many groups of invertebrates e.g. native pollinators (Kremen, Albrecht and Ponisio, no date) including bumble bees (Sardiñas and Kremen, 2015), hoverflies (Garratt *et al.*, 2017), Diptera (including saprophagous larvae) (Frouz and Paoletti, 2000), aphids (Mitschke, Rathjen and Baymung, 2000; Holland, 2019), thrips (Maudsley, 2000), spiders (particularly during winter months and early spring) (Maudsley, 2000; Garratt *et al.*, 2017; Holland, 2019), and carabids (Varchola and Dunn, 2001; Fusser *et al.*, 2017).

Invertebrates constitute the vast majority of species within hedgerows with 1,500 insect species found (Pollard et al., 1974; Dowdeswell, 1987 in Maudsley, 2000) and some groups are closely connected to a hedge as primary habitat e.g. Heteroptera and Hymenoptera (Maudsley, 2000). In some landscapes, and during some seasons, there may be little other suitable semi-natural habitat available and in such times the abundance of invertebrates within a hedge is higher, a phenomenon known as ecological contrasts (Garratt *et al.*, 2017) which was reflected in the invertebrate groups mentioned above. This removal of large areas of vegetation may not be quite the same in urban environments as crops are not often grown and cut annually, however in some areas, such as gardens or densely build up areas, hedges may offer the only undisturbed or suitable habitat type available. Hedgerows become more valuable as a forage habitat for pollinators when surrounding land is more intensively managed (Garratt *et al.*, 2017). Hedgerows can be a source of many invertebrate taxa which then utilise the surrounding landscapes. Some of these species provide important ecosystem services such as nutrient cycling and pollination (Garratt *et al.*, 2017). Understanding how invertebrates interact with hedges is key to effective management for biodiversity (Maudsley, 2000).

Different invertebrates will occupy different niches within hedges (Maudsley, 2000; Cole *et al.*, 2017). The greater the heterogeneity of a hedge then the greater the diversity of species it is likely to support (Whittingham and Evans, 2004; Batáry, Matthiesen and Tscharntke, 2010; Hall *et al.*, 2017). The richness of caterpillar and pollinator species varies with the habitat and niche heterogeneity as with more niches there is likely to be greater resource provision during different times of the year (Cole *et al.*, 2017; Goodwin, Keep and Leather, 2017). Diverse hedge architecture is particularly important for spiders (Maudsley, 2000). Hedge structural diversity usually results from age, structure and diversity of plant forms, and species within the hedge, management can also increase the structural diversity by the creation of layers and by including an abundant understory of plants (Maudsley, 2000; Garratt *et al.*, 2017). This adjacent vegetation may act as a corridor for movement and is important as forage habitat for many species of invertebrate (Garratt *et al.*, 2017) e.g. plant bugs which use the lower branches (Maudsley, 2000) and, if the adjacent vegetation includes wildflowers, there is an increase in pollinator numbers (Cole *et al.*, 2017) including bumble bees (Sardiñas and Kremen, 2015) and hoverflies (Garratt *et al.*, 2017) due to the succession of flower emergence (Maudsley, 2000). Hoverflies are found to use understory plants for forage significantly more frequently than plants within the hedge itself but this was not shown for solitary bees, bumblebees or honey bees (Garratt *et al.*, 2017). However, tall vegetation cover is negatively associated with flying Diptera abundance (Frouz and Paoletti, 2000). In general the diversity of host plant species within a hedge is related to the diversity of herbivorous invertebrates. These species may be divided into those that feed on the leaves, stems, bark, buds, flowers, galls, fruits and seeds (Maudsley, 2000) and the more of these features available, the more biodiversity the hedge can support. If a hedge is to provide breeding habitat for butterflies it must have the host plants present (Goodwin, Keep and Leather, 2017) however, even without the host plants a hedge can still supply other resources such as shelter from wind and retain species in the local environment (Dennis, Shreeve and Van Dyck, 2006). There is much interaction between species within the hedge and the surrounding (composite) habitats, and hedges with additional features such as trees and verges, ditches or banks may support a wider range of invertebrates (Maudsley, 2000; Stoate, 2019). Many invertebrate groups benefit from hedges having fewer gaps including spiders (Garratt *et al.*, 2017) and bumblebees (Sardiñas and Kremen, 2015). Gaps have been observed to provide routes for moths moving from field to field and therefore infilling these gaps (<1 m) may restrict moth movement (Dover, 2019b).

Emergent hedgerow trees are important for flying insects, most families showed a marked increase in abundance in proximity to the tree (Peng, Sutton and Fletcher, 1992) including moths (Merckx *et al.*, 2010). The abundance of invertebrates in mature hedgerow trees can be greater than that of woodland trees (Hinsley and Bellamy, 2019). Hedgerow trees provide a specialised habitat for some Diptera (Maudsley, 2000), forage habitat for numerous species (Hinsley and Bellamy, 2019) and support the generalist lycosid spiders and also lyniphid spiders which predate on canopy-dwelling species, particularly aphids (Garratt *et al.*, 2017). Gatekeeper and Meadow Brown butterflies (Merckx and Van Dyck, 2002) and aphids (Lewis, 1965) are benefited by the shelter provided by trees which facilitates activities including feeding, roosting, and courtship (Dover, 2019b). If tree species are native there is likely to be a greater abundance of Hemiptera (Helden and Leather, 2004). However, large hedgerow trees may supress the growth of the hedgerow shrubs and adjacent herbaceous vegetation (Hinsley and Bellamy, 2019) due to shading.

Distributions of hedgerows in a landscape can affect invertebrate populations (Garratt *et al.*, 2017). Small islands of hedge habitats are unlikely to support predatory insects, e.g. carabids, long term. The presence of other local woody habitats is important for these species (Maudsley, 2000; Davies and Pullin, 2007); close proximity and fewer gaps facilitate recolonisation (Maudsley *et al.*, 2000). The distance that would be close enough to support this would differ between groups of invertebrates and habitats would need to be connected or a very short distance away for some groups e.g. snails, whilst Diptera can recolonise over short distances relatively quickly. The ability for recolonisation is important within hedgerow habitats due to local extinctions during times of disturbance such as hedge cutting (Maudsley, 2000). It is possible that where landscapes permit, many species can be present in a hedge by being blown there by the wind from other populations in the landscape, and are known as aeroplankton (Frouz and Paoletti, 2000).

The woody species of a hedge is likely to impact its suitability to support invertebrates (Maudsley, 2000; Garratt *et al.*, 2017). Native tree species generally have more species associated with them and hawthorn was found to have a higher number (146) of such associated species than beech (64) (privet was not studied) (Southwood, 1961; Helden, Stamp and Leather, 2012). The phenology of invertebrates is closely aligned with hedge phenology. During the spring new growth provides food for abundant herbivorous fauna including weevils and caterpillars, and the emergent flowers during the spring and summer provides a source of nectar for Hymenoptera, Diptera and pollinators. If the woody hedge species produces flowers and abundant new leaves in the spring it is more likely to be richer in invertebrate species (Garratt *et al.*, 2017). However, the impact of woody hedge species can be overridden by the presence of an abundance of hostplants in the hedge base or adjacent vegetation (Maudsley, 2000).

5.1.4 Research gap

Before 2000 little research had been carried out on how invertebrates use the urban environments (McIntyre, 2000) and since then there has been an emergence of a small number of studies investigating the mechanisms that affect the distributions of invertebrate species in urban areas. A few studies have investigated invertebrates in urban landuse types such as brown field sites or woodland habitats and those that have been published have focused on specific invertebrate groups and little on comparisons of patterns of diversity. A large body of work highlights the importance of rural hedgerows for biodiversity (see Rationale section 1.7) but there is, as yet, little research on the importance of urban hedges for wildlife (Gosling *et al.*, 2016) or how characteristics of a hedge and its surrounding landscape features influence invertebrate abundance and richness.

Invertebrates are useful as indicators of general biodiversity, they are important for the ecosystem services they provide including pollination and nutrient cycling, and as prey for other species including birds and mammals (McIntyre, 2000; Jones and Leather, 2012).

5.1.5 Research questions

1. Does the woody hedge species affect the abundance and richness of invertebrates found within it?
2. Which other characteristics of the hedge and of the surrounding area affect the richness and abundance of invertebrates?

5.2 Methods

This section focuses on methods unique to this invertebrate study. For detailed methodology see Chapter 2 General Methods

5.2.1 Hedgerow selection

Hedges throughout the city of Stoke-on-Trent were identified through driving tours around the city. Hedges were deemed suitable based on criteria similar to that of the National Hedgerow Survey (Defra, 2007a). Hedges also needed to be adjacent to some form on urban landuse (e.g. a road, track or car park) and be composed of its woody species for at least 95% of the study section. As the most abundant species were found to be hawthorn, privet and beech, these species were selected for study. (See General Methods section 2.2) A minimum of 10 hedges of each of these species were selected.

5.2.2 Hedge and adjacent landuse surveys

The data on the physical properties of the hedge and adjacent landuse were surveyed (Appendix B). Variation in the landuse of the landscape surrounding study hedges was measured using classified aerial photography in ArcGIS (Figure 5-1).

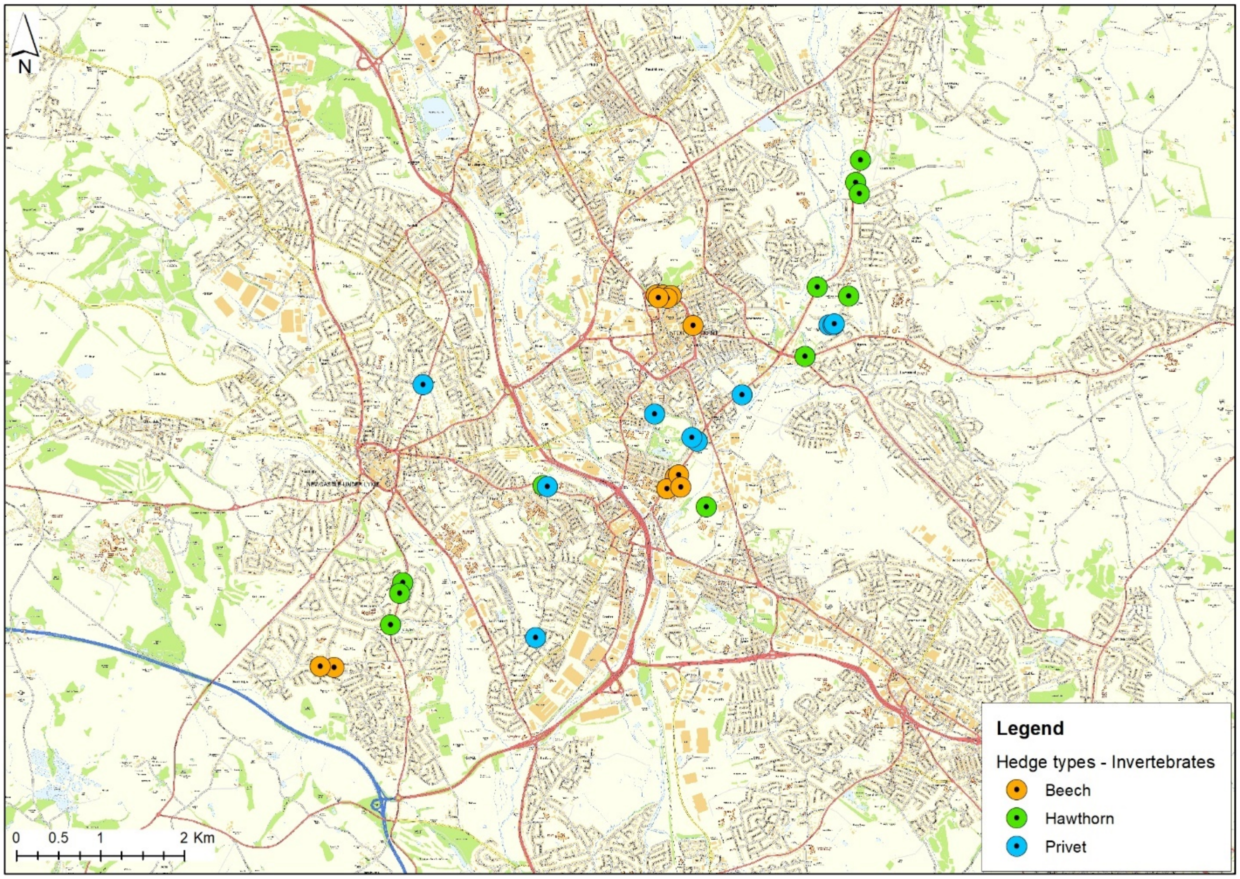


Figure 5-1 Locations of study hedges and control sites used for invertebrate surveys within Stoke-on-Trent. ©ESRI digital data, 2018 Staffordshire University Licence

5.2.3 Invertebrate surveys

5.2.3.1 Sample collection

Vortis® samples were taken between 11:00 am and 14:00 pm during warm, sunny, still days in July 2014. Temperatures were over 22°C each day. Hedge invertebrates were sampled using a Vortis® sampler. The Vortis® was held at hip height (approx. 1.3 m) against the hedge. A sample was taken using full power for 10 seconds 5 m in from the start of the 30 m study section of the hedge. The sampler was moved a further 5 m along the hedge and another 10 second sample was taken (again at hip height) without detaching the collection pot. This process was repeated another 3 times making a total of 50 seconds of suction time over 5 separate 5 m-apart locations.

Once sampling was complete for a particular hedge the Vortis® sample pot was detached, immediately sealed with a lid, and placed for a minimum of 15 minutes in a coolbox. The pot was then placed in a fine mesh draw string bag and carefully emptied, and then removed; the bag was then pulled closed and placed into a killing jar containing Ethyl Acetate. Once back in the laboratory the bags were emptied into a pot and stored below -5°C

5.2.3.2 Identification of invertebrates

Extraction of invertebrates from samples was done by spreading the debris from the pot onto a sheet of paper with numbered squares inside a white tray. All squares were searched using a binocular microscope at 10 x 3.5 magnification. All debris were turned and examined. Any invertebrates found were placed into a sample jar containing 70% ethanol and stored for identification.

A broad range of invertebrate groups were collected and therefore it was impractical to identify all individuals to species; soft-bodied species also suffered significant damage hampering identification. Invertebrates were initially identified to major groups using Tillling, (1987); subsequently, groups which contained a substantial number of individuals were further divided, where possible, to family. In groups where numbers were low (there were no more than 2 individuals collected from any hedge) then invertebrates were identified to morphospecies (organisms of similar characteristics (morphology) – i.e. those that appeared to be visually the same species) per hedge (The exception was for Acari where 9 individuals were found in a single hedge – these were identified to 2 morphospecies). This still facilitated an estimation of richness to family but was much more time efficient.

5.2.4 Data analysis

(See General Methods section2.4) Data were initially assessed to identify differences in invertebrate communities between woody hedge species. Using Shapiro-Wilk normality tests, all data were found to be non-parametric for all hedge and were compared using the Kruskal-Wallis 1-way ANOVA followed by Dunn's tests; Bonferroni corrections were applied.

There were a large number of hedge and landuse variables that may have potentially impacted on invertebrate numbers/richness. Following dimension reduction using PCA the resultant (consolidated) variables were analysed for their influence on the invertebrate communities within the hedges using a Generalised Linear Model (GLM) multiple regression (Graften and Hails, 2002), rather than the GLMM used in the bird and mammals studies, as there was shown to be no significant impact of woody hedge species on invertebrate abundance or richness to family. The glm model was used from the library mlmrev in R version 3.4.1 (Team, 2008).

Table 5-1 shows the variables included in each multivariate analysis.

5.3 *Results*

5.3.1 Initial findings

Thirty two variables were included in the PCA and from the groups of variables highlighted for collinearity, 7 representative variables were selected (Table 5-1). These, plus inverse proximity to road, were included in the GLM. As Random Forest analysis is not affected by collinearity additional factors could be included. These further factors were selected based on those that had scientific evidence that they were particularly influential on invertebrate species richness and abundance to assist in identifying which of the variables with collinearity were exerting the most influence.

Thirty-three hedges were surveyed and a total of 736 invertebrates of 14 major groups and over 79 families were sampled. The major groups and the abundance of individuals and families within these groups are shown in Table 5-2.The most abundant groups were Hemiptera, Diptera and Hymenoptera accounting for 74% of individuals found.

Table 5-1 Variables included in the multivariate analysis. ✔ indicates where a factor was included. Thirty two variables were included in the PCA to identify collinearity. Seven representative variables were selected plus inverse proximity to road were included in the GLM. As Random Forest analysis is not affected by collinearity additional factors (17) could be included.

Variables	**Input to PCA**	**Out of PCA**	**Included in GLM**	**Included in Random Forest**
% Smooth Grass within 250 m	✔			
% Smooth Grass within 100 m	✔			
% Smooth Grass within 50 m	✔			
% Green Space within 250 m	✔			
% Impervious surfaces within 250 m	✔			✔
% Impervious surfaces within 100 m	✔			
% Green Space within 100 m	✔			
% Woody Vegetation within 100 m	✔			
% Woody Vegetation within 250 m	✔			✔
% Woody Vegetation within 50 m	✔			✔
% Green Space within 5 m	✔			
% Impervious surfaces within 5 m	✔			
% Woody Vegetation within 5 m	✔			
% Impervious surfaces within 50 m	✔	✔	✔	✔
% Green Space within 50 m	✔			
Hedge Species	✔			
% Rough Grass within 100 m	✔			
% Rough Grass within 250 m	✔			
Total Length of Hedge	✔	✔	✔	✔
% Rough Grass within 50 m	✔			✔
Hedge Volume	✔	✔	✔	✔
Hedge Width	✔			
Hedge Height	✔			✔
Vegetation Height in 5 m A	✔			✔
Average Tree DBH	✔	✔	✔	✔
Average Tree Distance	✔			
% Rough Grass within 5 m	✔			
% Canopy Cover	✔			✔
% Vegetation Cover in 5m A	✔	✔	✔	✔
% Smooth Grass within 5 m	✔			
% Vegetation Cover in 5 m B	✔	✔	✔	✔
Vegetation Height in 5 m B	✔	✔	✔	✔
Inverse proximity to road			✔	✔
Vegetation adjacent				✔

Table 5-2. Abundance and richness to family of invertebrates within the major groups found in all hedges. Ordered with most abundant to least. ≈ indicates that individuals were not identified to family due to 2 or fewer individuals being collected per hedge.

Invertebrate Group	Common Name	Abundance	% of total individuals	Richness to family
Hemiptera	True bugs	236	32	11
Diptera	Flies	196	27	30
Hymenoptera	Wasps, bees, ants, sawflies	113	15	13
Psocoptera	Booklice	60	8	7
Araneae	Spiders	58	8	7
Collembola	Springtail	25	3	3
Acari ≈	Mites & Ticks	21	3	≥1
Coleoptera ≈	Beetles	8	1	≥1
Lepidoptera ≈	Butterflies & Moths	6	<1	≥1
Opilliones ≈	Harvestmen	5	<1	≥1
Isopoda ≈	Woodlice etc.	3	<1	≥1
Dermaptera ≈	Earwigs	2	<1	≥1
Thysanoptera ≈	Thrips	2	<1	≥1
Chilopoda ≈	Centipedes	1	<1	≥1
Total		**736**		**≥79**

5.3.2 Comparison of woody hedge species

No significant difference was found in the abundance (*p = 0.281*) or richness of families (*p=0.364*) of all invertebrates with hedge woody species (Figure 5-2). Nor were there any significant differences between the abundance or richness of families within each of the major groups of invertebrates (Figure 5-3a). There was variation in which woody hedge species was favoured by the major groups of invertebrates (Figure 5-3b), but not significantly. For example, there were generally more Collembola found in beech hedges than those of other woody species (Figure 5-3 c & d) and a greater range in the numbers of and richness of total invertebrates in hawthorn hedges than in hedges of beech or ptivet (Figure 5-2).species (Figure5-3 c & d) and a greater range in the numbers of and richness of total invertebrates in hawthorn hedges than in hedges of beech or privet (Figure 5-2).

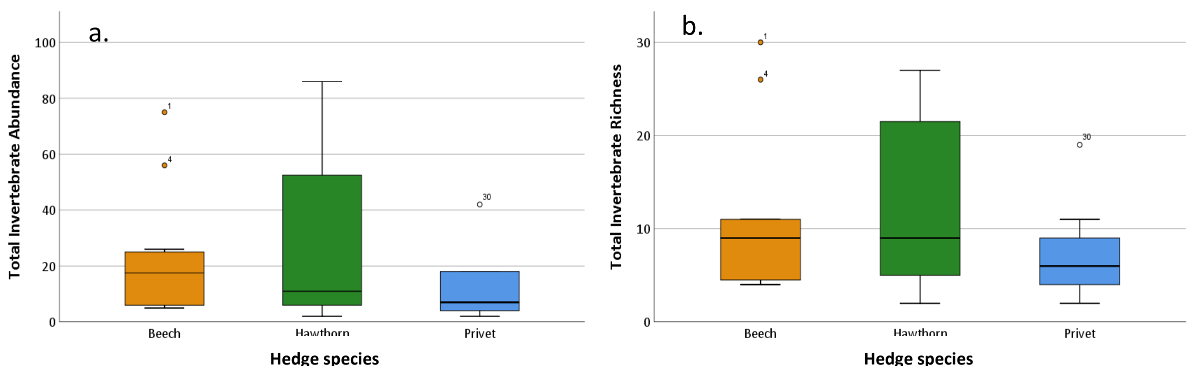
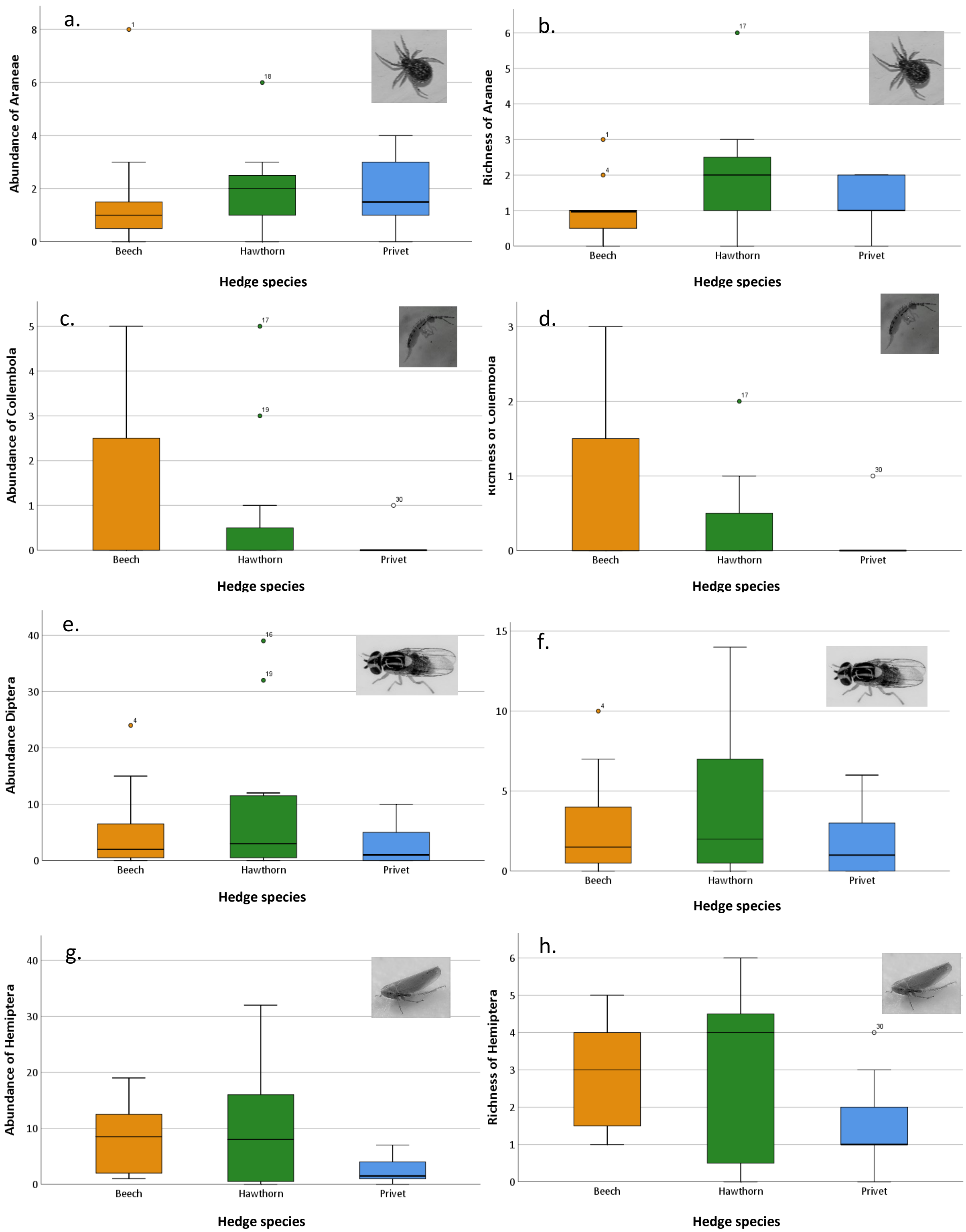


Figure 5-2. a) Boxplot of total invertebrate abundance by woody hedge species. No significant difference shown using Kruskal-Wallis (p=0.281). b) Boxplot of total invertebrate richness to species by woody hedge species. No significant difference shown using Kruskal-Wallis (p=0.364) however, overall numbers were low.

5.3.3 influence of other factors

Tables 5-3 & 5-4 show the results from the GLM analyses and Figures 5-4 & 5-5 display the results from the Random Forest analyses. Table 5-6 summarises the significant, or most important, factors that correlate most strongly with the abundance and richness of the total invertebrates and those groups which were present in high numbers. Hedge length and distance from the road (inverse proximity) are frequently associated positively with richness and abundance of invertebrates in the GLM analysis. The percentage of vegetation in front of the hedge is sometimes positively associated and sometimes negatively in the GLM and is often of the most important in the Random Forest, although importance scores were low. The quantity of impervious surfaces is strongly negatively significant in the GLM for total richness and abundance and weakly positively significant for the abundance of Hemiptera. In the GLM the percentage of impervious surfaces also represented the inverse of green space including woody and grassy habitats and thus this may suggest that the lack of these habitats was negatively associated with invertebrate richness and abundance. In the Random Forest analysis, the percentage of rough grassland within 50 m, and the percentage of woody vegetation in 250 m both scored highly for importance in explaining the variation in total richness and these and/or the percentage of impervious surfaces, were often important in explaining the variation in the richness and abundance of species groups also, although importance scores were low. The DBH of associated trees was included to represent the presence of, and give an indication of, the age of associated trees. This received a high importance score for total abundance (Figure 5-4, Table 5-6) and was the highest scoring in explaining total richness (Figure 5-5, Table 5-6). The percentage cover of vegetation in front of the hedge also scored highly in explaining total abundance but was significantly negatively associated with total abundance with Araneae abundance and Hymenoptera abundance. Height and percentage cover of adjacent vegetation both behind and in front was suggested to be one of the most important factors for many groups but scores were low. These factors were also important for total abundance. Distance from the road (inverse proximity) was suggested by the GLM to be positively significant in the total abundance and total richness and for Hymenoptera, Diptera and Araneae abundance. Total length of the hedge was significantly positively associated with total abundance, total richness and for Araneae, Hymenoptera, and Diptera abundance but significantly negatively associated with Collembola abundance (Figure 5-6, Table 5-6).


a.
Abundance of Araneae
Beech
Hawthorn
Privet
Hedge species
b.
Richness of Aranae
Beech
Hawthorn
Privet
Hedge species
c.
Abundance of Collembola
Beech
Hawthorn
Privet
Hedge species
d.
Richness of Collembola
Beech
Hawthorn
Privet
Hedge species
e.
Abundance Diptera
Beech
Hawthorn
Privet
Hedge species
f.
Beech
Hawthorn
Privet
Hedge species
g.
Abundance of Hemiptera
Beech
Hawthorn
Privet
Hedge species
h.
Richness of Hemiptera
Beech
Hawthorn
Privet
Hedge species

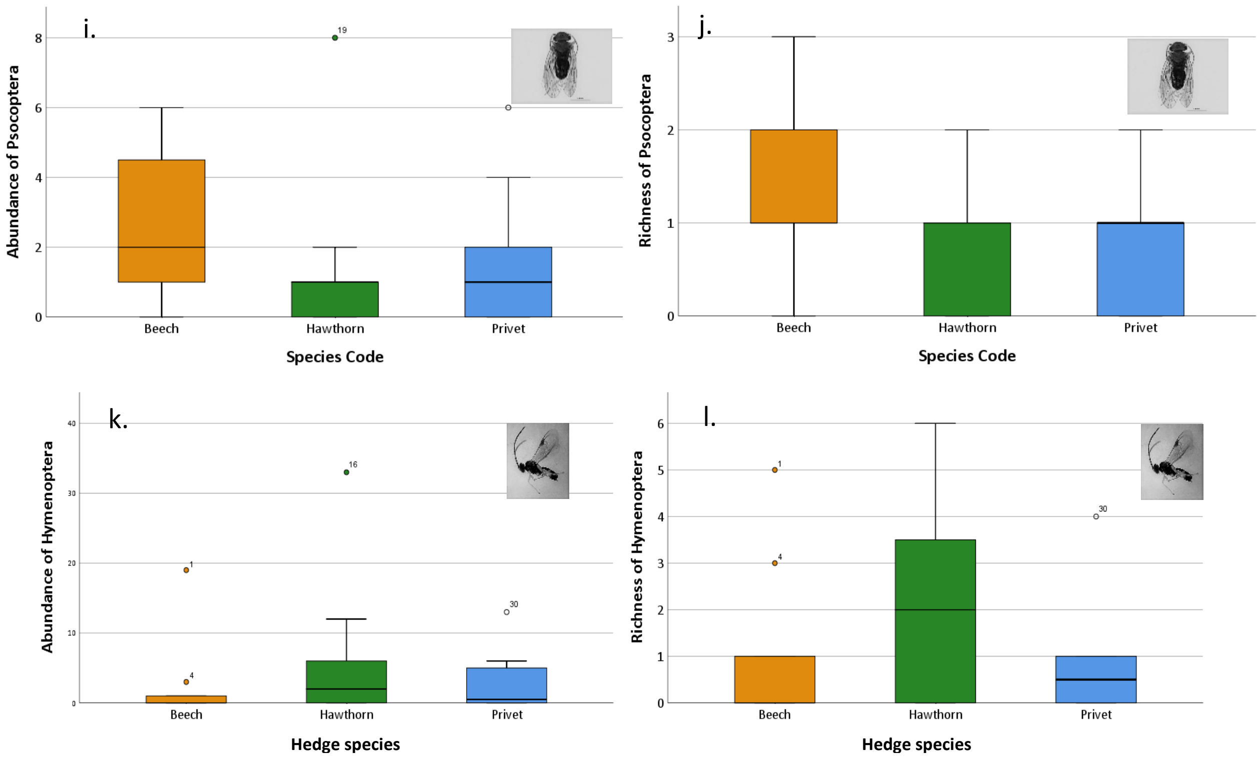


Figure 5-3 Boxplots of invertebrate richness and abundance to family of each major group by woody hedge species. Analysis using Kruskal-Wallis; no significant differences were shown (n=33). a) Araneae abundance (H= 1.529, p=0.466) b) Araneae richness to family (H= 2.550, p=0.279). c) Collembola abundance (H=3.077, p=0.215) d) Collembola richness to family (H=3.172, p=0.205) e) Diptera abundance (H=1.217, p=0.544) f) Diptera richness to family (H=0.847, p=0.655) g) Hemiptera abundance (H=5.392, p=0.067) h) Hemiptera richness (H=4.331, p=0.115). i) Psocoptera abundance (H=3.781, p=0.151) j) Psocoptera richness to family (H=0.847, p=0.195). k) Hymenoptera abundance (H=1.247, p=0.536) l) Hymenoptera richness to family (H=1.602, p=0.449). Note differences in y axis scale.

Table 5-3 Results of the GLM for Total invertebrate abundance and total invertebrate richness (n=33). Hedge volume, total length of hedge, inverse proximity to road show significant positive correlations and % impervious within 50 m buffer and the % vegetation in front of the hedge show significant negative correlations with total abundance.

Total Abundance

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	1.260	0.21	*ns*
Hedge volume	2.147	0.03	*
Percentage of vegetation in front of hedge (5 m)	-3. 364	0.00	***
Total length of hedge	6.750	0.00	***
Inverse proximity to road	2.653	0.01	**
% impervious within 50 m buffer	-6.475	0.00	***
% vegetation behind the hedge within 5 m	-1.587	0.11	ns
Vegetation height behind hedge	-0.390	0.70	ns
Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1			

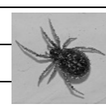
Total Richness to family

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	1.37	0.17	*ns*
Hedge volume	-0.54	0.59	*ns*
Percentage of vegetation in front of hedge (5 m)	-1.76	0.08	.
Total length of hedge	2.64	0.01	**
Inverse proximity to road	3.20	0.00	**
% impervious within 50 m buffer	-2.70	0.00	**
% vegetation behind the hedge within 5 m	-1.50	0.13	*ns*
Vegetation height behind hedge	-0.88	0.38	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

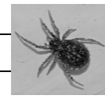
Table 5-4 GLM scores for invertebrate major groups. n=33. Total length of hedge commonly positively associated with abundance.

a. Abundance Araneae



Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	-1.83	0.07	.
Hedge volume	1.29	0.20	ns
Percentage of vegetation in front of hedge (5 m)	-2.49	0.01	*
Total length of hedge	0.84	0.40	ns
Inverse proximity to road	2.22	0.03	*
% impervious within 50 m buffer	0.38	0.70	ns
% vegetation behind the hedge within 5 m	0.39	0.70	ns
Vegetation height behind hedge	-0.20	0.84	ns
Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1			

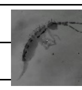
b. Richness Araneae



Variable	Z value	*P value*	Level of significance
DBH of trees	-0.81	0.40	*ns*
Hedge volume	0.0519	0.60	*ns*
Percentage of vegetation in front of hedge (5 m)	-1.02	0.30	*ns*
Total length of hedge	0.70	0.18	*ns*
Inverse proximity to road	-0.19	0.85	*ns*
% impervious within 50 m buffer	-1.16	0.25	*ns*
% vegetation behind the hedge within 5 m	-1.39	0.17	*ns*
Vegetation height behind hedge	1.06	0.29	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

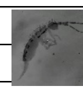
c. Abundance Collembola



Variable	Z value	*P value*	Level of significance
DBH of trees	0.70	0.48	*ns*
Hedge volume	-2.51	0.01	*
Percentage of vegetation in front of hedge (5 m)	1.55	0.12	*ns*
Total length of hedge	2.57	0.01	*
Inverse proximity to road	-2.86	0.00	**
% impervious within 50 m buffer	-0.50	0.62	*ns*
% vegetation behind the hedge within 5 m	0.69	0.49	*ns*
Vegetation height behind hedge	-1.42	0.16	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

d. Richness Collembola



Variable	Z value	*P value*	Level of significance
DBH of trees	0.22	0.82	*ns*
Hedge volume	-1.03	0.31	*ns*
Percentage of vegetation in front of hedge (5 m)	-0.01	0.92	*ns*
Total length of hedge	-0.74	0.46	*ns*
Inverse proximity to road	-0.34	0.73	*ns*
% impervious within 50 m buffer	0.20	0.62	*ns*
% vegetation behind the hedge within 5 m	1.53	0.60	*ns*
Vegetation height behind hedge	-1.13	0.26	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

e. Abundance Diptera

Variable	Z value	*P value*	Level of significance
DBH of trees	0.53	0.13	*ns*
Hedge volume	-1.93	0.05	.
Percentage of vegetation in front of hedge (5 m)	-0.69	0.49	*ns*
Total length of hedge	5.47	0.00	***
Inverse proximity to road	2.03	0.04	*
% impervious within 50 m buffer	-0.28	0.89	*ns*
% vegetation behind the hedge within 5 m	-1.71	0.09	.
Vegetation height behind hedge	-0.55	0.58	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

f. Richness Diptera

Variable	Z value	*P value*	Level of significance
DBH of trees	0.165	0.10	*ns*
Hedge volume	-1.19	0.23	*ns*
Percentage of vegetation in front of hedge (5 m)	0.96	0.34	*ns*
Total length of hedge	2.10	0.04	*
Inverse proximity to road	0.02	0.98	*ns*
% impervious within 50 m buffer	-1.23	0.22	*ns*
% vegetation behind the hedge within 5 m	-1.57	0.12	*ns*
Vegetation height behind hedge	-0.18	0.86	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

g. Abundance Hemiptera

Variable	Z value	*P value*	Level of significance
DBH of trees	-2.14	0.03	*
Hedge volume	-3.295	0.00	***
Percentage of vegetation in front of hedge (5 m)	-0.27	0.79	*ns*
Total length of hedge	2.60	0.01	**
Inverse proximity to road	-0.76	0.45	*ns*
% impervious within 50 m buffer	2.43	0.02	*
% vegetation behind the hedge within 5 m	0.29	0.77	*ns*
Vegetation height behind hedge	1.07	0.28	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

h. Richness Hemiptera

Variable	Z value	*P value*	Level of significance
DBH of trees	1.43	0.15	*ns*
Hedge volume	-2.00	0.05	*
Percentage of vegetation in front of hedge (5 m)	-0.63	0.53	*ns*
Total length of hedge	0.95	0.34	*ns*
Inverse proximity to road	1.10	0.27	*ns*
% impervious within 50 m buffer	1.55	0.12	*ns*
% vegetation behind the hedge within 5 m	0.79	0.43	*ns*
Vegetation height behind hedge	0.79	0.43	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

i. Abundance Psocoptera

Variable	Z value	*P value*	Level of significance
DBH of trees	2.83	0.00	**
Hedge volume	-2.68	0.01	**
Percentage of vegetation in front of hedge (5 m)	0.17	0.86	*ns*
Total length of hedge	-1.18	0.24	*ns*
Inverse proximity to road	1.80	0.07	†
% impervious within 50 m buffer	1.53	0.13	*ns*
% vegetation behind the hedge within 5 m	2.64	0.01	**
Vegetation height behind hedge	-2.07	0.04	*

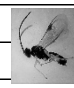
Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, † = p< 0.1, ns = p> 0. 1

j. Richness Psocoptera

Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	1.40	0.16	*ns*
Hedge volume	-1.45	0.15	*ns*
Percentage of vegetation in front of hedge (5 m)	-0.15	0.88	*ns*
Total length of hedge	0.03	0.98	*ns*
Inverse proximity to road	0.69	0.49	*ns*
% impervious within 50 m buffer	1.17	0.24	*ns*
% vegetation behind the hedge within 5 m	1.40	0.16	*ns*
Vegetation height behind hedge	-1.15	0.25	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, . = p< 0.1, ns = p> 0. 1

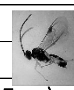
k. Abundance Hymenoptera



Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	3.55	0.00	***
Hedge volume	0.48	0.63	*ns*
Percentage of vegetation in front of hedge (5 m)	-5.07	0.00	***
Total length of hedge	6.18	0.00	***
Inverse proximity to road	5.05	0.00	***
% impervious within 50 m buffer	1.39	0.17	*ns*
% vegetation behind the hedge within 5 m	2.26	0.02	*
Vegetation height behind hedge	-1.81	0.07	†

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, † = p< 0.1, ns = p> 0. 1

l. Richness Hymenoptera



Variable	**Z value**	***P value***	**Level of significance**
DBH of trees	1167	0.24	*ns*
Hedge volume	-1.13	0.26	*ns*
Percentage of vegetation in front of hedge (5 m)	-1.80	0.07	†
Total length of hedge	2.47	0.01	*
Inverse proximity to road	1.81	*0.07*	†
% impervious within 50 m buffer	0.55	*0.59*	*ns*
% vegetation behind the hedge within 5 m	-0.23	0.82	*ns*
Vegetation height behind hedge	0.71	0.48	*ns*

Significance codes: *** = p< 0.001, ** = p < 0.01, * = p< 0.05, † = p< 0.1, ns = p> 0. 1

Table 5-5 Summary of the variables with significant positive and negative associations identified in the GLM for each invertebrate group. – indicates a significant negative association and + indicates a significant positive association.

	Total abundance of invertebrates	Total richness of invertebrates	Abundance of Araneae	Richness of Araneae	Abundance of Collembola	Richness of Collembola	Abundance of Diptera	Richness of Diptera	Abundance of Hemiptera	Richness of Hemiptera	Abundance of Psocoptera	Richness of Psocoptera	Abundance of Hymenoptera	Richness of Hymenoptera
DBH of trees									-		+		+	
Hedge volume	+				-				-	-	-			
Percentage of vegetation in front of hedge (5 m)	-		-										-	
Total length of hedge	+	+			+		+	+	+				+	+
Inverse proximity to road	+	+	+		-		+						+	
% impervious within 50 m buffer	-	-							+					
% vegetation behind the hedge within 5 m											+		+	
Vegetation height behind hedge											-			

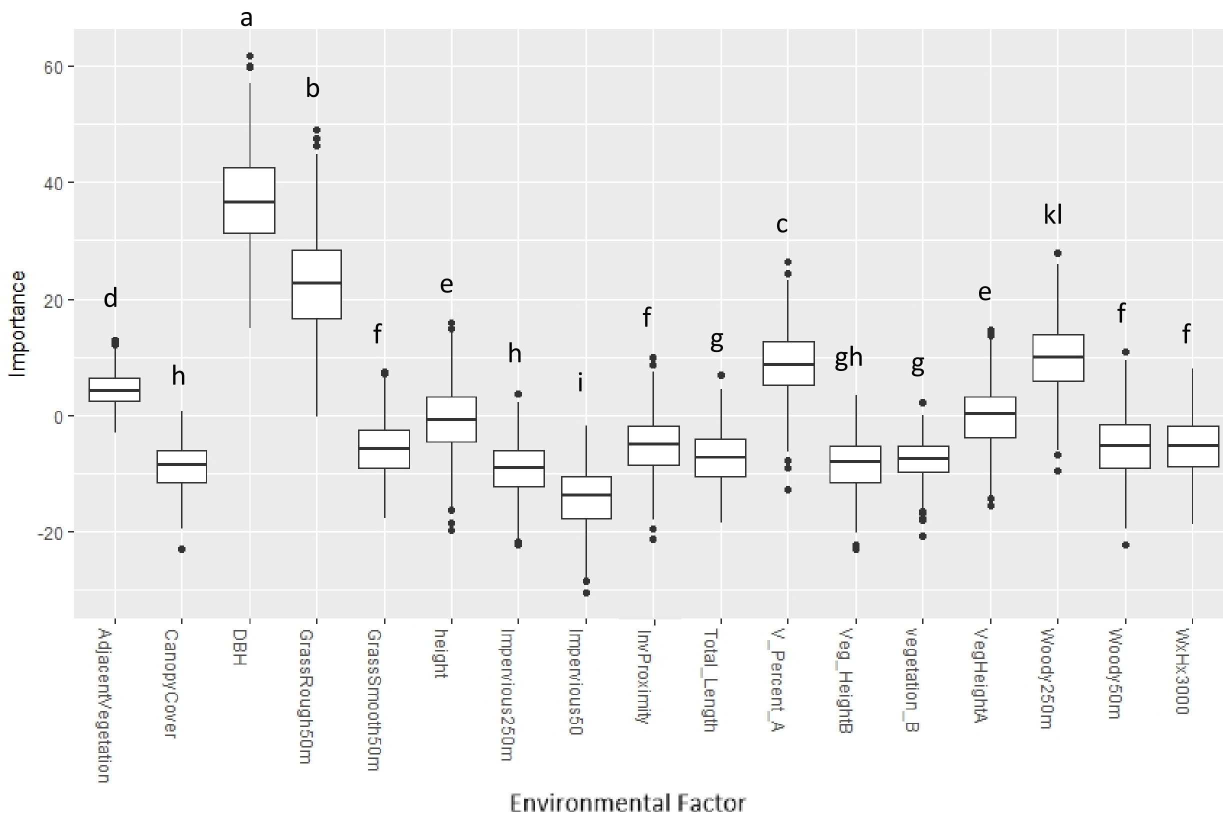


Figure 5-4 Boxplot of importance of impact the environmental factor has on explaining the variation in total invertebrate abundance per run of the Random Forest algorithm (500 runs, n=33). Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are DBH, % of rough grass within 50 m of the hedge and the % of vegetation in front of the hedge.

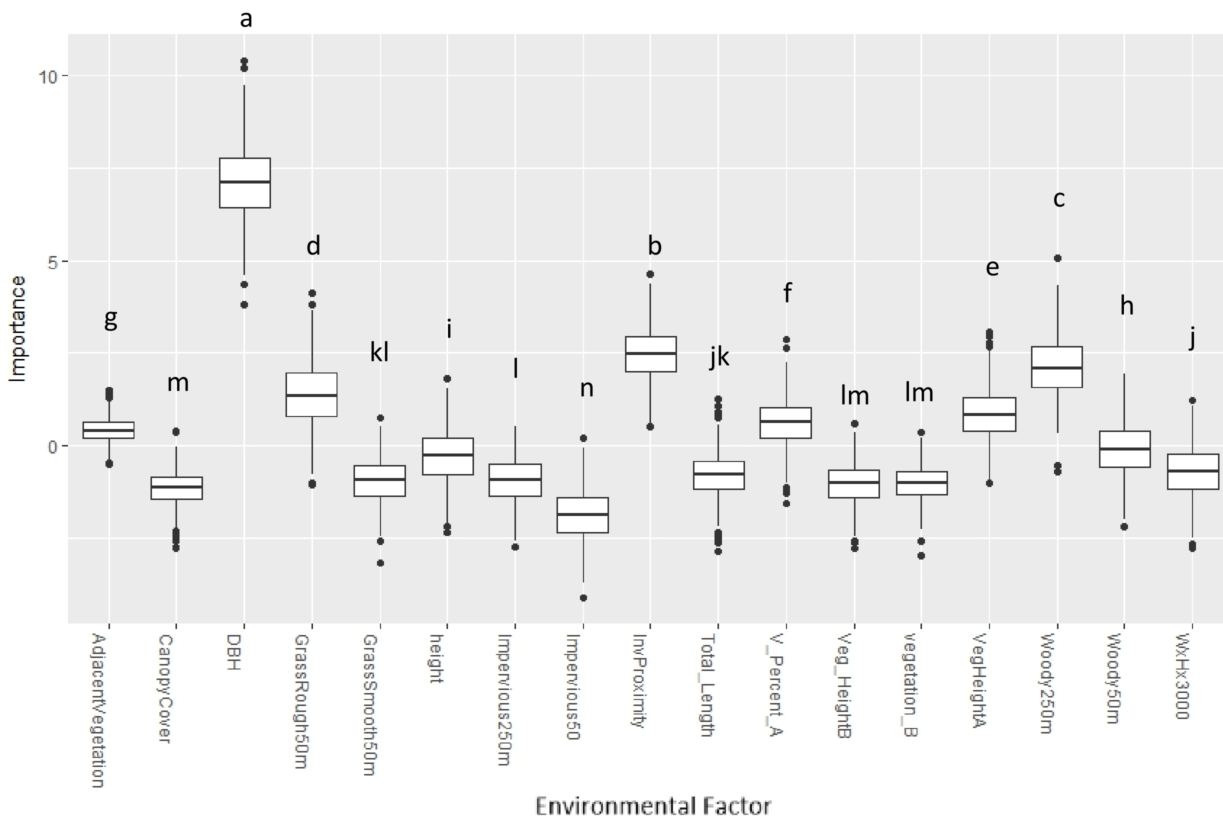
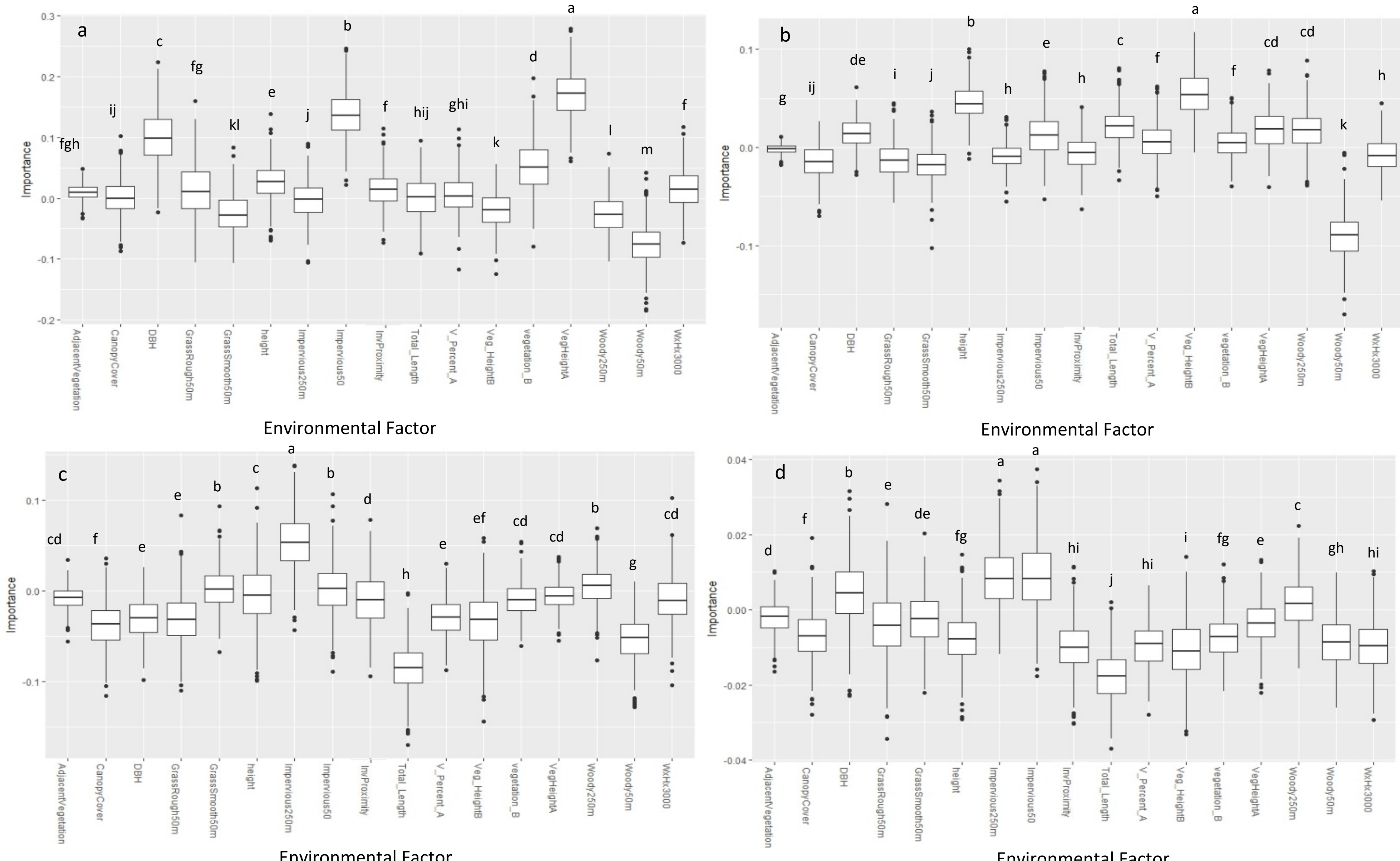


Figure 5-5 Boxplot of importance of impact the environmental factor has on explaining the variation in total invertebrate richness per run of the Random Forest algorithm (500 runs, n=33). Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. Variables with highest importance score are DBH, Inverse proximity to road, and % of woody vegetation within 250 m of the hedge.


a
b
c
d
Importance
Environmental Factor
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CanopyCover
DBH
GrassRough50m
GrassSmooth50m
height
Impervious250m
Impervious50
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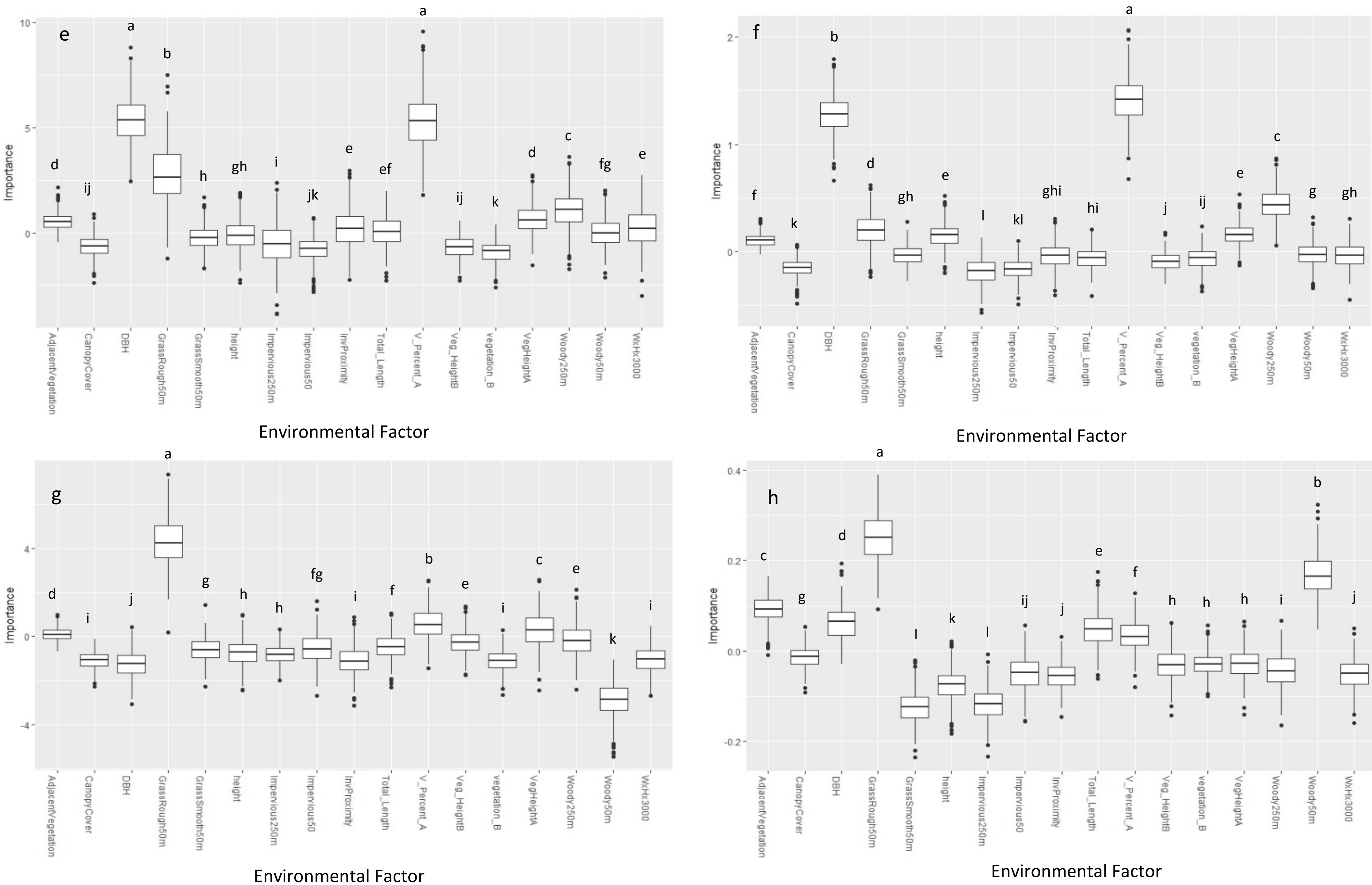
Veg_HeightB
vegetation_B
VegHeightA
Woody250m
Woody50m
WxHx3000


e
Importance
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CanopyCover
DBH
GrassRough50m
GrassSmooth50m
height
Impervious250m
Impervious50
InvProximity
Total_Length
V_Percent_A
Veg_HeightB
vegetation_B
VegHeightA
Woody250m
Woody50m
WxHx3000
Environmental Factor
f
Importance
2
1
0
AdjacentVegetation
CanopyCover
DBH
GrassRough50m
GrassSmooth50m
height
Impervious250m
Impervious50
InvProximity
Total_Length
V_Percent_A
Veg_HeightB
vegetation_B
VegHeightA
Woody250m
Woody50m
WxHx3000
Environmental Factor
g
Importance
4
0
-4
AdjacentVegetation
CanopyCover
DBH
GrassRough50m
GrassSmooth50m
height
Impervious250m
Impervious50
InvProximity
Total_Length
V_Percent_A
Veg_HeightB
vegetation_B
VegHeightA
Woody250m
Woody50m
WxHx3000
Environmental Factor
h
Importance
0.4
0.2
0.0
-0.2
AdjacentVegetation
CanopyCover
DBH
GrassRough50m
GrassSmooth50m
height
Impervious250m
Impervious50
InvProximity
Total_Length
V_Percent_A
Veg_HeightB
vegetation_B
VegHeightA
Woody250m
Woody50m
WxHx3000
Environmental Factor

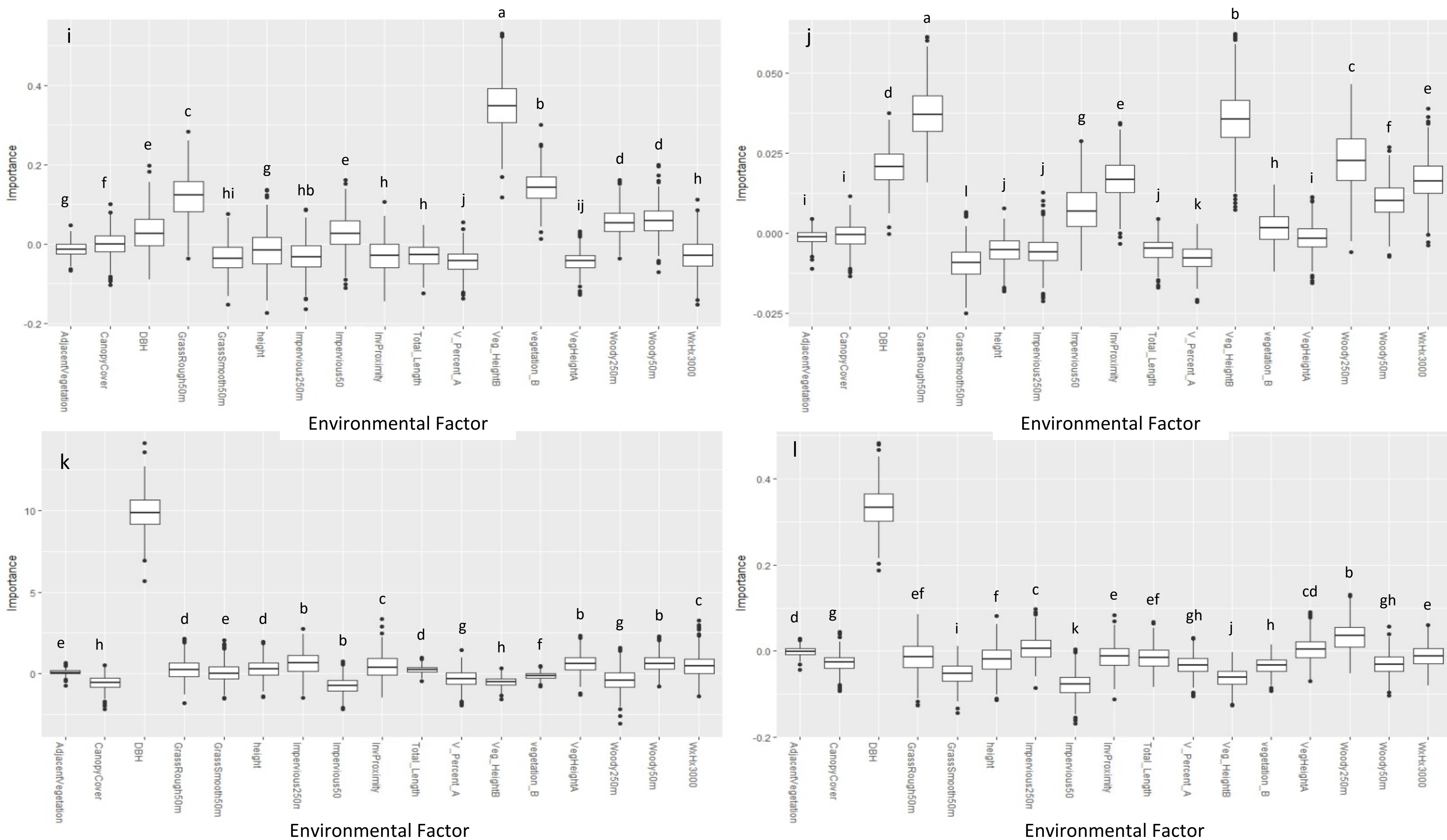

Figure 5-6 Boxplot of importance of impact the environmental factor has on explaining the variation in a) Abundance Araneae, b) Richness Araneae, c) abundance Collembola, d) richness Collembola, e) Abundance Diptera, f) Richness Diptera, g) Abundance Hemiptera h) Richness Hemiptera, i) Abundance Psocoptera, j) Richness Psocoptera, k) Abundance Hymenoptera, l) richness Hymenoptera, per run of the random forest algorithm (500 runs, n=33). Scores for variables with different lower-case letters are significantly different (ANOVA & Tukey's post-hoc). Dots represent outliers. y axis scales indicate that importance scores are low.

*Table 5-6 Summary of significant factors from the GLM and important factors from the Random Forest analysis. Level of significance given by the GLM is indicated by asterisks (***= p<0.001, *** = p< 0.001, ** = p < 0.01, * = p< 0.05). Importance score from the Random Forest is given in brackets – Score represents % change in model accuracy when that variable is removed.*

	GLM -ve	GLM +ve	RF important
Total abundance	• % of vegetation in front of the hedge*** • % of impervious surfaces within 50 m buffer***	• Total Length of the hedge*** • Inverse Proximity to road** • Hedge Volume*	• DBH (36.95) • % rough grass within the 50 m buffer (22.83) • % Woody vegetation within 250 m buffer (9.81) • % of vegetation in front of the hedge (8.89)
Total Richness	• % of impervious surfaces within a 50 m buffer**	• Total Length of the hedge** • Inverse Proximity to road**	• DBH (6.22) • % of Woody vegetation within 250 m buffer (2.33) • % of Rough Grass within 50 m buffer (1.24)
Araneae Abundance	• % of vegetation in front of the hedge*	• Inverse Proximity to road*	• Height of vegetation in front of the hedge (0.17) • % of impervious surfaces within a 50 m buffer (0.14) • DBH (0.10)
Araneae Richness	-	-	• Vegetation Height Behind hedge (0.06) • Hedge Height (0.05) • Total Length of the hedge (0.02) • height of vegetation in front of the hedge (0.02) • % Woody vegetation within 250 m buffer (0.02)
Collembola Abundance	• Hedge Volume* • Inverse Proximity to road**	• Total Length of the hedge*	• % of impervious surfaces within a 250 m buffer (0.05) • % Woody vegetation within 250 m buffer (0.00)

			• % of smooth grass within a 50 m buffer (0.00) • Hedge height (-0.00) • height of vegetation behind the hedge (-0.00)
Collembola Richness			• % of impervious surfaces within a 50 m buffer (0.01) • % of impervious surfaces within a 250 m buffer (0.01) • DBH (0.00) • % Woody vegetation within 250 m buffer (0.00)
Diptera Abundance		• Total Length of the hedge *** • Inverse Proximity to road*	• DBH (5.38) • % of vegetation in front of the hedge (5.31) • % of rough grassland within a 50 m buffer (2.73) • % Woody vegetation within 250 m buffer (1.06)
Diptera Richness		• Total Length of the hedge*	• % of vegetation in front of the hedge (1.42) • DBH (1.28) • % Woody vegetation within 250 m buffer (0.44)
Hemiptera Abundance	• DBH* • Hedge Volume***	• Total Length of the hedge** • % of impervious surfaces within a 50 m buffer *	• % of rough grassland within a 50 m buffer (4.31) • % of vegetation in front of the hedge (0.57) • Vegetation Height in front of hedge (0.28) •
Hemiptera Richness	• Hedge Volume*		• % of rough grassland within a 50 m buffer (0.25) • % Woody vegetation within 50 m buffer (0.17)

			• Adjacent vegetation (0.09)
Psocoptera Abundance	• Hedge Volume** • Height of vegetation behind the hedge*	• DBH** • % of vegetation behind the hedge**	• Vegetation Height Behind hedge (0.35) • % of vegetation behind the hedge (0.14) • % of rough grassland within a 50 m buffer (0.12)
Psocoptera Richness			• % of rough grassland within a 50 m buffer (0.04) • Vegetation Height behind hedge (0.04) • % Woody vegetation within 250 m buffer (0.02)
Hymenoptera Abundance	• % of vegetation in front of the hedge***	• Total Length of hedge*** • DBH*** • Inverse Proximity to road *** • % of vegetation behind the hedge*	• DBH (9.90) • % Woody vegetation within 50 m buffer (0.64) • % of impervious surfaces within a 250 m buffer (0.61) • Vegetation Height in front of hedge (0.61) • Hedge Volume (0.47) • Inverse Proximity to road (0.43)
Hymenoptera Richness		• Total Length of the hedge *	• DBH (0.33) • % Woody vegetation within 250 m buffer (0.03) • % of impervious surfaces within a 250 m buffer (0.01)

5.4 *Discussion*

Thirty-three hedges within Stoke-on-Trent and urban Newcastle-under-Lyme were vacuum sampled to collect the invertebrates present within them during the summer of 2014. Hedges were found to be used by invertebrates from 14 different major groups. Hemiptera were found to be the most numerous group, and Diptera were found to have the greatest richness of families. The results found a low number of Carabidae, Araneae, Opilliones, and Lepidoptera. These invertebrate groups were generally found to be lacking in urban hedges compared to the numbers found in rural areas in a study by Gosling *et al.* (2016). The low number of carabids may be explained by the sampling technique as many Carabidae are ground dwelling and would therefore not be collected by vacuuming at hip height. Another possible explanation for their low numbers may by the lack of taller herbs associated with urban hedges, as it is influential in their abundance (Angold *et al.*, 2006). Hedges in urban environments are often lacking in heterogeneity of structure (Faiers and Bailey, 2005; Gosling *et al.*, 2016) and are often composed of a single woody species, this homogeneity may have some bearing on the low number of Araneae (Maudsley, 2000) and harvestmen. There is very rarely a rich hedge understory, offering nectar or host plants, associated with urban hedges which may explain the low abundance of Lepidoptera. The groups of invertebrates found may also be a reflection on the sampling methods used. However, Maudsley *et al.*, (2000) found Coleoptera (mainly weevils) and Lepidoptera using a similar suction based sampling technique in studies of rural hedges.

5.4.1 *Impacts of the woody hedge species*

Woody hedge species was not found to significantly affect the richness or abundance of invertebrates found within them, nor was hedge species found to significantly affect the abundance of any of the major groups of invertebrate. The work of Southwood (1961) and Helden, Stamp and Leather (2012) suggests that tree species are associated with different numbers of invertebrates and that native species are associated with a higher number than non-natives. It was expected, therefore that hawthorn hedges would be associated with a larger number of invertebrates than beech or privet (Maudsley, 2000) but this was not shown. This may be partly explained by the hedges not being managed to allow them to flower or fruit which strongly influences their ability to support invertebrates. Although allowing a beech hedge to grow sufficiently to bear mast is likely to be highly impractical, privet and hawthorn can produce flowers and berries by simply changing the intensity and timing of management. It was expected that privet hedges may support fewer invertebrates due to not producing a flush of new leaves in the spring which has been shown to be linked to increased invertebrate biodiversity (Garratt *et al.*, 2017); however, by summer, when this study was undertaken, this influence may be much reduced.

The lack of impact of hedge species on invertebrates may thus be a result of urban hedge management, the timing of the surveys, or other physical properties of the hedge or surrounding area as suggested by Maudsley (2000).

5.4.2 Impacts of characteristics of the hedge and of the surrounding area

The results indicate that there is a positive relationship between the distance from the road and the abundance and richness of total invertebrates. This could be due to the levels of disturbance, pollution, air turbulence (Jones and Leather, 2012), and the reduced richness may be due to a reduction in specialist species for those more able to cope with the challenging environment (Angold *et al.*, 2006; Sadler *et al.*, 2006). There are many other influencing factors of habitats adjacent to roads such as increased levels of nitrogen, pollution, higher temperatures, less moisture, high levels of emissions, high turbulence, noise, dust, night lights (headlights), high salinity (pH) and a different composition of plant species (see Jones and Leather, 2012).

The frequently negative association with hedge volume and invertebrate abundance and richness is difficult to explain and I have been unable to evidence a reasonable explanation. It may be a limitation of the survey methodology being unable to penetrate to the depths of a dense hedge and therefore not sampling invertebrates from both sides in wide hedges. Further work into this is required. The length of a hedge being positively associated may be due to the hedges acting as drift nets to some species e.g. beetles. However beetle numbers were low.

The vegetation on either side of the hedge was shown to be important. The percentage of vegetation in front of the hedge was negatively associated with total invertebrate abundance and also with Araneae abundance and Hymenoptera abundance. This is more difficult to explain as it would be assumed that the presence of more vegetation near to the hedge would be beneficial to invertebrates. It may be however that when vegetation is in front of the hedge is of high quality then the beetles for example, may be preferentially using this area. The top four highest scoring hedges for Hymenoptera had dense tall vegetation behind the hedge but little vegetation in front of the hedge and where vegetation was present it was low-mown grassland, so this is unlikely to be the case. Of the hedges with little vegetation in front, many were mature hedges with associated trees. It has also been suggested that having vegetation on both sides is not significantly more beneficial to hedge biodiversity than vegetation on just one side (Gosling *et al.*, 2016), however, there is no suggestion that having vegetation on both sides has any detrimental effects. The importance of the presence of tall vegetation on one side may be reduced by the presence of vegetation on the other, perhaps by a dilution effect. However, this does not explain an apparent negative influence. The height of vegetation in front of the hedges showed very little variation in height with only four hedges having vegetation taller than 6 cm, meaning this is a variable that requires further research in areas where vegetation adjacent to hedges is taller and more diverse to effectively study the impacts of adjacent vegetation in urban areas. Including a dense understory of plants has been shown to be important for increasing heterogeneity and acts as forage for many species in rural hedges (Maudsley, 2000; Garratt *et al.*, 2017) and if wildflower rich then there is an increase in pollinator numbers (Sardiñas and Kremen, 2015; Cole *et al.*, 2017; Garratt *et al.*, 2017). Butterflies and bumble bees were not found in this survey, this is likely to be at least in part due to the survey technique used, as such species and many other flying insects are likely to have dispersed from the area due to the noise of the Vortis® but also their absence or low numbers may be due to the lack of flowers. Abundance of such species in urban hedges requires further investigation, especially in relation to flowering management. There were very few survey hedges with a tall vegetated strip on the near-road side. The height of vegetation on the opposite side was more variable, yet still only four of the study hedges had what could be described as a dense hedge understory behind the hedge. In the urban areas of Stoke-on-Trent and Newcastle-under-Lyme there are very few hedges that have been managed to facilitate the development of floristic adjacent vegetation even in locations where there is space to do so as grassland tends to be mown very close to the hedge in most locations. Of the eight hedges with vegetation height of between 20-100 cm behind, five abutted allotments, two were open green space, and one was waste ground with a diverse ruderal flora. Further investigation of the impact of the quality of adjacent vegetation on urban hedges may best be investigated though the introduction of adjacent vegetation strips on some sections of a hedge and comparing the difference in invertebrate abundance between the newly more diversely vegetated sections to those with continued mown grassland.

The proportion of impervious surfaces was negatively associated with total abundance and richness of invertebrates. This was included to represent both the amount of built-up land but also the lack of green space including habitats such as rough grassland and woody vegetation. The results suggest that there are more invertebrates and a greater richness in areas with fewer impervious surfaces. This could be due to the increasing urban intensity which is generally accepted to reduce the number of invertebrates (McIntyre, 2000; Helden and Leather, 2004; Evans, Newson and Gaston, 2009; Goodwin, Keep and Leather, 2017) or possibly that they are further from sources of colonisation (McIntyre, 2000) and are more isolated, which is well documented to have a negative impact on species richness (Breuste, Niemelä and Snep, 2008). It is also likely to be indicative of the reduction in semi-natural habitats such as woodland and grassland. The proportion of woody vegetation and rough grassland were suggested to be important factors in determining the total abundance and richness of invertebrates (Angold *et al.*, 2006; Jones and Leather, 2012). The positive correlation of percentage of sealed surfaces with Hemiptera abundance may be due to the hedges being one of very few alternative habitats available in areas with a high proportion of sealed surfaces and as a result the hedges have a higher than expected abundance of individuals (McIntyre, 2000) this phenomenon has been called ecological contrasts (Garratt *et al.*, 2017).

Woody vegetation and associated trees were identified as being one of the most important (in the top three) variables in explaining the variation in richness and abundance for total species and for each group of species except for Psocoptera abundance and Hemiptera abundance where it ranked 4th and 5th in importance respectively; but % woody vegetation was in the top three importance groups for richness of both Hemiptera and Psocoptera, however importance scores are low. In rural areas the presence of hedgerow trees increases the abundance of most species of flying insects (Peng, Sutton and Fletcher, 1992) and also increases the range of invertebrates that a hedge supports (Maudsley, 2000; Hinsley and Bellamy, 2019), including spiders (Garratt *et al.*, 2017), and the results of this study suggest this to also be true of urban hedges. This increase is likely to be greater if the tree species are native (Helden and Leather, 2004). DBH was, however, shown to be significantly negatively correlated with Hemiptera abundance by the GLM analysis but received a low importance score in the Random Forest analysis. This may be due to the mature hedges with a high volume in which the Hemiptera were found not having many trees adjacent to them. These hedges were also found in areas with a large proportion of rough grassland. This may mean that other factors are more important such as proportion of rough grassland and height of adjacent vegetation, but these factors were not included in the GLM due to collinearity.

Physical hedge properties related to richness and abundance of invertebrates were total length and hedge volume. Longer hedges are more likely to have a higher abundance and greater richness of invertebrates than shorter hedges (Batáry, Matthiesen and Tscharntke, 2010). This may be due to the longer hedges being a larger patch size (Graham *et al.*, 2018) which is known to increase the abundance and richness of total invertebrates and specific invertebrate groups (Faeth and Kane, 1978; Giuliano, Accamando and Mcadams, 2004; Angold *et al.*, 2006; Breuste, Niemelä and Snep, 2008; Jones and Leather, 2012). The negative relationships with hedge volume and many groups of invertebrate is difficult to explain. Hedges with a large volume are usually, in rural areas, expected to have a higher biodiversity (Hinsley and Bellamy, 2000; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Staley *et al.*, 2016; Newton, 2017; Graham *et al.*, 2018). Hedge volume is often associated with hedge age and structural heterogeneity (Maudsley, 2000); however, in urban environments with space at a premium, many hedges even though they are mature are trimmed very closely and frequently and have a reduced structural diversity (Faiers and Bailey, 2005; Gosling *et al.*, 2016).

To increase richness and abundance of invertebrates in urban hedges, consideration should be given to increasing their length where possible, and fragmenting hedges into shorter length sections should be avoided. Allowing a hedge to increase in volume is recommended to increase the total abundance of invertebrates. Associated trees and woody vegetation in the surrounding areas are important for total richness and should be included in planting schemes and maintained where they occur already to increase total richness and abundance and the richness and abundance of Collembola, Hymenoptera and Diptera, and the richness of Hemiptera and Psocoptera. Hedges would be most beneficial for invertebrates if they are integrated into planting schemes with trees and rough grassland in close proximity. Green infrastructure plans should accommodate this where possible. In many roadside locations there are opportunities to increase the proportion of woody vegetation and rough grassland without affecting the safety of residents of urban areas.

The method of using suction sampling generated a large number of small invertebrates from 14 different major groups but did not effectively collect larger species such as bees, larger beetles and butterflies. It was intended, in this study, to combine the Vortis® data with a pollinator survey. However, during two consecutive summer survey seasons (2016 -2017) there were too few days when weather conditions reached minimum criteria hence too little data was generated to be included in the analysis. This is therefore an area where further investigation is recommended. The suction sampling methodology led to substantial damage to many of the specimens collected and identification was hindered by the lack of body parts on many individuals; alternative survey techniques such as sweeping and beating may prove more effective.

5.5 *Conclusion*

The urban hedges of Stoke-on-Trent and urban Newcastle-under-Lyme were found to be used by invertebrates of 14 different major groups. Hedge species was not found to significantly affect the richness and abundance of total invertebrates or any invertebrate group, but hedge length and aspects of the surrounding vegetation did. Longer, taller hedges were richer and more abundant in invertebrates and the proportions of woody vegetation and rough grassland in the local areas are important to both richness and abundance of invertebrates.

6 The Public's Perception of Urban Hedgerows

6.1 *Abstract*

As our populations are urbanising rapidly, concerns are mounting that the disconnect between humans and nature is detrimental to our health and wellbeing. Therefore, the integration of green infrastructure into our cities is more important than ever. Urban hedges may offer great potential to increase local biodiversity and offer experiences of nature in our city streets. The success of greening initiatives ultimately depends on their acceptance by the local populations. This small-scale study assesses public perceptions of urban hedges and uses photographs of a range of boundary types to gauge public opinion on which boundaries they perceive to be more attractive, have most value to wildlife and which have a higher 'feel-good factor'. The results suggest that the participants prefer hedges to other boundary types in terms of aesthetics, believe they offer more value to wildlife, and have the greatest positive impact on how they feel. Broad, dense hedges adjacent to other green elements were preferred to severely managed hedges or those surrounded by hard surfaces. Hedges which were allowed to flower and fruit were particularly liked. It was noted that some hedges may be more difficult to maintain but this was not seen to be more important than the aesthetic and/or wildlife value by 98% of the participants.

6.2 *Introduction*

6.2.1 1.1 Urbanising populations and health and wellbeing

The human population is rapidly urbanising (Yuen and Hien, 2005; Fuller *et al.*, 2007), the percentage of the UK population living in cities from the mid-year estimates for 2014 was 83% (DEFRA, 2018), over 70% in Europe, and 54% globally (United Nations, 2014b). Sixty-six % of the world's population is expected to live in cities by 2050 (United Nations, 2014b). The urban environment is quite distinct from the habitats that we, as humans, have evolved to live in over thousands of years (Heerwagen and Orians, 1993). Although cultures have assimilated to, or even been formed by, these new conditions our biology may have not yet caught up, and concern is growing about the impacts on people's wellbeing as the gap between humans and nature widens (Miller, 2005; Fuller *et al.*, 2007; Dallimer *et al.*, 2012; Panagopoulos, Duque and Dan, 2016; Cox, Hudson, *et al.*, 2017; Jennings *et al.*, 2017).

Health benefits of greenspaces include fresh air, peace and quiet, stress relief and opportunities for physical activity. In the city there are many aspects that would promote healthier lifestyles such as safe walkable routes and access to activity spaces. There are, however, a high proportion of people in sedentary jobs and there are increasing issues with obesity, and cardiovascular disease (Sarkar and Webster, 2017). Other health conditions associated with the impacts of urban life (Jackson, 2003) include asthma and respiratory conditions, psychological distress and child development problems (Andersson *et al.*, 2014). Air pollution has been linked to increases in hospital admissions, many acute and chronic health effects (Seaton *et al.*, 1995; Brunekreef and Holgate, 2002; Cohen *et al.*, 2005; WHO, 2018), and over 800 000 premature deaths annually throughout the world (Cohen *et al.*, 2005; Curtis *et al.*, 2006). It is estimated that 3,500 people die early in Barcelona, Spain alone each year from breathing in the smog and particulate matter (Eldredge, 2016). Noise pollution is a major and increasing problem in urban areas (Enderle and Weihjr, 2005). The impacts of this increased pollution have economic costs as well as being detrimental to health and wellbeing (Goines and Hagler, 2007; Basner *et al.*, 2014; Stansfeld, 2015) and community relationships (Jackson, 2003). There are also frequent reports of the negative health impacts of artificial light which has been linked to breast cancer and sleep disorders (e.g. Cho *et al.*, 2015).

6.2.2 Benefits of urban greening on wellbeing

There is mounting evidence of the wider benefits of human contact with the natural environment (Barr and Gillespie, 2000; Jackson, 2003; Miller, 2005; Dallimer *et al.*, 2012; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Jennings *et al.*, 2017). These benefits include interaction with outdoor environments specifically; sensory contact with plants, the aesthetic appeal, and the opportunity for proximity with wildlife (Jackson, 2003; Todorova, Asakawa and Aikoh, 2004; Matsuoka and Kaplan, 2008; Brown and Grant, 2016; Snep *et al.*, 2016). Appropriately planned and/or maintained greenspaces support wellbeing in many ways (Ambrey and Jamali, 2017), including providing open space for physical activity and a place to play for children whilst simultaneously providing other important ecosystem services (Jorgensen, Hitchmough and Calvert, 2002) such as pollution capture (Weerakkody *et al.*, 2017)**,** flood mitigation (Liu, Chen and Peng, 2014), adaptation to climate change (Forest Research, 2010; Demuzere *et al.*, 2014; Dover, 2015; Derkzen, van Teeffelen and Verburg, 2017; Vivid Economics, 2017) and multiple potential health benefits (Cox, Shanahan *et al.*, 2017). Psychological benefits include the induction of positive states of mind (Hull, 1992;

Jorgensen, Hitchmough and Calvert, 2002), helping to combat stress (Jorgensen, Hitchmough and Calvert, 2002; Matsuoka and Kaplan, 2008), mitigation of mental fatigue, improved attention (Kuo and Sullivan, 2001), and reducing aggression, which is more widely experienced by residents living in more barren areas than those living in greener areas (Kuo and Sullivan, 2001). Mood has significant impacts on our productivity and health (Hull, 1992) with consequential benefits for employers of a more productive workforce (Hull, 1992). Even brief access to, or views or sounds of, nature, such as being able to view nature from a window or car window, or walking past trees or a park, or hearing birdsong (Brown and Grant, 2016), produces positive changes in mood and wellbeing. These passive experiences are often the most common experience of nature that people have (Kaplan, 2001; Kaplan and Austin, 2004; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Cox, Shanahan, *et al.*, 2017) and most occur within streets and residential areas (Cox, Hudson *et al.*, 2017). Neighbourhood satisfaction was found to be increased by the ability to see natural elements from windows (Fuller *et al.*, 2001).

There are progressively fewer opportunities for humans to experience other life forms first hand (Gaston and Evans, 2004) yet urban residents the world over express a desire for contact with nature (Matsuoka and Kaplan, 2008) and this is often linked to their eventual migration from the city centre with its dominant built fabric to the edges of cities (Kaplan and Austin, 2004). The suburbs offer greater opportunity for interaction with the rural environment due to their edge location but this “shared aspiration” for a greener view actually perpetuates the spread of the city, increasing urban sprawl and its associated pronounced detrimental effect on the environment (Benfield, Chen and Raimi, 1999), or people move out of the city altogether increasing pressure on rural villages and increasing commuter traffic (Kaplan and Austin, 2004). Therefore, in our increasingly urbanised world, making our cities better by the incorporation of green spaces and green elements could reduce the environmental impacts of suburbs.

6.2.3 Public perception of urban greening

Recently, there has been a move towards integration of environmental values alongside aesthetics and ease of management in the design of urban landscapes with growing recognition of the city as an important habitat for other species apart from humans (Panagopoulos, Duque and Dan, 2016). Therefore, there is a growing need for studies that provide quality information on the functioning of these micro-habitats within urban environments (Miller and Hobbs, 2002). For such biodiversity to be successfully incorporated within the built environment, planners need to understand how people respond to these features (Panagopoulos, Duque and Dan, 2016).

Positive associations have been measured between the species richness of plants and birds within an urban greenspace and the mental health and wellbeing benefits to visitors (Fuller *et al.*, 2007). Except for the possibility of ecotourism (see Gibson *et al.*, 2003), green infrastructure is not usually a marketable commodity or measurable service, biodiversity is an essential component of sustainable ecosystems and important in preserving our future (Blignaut and Aronson, 2008). 'Designing-in' biodiversity to urban plans effectively could be key to the success of our future cities, but there is a large body of literature suggesting that there may be conflict between the goals of designing and managing landscapes for wildlife and for aesthetics (Hull, 1992; Parsons, 1995; Jorgensen, Hitchmough and Calvert, 2002; Fuller *et al.*, 2007; Qiu, Lindberg and Nielsen, 2013). The benefit to wellbeing from exposure to green elements increases when people perceive the biodiversity value to be higher; but, participants' levels of understanding means that areas they believe to be better for wildlife may not actually be better (Dallimer *et al.*, 2012). Modern plant hybrids with multiple layers of petals may be more attractive but often have less pollen and nectar or the nectar may be inaccessible to some species of insects, whereas species such as hawthorn and native arable flowers offer food for many species of insect (RSPB, no date). Landscapes and habitats that offer greatest benefits to biodiversity often look untidy, and if people can correctly identify areas of high biodiversity it may not correlate with the areas that they find aesthetically pleasing (Nassauer, 1995; Fuller *et al.*, 2007; Qiu, Lindberg and Nielsen, 2013). Likewise, there may be a lack of correlation between the 'well maintained' and 'good natural environment' which suggests that conflict may arise in how to maintain the area whilst still providing a healthy natural environment. Even when people appreciate the benefit of improving ecological quality they may not wish to do so at the expense of the attractiveness of their neighbourhoods (Nassauer, 1995).

Todorova et al. (2004) and Hoyle et al. (2017) found that people enjoyed seeing flowers incorporated in to their street plantings and that they offered benefits to psychological wellbeing (Todorova, Asakawa and Aikoh, 2004). Colourful non-natives in ordered formation were found to be the most aesthetically pleasing and to a lesser extent were generally thought to offer the greatest benefit to invertebrates (Todorova, Asakawa and Aikoh, 2004), however this is unlikely to be the case. Asakawa *et al.* (2004) found that people preferred areas to be mown suggesting that although they liked natural looking scenery they liked a 'controlled' or 'refined' version of nature. These studies were conducted in Japan and their findings may reflect the cultural preferences of those people included in the surveys, so caution must be taken when applying these findings to UK surveys.

A survey of people in Sweden found that they perceived features of natural decay such as deadwood and swampy areas as being inappropriate for parkland areas when they had little ecological knowledge, but these features were much more tolerated by those with greater knowledge of ecology (Qiu, Lindberg and Nielsen, 2013). However, Southon et al. (2017) found that people did not perceive meadow areas as scruffy or unkempt but were receptive to naturalistic vegetation in urban green spaces. Participants were found to actually prefer meadows over highly managed areas such as formal planting or amenity grassland and even over herbaceous borders. Meadows containing a higher plant and structural diversity were most preferred. The majority of respondents were likely to tolerate meadows out of flowering season especially when they understood the benefits to biodiversity (Southon *et al.*, 2017). This was also found in a study by Jiang & Yuan (2017), where wildflower meadows were welcomed in parks, residential areas, rural areas and roadsides. The most frequently valued were natural looking meadows with long flowering periods, requiring low maintenance.

Ultimately, the success of urban planning depends on public support (Miller and Hobbs, 2002). Therefore, we need to consider the viewpoint of many different people when planning our urban landscape to ensure benefit to both ecology and human health and wellbeing. Much consideration must be taken to understand peoples' perceptions (Burel and Baudry, 1995; Jorgensen, Hitchmough and Calvert, 2002) and if planners are going to continue the trend of moving towards more naturalistic vegetation within towns and cities, understanding how the public feel about natural vegetation is important (Jorgensen, Hitchmough and Calvert, 2002; Derkzen, van Teeffelen and Verburg, 2017). Also, to increase the benefit to society, green elements must be located where they can offer the greatest impact on wellbeing (Dover, 2015).

Green spaces are chronically under-provided within many UK cities so access is limited, and green spaces are not accessible to all to the same extent (Barbosa *et al.*, 2007; Shen, Sun and Che, 2017). In a study by Cox, Hudson *et al.* (2017) it was found that a significant number of people had no good view of nature at work (33%) or at home (18.1%). Places where people live and work should be designed to allow access to nature, thus protecting native species and increasing human wellbeing (Miller, 2005). A multi-study report by Barton & Pretty (2010) suggests that the greatest benefits to both self-esteem and mood can be gained from light exercise (such as walking) for approximately five minutes adjacent to an element of nature suggesting health benefits from any short exposure to nature.

Much of our time is spent in streetscapes, many of which are not attractive to pedestrians or drivers; others, however, are appealing to both (Todorova, Asakawa and Aikoh, 2004). Streets represent 25 to 30% of developed urban land, which is a much higher figure than that of all parks and other public spaces added together (Jacobs, 1997); thus streets and residential areas may be where we need to focus when incorporating nature. A good street has place to walk at leisure and be safe and efficient (Antupit, Gray and Woods, 1996; Jacobs, Rofe and Macdonald, 1997). Streets should be comfortable, e.g. offer shade in hot conditions, allow you to be warmed by the sun when it is cold (Jacobs, 1997) and have elements on them to engage the eye. Boulevards are great streets when they are properly designed, built and maintained (Jacobs, Rofe and Macdonald, 1997). If designed properly streets can facilitate social interaction and be a pleasurable place to be or move through (Jacobs, Rofe and Macdonald, 1997) and offer great potential for wildlife (Atkins, 2018). Improvements in individual streets are important but the greatest improvements accrue when streets are considered as a group (Antupit, Gray and Woods, 1996). In Barcelona, there are plans to create more superblocks where small interior streets will be repurposed, only permitting access to vehicles traveling at below 10 mph thus providing space for cultural and physical activities. Vehicles will be restricted to roads on the perimeter with the aim of improving air quality and reducing the number of health issues and premature deaths, and increasing the quantity of the city's public green space (Bausells, no date; Eldredge, 2016; Lam, Taylor-Foster and Mes, 2016; Garfield, 2017; O'Sullivan, 2017; Roberts, 2017; Sorrel, 2017). To achieve effective, ecologically sustainable, economically viable and socially productive cities which would be of vastly greater benefit to their residents (Panagopoulos et al., 20106) requires much closer links between the disciplines of urban designers, ecologists and social scientists (Pickett, Cadenasso and Grove, 2004). As there is limited horizontal space available in urban streets, understanding how to maximize biodiversity potential with minimal use of space is crucial. Hedges may offer a viable solution to the biodiversity and this study seeks to provide an evidence base to inform planners and urban designers of the perceptions of urban residents on the inclusion of hedges to our urban streets.

6.2.4 Hedges of Urban Areas

Hedges are defined for this study as managed rows of shrubs. Although predominantly associated with rural areas, hedges are also commonplace within our towns and cities (Faiers and Bailey, 2005; Gosling *et al.*, 2016). These often overlooked natural elements not only provide important habitat and a source of food for birds, mammals and invertebrates, but also have the potential to offer ecosystem services within towns and cities delivering benefit in a range of forms: cultural, functional, ecological and visual (Burel and Baudry, 1995; Oreszczyn, 2000). Hedges can be directly incorporated into streets and residential areas thus offering experiences of nature to a large proportion of people without taking up much valuable horizontal ground space. As hedges offer valuable habitat for biodiversity they can potentially offer sights and sounds of nature and opportunities for contact with wildlife. Hedges can be thought of as bringing some of the countryside into the towns and cities (Oreszczyn and Lane, 2001). Yet there are aspects of hedges that can be perceived as disbenefits such as the requirement for management, opportunities for people to hide behind them, and their sometimes 'untidy' appearance (Oreszczyn, 2000).

Dense hedges, with fruiting and flowering species trimmed on a three-year rotation or managed via cutting, coppicing or laying, facilitating provision of diversity of structure and a constant supply of food throughout the year, will provide habitat for an abundance of birds, mammals and invertebrate species (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017). Provision for species within a hedge is also facilitated by sensitively managed land on either side - an area of less intensely managed land e.g. rough grassland, at least 1 m wide cut infrequently, with arisings collected. This should ideally be cut in sections to increase heterogeneity (See section 7.7). Hedges offer better provision for wildlife if they are part of a connected network (Dover and Sparks, 2000; Barr *et al.*, 2010; Staley *et al.*, 2016). This study seeks to investigate whether people who live in urban areas would find these types of hedges attractive and whether they appreciate that less intensive management offers increased biodiversity value.

Aesthetic aspects of hedges are rarely assessed but this seems to be the most important value to members of the public and most people are not aware of the ecological importance of hedgerow networks (Burel and Baudry, 1995). Oreszczyn & Lane 's (2001) study suggested that, in general, people in urban environments considered that the hedges of towns and cities should be well manicured, and that privacy was paramount. When asked about the preference for the appearance of rural hedgerows, members of the public preferred hedges to look bushy with a 'wilder' appearance. Some people preferred urban hedges that contained flowers (such as rose hedges) or were more diverse, rather than the 'common conifer hedges'. Visual impact was seen to be important as was the contribution to their local environment. There were concerns over taller hedges being dangerous to traffic but the birdlife that used them was appreciated. Poor management, and management undertaken at the wrong time of year, were particularly disliked (Oreszczyn and Lane, 2001).

Most studies on hedgerows are either concerned with wildlife or with people but a study that looks into both of these is rare (Oreszczyn, 2000); the integration of both offers a more encompassing assessment of what is delivered by hedges that are present in a very human-focused environment. If an integration of what people want and what offers most for wildlife can be found, then this may be important information to facilitate the maximum benefits to both humans and wildlife through the inclusion of green elements within our future cities.

My aim therefore, is to assess which types of urban boundary people perceived to be more aesthetically appealing, to ascertain whether maintenance, aesthetics, or wildlife value were more important, and to gauge some measure of the extent of the difference in the importance placed on these values. Questionnaires were used to address the following three research questions:

6.2.5 Research questions

1. Is there any preference for a particular type of boundary in an urban environment?
2. Do members of the public perceive wildlife, aesthetics or ease of maintenance to be more important attributes of a boundary?
3. Do people perceive correctly, which type of hedgerow offers better provision for wildlife?

6.3 *Method*

6.3.1 Survey production and distribution

A photographic preference survey was conducted with members of the public residing/working and visiting Stoke-on-Trent (SoT) during the summer of 2017. As it was desired to reach a diverse audience an online approach was selected. The survey was created within Qualtrics © software (Qualtrics, 2017) and ran from March to July 2017. It was publicised using social media, a radio interview with a local radio station (BBC Radio Stoke) during drivetime, and via a small article in the local paper (The Evening Sentinel). Staffordshire Wildlife Trust (SWT) and the British Trust for Ornithology (BTO) publicised the questionnaire on their websites and the survey was introduced to people at local community groups' meetings. Posters advertising the questionnaire were placed in local shops, bus stops and at Staffordshire University.

This online-only method may have excluded people who did not have access to the internet and people had to choose to act upon the invitation to take the survey and may only have done so if they had a specific interest in hedges within their local area. It also reduced the ability to target specific people in specific locations. The advantages were that a larger number of people could be reached than we would expect to from face-to-face surveys.

6.3.2 Questions within the questionnaire

For a copy of the questionnaire please see Appendix D

All responses to the questionnaire were anonymous and a no ethics declaration was made.

Section 1: Demographics

Background information on participants was collected. This included, age category, employment status, type of location that they grew up in and in which they currently reside.

Section 2: Personal Views

An assessment of how the participants feel about hedges and the relative importance they place on ecosystem services offered by hedges and their possible negative impacts were made using a statement scoring question using a Likert-type scale from 0 to 5 where 0 = strongly disagree & 5 = strongly agree.

Section 3: Evaluation of Boundaries

Each participant was shown four randomly selected images of boundaries from a total of 18 (Figure 6-1). The images were randomly selected by the survey software for each questionnaire. Participants were asked to score the images in terms of attractiveness, importance for animals, ease of maintenance, and feel good factor. Feel good factor is defined for the purpose of this survey as a the amount by which the image provokes feelings of happiness and positivity. The images included showed five different hawthorn hedges, four privet hedges, four examples of hedges of other species (laurel, yew, laylandii and beech) and five images of other boundaries (railings, a stone wall, a concrete fence and a picket fence with a climber growing over it).

Section 4: Hedgerow Value

Participants were asked to select the factor which was most important to consider when planting a hedgerow, the options were: the hedge's contribution as a habitat for animals; the attractiveness of the hedge, and ease of maintenance. There was also the option to select that all of the first three choices were equally important.

Section 5: Open Question Section

Finally, participants were invited to give any other information that they felt would be relevant.

‘Feel free to write any feelings you have towards hedges, such as what improvements you believe can be made, what interests you that has not been asked’

This was included to generate information to assess themes of what participants considered to be good, bad or important about urban hedgerows.

6.3.3 Data analysis

6.3.3.1 Quantitative analysis

Data were non-normally distributed so Kruskal-Wallis statistical tests were used to identify significant differences between the scores given to the different images for each of the following categories: Attractiveness, Importance for Animals, Ease of Maintenance, Feel Good Factor, and Wildlife and Wellbeing. Post-hoc analysis for identification of where these differences occurred, used Dunn tests with Bonferroni correction.

6.3.3.2 Qualitative analysis

Thematic analysis was applied to all the free-text responses as it is accepted that such an approach is more likely to provide a thorough analysis of the views given (Barbour, 2014; Cope and Kurtz, 2016). Due to the very open nature of this question, many aspects are likely to be included and some will only be mentioned in a few (or possibly only one) participant's answers, and so these statements will be categorised into themes.

Due to the qualitative nature of the results for this section a more manageable data set was produced using an iterative, three stage coding approach (Barbour, 2014; Cope and Kurtz, 2016) where key words were used as codes or signposts to help to identify where they were used and in what context within the transcripts to assist in the development of themes.

Initially an 'index' of common (*in vivo*) words was produced and used alongside the transcripts of the answers in accordance with 'grounded theory' (Barbour, 2014) to develop themes (analytic codes) (Cope and Kurtz, 2016). Themes were subsequently subdivided into smaller sub-themes. In most thematic analysis, a theme is identified and then the positives and negatives for that theme identified and highlighted within that theme. To further contextualise the information provided by the participants their original transcriptions were revisited again to select direct quotes providing specific examples that illustrated the themes identified. Many themes were included in most individuals' responses, therefore, different sections of a respondent's answer may feature in different themes, thus enabling a much more informed use of what they have said.

Figure 6-1 Images of boundaries included in the survey

6.4 Results

6.4.1 Demographic data

Of 87 participants who took the survey, 83 completed. The data from the four who did not complete was not used for the study. One of the 83 who completed did not give their age category, but the rest of their responses are included in subsequent analysis. The remaining 82 respondents were distributed between all age categories with the majority being aged between 25 and 64 (69.5%) (Table 6-1). When compared against the population age distribution for SoT based on 2011 census data it can be seen that the hedge survey excluded young people and children and had a slightly larger proportion of participants aged 25 – 44 than the 2011 census data would suggest.

Table 6-1 Numbers and % of respondents in each age category compared to total population information from census data. The distribution of ages within the study appears to be fairly representative

Survey Participants			**S-o-T 2011 census data**		
Age Group	**%**	**Count**	**Age Group**	**%**	**Count**
<18	0.0	0	**<20**	24.7	61,576
18-24	15.9	13	**20-24**	7.7	19,089
25-44	36.6	30	**25-44**	27.3	67,967
45-64	32.9	27	**45-64**	24.7	61,617
65+	14.6	12	**65+**	15.6	38,818
	Total	**82**		**Total**	**249,067**

Figure 6-2 represents the location selected by participants of their past and present residence. Participants selected which location type best described where they live currently and where they grew up. No specific sizes of city, town or hamlet were given, participants chose the title that best describes their interpretation of the type of place they grew up in and currently reside. It is people's perception of where they live that is important to this study rather than the specific population size. The figure illustrates that there is a large proportion of participants who no longer live in the same type of area that they grew up in as much movement occurs. The direction of movement is not dominated by a move to smaller conurbations from larger or vice versa suggesting that there is no trend to move out of cities to more rural areas nor is there a trend for urbanisation. Therefore the degree of movement limited the impact of the type of residence on their perception as numbers of groups for each category were small, i.e. people who have only resided in a small town or hamlet was only 1, and only 5 people had lived in a city whilst growing up and currently. Participants were from a diverse range of places of residence with similar numbers living in the city centre, outskirts of the city and small towns or villages. Forty five % of participants were in full time employment, 25% in full time education and 25% were retired. Of those in employment 9% worked outdoors and 9% worked outdoors for part of their role. Over 77% of participants walk in Stoke-on-Trent at least once a week.

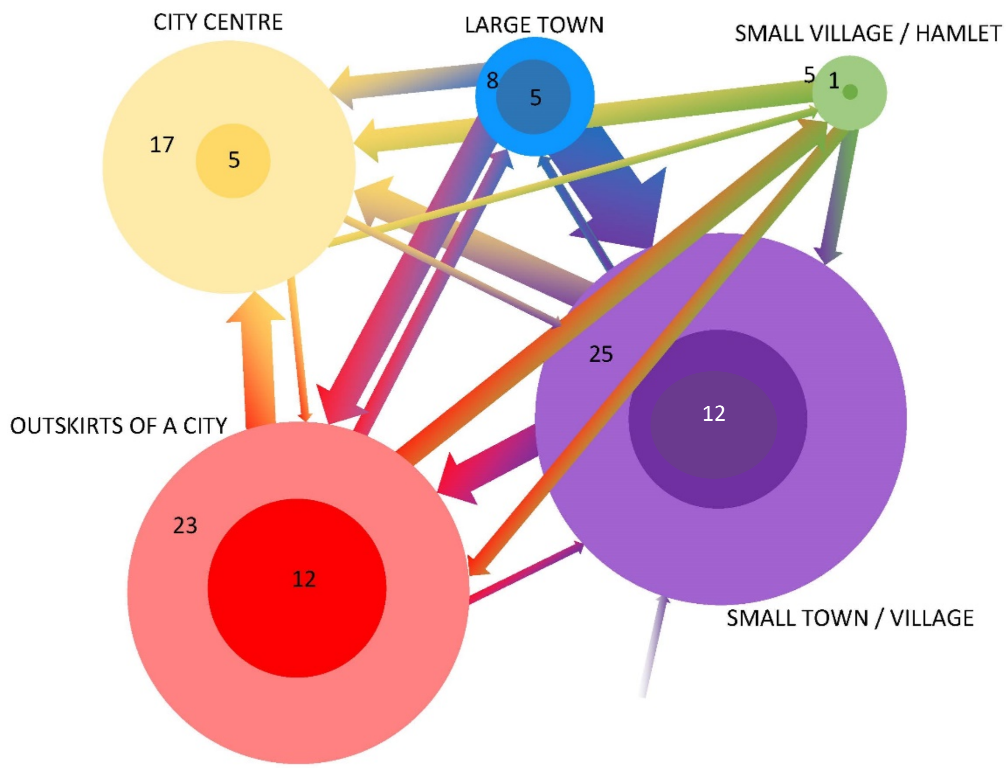

Figure 6-2 A representation of location of current and childhood residence. Darker central circle represents the number of individuals who have resided in that type of location both growing up and currently. Whilst the lighter larger circle represents the number of individuals that have lived in that type of area either growing up or currently. The direction and width of the arrows shows direction and number of movement. E.g. most people who now live in the city centre have moved there from other area types and a much smaller number of people have moved away from the city centre.

6.4.2 How do participants feel about hedges?

The scores given to the statements about hedges are shown in Figure 6-3. There were significant differences in the scores given to the different statements (*H=470.867, p=<0.01, n=845*). Assumed negative statements scored significantly lower than assumed positive statements post-hoc analysis results are shown in Appendix E.

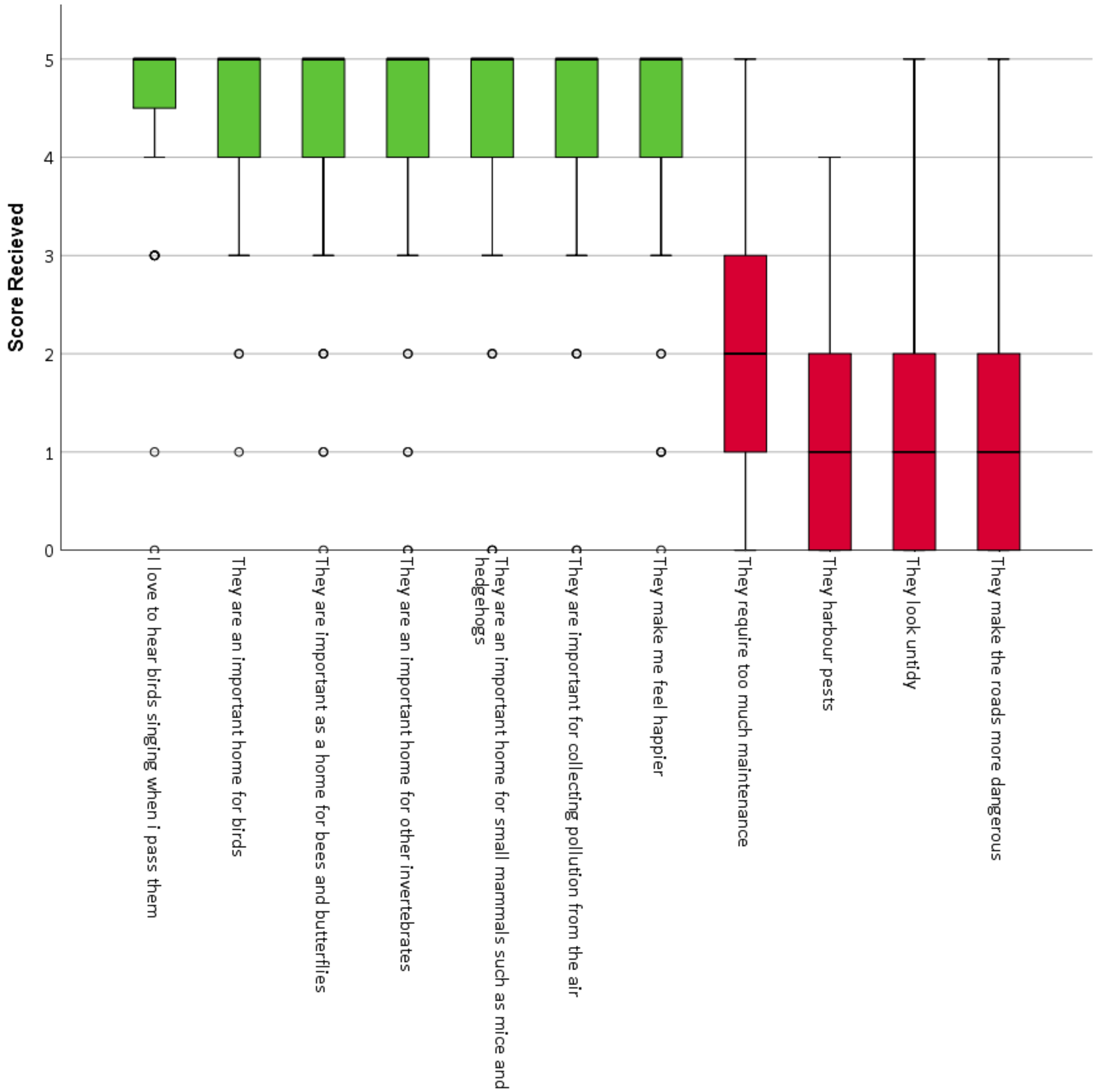

Figure 6-3 Boxplot of the scores given to each statement. The statements were scored on a Likert style scale between 0 (strongly disagree) and 5 (strongly agree) by each participant. Assumed positive statements are represented by green boxes, negative statements by red.

6.4.3 Images of boundaries

6.4.3.1 Attractiveness

Which boundary types are perceived to be more attractive?

The mean scores received by the images for attractiveness were analysed using Kruskal-Wallis tests. Scores varied significantly between the photographs (Figure 6-4) (*H= 102.030, p=0.00, n=258*). See Appendix F for post-hoc results. The highest scoring hedges were a beech hedge and four hawthorn hedges, and the lowest scores were received by images containing other types of boundary (Table 6-2).

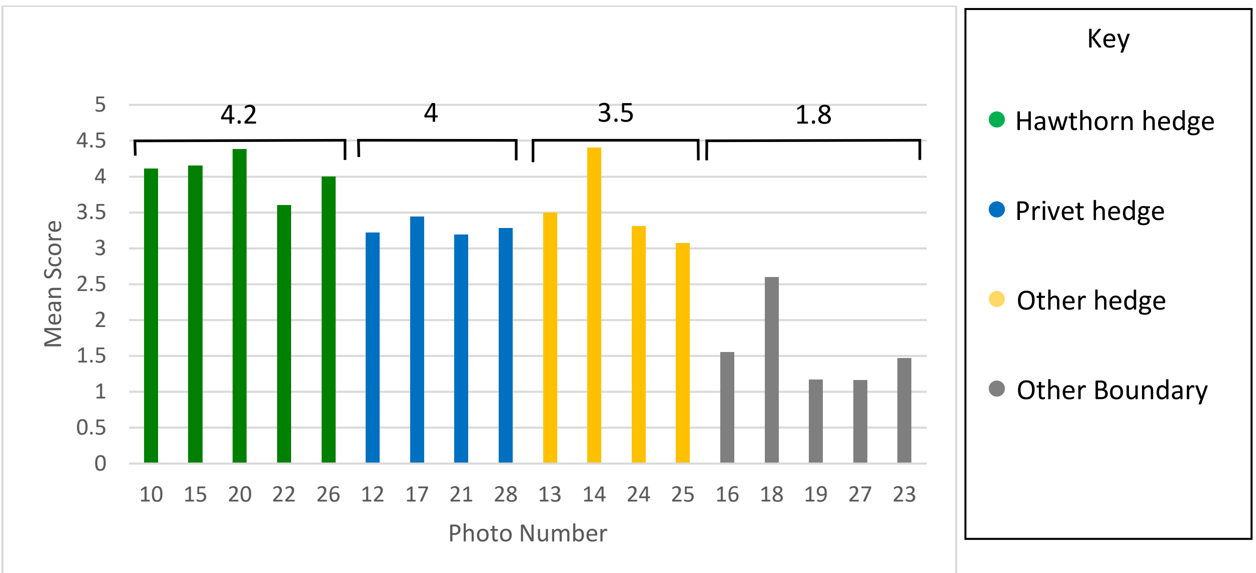

Figure 6-4 Mean scores (0-5) given by participants to each photograph. Mean values for groups of photographs containing each boundary type are included above the bars.

Table 6-2 a) Highest mean scores given for attractiveness of the boundary shown in the photograph and the boundary type. b) Lowest mean scoring photographs and boundary type.

a. Highest Scoring ≥4		
Score	Photo No	**Type**
4.4	14	Beech Hedge
4.4	20	Hawthorn Hedge
4.2	15	Hawthorn Hedge
4.1	10	Hawthorn Hedge
4.0	26	Hawthorn Hedge

b. Lowest Scoring ≤2		
Score	Photo No	**Type**
1.2	27	Fence
1.2	19	Railings
1.5	23	Railings
1.6	16	Concrete Fence

6.4.3.2 Importance for animals

Figure 6-5 shows the mean of the scores given to the images for importance for animals. The highest scoring hedges were a beech hedge and four hawthorn hedges, and the lowest scores were received by images containing other types of boundary (Table 6-3).

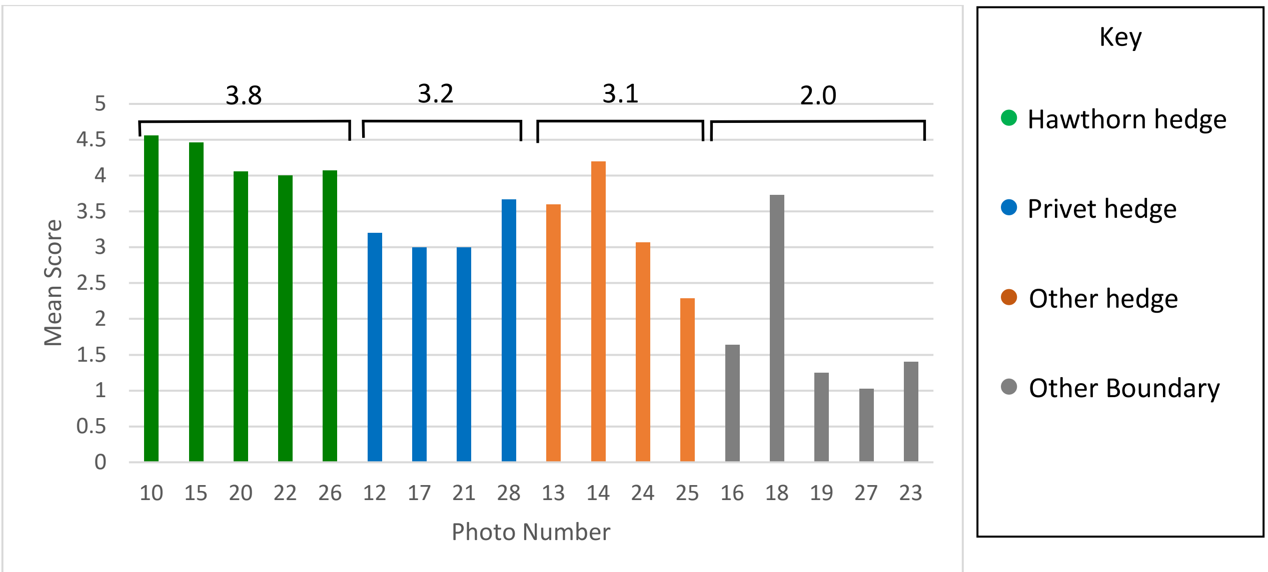

Figure 6-5 Mean scores given for perceived importance for animals of the boundary shown in the photograph. Brackets above show the mean for the hedge species/boundary type.

Table 6-3 a) Highest mean scores given for importance for animals of the boundary shown in the photograph and the boundary type. b) Lowest mean scoring photographs and boundary type.

a. Highest Scoring ≥4		
Score	Photo No	**Type**
4.6	10	Hawthorn
4.5	15	Hawthorn
4.2	14	Beech
4.1	20	Hawthorn
4.0	26	Hawthorn

b. Lowest Scoring ≤2		
Score	**Photo No**	**Type**
1.0	27	Fence
1.4	23	Railings
1.6	19	Railings
1.6	16	Concrete Fence

There scores varied significantly between the photographs (*H= 105.087, p=0.00, n=258*). See Appendix G for post-hoc results. The highest scoring hedges were the same four hawthorn hedges and one beech hedge as those that scored most highly for attractiveness. The lowest scoring boundaries were the same non-hedged boundaries as scored lowest for attractiveness.

6.4.3.3 Ease of maintenance

Which boundaries are perceived to be easiest to maintain?

Figure 6-6 shows the mean of the scores given to the images for ease of maintenance. There was very little variation in scores for ease of maintenance. All scored a mean value of between 2.50 and 3.60 except 27 which was a picket fence that scored 1.29 and a sculptured privet hedge that scored 2.05, these were deemed as difficult to maintain. When photographs were analysed, the Significance test (ANOVA) identified no significantly different scores for ease of maintenance for the boundaries in the photographs (*F= 1.200, p=0.264, n=266*)

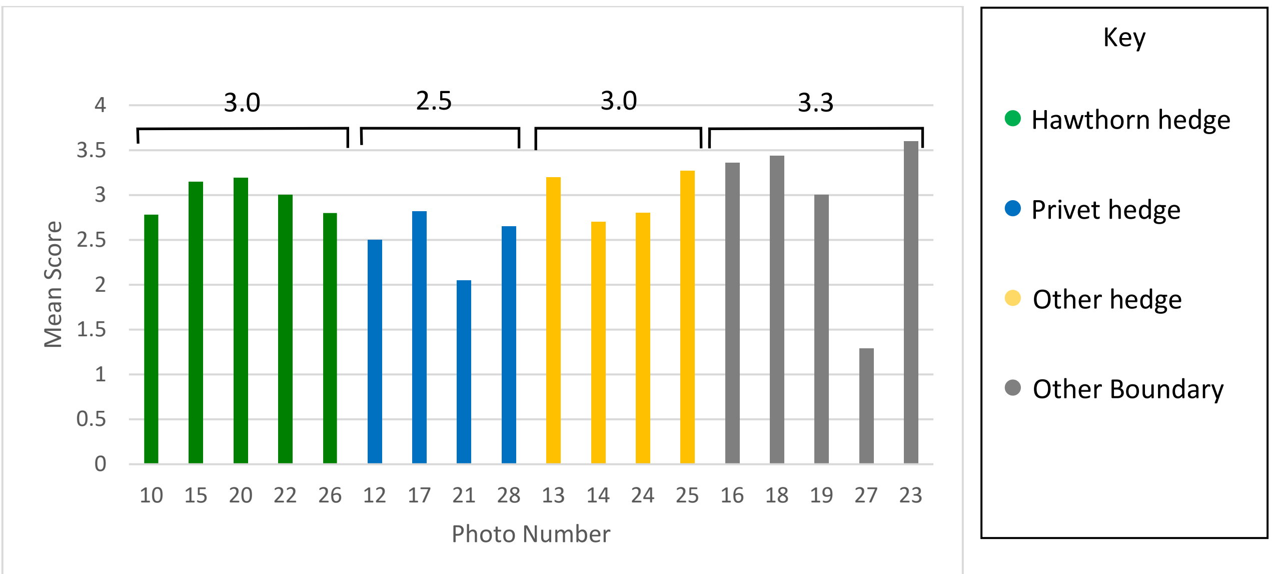

Figure 6-6 Mean scores given for perceived ease of maintenance of the boundary shown in the photograph.

Table 6-4 a) Highest mean scores given for Ease of maintenance of the boundary shown in the photograph and the boundary type. The mean score was not over 4 for any photograph so a score of ≥3 is used here. b) Lowest mean scoring photographs and boundary type.

a. Highest Scoring ≥3		
Score	Photo No	**Type**
3.60	23	Railings
3.44	18	Railings
3.36	16	Fence (Concrete)
3.27	25	Laurel
3.20	13	Laurel
3.19	20	Hawthorn
3.15	15	Hawthorn
3.00	19	Fence (mesh)
3.00	22	Hawthorn 'Wild'

b. Lowest Scoring ≤2		
Score	**Photo No**	**Type**
1.29	27	Fence (picket)
2.05	21	Privet hedge (shaped)
2.50	12	Privet

6.4.3.4 Feel-good factor

Figure 6-7 shows the mean of the scores given to the images for 'feel good factor'. The highest scoring hedges were three hawthorn hedges and a beech hedge, and the lowest scores were received by images containing other types of boundary (Table 6-5). The top 4 highest scoring hedges were the same as some of the top scoring hedges for attractiveness and importance for wildlife .

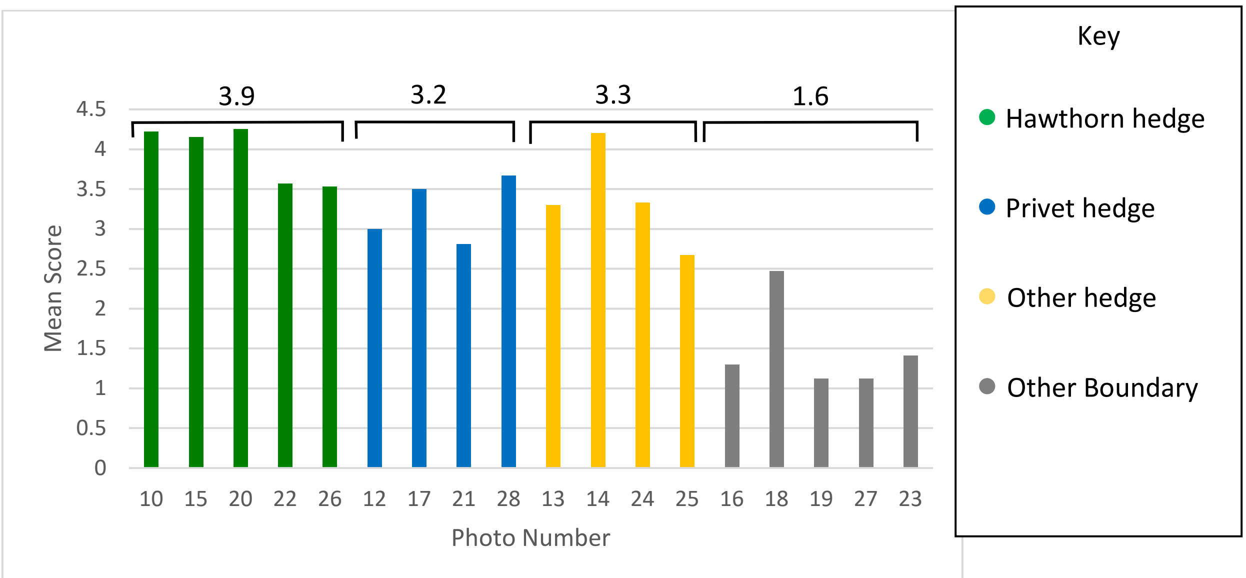

Figure 6-7 Mean scores given for feel good factor of the boundary shown in the photograph

Table 6-5 a) Highest mean scores given for feel good factor of the boundary shown in the photograph and the boundary type. b) Lowest mean scoring photographs and boundary type.

a. Highest Scoring ≥4		
Photo No	Score	**Type**
10	4.26	Hawthorn
20	4.25	Hawthorn
14	4.20	Beech
15	4.15	Hawthorn

b. Lowest Scoring ≤2		
Score	**Photo No**	**Type**
1.12	27	Fence
1.30	19	Railings
1.30	16	Concrete Fence
1.41	23	Railings

There were significant differences between the individual images (*H= 94.665, p= 0.00, n=266*). Post-hoc analysis can be found in Appendix H.

6.4.3.5 *Wildlife and wellbeing*

Wildlife value, aesthetics and feel good factor suggest that there are benefits of hedges to both the wellbeing of people and wildlife in the area. A combined mean value for all three scores for each hedge is calculated.

Figure 6-8 shows the mean of the scores given to the images for ‘feel good factor’. The highest scoring hedges were three hawthorn hedges and a beech hedge, and the lowest scores were received by images containing other types of boundary (Table 6-6).

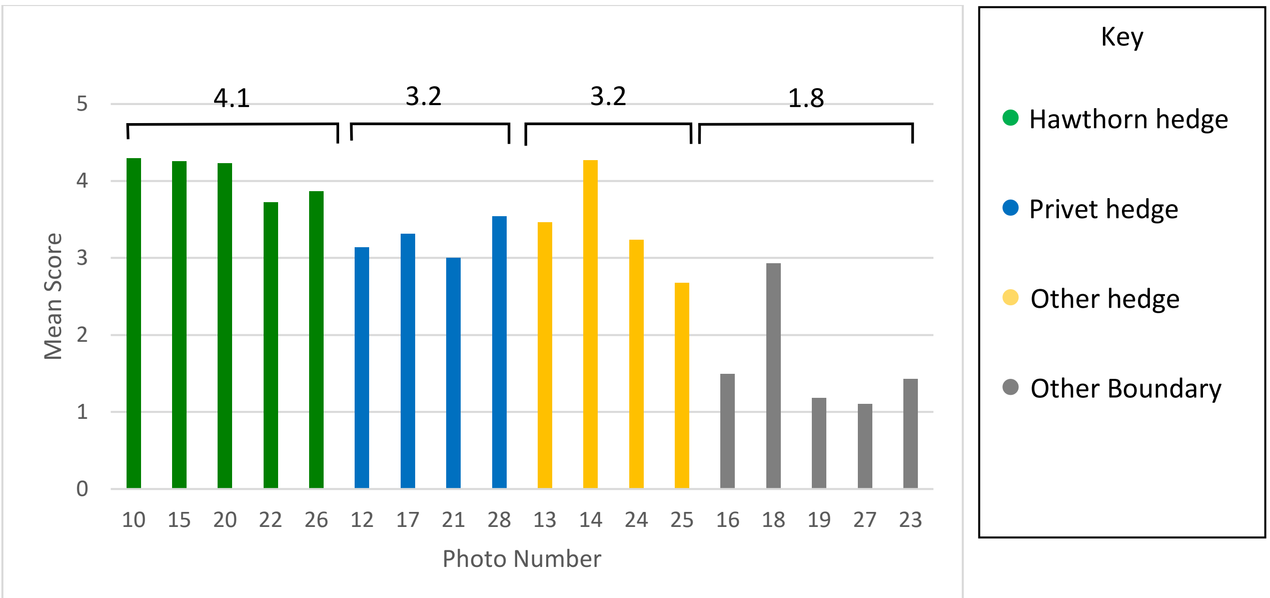

Figure 6-8 Mean scores given for attractiveness, value for wildlife and ‘ feel good factor’ of the boundary shown in the photograph are added together and divided by 3.

Table 6-6 a) Highest of the mean scores given for attractiveness, value for wildlife and ‘ feel good factor’ of the boundary shown in the photograph added together and divided by 3 b) Lowest mean scoring photographs and boundary type.

a. Highest Scoring ≥4		
Photo No	Score	**Type**
10	4.30	Hawthorn
14	4.27	Beech
15	4.25	Hawthorn
20	4.23	Hawthorn

b. Lowest Scoring ≤2		
Photo No	**Score**	**Type**
19	1.18	Railings
23	1.43	Railings
27	1.10	Fence
19	1.18	Concrete Fence

The differences between the scores given for wildlife and wellbeing to the images were significant (*p=0.000, H=288.443, n=772*). For post-hoc analysis see Appendix I.

6.4.4 Overall interpretation

The same four images (10, 14, 15 & 20) (Figure 6-1) scored the highest for attractiveness, importance for wildlife, feel-good factor and for wildlife and wellbeing. These images contain wide, dense hedges with other green elements in close proximity. Three of the top four highest scoring images contained hawthorn hedges. The hedges are not untidy hedges and are of a shape indicative of sequential maintenance but not to the extent that prevents flowering of the whole hedge (in hawthorn hedges) and there is evidence of some regrowth suggesting that there is a longer period between the maintenance for this to occur.

The overall top scoring image for wildlife and wellbeing (aesthetics, importance for wildlife and feel-good factor) was image 10 (Figure 6-1) which showed a dense, wide hawthorn hedge in flower with adjacent tall ground vegetation. The image considered to be the most attractive was image 14 which contained a dense, beech hedge with a shape indicative of regular trimming. There was low mown grass adjacent to the hedge and trees in proximity behind. The second highly scoring image (20) in this category contained a dense hawthorn hedge with regrowth in gaps permitting flowering and tall unmown vegetation adjacent. The more 'wild' hedge (a line of trees) in image 22 scores slightly less (not significantly) in both the attractiveness category and in the importance for animals category

Although images containing a non-hedges boundary scored significantly lower than images containing hedges in categories of attractiveness, importance for wildlife and feel-good factor (all categories except ease of maintenance), except for image 18 which contained a set of railings in front of a densely shrubby bank (almost hedge-like) with trees behind (Table 6-7). Image 18 scored significantly higher than most other images not containing a hedge and did not score significantly lower than most images containing a hedge. Full post-hoc analysis is shown in Appendix I. There were not significant differences between any of the images containing a hedge when compared to any other image containing a hedge in the same categories except for wildlife and wellbeing where hedges 25 and 21 scored significantly lower than hedges 20,10,15 and 14 (Tables 6-7 & 6-8).

Due to the unusual management of hedge 21 it was felt that this may be more to do with the uniqueness not appealing to everyone rather than the aspects the study was mainly focused on so that the test was run again with image 21 removed and again hedge 25 scored significantly lower than images 20,10,15 and 14 with no other hedges significantly different from each other (Table 6-9). Full post-hoc analysis is shown in Appendix J.

Table 6-7 Dunn-Bonferroni pairwise comparison of wildlife and wellbeing test scores for comparison of image 18 with other images (n=709). Images without a hedge are coloured red, significant differences are highlighted yellow.

Image Numbers compared	Test Statistic (T)	*p* value
18-19	4.953	.000
18-16	-3.937	.013
18-23	4.280	.003
18-27	3.175	.229
18-21	-.117	1.000
18-24	-.640	1.000
18-12	.680	1.000
18-17	1.244	1.000
18-13	1.480	1.000
18-28	-1.945	1.000
18-22	-2.363	1.000
18-26	-2.972	.453
18-20	-4.103	.006
18-10	3.591	.050
18-15	4.007	.009
18-14	3.792	.023

Table 6-8 Dunn-Bonferroni pairwise comparison of wildlife and wellbeing test scores for significant differences between images containing a hedge.

Image Numbers compared	Test Statistic (T)	p value
25-20	4.719	.000
25-10	4.128	.006
25-15	4.593	.001
25-14	4.338	.002
21-20	4.325	.002
21-10	3.706	.032
21-15	4.191	.004
21-14	3.926	.013

Table 6-9 Dunn-Bonferroni pairwise comparison of wildlife and wellbeing test scores for significant differences between images containing a hedge once hedge 21 had been removed (n=709).

Image Numbers compared	Test Statistic (T)	p value
25-20	4.665	.000
25-10	4.080	.006
25-15	4.549	.001
25-14	4.303	.002

6.4.4.1 What is the most important attribute of hedges?

Just under half of the participants (41%) thought that wildlife was the more important benefit of a hedge than aesthetics and ease of maintenance whilst almost half (48%) thought that all three of these factors were equally important. Only 2% and 7% though that ease of maintenance, or attractiveness respectively was more important. Although slightly more people thought that all three elements were equally important, wildlife scored very highly alone; suggesting that the vast majority (89%) perceive wildlife to be equally or more important than aesthetics or ease of maintenance when choosing a boundary type (Figure 6-9).

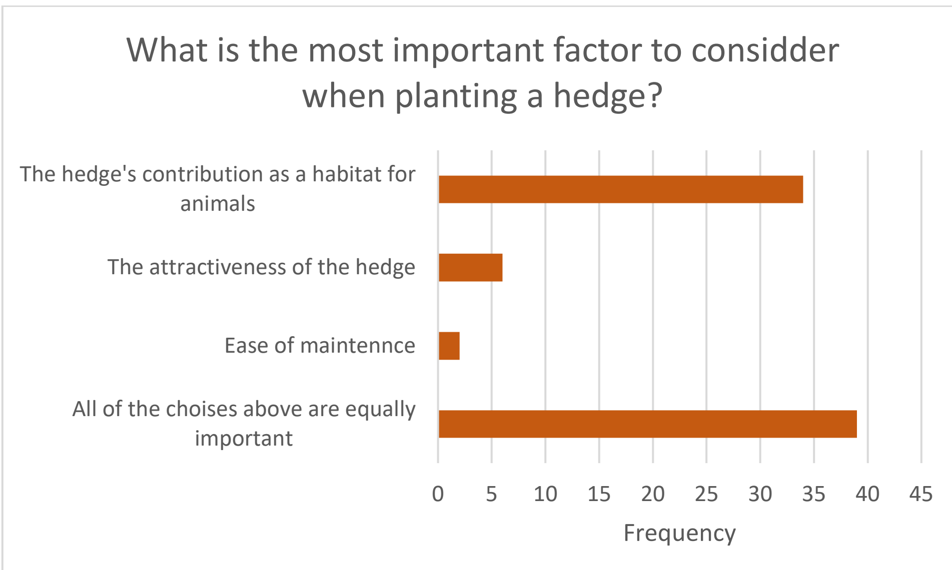

Figure 6-9. The frequency which each statement was selected as the most important factor to consider when planting a hedge .

6.4.4.2 Open question analysis

The most frequently used words in the participants' answers were identified. After the word hedges, the most commonly used word is wildlife followed by birds then planted species. This suggests that participants frequently discussed biodiversity aspects of hedges.

6.4.4.3 Open question coding

These words were then grouped into themes (Figures 6-10, 6-11, 6-12, 6-13 and 6-4). The key themes identified were wildlife and ecosystem services. Other themes identified were maintenance, information and negatives.

Wildlife

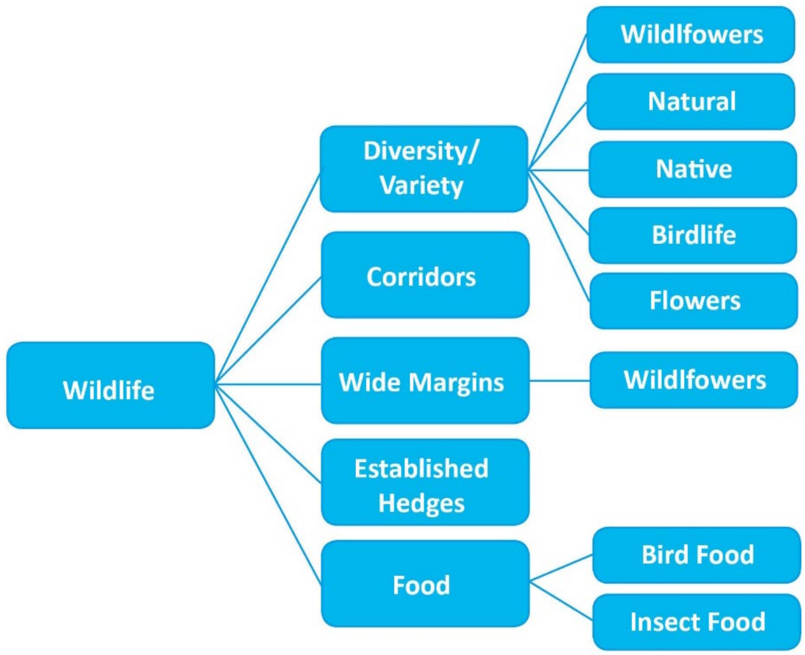

Figure 6-10. Theme of wildlife with sub-themes identified from responses to the open question

Ecosystem services

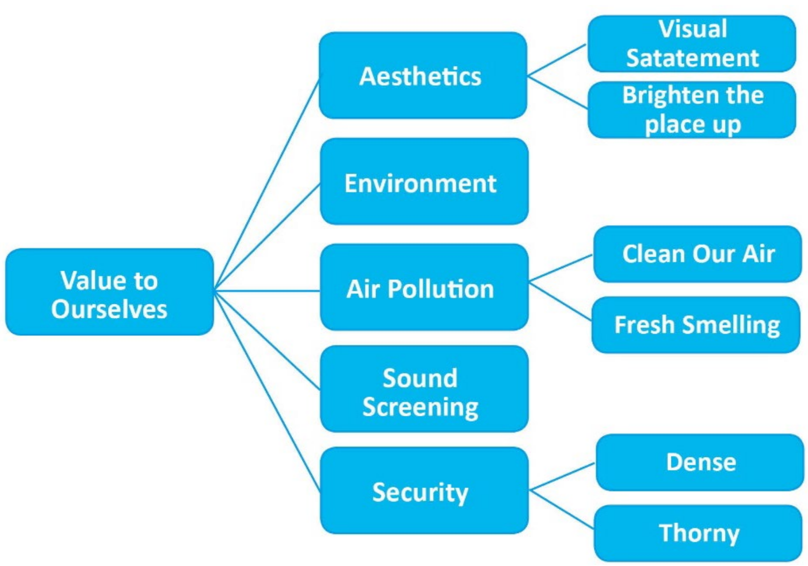

Figure 6-11 Theme of Ecosystem Services (Value to Ourselves) with sub-themes identified from responses to the open question

Maintenance

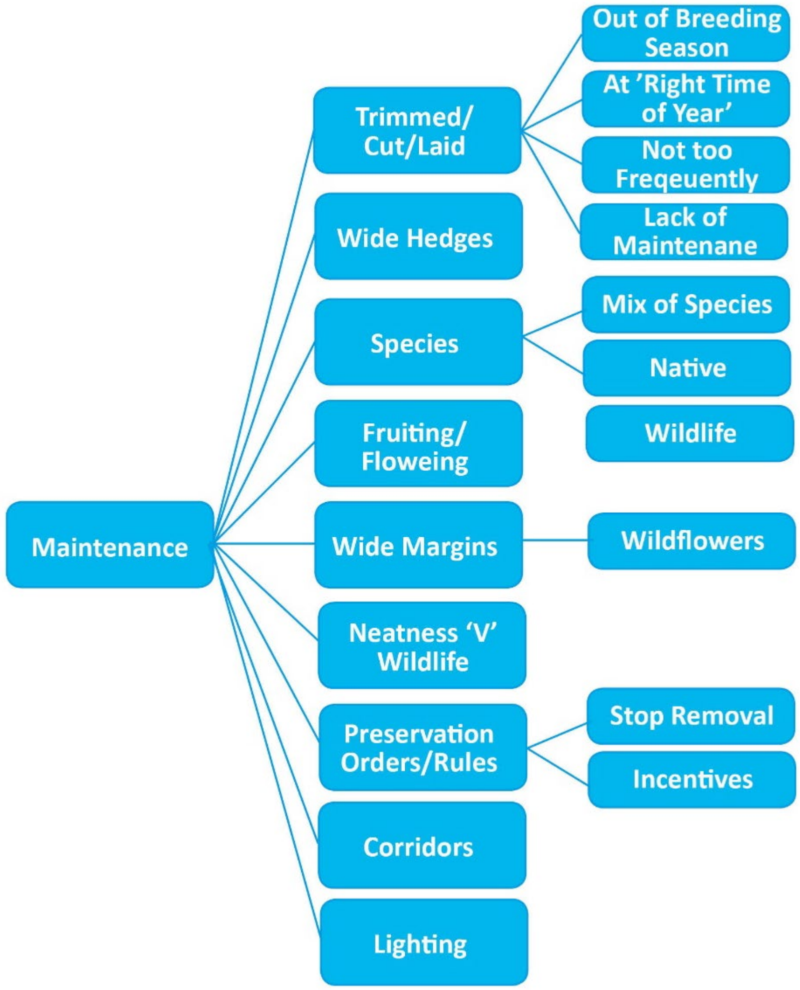

Figure 6-12 Theme of Maintenance with sub-themes identified from responses to the open question

Information

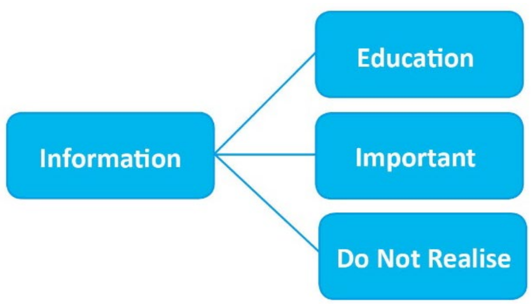

Figure 6-13 Theme of Information with sub-themes identified from responses to the open question

Negatives

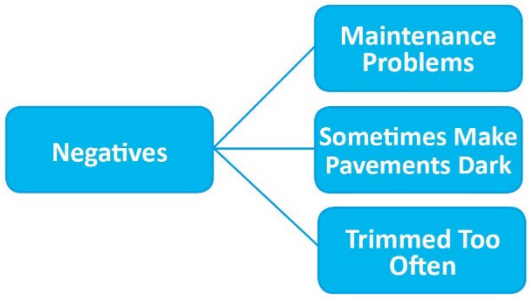

Figure 6-14 Theme of Negatives with sub-themes identified from responses to the open question

The themes are briefly explained, and exemplar quotes included below:

Wildlife

The most discussed theme was the value of hedges to wildlife. Participants felt that hedges were very important for wildlife, especially for birds and that not only is the presence of the hedge itself important, but also that it needs to be sympathetically managed for wildlife. The participants who answered this question appreciated that having a variety of the appropriate species planted within and adjacent to the hedge plays an important role in the value that a hedge has to offer to wildlife. They understood that over management or ill-timed management was detrimental to wildlife value and that more needs to be done to protect, improve and increase the urban hedgerow resource such as providing incentives and preservation orders

"Hedges are extremely important for wildlife and should therefore be encouraged and protected"

"Hawthorn hedges, with a good wild flower under-story are the best!"

"Species diversity of hedging plants, should be considered as this increases the value to wildlife."

Value to ourselves

Not only are hedges perceived as important to wildlife but they are also seen to be beneficial to our health and wellbeing, offering many ecosystem services such as pollution mitigation and aesthetic appeal.

"However they have a bigger role to play in asthetics [sic], air pollution and sound screening in urban area."

"Variety of hedging plants not only adds to attractiveness and habitat but also adds varied interest throughout the year."

"…hedges would really brighten the place up."

Maintenance

They understood that over management or ill-timed management was detrimental to wildlife value

"Correct management by land owners etc is the key to the survival of hedges and their many inhabitants"

"Hedges should only be trimmed outside the breeding season. Grass verges should be planted with wild flowers and not trimmed during the flowering / breeding season - where they don't cause any danger to traffic etc."

"Neatness and tidiness should not be the main consideration (in many respects, the wilder the better)."

Education

There is concern that a lack of education could be detrimental to urban hedgerows and that many people do not realise their importance.

"too many gardeners(professional and owners), do not realise when they should be cutting their hedges"

"Children need to be educated so that they understand how important hedges are to local wildlife."

Negatives

Two participants noted that hedges appear to be more difficult to maintain and one participant suggested that they may make an area dark. Concerns however, were very infrequently mentioned (all quotes containing negatives are included below).

Now they are a bit of a pain in the neck to maintain."
"…sometimes make pavements very dark depending on where the light is."
"I feel that maintenance is an issue sometimes."

6.4.5 Where did participants hear about the survey?

Of the 82 participants who took the survey, 80 provided information on where they heard about the survey (Figure 6-15).

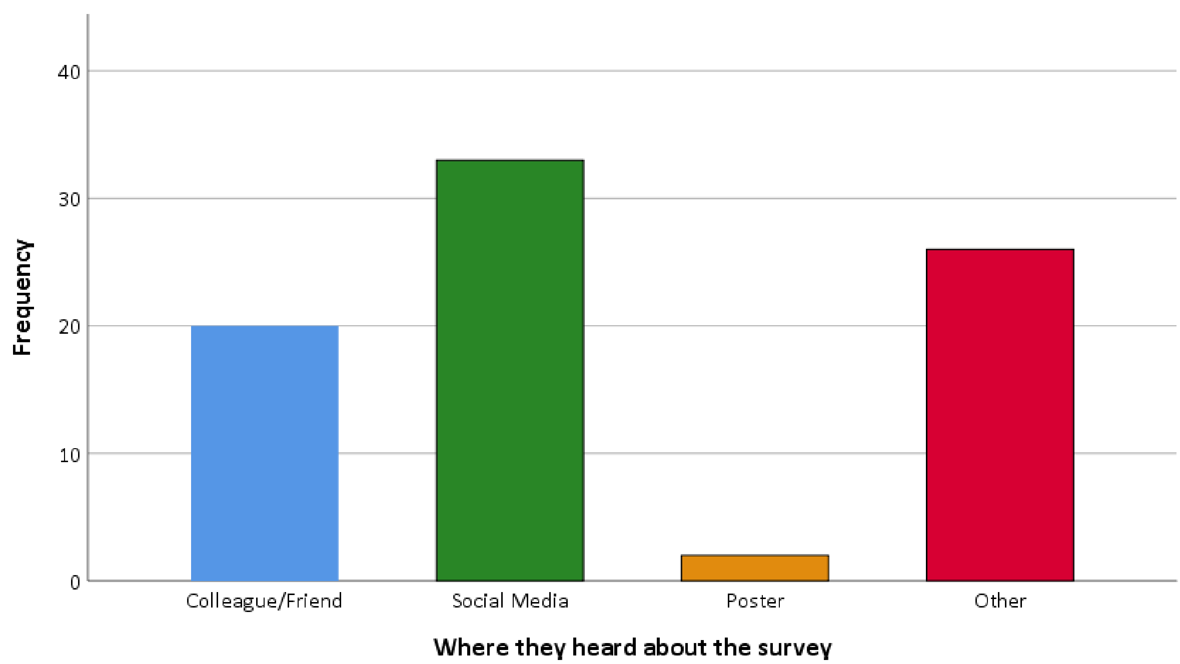

Figure 6-15 Participants were asked where they heard about the survey. Of the 4 selectable options Social media scored highest with 33 participants hearing via this method.

Only 2 of the participants heard about the study from looking at posters, 20 heard through word of mouth (colleague or friend) and 33 from social media. There were 26 participants who heard via other methods. Of these other methods there were 10 who heard from an environmental organisation (BTO or Wildlife Trusts) newsletter or webpage. 8 from Staffordshire University's webpage or newsletter, 2 who responded after hearing the radio broadcast and 5 who were directly emailed. Those directly emailed included those employed by Stoke-on-Trent City council and hedge management was part of their role however the anonymity does not permit us to identify if these undertook the survey.

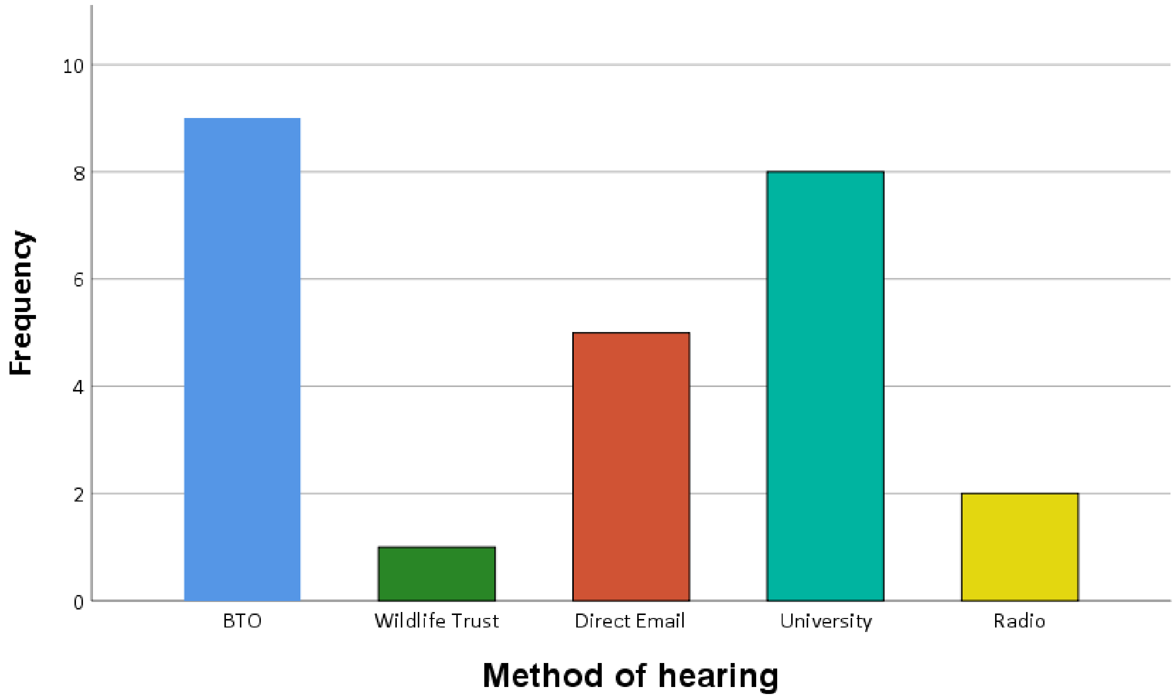

Figure 6-16. For 26 participants who selected 'other' the specified methods which they gave were analysed. Nine participants heard via the BTO, 8 heard via Staffordshire University either by a newsletter or the university webpage.

The participants who heard about the survey via one of the environmental groups are likely to have a higher level of environmental understanding and so may some who heard through the university but the subject specialism of the participant is unknown. The level of environmental knowledge of the participants who heard via social media or the radio remains unknown.

6.5 *Discussion*

A questionnaire was completed by 83 self-selecting participants from the areas in and around Stoke-on-Trent, England. The results indicate that the positive aspects of hedges were seen by participants as significantly more important than negative aspects and as such, would be a valued element of their environment. This would suggest that people would rather hedges were present than not, and that they would prefer to see hedges than other boundary types, as the benefits of hedges outweigh the negatives. There is little published material with which to compare these findings. The following sections will seek to answer the research questions by discussing the results relevant to that area of study.

6.5.1 Is there any preference for a particular type of boundary in an urban environment?

Images that contained hedges were preferred to those of other boundary types by participants who scored them significantly higher in terms of attractiveness, importance for wildlife and feel-good factor. Hedges scored significantly more highly for wildlife and wellbeing value than other boundaries i.e. walls, railings and fences. This may be associated with the mounting evidence of benefits offered by green spaces within towns and cities through sensory contact, aesthetic appeal and opportunities for proximity with nature (Todorova, Asakawa and Aikoh, 2004; Matsuoka and Kaplan, 2008; Brown and Grant, 2016; Snep *et al.*, 2016). These findings agree with those of Oreszczyn & Lane (2001) where participants in their study deemed hedges to be important contributor to the aesthetics of their local environment.

The significantly higher feel-good factor scores of the images containing hedges may come from the views of nature offering reduced stress (Jorgensen, Hitchmough and Calvert, 2002; Matsuoka and Kaplan, 2008), and induction of positive states of mind (Hull, 1992; Jorgensen, Hitchmough and Calvert, 2002). If this can be seen even through photographs of hedges then can it be assumed that if people can see hedges from their car, home, or office windows or along the routes that people walk then this would help to improve wellbeing of those living, walking, and/or working in our towns and cities, as suggested by Brown and Grant (2016). These are the most likely ways that people in urban areas are likely to experience nature (Kaplan, 2001; Kaplan and Austin, 2004; Brown and Grant, 2016; Cox, Hudson *et al.*, 2017; Cox, Shanahan *et al.*, 2017). With this in mind I would recommend that we improve, or at least maintain, the hedgerow resource on streets and residential areas where people spend most of their time, not just for the improved mood and well-being of people, but also for the potential to increase productivity (Hull, 1992).

Images of dense, wide hedges with other green elements scored more highly in terms of attractiveness, importance for wildlife and feel-good factor, and for wildlife and wellbeing. The management of the hedges in the highest scoring images was regular (probably annually, possibly less frequent) but not too frequent or severe. The image containing the much wilder hedge (a line of trees) in this study image 22 (Figure 6-1) scored slightly less well but those which were cut very closely scored even lower. This sentiment was echoed in the open question where over-management was seen as bad by many participants. This small-scale study indicates that less severely managed hedges would be preferred and be more beneficial to wildlife. However, these differences in the photograph scores were not significant and where there was a hedge it did not score significantly less than any other hedge for aesthetics, importance for wildlife and feel-good factor. The only hedge that did score significantly less than the highest scoring examples was in Image 21 (Figure 6-1). This image contained a highly manicured/topiarised hedge which scored significantly lower than the top four images in the wildlife and wellbeing category. It was considered that this hedge could be disliked due to the maintenance style not being to everyone's taste and that this may be affecting the results, so the significance test was conducted again with this image removed. Image 25 (Figure 6-1) scored significantly lower than the four top scoring hedge. This showed a dense, regularly managed beech hedge adjacent to a block paved driveway with no other green elements visible in the picture; the hedge terminated against a house. It appears less severely managed than the hedge in images 17 and 12 so the lack of other green elements may be why this imaged received a low score.

It was expected that hedges would be perceived as harder to maintain than walls, railings or fences, and although maintenance was a theme identified in the participants' answers in the open question this was mainly discussion of the 'poor' management of urban hedges in terms of wildlife value. As there was a significant difference shown between the ease of maintenance between privet hedges and other boundary types, when the results are analysed in categories, then it may be that hedges are still perceived to be difficult to maintain. There is, however, little difference between all other categories of hedges, and the highest scoring images for ease of maintenance were two of railings and one of a concrete fence (although these did not score significantly higher). The images scoring lowest (not significantly) for ease of maintenance included a fence and two privet hedges. The fence was a picket fence with a climber growing along it (image 27 Figure 6-1) and of the two privet hedges one of which was topiarised (image 21 Figure 6-1) and the other severely maintained and recently cut (image 17).

The results suggest that people like urban hedges to be not too overmanaged but not too wild. This aligns with research such as Asakawa, Yoshida, & Yabe (2004) which suggests that people like to see a ‘refined’ or ‘controlled’ version of nature. These results agree with the findings of Oreszczyn & Lane 's (2001) study which suggested that, in general, people in urban environments considered that the hedges of towns and cities should be well manicured but there was a preference for hedges that were allowed to produce flowers and not to be too manicured. When asked about the preference for the appearance of rural hedgerows members of the public preferred hedges to look bushy with a ‘wilder’ appearance (Oreszczyn and Lane, 2000), this appears to be reflected, to at least some degree, in the appreciation of urban hedges.

6.5.2 *Do members of the public perceive wildlife, aesthetics or ease of maintenance to be more important attributes of a boundary?*

A surprisingly high proportion of respondents thought that the hedge's contribution as a habitat for animals was the most important factor to consider and the vast majority perceive that contribution to wildlife is equally or more important to attractiveness and ease of maintenance and very few considered ease of maintenance or aesthetics were most important. This is contradictory to what was found by Burel & Baudry (1995) where aesthetics was found to be the most important factor. This may be affected by the level of environmental knowledge of participants.

Of the 84 participants who completed the survey one third of them (28, 33.3%) provided further information in the open questions (Q31 Appendix D). Analysis of their answers revealed that of those who completed the question 86% (24 people) mentioned the importance of hedges for wildlife. Only 2 people (7%) were concerned about hedges needing maintenance, one suggesting that they can make it more difficult to walk the dog (this has been assumed to mean encroachment of pavements), and the other that hedges can sometimes increase the darkness in poorly lit areas. Thirty two % of participants mentioned the aesthetic value of urban hedges which is far fewer than mentioned the importance for wildlife (86%). It is likely that those who mentioned the wildlife and how hedges should be managed to increase their value to wildlife were also accepting of the wilder appearance otherwise they would not recommend the creation of more wildlife friendly hedges. Seven participants (25%) mentioned both value for wildlife and aesthetics could be achieved together. None of the statements that suggested ways to increase biodiversity were inaccurate such as planting wildflowers in vegetated strips on either side and reducing cutting frequency. Methods people indicated to increase attractiveness such as creating a wilder appearance, facilitating fruiting and flowering, and incorporating a diverse mix of species would also be of benefit to wildlife. This indicates that the types of hedges that people find more attractive are those which are also more beneficial to wildlife.

As found by Southon *et al.* (2017) and Jiang and Yuan (2017), people who understand the benefits wildflowers and correct species selection can have on wildlife are more accepting of the wilder appearance of green elements. This may suggest that in this study those who understood the importance of hedges may have been more inclined to complete the open question. The demonstration of the understanding that wilder hedgerows with flowers are better for wildlife and that management needs to be sensitive to the wildlife breeding times suggests that most participants who completed the extended question possessed a relatively high level of understanding. As the level of environmental understanding was not investigated of the participants of this study it can only be assumed from their answers. The self-selecting nature of this survey may have facilitated those with an interest in hedgerows to be more highly represented in the sample than would be expected from the population as a whole.

The more knowledge people have the more likely they are to find elements of biodiversity attractive (Qiu, Lindberg and Nielsen, 2013; Hoyle, Hitchmough and Jorgensen, 2017; Southon *et al.*, 2017). A lack of understanding of the benefits of conservation design elements leads to a resistance from residents for their incorporation, whereas if they are more aware then they are more embracing of their integration (Bowman, Thompson and Tyndall, 2012; Derkzen, van Teeffelen and Verburg, 2017; Jiang and Yuan, 2017). As the long answers from the 33.3 % of our participants who completed this question suggest a higher level of understanding, then they may be more accepting of the wilder appearance of the hedgerows than would the population at large. This is suggestive of the potential of environmental education (Qiu, Lindberg and Nielsen, 2013) and educating residents may be integral to the success of more wildlife friendly green infrastructure schemes. However, of all of the participants there was a clear preference for images containing hedge than for images with other boundaries.

Previous questions to the open question may have primed participants to discuss the aforementioned ideas of aesthetics, positives and negatives and value for wildlife. There was however, only 32% of the people who completed the question used terms or phrases that could be categorised into talking about aesthetics and 86% who used terms relating to the value of hedges to wildlife. Only 2 people mentioned anything negative about hedges.

6.5.3 Do people perceive correctly which type of a hedgerow offers better provision for wildlife?

At a very basic level there is evidence of understanding as participants were able to identify that the presence of a hedge as opposed to other types of boundary was better for wildlife when scoring the photographs as images containing a hedge scored significantly higher than those without. The images that scored more highly in this category were dense, broad hedges with adjacent green elements of green infrastructure such as trees or a tall buffer strip. There is currently little scientific evidence as to which hedges within urban areas offer more to wildlife, so assumptions on the wildlife potential are based on rural hedges. In rural areas, the density, breadth, and quality and quantity of adjacent vegetation are considered as factors that influence the hedge in terms of value for wildlife (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017). The lowest scoring image that contained a hedge was image 25 (Figure 6-1). This was again a dense, fairly wide hedge but adjacent to a hard surface and terminating at the side of a house. The lack of connectivity to other green elements would likely be detrimental to its wildlife value (Pollard and Relton, 1970; Hinsley and Bellamy, 2000; Hinsley *et al.*, 2002; Faiers and Bailey, 2005; Batáry, Matthiesen and Tscharntke, 2010). The next lowest scoring images containing hedges were images 12 and 21 (Figure 6-1). These hedges were tightly cut hedges, possibly perceived as over-managed.

Consideration needs to be made as to the practicalities of these management methods. The right management needs to be undertaken in the right places. Wildlife friendly management may be more suitable in some areas, e.g. areas surrounding football pitches or parks, than hedges in other areas. Hedges bounding busy thoroughfares may lack sufficient surrounding space to allow for larger, wilder hedges and still permit the required space for access. One side of a hedge may be managed in a more wildlife friendly manner than the other where available space is not sufficient on one side.

It could be recommended that, where possible (locations where the functionality of the area is not negatively impacted), management practices to encourage wildlife such as reduced trimming frequency should be considered. These practices not only benefit wildlife (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB, 2017); and as a consequence improve mental wellbeing of the people who can experience them (Barr and Gillespie, 2000; Jackson, 2003; Miller, 2005; Dallimer *et al.*, 2012; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017; Jennings *et al.*, 2017), but are perceived to be more attractive. Naturalistic vegetation is also cheaper to maintain than more manicured vegetation (Jorgensen, Hitchmough and Calvert, 2002). In new urban designs hedges should be incorporated as an element of a green infrastructure scheme that provides space to allow the hedge to be dense, grow out for three years to facilitate flowering (PTES, 1993; Dover and Sparks, 2000; Anderson, 2002; Amy *et al.*, 2015; Staley *et al.*, 2016; Hedgelink, 2017; RSPB,

2017) and afford space for an adjacent, less intensively managed, strip of land (Dover and Sparks, 2000; Barr *et al.*, 2010; Staley *et al.*, 2016). Plans should seek to provide connections of these hedged elements to other green spaces within the city (Burel and Baudry, 1995).

6.6 *Conclusion*

This small-scale study suggests that the people of Stoke-on-Trent and surrounding areas prefer hedges to other types of boundary in terms of aesthetics and how they make them feel. They also consider the value offered to wildlife as important. They would prefer to have more 'natural looking' hedges that offer benefit to biodiversity in their area. They appear to correctly identify that hedges offer more value to wildlife and describe their preferred hedges to be those that would have more potential for wildlife habitat. Hedges may be perceived to require more effort in terms of maintenance than other types of boundary. This was however, perceived to be less important than aesthetics or wildlife value by the vast majority of the participants (98%). However, caution is required as this is a self-selecting questionnaire and therefore may be biased towards those who consider hedges to be important enough to participate in a survey. The number of responses is also fairly small. Further study would include a targeted approach selecting participants form pre-selected demographics to encompass a wide range of opinions.

The greatest benefits to health and wellbeing come from short (5 min) exposures to nature whilst undertaking low impact exercise and there is great benefit to peoples' productivity from viewing nature through their windows. Suggesting it would make sound planning sense to incorporate hedges, and hedgerows where possible, into the areas around where people live and work and especially on routes where people walk to schools, colleges or places of employment. Hedgerows are popular with members of the public and offer great benefit to wildlife without taking up much valuable horizontal space.

7 Discussion

7.1 *Introduction*

Urban hedges are an understudied, yet commonly occurring, element of the urban green infrastructure of the UK and at the start of this study only two significant papers which made reference to urban hedges had been published. One of these discussed people's perceptions of hedges and the other on the condition and management of canalside hedges. The first of these studies was by Oreszczyn and Lane, (2001) and investigated people's views on hedges in both rural and urban locations and in both English and Canadian study areas. Urban hedges were considered to be important by participants for the functions they provide, even more so than in rural locations. Diversity of urban hedges was seen to be important, particularly if hedges contained flowers. The second study was by Faiers and Bailey (2005) who aimed to produce a method of valuing canalside hedgerows in terms of biodiversity and habitat quality. They studied hedgerows along a canal stretching from rural to urban areas and found urban hedges to be less structurally sound and less biodiverse than those in rural locations. In contrast to the well-studied rural hedges of the UK (e.g. Boughey *et al.*, 2011; Dainese *et al.*, 2015; Staley *et al.*, 2016; Lecq *et al.*, 2017) there is little research on the importance of urban hedges to birds, mammals and invertebrates and this highlights a clear research gap as urban hedges are in a much altered environment to that of rural locations (Rees, 1997; Marzluff, 2001; McIntyre *et al.*, 2001; Evans, Newson and Gaston, 2009; Ahern, 2011; Arroyo-Solís *et al.*, 2013) and this, alongside management practices applied to urban hedges may mean that their biodiversity value maybe somewhat different. The ecological surveying in chapters 3, 4 and 5 has provided some evidence to bridge some of these knowledge gaps. The 30 m in length requirement did prevent the inclusion of many domestic hedges and a study encompassing these would be a recommendation for further study as these hedges would make up a high proportion of the urban hedgerow resource. To achieve this different surveying strategies would need to be employed.

The urban context is important to any management recommendations as these hedges are positioned side-by-side with people and hedges provide aspects of the landscape in which people travel, work, rest and play. Management therefore, has to fit with the demands of the urban population rather than the traditional requirement of farmers and rural land managers. How urban dwellers value and perceive hedgerows is important to their continued presence in our cities. This aspect was investigated in chapter 6, together with a comparison of respondent's views of how urban hedges should look and be managed with current recommendations for management of hedge biodiversity derived from rural studies.

In urban environments there is often conflict over how space is utilised and there is not necessarily a common vision of what is preferred by humans, what is preferred by other species (Hull, 1992; Parsons, 1995; Jorgensen, Hitchmough and Calvert, 2002; Fuller *et al.*, 2007; Qiu, Lindberg and Nielsen, 2013), and what is achievable in spaced-starved urban areas. With people in urban locations showing a high level of appreciation of urban hedges and dislike of poor management (Oreszczyn and Lane, 2001) and research suggesting that urban hedges are less well managed (Faiers and Bailey, 2005) than those of rural locations, there is a problem which needs to be addressed. There is a clear need to identify areas of common ground between biodiversity, space, and the perceptions of the urban human population.

The aim of this final discussion chapter is therefore fivefold:

1. To collate the key findings from the bird, mammal and invertebrate surveying undertaken in SoT and NuL.
2. To summarise the impact of hedge characteristics (determined by management) and surrounding landuse on species abundance and diversity.
3. To identify commonalities between species groups as a means to inform better management
4. To link these findings to peoples' preferences in the appearance of hedges.
5. To distil these findings into a set of clear management guidance for city authorities to maximise both the ecological and social benefit of hedges.

7.2 *Urban hedges and biodiversity*

Sixteen species of bird were found to use urban hedges and 66% of the study hedges were used by small mammals. Birds and evidence of small mammals were found in significantly greater numbers in hedges than in areas without a hedge indicating that hedges do increase their abundance and as such offer benefit to these groups of species. A total of 734 invertebrates of 14 major groups and 341 families were found and invertebrates were present in all hedges surveyed. Birds were shown to use hedges for a variety of activities including nesting, feeding, shelter and attracting a mate. Small mammals used hedges as 3-dimensional habitats using the upper levels as frequently as the base suggesting that they are gaining some benefit from being in the canopy. This is likely to be due to the provision of insect food, protection from predators or competition for resources (Baker, Bentley and Ansell, 2005; Buesching *et al.*, 2008; Scott *et al.*, 2014). The large numbers of invertebrates found in hedges suggests that hedges provide a supply of invertebrate food for birds and mammals.

7.3 *Impact of hedge species*

More birds were found to be using hawthorn hedges than beech or privet hedges but more nests were found in privet hedges than in beech hedges. Significantly more mice/voles and shrews were found in both privet hedges and hawthorn hedges than within beech hedges. There was no significant different in the abundance or richness of families of invertebrates with hedge species. Hawthorn hedges may offer more in terms of flowers and berries if management permits (PTES, 1993; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Croxton and Sparks, 2002; Staley *et al.*, 2012, 2016; Amy *et al.*, 2015; Hedgelink, 2017; RSPB, 2017), hawthorn is usually associated with more insect species than beech (Southwood, 1961) and birds tend to prefer areas with more native species (Chace and Walsh, 2006). It may be this provision of food that make hawthorn more attractive to birds and mammals than beech or privet. However, management to permit this was not commonly the case in the study hedges as most were frequently trimmed and this may go some way to explain why there was no difference in the richness or abundance of insects with hedge species. Also, surveys were not undertaken at times of year when fruiting or flowering would be expected. As the DAPC analysis eliminated the idea that the hedge physical properties such as height and length as well as the characteristics of the surrounding land cover may have differed with the hedge species, then this difference is still not clearly explained.

Privet hedges may offer a denser internal structure (Oreszczyn and Lane, 2001; RHS, 2018) than beech and hawthorn hedges which may make them more attractive for nesting due to greater difficulty in nest detection by predators (Hinsley and Bellamy, 2019). Observations during the studies highlighted that the internal structure of hawthorn hedges is more complex than beech. The evergreen nature of privet, and the presence of last year's leaves on beech may offer cover during early spring when nest site selection is taking place. Blackbirds have been noted by the Woodland Trust to be nesting as early as January and hawthorn does not usually come into leaf until the second week in March (Hawksford, Hopkins and Cadman, 2011). New planting schemes may look to increase the use of hawthorn hedges thus increasing the likelihood of providing suitable habitat for mammals but there is no evidence to suggest that removing existing beech or privet hedges to replace them with hawthorn hedges would be beneficial and their thorny and deciduous nature makes them less desirable for use in urban areas (Oreszczyn and Lane, 2001). Hawthorn hedges may be older than the beech hedges found within the city, this may also have an impact on their wildlife value and warrants further study. Urban hawthorn hedges may be remnants of rural landscapes encapsulated by urban expansion (Hoskins, 1955; Rackham, 1976, 1986, 1990; Gosling *et al.*, 2016; Graham *et al.*, 2018), and as such may contain relict dependent communities which they continue to support.

7.4 *Impacts of hedge characteristics*

The abundance of birds, mammals and invertebrates and the richness of birds and invertebrates were compared against physical hedge properties and characteristics of the adjacent and surrounding landscape to identify whether any of these factors showed important relationships. Hedge volume was highly significantly related to bird, mice/vole and shrew, and total invertebrate abundance and bird richness of the hedges and the immediately surrounding areas. This concurs with the findings of many studies of rural hedges for mammals (Kotzageorgis and Mason, 1997; Croxton and Sparks, 2002; Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Bates and Harris, 2009) and for birds (Hinsley and Bellamy, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018) and for invertebrates (Kremen, Albrecht and Ponisio, 2019; Stoate, 2019). A large hedge volume is often associated with a lower cutting frequency which is also well documented as beneficial for small mammal populations (Croxton and Sparks, 2002; Bates and Harris, 2009; Staley *et al.*, 2016). Both this research and research on rural hedges agree that the longer the hedge the more likely that the hedge will contain more invertebrates and a greater species richness (Batáry, Matthiesen and Tscharntke, 2010). Longer hedges may present a larger collection point for aeroplankton (Frouz and Paoletti, 2000) where the hedges act as drift fences (Fried, Levey and Hogsette, 2005), especially if they are the only tall vegetation element in a given area. Larger, longer hedges could be considered as larger habitat area or patch size (Batáry, Matthiesen and Tscharntke, 2010; Graham *et al.*, 2018) so potentially a species area relationship (Jones, 1992), which in urban areas, is influential on both birds (Evans, Newson and Gaston, 2009; Beninde, Veith and Hochkirch, 2015; Concepción *et al.*, 2016; Snep *et al.*, 2016), mammals (Croxton and Sparks, 2002; Bates and Harris, 2009) and invertebrates (Bolger, Scott and Rottenberry, 2001; Breuste, Niemelä and Snep, 2008; Jones and Leather, 2012). As hedges are unlikely to be uniform along the entire length of the hedge (Burel and Baudry, 1995; Graham *et al.*, 2018), longer hedges are likely to offer increased habitat heterogeneity. Wider hedges have a larger area in which to provide shelter at ground level, thus increasing opportunity for foraging and shelter (from predators and weather) (Croxton and Sparks, 2002; Bates and Harris, 2009).

7.5 *Impacts of adjacent vegetation and surrounding landuse*

The hedge physical properties, adjacent vegetation and surrounding landuse were investigated and the results are summarised in (Table 7-1).

Table 7-1 Summary table of results of the impacts of the hedge physical properties, adjacent vegetation, and surrounding landuse on the richness and abundance of the species groups studied. + indicates a significant positive association identified in the GLM(M), - indicates a significant positive association identified in the GLM(M), and i indicates that this variable was identified as one of the most important in explaining the variation of abundance or richness from the Random Forest analysis.

	Bird Abundance in the area	Bird Richness in the area	Bird Abundance in the Hedge	Bird Richness in the Hedge	Mammal Abundance Hair	Mammal Abundance	Total abundance of	Total richness of invertebrates
DBH of trees		**i**	**-**		**-**		**i**	**i**
Hedge volume	**+**	**i**	**+**		**-**			
Percentage of vegetation in front of hedge (5 m)	**i**		**i**	**i**			**- i**	
Total length of hedge							**+**	**+**
Inverse proximity to road	**+ i**			**i**			**+**	**+**
% impervious within 50 m buffer	**+ i**					**i**	**-**	**-**
% vegetation behind the hedge within 5 m	**+**		**+**					
Vegetation height behind hedge								
Adjacent vegetation								
% Canopy Cover								
% Rough Grass within 50 m				**i**	**i**	**i**	**i**	**i**
% Smooth Grass within 50 m								
Hedge Height								
Vegetation height in front of hedge		**i**						
% woody habitats within 250 m			**i**				**i**	**i**
% Impervious surfaces within 250 m	**i**							
% Woody Vegetation within 50 m	**i**		**i**		**i**			

7.5.1 Proximity to road

The further a hedge is from the adjacent road then the more birds and invertebrates are likely to be found. Obviously, moving existing hedges further from a road to make it more attractive to birds is not possible, but locating new hedges as far from roadsides as possible may mitigate some of the negative impacts a road may have (See chapter 1 section 1.2).

7.5.2 Adjacent vegetation and tree DBH

Hedges with more vegetation in front and behind contained a greater abundance of birds and if such vegetation adjacent to hedges can be improved in terms of heterogeneity, floral diversity and extent, then this should be considered in both existing hedges and in new planting schemes. The DBH of trees behind, which may also represent the decreased average tree distance from the hedge, was indicated to have a negative influence on the number of birds seen to be using the hedges and the evidence of small mammals. This is unlikely to be the case and it is probably more likely that the birds were not seen by the observer as they did not fly out towards the hazards of the road but flew into the protection and other benefits of the trees behind the hedge, or, were preferentially using the area behind due to the protection afforded them by the hedge structure; particularly as none of the hedges had trees or a dense ground flora in front. This issue may have been rectified, in part, by including bird calls when surveying birds in the area. There is an increase in bird richness using the area with height of vegetation behind the hedge and there is a very slight positive relationship between bird richness using the hedges and the area in front, as woody vegetation increases. If we consider the area as a whole, including the vegetation behind the hedges, then it may be that bird richness and abundance increases but with preferential foraging in the areas behind much more than the areas in front of the hedge, this aspect requires further research.

Using both Random Forest and GLMM analysis, vegetation on either side of the hedge was indicated to be important for total invertebrates and bird richness and abundance. However, the percentage of vegetation in front of the hedge was negatively associated with total invertebrate abundance and with abundance of Araneae and Hymenoptera. As Hymenoptera was the most abundant group this may have exerted an influence on the total invertebrates and these negative associations are difficult to explain. The proportion of vegetation behind the hedge was shown to be significantly positively associated with Hymenoptera abundance using the GLMM and it may be that this was more important in explaining the presence of invertebrates than the proportion of vegetation in front of the hedge. The hedgerow selection methodology identified hedges with vegetation behind, this was however not the case in front of most hedges, hence vegetation behind the hedge seems to assume greater importance in the urban context. It has previously been found that the presence of vegetation on both sides of a hedge is not necessarily more beneficial to biodiversity than vegetation on just one side (Gosling *et al.*, 2016). This suggests that sufficient forage and shelter can be found from reasonable adjacent vegetation on one side to compensate for a lack of vegetation on the other. Results from this study however suggest that richness of birds using the hedge was significantly higher when vegetation was present on both sides of the hedge compared to just one. These findings however, do not explain the significant negative association, as if it was not important then a non-significant impact would be expected. Higher quality abundant vegetation on the side of the hedge away from the road may be more influential in explaining this relationship as the hedges with a high abundance of invertebrates have little vegetation in front but trees or taller vegetation behind.

A large proportion of vegetation in front of the hedges was found to be important for bird abundance in the Random Forest analysis but this type of modelling does not indicate whether the relationship is positive or negative. Examination of the data suggests the relationship is positive as two-thirds of the hedges with an abundance above ten birds had over 60% of the area in front of the hedge with vegetation and all have over 30%. The percentage of vegetation behind the hedge was also positively related to bird and Hymenoptera abundance, with the hedges with the highest abundance of birds having 100% vegetation cover behind the hedges. However, there were, surprisingly, no significant relationships identified for height of the vegetation behind the hedge. This may be a consequence of management practices in urban environments whereby there is little variation in the height of vegetation: the vast majority of the vegetation adjacent to hedges, even very close to the hedge, is regularly mown (amenity) grassland. Due to the lack of variation in the height of vegetation both in front and behind the study hedges there is clearly a need for further study into the impact of vegetation management and to the role of diversity of plantings and structures. This will require the use of in-situ field studies where a minimally managed vegetated strip is added adjacent to some hedges or hedge sections. It is, however, likely that similar impacts of adjacent vegetation in rural environments is applicable to urban hedges where dense stirps with diverse plantings and structures have been found to be beneficial for birds (Barr and Gillespie, 2000; Dover and

Sparks, 2000; Hinsley and Bellamy, 2000; Whittingham and Evans, 2004; Staley *et al.*, 2016; Graham *et al.*, 2018), invertebrates (Maudsley *et al.*, 2000; Cole *et al.*, 2017; Garratt *et al.*, 2017; Goodwin, Keep and Leather, 2017) and mammals (Pollard and Relton, 1970; Todd, Tew and Macdonald, 2000).

7.5.3 Surrounding landuse

Generally increasing urbanisation has negative effects on birds (Lancaster and Rees, 1979; Marzluff, 2001; Chace and Walsh, 2006; Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013; Lepczyk *et al.*, 2017), mammals (Baker and Harris, 2007; McCleery, 2010) and invertebrates (Helden and Leather, 2004). Taking the percentage of impervious surfaces as a proxy for level of urbanisation, my results did not identify the negative impact of urbanisation in birds but it did in mammals (at the 10% level) and highly significant for invertebrates, implying the positive impact of green space.

Reasons for this in the bird data may be that bird diversity is often found to be lowest in city areas and highest in moderate levels of development (Evans, Newson and Gaston, 2009; Beninde, Veith and Hochkirch, 2015) and with Stoke-on-Trent, being a very green city, even the most urban areas may be more representative of moderate levels of development due to its unusual pattern of settlement resulting from it being formed by the amalgamation of 6 towns (Jayne, 2004) and the less 'city like' (Ball and Studies, 2007) layout of the area. This however does not explain the findings indicating that the proportion of impervious surfaces being positively associated with bird abundance (table 2-3). It may follow with the findings or Marzluff, (2001); Sandström, Angelstam and Mikusiński, (2006) and Evans, Newson and Gaston, (2009) who found an increase in bird abundance in more urban areas and of Lancaster and Rees, (1979) who suggest that bird density for some species might be higher in urban areas.

The loss of species as urbanisation increases is generally linked to decreased habitat availability (quantity of greenspaces of good quality such as woody or rough grassland), reduced patch size, increased edge, an increase in non-native vegetation, reduced habitat heterogeneity (Marzluff, 2001; Evans, Newson and Gaston, 2009; Arroyo-Solís *et al.*, 2013) and isolation, (Dickman and Doncaster, 1987). A lack of green spaces in the surrounding landscape impacts on invertebrate abundance (Angold *et al.*, 2006; Jones and Leather, 2012). Isolated urban semi-natural habitat patches are associated with reduced invertebrate richness and diversity (Breuste, Niemelä and Snep, 2008).

Woody vegetation in the areas surrounding the hedges was identified as being important to abundance and richness (where measured) in all surveyed species groups. This was unsurprising as birds respond positively to increases in woody vegetation and woody species diversity (Lancaster and Rees, 1979; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009) and invertebrate richness and abundance is linked to native tree species richness and abundance (Angold *et al.*, 2006; Helden, Stamp and Leather, 2012; Goodwin, Keep and Leather, 2017). Having smaller distances between patches reduces the time and energy expenditure in birds and thus increases breeding success, also, the use of woody habitats for cover when moving between patches reduces the predator risk (Hinsley *et al.*, 2002). The house sparrow, however, may be deterred by increased woody vegetation at the expense of grassy vegetation (Churcher and Lawton, 1987; Summers-smith, 2003; Laet and Summers-Smith, 2007; Węgrzynowicz, 2013) and rough grassland was also important to bird abundance and richness, Psocoptera richness and abundance and Diptera abundance.

Generally, there is an increase in abundance of birds using a hedge when there are more associated taller trees (Newton, 2017); however, the results from the GLMM analysis within this study suggest that increased DBH of associated trees is negatively correlated with bird abundance using the hedge and the Random Forest identifies it as one of the most important variables for bird richness (albeit with a low importance score). There is not necessarily a direct relationship between DBH and tree height but the DBH is considered a proxy for the age of trees and for the presence of trees (as if no trees were present then the value would be 0). This negative association when trees are present behind the hedge is difficult to explain as many rural studies conclude that hedgerow trees are beneficial for many species (Baldock *et al.*, 2015; Newton, 2017; Hinsley and Bellamy, 2019) including birds (Newton, 2017), mammals (Todd, Tew and Macdonald, 2000), and invertebrates (Merckx *et al.*, 2009). Trees are also associated with increased numbers of birds in urban areas and have been suggested to be the most important factor in increasing bird richness in urban areas (Lancaster and Rees, 1979; Sandström, Angelstam and Mikusiński, 2006; Evans, Newson and Gaston, 2009). The explanation may simply be that birds are preferentially using the trees behind the hedge (further from the road and pavement) and therefore not being visible to the observer. This warrants further study with birds being observed from both sides of the hedge and in the associated trees and habitats behind the hedge simultaneously. Interestingly, however DBH was also negatively related using the GLMM to and mice/vole and shrew abundance when using the baited hair tube method, is more difficult to explain especially as two of the top three hedges that had a high score for DBH had evidence of small mammals from both methods. It may be that this is simply down to chance However, there were also a number of the hedges that did not have trees also showed evidence of small mammals. It may be that many other factors aside from trees varied between the hedges which more strongly influenced the variation in small mammals. Those indicated by the Random Forest analysis were the percentage of woody vegetation and rough grassland in the surrounding 50 m.

Rough grassland provides denser and taller vegetation which is important for small mammals species for forage and for cover (Todd, Tew and Macdonald, 2000). Bank voles require a denser vegetation to move from the hedge (Pollard and Relton, 1970), if this is not available in the areas surrounding the hedge then species including voles and other small mammals (Brown and Twigg, 1970) would be unlikely to find sufficient opportunity for forage. A sufficiently large area of rough grassland providing a denser more varied ground layer with a diverse flora is important for shrews (Bates and Harris, 2009). Rough grassland is also important for invertebrates as longer grass increases food resources and increases protection (Whittingham and Evans, 2004).

In summary, hedges that are the most likely to have a larger bird, invertebrate and mammal abundance are wide tall hedges with good quality adjacent vegetation and a high proportion of woody vegetation in the surrounding landscape. The proportion of impervious surfaces within the local area provided conflicting results as do the DBH data.

7.6 *Linking findings on people's preferences of hedges to biodiversity*

Hedges were perceived by the participants of this study to be beneficial in urban environments. They were seen to be more attractive, better for wildlife and have a greater 'feel-good' factor than other boundaries such as walls, railings and fences. The work by Oreszczyn and Lane (2001) found that people considered urban hedges to improve the aesthetics of their local environment. However, there is little else published on how people perceive urban hedges although there is a growing body of literature on how people perceive urban green spaces. Of the images which scored most highly for attractiveness 4 out of 5 were hawthorn and images of hawthorn hedges scored significantly higher than privet hedges but not significantly higher than images containing 'other' hedges. The lower scores for privet hedges could be due to the lack of heterogeneity of managed privet hedges which form a more uniform looking hedge, particularly in the images included. Five out of the top 6 scoring hedges rated by the participants as being more important for animals were hawthorn. Hawthorn hedges appear less uniform in their structure and this heterogeneity is beneficial to animals (Whittingham and Evans, 2004; Bates and Harris, 2009) and heterogeneity of colours, scents and patterns will also increase the aesthetic appeal of the hedge (Oreszczyn and Lane, 1999; Gosling *et al.*, 2016). As the majority of the images which were deemed more attractive were of the same hedges as those deemed most important for wildlife it may be that people and wildlife like similar hedges. It may be as suggested by precious studies, that people are more accepting of the wilder-looking habitats if they perceive them to be better for wildlife and people are more accepting of wilder habitats than in previous years (Jiang and Yuan, 2017; Southon *et al.*, 2017).

In this study, images of dense wide hedges adjacent to other green elements were considered more attractive and dense tall (Whittingham and Evans, 2004; Bates and Harris, 2009), high volume (Michel, Burel and Butet, 2006; Gelling, Macdonald and Mathews, 2007; Newton, 2017) hedges are also associated with increased biodiversity value. The adjacent elements shown in the top scoring images were either associated with trees or woody areas or a tall vegetated strip. Most previous research associates an adjacent buffer strip with increased biodiversity provision (Barr and Gillespie, 2000; Dover and Sparks, 2000; Hinsley and Bellamy, 2000; Todd, Tew and Macdonald, 2000; Staley *et al.*, 2016; Graham *et al.*, 2018). Trees or woody vegetation in close proximity are linked to increased biodiversity (Peng, Sutton and Fletcher, 1992; Maudsley, 2000; Todd, Tew and Macdonald, 2000; Merckx *et al.*, 2009; Graham *et al.*, 2015; Garratt *et al.*, 2017; Goodwin, Keep and Leather, 2017; Newton, 2017), yet this was not clearly identified in this study due to a lack of variation of these elements within the study areas. There are some studies which identify that in areas where vegetation in more abundant and of good quality, a hedgerow is less diverse and/or abundant in species due to ecological contrasts (McIntyre, 2000; Batáry, Matthiesen and Tscharntke, 2010; Garratt *et al.*, 2017). If we are considering biodiversity of an area as a whole in a composite patch of hedges and other vegetation then there is much to be gained for urban biodiversity from a heterogeneity of habitats offered by a range of vegetation elements (Racey and Euler, 1982;

Whittingham and Evans, 2004; Helden and Leather, 2004; Angold *et al.*, 2006; Michel, Burel and Butet, 2006; Evans, Newson and Gaston, 2009; Batáry, Matthiesen and Tscharntke, 2010; Jones and Leather, 2012; Andersson *et al.*, 2014; Beninde, Veith and Hochkirch, 2015; Dover, 2015; Cole *et al.*, 2017; Hall *et al.*, 2017; Graham *et al.*, 2018).

Hedges where management permitted some flowering, scored highly for attractiveness and feel good factor; however, an image of a very wild hedge which had become a row of hawthorn trees was just out of the top five scoring hedges being 6th for attractiveness, importance for animals and feel good factor. It is likely that Hawthorn hedges would score even higher if they had been in full flower. Suggesting that people would tolerate a wilder aesthetic but prefer a slightly tidier version of nature, agreeing with research such as Asakawa, Yoshida and Yabe (2004) and Qiu, Lindberg and Nielsen (2013). A balance between over and under management is likely to be preferred (Oreszczyn and Lane, 2001) as the severely cut hedges producing a very narrow, uniform hedge did not score highly and uniform hedges adjacent to sealed surfaces were also less attractive. People, as found by Southon *et al.* (2017), are receptive to naturalistic vegetation preferring areas with higher structural heterogeneity, particularly if the benefits to wildlife were understood (Jiang and Yuan, 2017; Southon *et al.*, 2017).

The inclusion and improvement of roadside hedges is likely to improve the ecosystem services offered including pollution capture (Weerakkody *et al.*, 2017)**,** flood mitigation (Liu, Chen and Peng, 2014) and multiple health benefits (Cox, Shanahan, *et al.*, 2017). The presence of attractive hedges with greater aesthetic appeal on the routes people use to get to work or in views from home or office windows allows for benefits to the mental wellbeing of a large number of people. If improvement in the biodiversity value of an area are made then there is also an increased likelihood for experiences of nature such as hearing birdsong or seeing plants, birds, and butterflies, which increase positive states of mind (McCollin *et al.*, 2000; Kaplan, 2001; Kaplan and Austin, 2004; Todorova, Asakawa and Aikoh, 2004; Breuste, Niemelä and Snep, 2008; Brown and Grant, 2016; Cox, Hudson, *et al.*, 2017).

7.7 *Management recommendations*

Please read the enclosed leaflet.

8 Conclusions

Urban hedges of Stoke-on-Trent and Newcastle-under-Lyme are used by birds, mammals and invertebrates. Woody hedge species impacts on the abundance and richness of birds and abundance of mammals. Birds and mammals were most abundant in hawthorn hedges but there was no significant difference in the abundance or richness of invertebrates with woody hedge species. There was agreement between the hedge characteristics favoured by people with those more abundant in wildlife. Wide, dense hedges with less frequent management and greater heterogeneity were found more aesthetically pleasing and also benefit wildlife. Longer hedges were important for invertebrates and are likely to have an increased habitat area and habitat heterogeneity. Woody vegetation in proximity to the hedges is important to biodiversity but may be preferentially used by birds on the non-road side of the hedge yet is likely to increase biodiversity in the area as a whole.

There is very little variation in the vegetation adjacent to hedges in the urban areas studied as most of the landuse either side of a hedge is either mown verges, mown grasslands, allotments or sealed surfaces. Research from rural hedges indicates that heterogeneously structured, infrequently mown, verges with abundant, diverse wildflowers, on either side of the hedge has a great benefit for biodiversity and this is something that needs to be tested in urban environments. As this does not currently occur in more than a few locations, field trials and with the integration of wildflower rich borders adjacent to urban hedges to measure the variation in biodiversity is recommended. People also appear to be more accepting of the wilder looking more biodiverse habitats as understanding and appreciation of the importance of nature increases. The colours and textures provided by the inclusion of wildflower meadows and verges are seen to be aesthetically pleasing to local residents. However, most urban hedges and any associated verges are frequently intensively managed preventing the formation of flowers and fruits and limiting structural heterogeneity.

9 References

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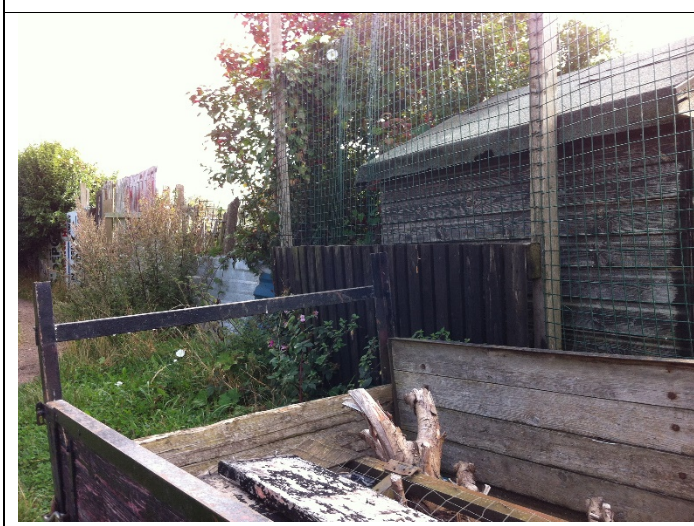
Appendices

Appendix A Exemplary hedges and control locations

Photo	Brief description of hedge
	**Reference Number**: CI **Woody Species:** No Hedge boundary (Stone wall) **Location:** High Street, Brampton **Surrounding landuse side 1:** Narrow pavement and major road **Surrounding landuse side 2:** Mown Grass verge and footpath **Depth:** N/A **Height:** N/A
	**Reference Number:** CD **Woody Species:** No Hedge boundary (mesh and panel fence) **Location:** Leek Rd - Poultry Allotments **Surrounding landuse side 1:** Unmown verge and track/path **Surrounding landuse side 2:** Poultry allotment **Depth:** N/A **Height:** N/A

	**Reference Number:** C0 **Woody Species:** No Hedge boundary (mesh and panel fence) **Location:** Leek Rd Jumbo Storage unit's fence **Surrounding landuse side 1:** Wide area of mown (but fairly long -10cm) grassland **Surrounding landuse side 2:** Carpark & warehouse **Depth:** N/A **Height:** N/A
	**Reference Number:** CJ **Woody Species:** No Hedge **Location:** A53 Leek Rd **Surrounding landuse side 1:** Busy residential road linking two A roads **Surrounding landuse side 2:** Regularly mown amenity grassland (public open space) with trees of a mix of species and age. Close proximity to area of mixed shrubs and trees **Depth:** N/A **Height:** N/A

Reference Number: H1
Woody Species: Privet
Location: A53 Leek Rd
Surrounding landuse side 1:
Narrow pavement, mown verge and major road
Surrounding landuse side 2: Allotments
Depth: 232 cm
Height: 222 cm

Reference Number: H47
Woody Species: Privet
Location: College Rd, adjacent to Hanley Park
Surrounding landuse side 1:
Wide pavement and busy road
Surrounding landuse side 2: Amenity grassland with trees (edge of park)
Depth: 34 cm
Height: 135 cm

Reference Number: H73
Woody Species: Privet
Location: High Street, Brampton
Surrounding landuse side 1:
Busy road
Surrounding landuse side 2: Mown Verge, footpath, another hedge and then amenity grassland with trees
Depth: 230 cm
Height: 209 cm

Reference Number: H2
Woody Species: Beech
Location: A53 Leek Rd
Surrounding landuse side 1:
Narrow pavement and major road
Surrounding landuse side 2: Amenity grassland with trees
Depth: 138 cm
Height: 173 cm

Reference Number: H34
Woody Species: Beech
Location: City Centre (Hanley) Ring Rd
Surrounding landuse side 1:
Mown verge, pavement and major road
Surrounding landuse side 2: Strip of woodland/ trees
Depth: 97 cm
Height: 180 cm

Reference Number: H72
Woody Species: Beech
Location: Ridgeway Rd. Opposite Hanley Park
Surrounding landuse side 1:
Narrow pavement and busy road
Surrounding landuse side 2: Sloping mown grassland with shrubs and trees
Depth: 48 cm
Height: 116 cm

Reference Number: H8
Woody Species:
Hawthorn
Location: A53, Abbey Houlton
Surrounding landuse side 1:
Pavement, narrow mown verge, and major road
Surrounding landuse side 2: Rough grassland (large field)
Depth: 161 cm
Height: 230 cm

Reference Number: H61
Woody Species:
Hawthorn
Location: Clayton Rd
Surrounding landuse side 1:
Narrow pavement, mown verge and major road
Surrounding landuse side 2: Amenity grassland with trees – large open green space
Depth: 97 cm
Height: 131 cm

Reference Number: H41
Woody Species:
Hawthorn
Location: Abbey Rd
Surrounding landuse side 1:
Minor road
Surrounding landuse side 2: Amenity grassland – large open green space
Depth: 207 cm
Height: 230 cm

Appendix B Hedge Survey Form

Hedge Survey Form

Hedge No	Location	Grid ref Orientation
Date	Time Start Finish	Weather

Description Photo Numbers
Sketch of cross section & adjoining landuse (undisturbed ground?) see notes
Sketch of long profile (highlight section surveyed)

Hh
Hw
Ga
Wl
Fc
Di
Ba
Dg
Udg
Vh
Ni
Hs

Woody Hedge Species	%	Adjacent notable spp s 1	%	Adjacent notable spp s 2	%
Tree Species	DBH	Vegetation height	cm	Vegetation Height	cm

Evidence of Management	Faunal evidence	Notes

Hh hedge height
Hw hedge width
Ga Gaps
Wl walls
Fc fences
Di ditches
Ba banks
Dg disturbed ground
Udg undisturbed ground
Vh vegetation height
Ni Nutrient indicator species
Hs hard surfaces
Measure and record vegetation height and measure expanse of vegetation from hedge or measure distance from hedge between changes in vegetation type e.g. if there is a tall strip adjacent to the hedge and then 50cm away this is mown.
Measure depth of pavement to road etc.

Appendix C Example of completed survey form

Hedge Survey Form

Hedge No	Location	Grid ref / Orientation
8.	Leek Rd. (Houses)	
Date 30.06.14.	**Time** Start 14:50 Finish 15:30	**Weather** Bright spells

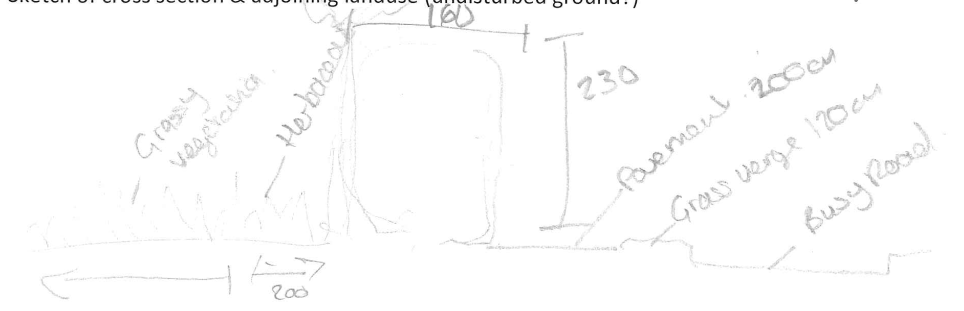
Description

Neatly managed hedge – good length (uniform)
Standard Ash trees Ash: adjacent to W edge of hedge
Managed by trimming?

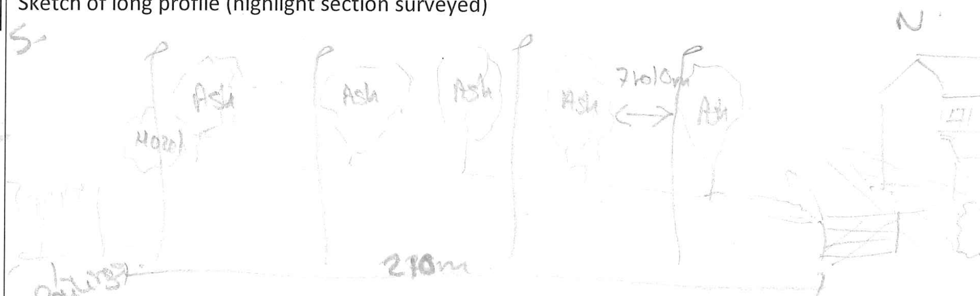
Photo Numbers E810 / W 809

Hh
Hw
Ga
Wl
Fc
Bi
Ba
Dg
Udg
Vh
Ni

Sketch of cross section & adjoining landuse (undisturbed ground?)



Sketch of long profile (highlight section surveyed)



Woody Hedge Species	%	Adjacent notable spp s 1	% W	Adjacent notable spp side 2 E	%
Hawthorn		Nettle	60	Horsetails (wood?)	8
Elder.		Yorkshire fog	50.	Ash	<1
		Cow parsley	80.	Bramble	2
		Purple spotted orchid	<1		
		Bramble.	<1		
		Hogweed.	1		

Tree Species	DBH cm
Ash	115
Ash.	110
Ash	107

Evidence of Management	Faunal evidence	Notes
Management by trimming?	Meadow brown. Burnet moth Butterfly Tortoiseshell BF	Wood tile on E side?

Appendix D Questionnaire questions

hedge_Perception_Survey (16.02)

Start of Block: First Questions

Intro The following questions are designed to find out how you feel about the hedges in your city. Thank you for deciding to complete this survey it should only take 3 to 5 minutes.

Q1 Please enter your postcode e.g. ST4 2DF

____

Q2 Please select your age category

○ Under 18 (1)

○ 18 - 24 (2)

○ 25 - 44 (3)

○ 45 - 64 (4)

○ 65+ (5)

Q3 Please select the answer that best describes your work situation

- ◯ Unemployed (1)
- ◯ Full time education (2)
- ◯ Part time education (3)
- ◯ Part time employment (4)
- ◯ Full time employment (5)
- ◯ Retired (6)
- ◯ Other (please state) (7) ____________________

Q4 Do you work outdoors

- ◯ Yes (1)
- ◯ For part of my role (2)
- ◯ No (3)

Q5 Please select the most accurate location to complete each of the starting statements

	A City Centre (1)	The outskirts of a city (2)	A large town (3)	A small town/ Village (4)	A small village or hamlet (5)	Other (6)
I grew up in (1)	◯	◯	◯	◯	◯	◯
I now live in (2)	◯	◯	◯	◯	◯	◯

Q6 Do you own a dog?

◯ Yes (1)

◯ No (2)

Q7 How often do you walk in Stoke-on-Trent - including walking your dog, walking to work or to the shops

◯ Less than once a week (1)

◯ Once or twice a week (2)

◯ 3 to 5 times a week (3)

◯ Almost every day (4)

◯ More than once a day (5)

Q8 How strongly do you agree with these statements about hedges? (0 = strongly disagree & 5 = strongly agree)

	0	1	2	3	4	5
I love to hear the birds singing when I pass them (1)						
They are an important home for birds (2)						
They are important as a home for bees and butterflies (3)						
They are an important home for other invertebrates (4)						
They are an important home for small mammals such as mice and hedgehogs (5)						
They are important for collecting pollution from the air (6)						
They make me feel happier (7)						

Q9 How strongly do you agree with these statements about hedges? (0 = strongly disagree & 5 = strongly agree)

	0	1	2	3	4	5
They require too much maintenance (1)						
They harbour pests (2)						
They look untidy (3)						
They make the roads more dangerous (4)						

End of Block: First Questions

Start of Block: The Images

Q10 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q12 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q13 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5

Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q14 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q15 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q16 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q17 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q18 Score the image below for the following categories (0 = very poor & 5 = excellent)

0 1 2 3 4 5

Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q19 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q20 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q21 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q22 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0	1	2	3	4	5
Attractiveness (1)						
Importance for animals (2)						
Ease of maintenance (3)						
Feel good factor (4)						

Q23 Score the image below for the following categories (0 = very poor & 5 = excellent)

0 1 2 3 4 5

Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q24 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q25 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q26 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q27 Score the image below for the following categories (0 = very poor & 5 = excellent)

	0 1 2 3 4 5
Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

Q28 Score the image below for the following categories (0 = very poor & 5 = excellent)

0 1 2 3 4 5

Attractiveness (1)	
Importance for animals (2)	
Ease of maintenance (3)	
Feel good factor (4)	

End of Block: The Images

Start of Block: Optional

Q29 What do you believe is the most important factor to consider when planting a hedgerow

- ◯ The hedges contribution as a habitat for animals. (1)
- ◯ The attractiveness of the hedge. (2)
- ◯ Ease of maintenance (3)
- ◯ All of the choices above are equally important. (4)

Q30 Finally, we would like to ask you where did you hear about the questionnaire?

- ◯ Colleague / Friend (1)
- ◯ Social Media (2)
- ◯ Billboard / Poster (3)
- ◯ Other (Please Specify) (4) ____

Q31 Optional.

Feel free to write any feelings you have towards hedges, such as what improvements you believe can be made, what interests you that has not been asked.

____

____

____

____

____

End of Block: Optional

Appendix E Post-hoc analysis for Statements questions

Pairwise Comparisons of Statement

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Assumed positive statements are coloured green an assumed negative, red. Significant differences are highlighted in yellow. Significant differences are found between all comparisons where an assumed positive is compared to an assumed negative except for one – the statements They look untidy and They require too much maintenance did not score significantly differently from each other.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
They harbour pests-They make the roads more dangerous	-8.200	40.346	-.203	.839	1.000
They harbour pests-They look untidy	-23.075	40.032	-.576	.564	1.000
They harbour pests-They require too much maintenance	39.835	39.591	1.006	.314	1.000
They harbour pests-They are important for collecting pollution from the air	356.213	37.911	9.396	.000	.000
They harbour pests-They are an important home for other invertebrates	365.906	37.911	9.652	.000	.000
They harbour pests-They are important as a home for bees and butterflies	370.069	37.911	9.762	.000	.000
They harbour pests-They make me feel happier	393.193	38.227	10.286	.000	.000
They harbour pests-They are an important home for small mammals such as mice and hedgehogs	393.337	37.810	10.403	.000	.000
They harbour pests-They are an important home for birds	410.032	37.911	10.816	.000	.000
They harbour pests-I love to hear birds singing when i pass them	417.581	37.911	11.015	.000	.000
They make the roads more dangerous-They look untidy	14.875	40.495	.367	.713	1.000
They make the roads more dangerous-They require too much maintenance	31.636	40.059	.790	.430	1.000
They make the roads more dangerous-They are important for collecting pollution from the air	348.014	38.399	9.063	.000	.000
They make the roads more dangerous-They are an important home for other invertebrates	357.706	38.399	9.316	.000	.000
They make the roads more dangerous-They are important as a home for bees and butterflies	361.869	38.399	9.424	.000	.000

They make the roads more dangerous-They make me feel happier	384.994	38.711	9.945	.000	.000
They make the roads more dangerous-They are an important home for small mammals such as mice and hedgehogs	385.137	38.299	10.056	.000	.000
They make the roads more dangerous-They are an important home for birds	401.833	38.399	10.465	.000	.000
They make the roads more dangerous-I love to hear birds singing when i pass them	409.381	38.399	10.661	.000	.000
They look untidy-They require too much maintenance	16.761	39.743	.422	.673	1.000
They look untidy-They are important for collecting pollution from the air	333.139	38.069	8.751	.000	.000
They look untidy-They are an important home for other invertebrates	342.831	38.069	9.006	.000	.000
They look untidy-They are important as a home for bees and butterflies	346.994	38.069	9.115	.000	.000
They look untidy-They make me feel happier	370.119	38.384	9.643	.000	.000
They look untidy-They are an important home for small mammals such as mice and hedgehogs	370.262	37.969	9.752	.000	.000
They look untidy-They are an important home for birds	386.958	38.069	10.165	.000	.000
They look untidy-I love to hear birds singing when i pass them	394.506	38.069	10.363	.000	.000
They require too much maintenance-They are important for collecting pollution from the air	316.378	37.605	8.413	.000	.000
They require too much maintenance-They are an important home for other invertebrates	326.070	37.605	8.671	.000	.000
They require too much maintenance-They are important as a home for bees and butterflies	330.233	37.605	8.782	.000	.000
They require too much maintenance-They make me feel happier	353.358	37.924	9.318	.000	.000
They require too much maintenance-They are an important home for small mammals such as mice and hedgehogs	353.501	37.504	9.426	.000	.000

They require too much maintenance-They are an important home for birds	370.197	37.605	9.844	.000	.000
They require too much maintenance-I love to hear birds singing when i pass them	377.745	37.605	10.045	.000	.000
They are important for collecting pollution from the air-They are an important home for other invertebrates	9.693	35.832	.271	.787	1.000
They are important for collecting pollution from the air-They are important as a home for bees and butterflies	13.855	35.832	.387	.699	1.000
They are important for collecting pollution from the air-They make me feel happier	-36.980	36.166	-1.023	.307	1.000
They are important for collecting pollution from the air-They are an important home for small mammals such as mice and hedgehogs	37.123	35.725	1.039	.299	1.000
They are important for collecting pollution from the air-They are an important home for birds	53.819	35.832	1.502	.133	1.000
They are important for collecting pollution from the air-I love to hear birds singing when i pass them	61.367	35.832	1.713	.087	1.000
They are an important home for other invertebrates-They are important as a home for bees and butterflies	4.163	35.832	.116	.908	1.000
They are an important home for other invertebrates-They make me feel happier	-27.287	36.166	-.755	.451	1.000
They are an important home for other invertebrates-They are an important home for small mammals such as mice and hedgehogs	-27.431	35.725	-.768	.443	1.000
They are an important home for other invertebrates-They are an important home for birds	44.127	35.832	1.231	.218	1.000
They are an important home for other invertebrates-I love to hear birds singing when i pass them	51.675	35.832	1.442	.149	1.000
They are important as a home for bees and butterflies-They make me feel happier	-23.125	36.166	-.639	.523	1.000

They are important as a home for bees and butterflies-They are an important home for small mammals such as mice and hedgehogs	-23.268	35.725	-.651	.515	1.000
They are important as a home for bees and butterflies-They are an important home for birds	39.964	35.832	1.115	.265	1.000
They are important as a home for bees and butterflies-I love to hear birds singing when i pass them	47.512	35.832	1.326	.185	1.000
They make me feel happier-They are an important home for small mammals such as mice and hedgehogs	.143	36.060	.004	.997	1.000
They make me feel happier-They are an important home for birds	16.839	36.166	.466	.641	1.000
They make me feel happier-I love to hear birds singing when i pass them	24.387	36.166	.674	.500	1.000
They are an important home for small mammals such as mice and hedgehogs-They are an important home for birds	16.696	35.725	.467	.640	1.000
They are an important home for small mammals such as mice and hedgehogs-I love to hear birds singing when i pass them	24.244	35.725	.679	.497	1.000
They are an important home for birds-I love to hear birds singing when i pass them	7.548	35.832	.211	.833	1.000

Appendix F Post-hoc analysis for the attractiveness scores given to each photograph

Pairwise Comparisons of Photo Number

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
19-23	-5.874	24.737	-.237	.812	1.000
19-16	6.139	27.993	.219	.826	1.000
19-27	-29.257	24.737	-1.183	.237	1.000
19-18	51.672	25.571	2.021	.043	1.000
19-25	-79.272	25.571	-3.100	.002	.296
19-21	-82.425	23.495	-3.508	.000	.069
19-24	-85.562	26.623	-3.214	.001	.200
19-28	-88.611	24.381	-3.634	.000	.043
19-12	90.083	29.861	3.017	.003	.391
19-13	98.089	28.848	3.400	.001	.103
19-17	99.983	25.132	3.978	.000	.011
19-22	-101.439	25.571	-3.967	.000	.011
19-26	-125.072	25.571	-4.891	.000	.000
19-10	130.083	29.861	4.356	.000	.002
19-15	133.062	26.623	4.998	.000	.000
19-20	-145.420	25.132	-5.786	.000	.000
19-14	146.339	28.848	5.073	.000	.000
23-16	.265	28.303	.009	.993	1.000
23-27	-23.382	25.088	-.932	.351	1.000
23-18	45.798	25.911	1.768	.077	1.000
23-25	-73.398	25.911	-2.833	.005	.706
23-21	76.550	23.864	3.208	.001	.205
23-24	-79.688	26.949	-2.957	.003	.475
23-28	-82.737	24.737	-3.345	.001	.126
23-12	84.209	30.152	2.793	.005	.800
23-13	92.215	29.150	3.163	.002	.239
23-17	94.108	25.477	3.694	.000	.034
23-22	95.565	25.911	3.688	.000	.035
23-26	-119.198	25.911	-4.600	.000	.001
23-10	124.209	30.152	4.119	.000	.006
23-15	127.188	26.949	4.720	.000	.000
23-20	139.546	25.477	5.477	.000	.000
23-14	140.465	29.150	4.819	.000	.000
16-27	-23.118	28.303	-.817	.414	1.000
16-18	-45.533	29.035	-1.568	.117	1.000
16-25	-73.133	29.035	-2.519	.012	1.000
16-21	-76.286	27.224	-2.802	.005	.777
16-24	-79.423	29.965	-2.651	.008	1.000
16-28	-82.472	27.993	-2.946	.003	.492
16-12	83.944	32.876	2.553	.011	1.000
16-13	91.950	31.959	2.877	.004	.614
16-17	-93.844	28.649	-3.276	.001	.161
16-22	-95.300	29.035	-3.282	.001	.158
16-26	-118.933	29.035	-4.096	.000	.006
16-10	123.944	32.876	3.770	.000	.025
16-15	126.923	29.965	4.236	.000	.003

16-20	-139.281	28.649	-4.862	.000	.000
16-14	140.200	31.959	4.387	.000	.002
27-18	22.416	25.911	.865	.387	1.000
27-25	50.016	25.911	1.930	.054	1.000
27-21	53.168	23.864	2.228	.026	1.000
27-24	56.305	26.949	2.089	.037	1.000
27-28	-59.355	24.737	-2.399	.016	1.000
27-12	60.827	30.152	2.017	.044	1.000
27-13	68.832	29.150	2.361	.018	1.000
27-17	70.726	25.477	2.776	.006	.842
27-22	72.182	25.911	2.786	.005	.817
27-26	95.816	25.911	3.698	.000	.033
27-10	100.827	30.152	3.344	.001	.126
27-15	103.805	26.949	3.852	.000	.018
27-20	116.164	25.477	4.560	.000	.001
27-14	117.082	29.150	4.017	.000	.009
18-25	-27.600	26.708	-1.033	.301	1.000
18-21	-30.752	24.727	-1.244	.214	1.000
18-24	-33.890	27.717	-1.223	.221	1.000
18-28	-36.939	25.571	-1.445	.149	1.000
18-12	38.411	30.840	1.245	.213	1.000
18-13	46.417	29.861	1.554	.120	1.000
18-17	48.310	26.288	1.838	.066	1.000
18-22	-49.767	26.708	-1.863	.062	1.000
18-26	-73.400	26.708	-2.748	.006	.917
18-10	78.411	30.840	2.542	.011	1.000
18-15	81.390	27.717	2.936	.003	.508
18-20	-93.748	26.288	-3.566	.000	.055
18-14	94.667	29.861	3.170	.002	.233
25-21	3.152	24.727	.127	.899	1.000
25-24	6.290	27.717	.227	.820	1.000
25-28	-9.339	25.571	-.365	.715	1.000
25-12	10.811	30.840	.351	.726	1.000
25-13	18.817	29.861	.630	.529	1.000
25-17	20.710	26.288	.788	.431	1.000
25-22	22.167	26.708	.830	.407	1.000
25-26	-45.800	26.708	-1.715	.086	1.000
25-10	50.811	30.840	1.648	.099	1.000
25-15	53.790	27.717	1.941	.052	1.000
25-20	66.148	26.288	2.516	.012	1.000
25-14	67.067	29.861	2.246	.025	1.000
21-24	-3.137	25.813	-.122	.903	1.000
21-28	-6.187	23.495	-.263	.792	1.000
21-12	7.659	29.141	.263	.793	1.000
21-13	15.664	28.103	.557	.577	1.000
21-17	17.558	24.272	.723	.469	1.000
21-22	-19.014	24.727	-.769	.442	1.000
21-26	-42.648	24.727	-1.725	.085	1.000
21-10	47.659	29.141	1.635	.102	1.000
21-15	50.637	25.813	1.962	.050	1.000
21-20	62.996	24.272	2.595	.009	1.000
21-14	63.914	28.103	2.274	.023	1.000
24-28	-3.049	26.623	-.115	.909	1.000
24-12	4.521	31.717	.143	.887	1.000
24-13	12.527	30.766	.407	.684	1.000
24-17	14.421	27.312	.528	.597	1.000
24-22	15.877	27.717	.573	.567	1.000

24-26	-39.510	27.717	-1.426	.154	1.000
24-10	44.521	31.717	1.404	.160	1.000
24-15	47.500	28.690	1.656	.098	1.000
24-20	59.858	27.312	2.192	.028	1.000
24-14	60.777	30.766	1.975	.048	1.000
28-12	1.472	29.861	.049	.961	1.000
28-13	9.478	28.848	.329	.743	1.000
28-17	11.372	25.132	.452	.651	1.000
28-22	12.828	25.571	.502	.616	1.000
28-26	36.461	25.571	1.426	.154	1.000
28-10	41.472	29.861	1.389	.165	1.000
28-15	44.451	26.623	1.670	.095	1.000
28-20	56.809	25.132	2.260	.024	1.000
28-14	57.728	28.848	2.001	.045	1.000
12-13	-8.006	33.607	-.238	.812	1.000
12-17	-9.899	30.477	-.325	.745	1.000
12-22	-11.356	30.840	-.368	.713	1.000
12-26	-34.989	30.840	-1.135	.257	1.000
12-10	40.000	34.481	1.160	.246	1.000
12-15	-42.979	31.717	-1.355	.175	1.000
12-20	-55.337	30.477	-1.816	.069	1.000
12-14	-56.256	33.607	-1.674	.094	1.000
13-17	-1.894	29.485	-.064	.949	1.000
13-22	-3.350	29.861	-.112	.911	1.000
13-26	-26.983	29.861	-.904	.366	1.000
13-10	31.994	33.607	.952	.341	1.000
13-15	-34.973	30.766	-1.137	.256	1.000
13-20	-47.331	29.485	-1.605	.108	1.000
13-14	-48.250	32.711	-1.475	.140	1.000
17-22	-1.456	26.288	-.055	.956	1.000
17-26	-25.090	26.288	-.954	.340	1.000
17-10	30.101	30.477	.988	.323	1.000
17-15	33.079	27.312	1.211	.226	1.000
17-20	-45.437	25.860	-1.757	.079	1.000
17-14	46.356	29.485	1.572	.116	1.000
22-26	-23.633	26.708	-.885	.376	1.000
22-10	28.644	30.840	.929	.353	1.000
22-15	31.623	27.717	1.141	.254	1.000
22-20	43.981	26.288	1.673	.094	1.000
22-14	44.900	29.861	1.504	.133	1.000
26-10	5.011	30.840	.162	.871	1.000
26-15	7.990	27.717	.288	.773	1.000
26-20	20.348	26.288	.774	.439	1.000
26-14	21.267	29.861	.712	.476	1.000
10-15	-2.979	31.717	-.094	.925	1.000
10-20	-15.337	30.477	-.503	.615	1.000
10-14	-16.256	33.607	-.484	.629	1.000
15-20	-12.358	27.312	-.452	.651	1.000
15-14	13.277	30.766	.432	.666	1.000
20-14	.919	29.485	.031	.975	1.000

Appendix G Post-hoc analysis for the importance for animals scores given to each photograph

Pairwise Comparisons of Photo

Number Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
19-23	-9.896	26.283	-.377	.707	1.000
19-16	12.670	26.764	.473	.636	1.000
19-27	-18.344	25.856	-.709	.478	1.000
19-25	-46.062	26.764	-1.721	.085	1.000
19-24	-71.229	26.283	-2.710	.007	1.000
19-21	-71.967	24.268	-2.965	.003	.462
19-17	73.531	25.856	2.844	.004	.682
19-12	83.563	29.480	2.835	.005	.702
19-13	104.063	29.480	3.530	.000	.064
19-28	-104.924	25.128	-4.176	.000	.005
19-18	109.663	26.283	4.172	.000	.005
19-22	-120.862	26.283	-4.598	.000	.001
19-20	-123.875	25.856	-4.791	.000	.000
19-26	-125.029	26.283	-4.757	.000	.000
19-14	133.313	29.480	4.522	.000	.001
19-15	144.409	27.307	5.288	.000	.000
19-10	149.451	30.472	4.905	.000	.000
23-16	2.774	27.177	.102	.919	1.000
23-27	-8.448	26.283	-.321	.748	1.000
23-25	-36.167	27.177	-1.331	.183	1.000
23-24	-61.333	26.704	-2.297	.022	1.000
23-21	62.071	24.723	2.511	.012	1.000
23-17	63.635	26.283	2.421	.015	1.000
23-12	73.667	29.856	2.467	.014	1.000
23-13	94.167	29.856	3.154	.002	.246
23-28	-95.028	25.567	-3.717	.000	.031
23-18	99.767	26.704	3.736	.000	.029
23-22	110.967	26.704	4.155	.000	.005
23-20	113.979	26.283	4.337	.000	.002
23-26	-115.133	26.704	-4.311	.000	.002
23-14	123.417	29.856	4.134	.000	.005
23-15	134.513	27.712	4.854	.000	.000
23-10	139.556	30.835	4.526	.000	.001
16-27	-5.674	26.764	-.212	.832	1.000
16-25	-33.393	27.641	-1.208	.227	1.000
16-24	-58.560	27.177	-2.155	.031	1.000
16-21	-59.298	25.233	-2.350	.019	1.000
16-17	-60.862	26.764	-2.274	.023	1.000
16-12	70.893	30.280	2.341	.019	1.000
16-13	91.393	30.280	3.018	.003	.389
16-28	-92.254	26.060	-3.540	.000	.061
16-18	-96.993	27.177	-3.569	.000	.055
16-22	-108.193	27.177	-3.981	.000	.010
16-20	-111.205	26.764	-4.155	.000	.005
16-26	-112.360	27.177	-4.134	.000	.005
16-14	120.643	30.280	3.984	.000	.010
16-15	131.739	28.168	4.677	.000	.000

16-10	136.782	31.245	4.378	.000	.002
27-25	27.719	26.764	1.036	.300	1.000
27-24	52.885	26.283	2.012	.044	1.000
27-21	53.624	24.268	2.210	.027	1.000
27-17	55.188	25.856	2.134	.033	1.000
27-12	65.219	29.480	2.212	.027	1.000
27-13	85.719	29.480	2.908	.004	.557
27-28	-86.580	25.128	-3.446	.001	.087
27-18	91.319	26.283	3.474	.001	.078
27-22	102.519	26.283	3.901	.000	.015
27-20	105.531	25.856	4.081	.000	.007
27-26	106.685	26.283	4.059	.000	.008
27-14	114.969	29.480	3.900	.000	.015
27-15	126.065	27.307	4.617	.000	.001
27-10	131.108	30.472	4.303	.000	.003
25-24	25.167	27.177	.926	.354	1.000
25-21	25.905	25.233	1.027	.305	1.000
25-17	27.469	26.764	1.026	.305	1.000
25-12	37.500	30.280	1.238	.216	1.000
25-13	58.000	30.280	1.915	.055	1.000
25-28	-58.861	26.060	-2.259	.024	1.000
25-18	63.600	27.177	2.340	.019	1.000
25-22	74.800	27.177	2.752	.006	.905
25-20	77.813	26.764	2.907	.004	.558
25-26	-78.967	27.177	-2.906	.004	.561
25-14	87.250	30.280	2.881	.004	.606
25-15	98.346	28.168	3.491	.000	.074
25-10	103.389	31.245	3.309	.001	.143
24-21	.738	24.723	.030	.976	1.000
24-17	2.302	26.283	.088	.930	1.000
24-12	12.333	29.856	.413	.680	1.000
24-13	32.833	29.856	1.100	.271	1.000
24-28	-33.694	25.567	-1.318	.188	1.000
24-18	38.433	26.704	1.439	.150	1.000
24-22	49.633	26.704	1.859	.063	1.000
24-20	52.646	26.283	2.003	.045	1.000
24-26	-53.800	26.704	-2.015	.044	1.000
24-14	62.083	29.856	2.079	.038	1.000
24-15	73.179	27.712	2.641	.008	1.000
24-10	78.222	30.835	2.537	.011	1.000
21-17	1.564	24.268	.064	.949	1.000
21-12	11.595	28.098	.413	.680	1.000
21-13	32.095	28.098	1.142	.253	1.000
21-28	-32.956	23.491	-1.403	.161	1.000
21-18	37.695	24.723	1.525	.127	1.000
21-22	-48.895	24.723	-1.978	.048	1.000
21-20	51.908	24.268	2.139	.032	1.000
21-26	-53.062	24.723	-2.146	.032	1.000
21-14	61.345	28.098	2.183	.029	1.000
21-15	72.441	25.809	2.807	.005	.765
21-10	77.484	29.136	2.659	.008	1.000
17-12	10.031	29.480	.340	.734	1.000
17-13	30.531	29.480	1.036	.300	1.000
17-28	-31.392	25.128	-1.249	.212	1.000
17-18	-36.131	26.283	-1.375	.169	1.000
17-22	-47.331	26.283	-1.801	.072	1.000
17-20	-50.344	25.856	-1.947	.052	1.000

17-26	-51.498	26.283	-1.959	.050	1.000
17-14	59.781	29.480	2.028	.043	1.000
17-15	70.877	27.307	2.596	.009	1.000
17-10	75.920	30.472	2.491	.013	1.000
12-13	-20.500	32.706	-.627	.531	1.000
12-28	-21.361	28.844	-.741	.459	1.000
12-18	-26.100	29.856	-.874	.382	1.000
12-22	-37.300	29.856	-1.249	.212	1.000
12-20	-40.312	29.480	-1.367	.171	1.000
12-26	-41.467	29.856	-1.389	.165	1.000
12-14	-49.750	32.706	-1.521	.128	1.000
12-15	-60.846	30.761	-1.978	.048	1.000
12-10	65.889	33.602	1.961	.050	1.000
13-28	-.861	28.844	-.030	.976	1.000
13-18	-5.600	29.856	-.188	.851	1.000
13-22	-16.800	29.856	-.563	.574	1.000
13-20	-19.812	29.480	-.672	.502	1.000
13-26	-20.967	29.856	-.702	.483	1.000
13-14	-29.250	32.706	-.894	.371	1.000
13-15	-40.346	30.761	-1.312	.190	1.000
13-10	45.389	33.602	1.351	.177	1.000
28-18	4.739	25.567	.185	.853	1.000
28-22	15.939	25.567	.623	.533	1.000
28-20	18.951	25.128	.754	.451	1.000
28-26	20.106	25.567	.786	.432	1.000
28-14	28.389	28.844	.984	.325	1.000
28-15	39.485	26.618	1.483	.138	1.000
28-10	44.528	29.856	1.491	.136	1.000
18-22	-11.200	26.704	-.419	.675	1.000
18-20	-14.212	26.283	-.541	.589	1.000
18-26	-15.367	26.704	-.575	.565	1.000
18-14	23.650	29.856	.792	.428	1.000
18-15	34.746	27.712	1.254	.210	1.000
18-10	39.789	30.835	1.290	.197	1.000
22-20	3.012	26.283	.115	.909	1.000
22-26	-4.167	26.704	-.156	.876	1.000
22-14	12.450	29.856	.417	.677	1.000
22-15	23.546	27.712	.850	.396	1.000
22-10	28.589	30.835	.927	.354	1.000
20-26	-1.154	26.283	-.044	.965	1.000
20-14	9.438	29.480	.320	.749	1.000
20-15	20.534	27.307	.752	.452	1.000
20-10	25.576	30.472	.839	.401	1.000
26-14	8.283	29.856	.277	.781	1.000
26-15	19.379	27.712	.699	.484	1.000
26-10	24.422	30.835	.792	.428	1.000
14-15	-11.096	30.761	-.361	.718	1.000
14-10	16.139	33.602	.480	.631	1.000
15-10	5.043	31.712	.159	.874	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Appendix H Post-hoc analysis for the feel good factor scores given to each photograph

Pairwise Comparisons of Photo Number

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
19-16	6.182	30.120	.205	.837	1.000
19-23	-11.794	25.923	-.455	.649	1.000
19-27	-29.668	27.276	-1.088	.277	1.000
19-18	59.149	26.773	2.209	.027	1.000
19-25	-69.549	26.773	-2.598	.009	1.000
19-21	-74.454	24.658	-3.020	.003	.387
19-12	87.582	30.120	2.908	.004	.557
19-24	-98.449	26.773	-3.677	.000	.036
19-13	98.982	30.120	3.286	.001	.155
19-28	-100.934	23.086	-4.372	.000	.002
19-17	109.257	26.325	4.150	.000	.005
19-22	-111.668	27.276	-4.094	.000	.006
19-26	-111.716	26.773	-4.173	.000	.005
19-15	140.729	27.846	5.054	.000	.000
19-14	142.882	30.120	4.744	.000	.000
19-10	143.771	31.155	4.615	.000	.001
19-20	-145.757	26.325	-5.537	.000	.000
16-23	-5.612	30.120	-.186	.852	1.000
16-27	-23.486	31.292	-.751	.453	1.000
16-18	-52.967	30.854	-1.717	.086	1.000
16-25	-63.367	30.854	-2.054	.040	1.000
16-21	-68.271	29.038	-2.351	.019	1.000
16-12	81.400	33.799	2.408	.016	1.000
16-24	-92.267	30.854	-2.990	.003	.426
16-13	92.800	33.799	2.746	.006	.924
16-28	-94.752	27.716	-3.419	.001	.096
16-17	-103.075	30.466	-3.383	.001	.110
16-22	-105.486	31.292	-3.371	.001	.115
16-26	-105.533	30.854	-3.420	.001	.096
16-15	134.546	31.790	4.232	.000	.004
16-14	136.700	33.799	4.044	.000	.008
16-10	137.589	34.725	3.962	.000	.011
16-20	-139.575	30.466	-4.581	.000	.001
23-27	-17.874	27.276	-.655	.512	1.000
23-18	47.355	26.773	1.769	.077	1.000
23-25	-57.755	26.773	-2.157	.031	1.000
23-21	62.660	24.658	2.541	.011	1.000
23-12	75.788	30.120	2.516	.012	1.000
23-24	-86.655	26.773	-3.237	.001	.185
23-13	87.188	30.120	2.895	.004	.581
23-28	-89.140	23.086	-3.861	.000	.017
23-17	97.463	26.325	3.702	.000	.033
23-22	99.874	27.276	3.662	.000	.038
23-26	-99.922	26.773	-3.732	.000	.029
23-15	128.934	27.846	4.630	.000	.001
23-14	131.088	30.120	4.352	.000	.002
23-10	131.977	31.155	4.236	.000	.003

23-20	133.963	26.325	5.089	.000	.000
27-18	29.481	28.085	1.050	.294	1.000
27-25	39.881	28.085	1.420	.156	1.000
27-21	44.786	26.077	1.717	.086	1.000
27-12	57.914	31.292	1.851	.064	1.000
27-24	68.781	28.085	2.449	.014	1.000
27-13	69.314	31.292	2.215	.027	1.000
27-28	-71.266	24.596	-2.897	.004	.576
27-17	79.589	27.659	2.878	.004	.613
27-22	82.000	28.566	2.871	.004	.627
27-26	82.048	28.085	2.921	.003	.533
27-15	111.060	29.110	3.815	.000	.021
27-14	113.214	31.292	3.618	.000	.045
27-10	114.103	32.290	3.534	.000	.063
27-20	116.089	27.659	4.197	.000	.004
18-25	-10.400	27.597	-.377	.706	1.000
18-21	-15.305	25.550	-.599	.549	1.000
18-12	28.433	30.854	.922	.357	1.000
18-24	-39.300	27.597	-1.424	.154	1.000
18-13	39.833	30.854	1.291	.197	1.000
18-28	-41.785	24.037	-1.738	.082	1.000
18-17	50.108	27.162	1.845	.065	1.000
18-22	-52.519	28.085	-1.870	.061	1.000
18-26	-52.567	27.597	-1.905	.057	1.000
18-15	81.579	28.639	2.849	.004	.672
18-14	83.733	30.854	2.714	.007	1.000
18-10	84.622	31.866	2.656	.008	1.000
18-20	-86.608	27.162	-3.189	.001	.219
25-21	4.905	25.550	.192	.848	1.000
25-12	18.033	30.854	.584	.559	1.000
25-24	28.900	27.597	1.047	.295	1.000
25-13	29.433	30.854	.954	.340	1.000
25-28	-31.385	24.037	-1.306	.192	1.000
25-17	39.708	27.162	1.462	.144	1.000
25-22	42.119	28.085	1.500	.134	1.000
25-26	-42.167	27.597	-1.528	.127	1.000
25-15	71.179	28.639	2.485	.013	1.000
25-14	73.333	30.854	2.377	.017	1.000
25-10	74.222	31.866	2.329	.020	1.000
25-20	76.208	27.162	2.806	.005	.768
21-12	13.129	29.038	.452	.651	1.000
21-24	-23.995	25.550	-.939	.348	1.000
21-13	24.529	29.038	.845	.398	1.000
21-28	-26.480	21.656	-1.223	.221	1.000
21-17	34.804	25.080	1.388	.165	1.000
21-22	-37.214	26.077	-1.427	.154	1.000
21-26	-37.262	25.550	-1.458	.145	1.000
21-15	66.275	26.672	2.485	.013	1.000
21-14	68.429	29.038	2.357	.018	1.000
21-10	69.317	30.111	2.302	.021	1.000
21-20	71.304	25.080	2.843	.004	.684
12-24	-10.867	30.854	-.352	.725	1.000
12-13	-11.400	33.799	-.337	.736	1.000
12-28	-13.352	27.716	-.482	.630	1.000
12-17	-21.675	30.466	-.711	.477	1.000
12-22	-24.086	31.292	-.770	.441	1.000
12-26	-24.133	30.854	-.782	.434	1.000

12-15	-53.146	31.790	-1.672	.095	1.000
12-14	-55.300	33.799	-1.636	.102	1.000
12-10	56.189	34.725	1.618	.106	1.000
12-20	-58.175	30.466	-1.909	.056	1.000
24-13	.533	30.854	.017	.986	1.000
24-28	-2.485	24.037	-.103	.918	1.000
24-17	10.808	27.162	.398	.691	1.000
24-22	13.219	28.085	.471	.638	1.000
24-26	-13.267	27.597	-.481	.631	1.000
24-15	42.279	28.639	1.476	.140	1.000
24-14	44.433	30.854	1.440	.150	1.000
24-10	45.322	31.866	1.422	.155	1.000
24-20	47.308	27.162	1.742	.082	1.000
13-28	-1.952	27.716	-.070	.944	1.000
13-17	-10.275	30.466	-.337	.736	1.000
13-22	-12.686	31.292	-.405	.685	1.000
13-26	-12.733	30.854	-.413	.680	1.000
13-15	-41.746	31.790	-1.313	.189	1.000
13-14	-43.900	33.799	-1.299	.194	1.000
13-10	44.789	34.725	1.290	.197	1.000
13-20	-46.775	30.466	-1.535	.125	1.000
28-17	8.323	23.536	.354	.724	1.000
28-22	10.734	24.596	.436	.663	1.000
28-26	10.782	24.037	.449	.654	1.000
28-15	39.794	25.226	1.578	.115	1.000
28-14	41.948	27.716	1.514	.130	1.000
28-10	42.837	28.838	1.485	.137	1.000
28-20	44.823	23.536	1.904	.057	1.000
17-22	-2.411	27.659	-.087	.931	1.000
17-26	-2.458	27.162	-.091	.928	1.000
17-15	31.471	28.220	1.115	.265	1.000
17-14	33.625	30.466	1.104	.270	1.000
17-10	34.514	31.491	1.096	.273	1.000
17-20	-36.500	26.721	-1.366	.172	1.000
22-26	-.048	28.085	-.002	.999	1.000
22-15	29.060	29.110	.998	.318	1.000
22-14	31.214	31.292	.998	.319	1.000
22-10	32.103	32.290	.994	.320	1.000
22-20	34.089	27.659	1.233	.218	1.000
26-15	29.013	28.639	1.013	.311	1.000
26-14	31.167	30.854	1.010	.312	1.000
26-10	32.056	31.866	1.006	.314	1.000
26-20	34.042	27.162	1.253	.210	1.000
15-14	2.154	31.790	.068	.946	1.000
15-10	3.043	32.773	.093	.926	1.000
15-20	-5.029	28.220	-.178	.859	1.000
14-10	.889	34.725	.026	.980	1.000
14-20	-2.875	30.466	-.094	.925	1.000
10-20	-1.986	31.491	-.063	.950	1.000

Appendix I Post-hoc analysis for the Wildlife & Wellbeing scores given to each photograph

Pairwise Comparisons of Photo Number

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
19-16	27.524	48.031	.573	.567	1.000
19-23	-28.283	43.773	-.646	.518	1.000
19-27	-76.749	44.246	-1.735	.083	1.000
19-25	-192.460	45.024	-4.275	.000	.003
19-18	221.668	44.755	4.953	.000	.000
19-21	-226.649	41.218	-5.499	.000	.000
19-24	-251.556	45.304	-5.553	.000	.000
19-12	257.117	50.893	5.052	.000	.000
19-17	278.136	44.005	6.321	.000	.000
19-13	298.007	50.349	5.919	.000	.000
19-28	-307.564	42.727	-7.198	.000	.000
19-22	-331.312	45.024	-7.359	.000	.000
19-26	-358.768	44.755	-8.016	.000	.000
19-20	-407.959	44.005	-9.271	.000	.000
19-10	410.824	51.469	7.982	.000	.000
19-15	413.503	46.548	8.883	.000	.000
19-14	417.224	50.349	8.287	.000	.000
16-23	-.759	48.428	-.016	.987	1.000
16-27	-49.226	48.856	-1.008	.314	1.000
16-25	-164.936	49.562	-3.328	.001	.134
16-18	-194.144	49.317	-3.937	.000	.013
16-21	-199.125	46.132	-4.316	.000	.002
16-24	-224.033	49.816	-4.497	.000	.001
16-12	229.593	54.948	4.178	.000	.004
16-17	-250.612	48.638	-5.153	.000	.000
16-13	270.483	54.445	4.968	.000	.000
16-28	-280.041	47.485	-5.897	.000	.000
16-22	-303.789	49.562	-6.130	.000	.000
16-26	-331.244	49.317	-6.717	.000	.000
16-20	-380.435	48.638	-7.822	.000	.000
16-10	383.300	55.482	6.909	.000	.000
16-15	385.979	50.950	7.576	.000	.000
16-14	389.700	54.445	7.158	.000	.000
23-27	-48.466	44.677	-1.085	.278	1.000
23-25	-164.177	45.448	-3.612	.000	.046
23-18	193.385	45.181	4.280	.000	.003
23-21	198.366	41.681	4.759	.000	.000
23-24	-223.273	45.725	-4.883	.000	.000
23-12	228.834	51.268	4.464	.000	.001
23-17	249.853	44.439	5.622	.000	.000
23-13	269.724	50.728	5.317	.000	.000
23-28	-279.282	43.173	-6.469	.000	.000
23-22	303.029	45.448	6.668	.000	.000
23-26	-330.485	45.181	-7.315	.000	.000
23-20	379.676	44.439	8.544	.000	.000
23-10	382.541	51.840	7.379	.000	.000
23-15	385.220	46.957	8.204	.000	.000

23-14	388.941	50.728	7.667	.000	.000
27-25	115.711	45.903	2.521	.012	1.000
27-18	144.919	45.639	3.175	.001	.229
27-21	149.900	42.176	3.554	.000	.058
27-24	174.807	46.178	3.786	.000	.023
27-12	180.368	51.672	3.491	.000	.074
27-17	201.387	44.904	4.485	.000	.001
27-13	221.258	51.136	4.327	.000	.002
27-28	-230.815	43.652	-5.288	.000	.000
27-22	254.563	45.903	5.546	.000	.000
27-26	282.019	45.639	6.179	.000	.000
27-20	331.210	44.904	7.376	.000	.000
27-10	334.074	52.239	6.395	.000	.000
27-15	336.754	47.398	7.105	.000	.000
27-14	340.474	51.136	6.658	.000	.000
25-18	29.208	46.393	.630	.529	1.000
25-21	34.189	42.992	.795	.426	1.000
25-24	59.096	46.924	1.259	.208	1.000
25-12	64.657	52.339	1.235	.217	1.000
25-17	85.676	45.671	1.876	.061	1.000
25-13	105.547	51.811	2.037	.042	1.000
25-28	-115.104	44.441	-2.590	.010	1.000
25-22	138.852	46.653	2.976	.003	.446
25-26	-166.308	46.393	-3.585	.000	.052
25-20	215.499	45.671	4.719	.000	.000
25-10	218.364	52.900	4.128	.000	.006
25-15	221.043	48.125	4.593	.000	.001
25-14	224.764	51.811	4.338	.000	.002
18-21	-4.981	42.710	-.117	.907	1.000
18-24	-29.888	46.665	-.640	.522	1.000
18-12	35.449	52.108	.680	.496	1.000
18-17	56.468	45.405	1.244	.214	1.000
18-13	76.339	51.577	1.480	.139	1.000
18-28	-85.896	44.168	-1.945	.052	1.000
18-22	-109.644	46.393	-2.363	.018	1.000
18-26	-137.100	46.132	-2.972	.003	.453
18-20	-186.291	45.405	-4.103	.000	.006
18-10	189.156	52.671	3.591	.000	.050
18-15	191.835	47.873	4.007	.000	.009
18-14	195.556	51.577	3.792	.000	.023
21-24	-24.907	43.285	-.575	.565	1.000
21-12	30.468	49.104	.620	.535	1.000
21-17	51.487	41.924	1.228	.219	1.000
21-13	71.358	48.540	1.470	.142	1.000
21-28	-80.915	40.581	-1.994	.046	1.000
21-22	-104.663	42.992	-2.434	.015	1.000
21-26	-132.119	42.710	-3.093	.002	.303
21-20	181.310	41.924	4.325	.000	.002
21-10	184.175	49.701	3.706	.000	.032
21-15	186.854	44.585	4.191	.000	.004
21-14	190.575	48.540	3.926	.000	.013
24-12	5.561	52.581	.106	.916	1.000
24-17	26.580	45.947	.578	.563	1.000
24-13	46.451	52.055	.892	.372	1.000
24-28	-56.008	44.725	-1.252	.210	1.000
24-22	79.756	46.924	1.700	.089	1.000
24-26	-107.212	46.665	-2.297	.022	1.000

24-20	156.403	45.947	3.404	.001	.102
24-10	159.267	53.138	2.997	.003	.417
24-15	161.947	48.388	3.347	.001	.125
24-14	165.667	52.055	3.183	.001	.223
12-17	-21.019	51.466	-.408	.683	1.000
12-13	-40.890	56.985	-.718	.473	1.000
12-28	-50.448	50.377	-1.001	.317	1.000
12-22	-74.196	52.339	-1.418	.156	1.000
12-26	-101.651	52.108	-1.951	.051	1.000
12-20	-150.842	51.466	-2.931	.003	.517
12-10	153.707	57.977	2.651	.008	1.000
12-15	-156.386	53.656	-2.915	.004	.545
12-14	-160.107	56.985	-2.810	.005	.759
17-13	19.871	50.928	.390	.696	1.000
17-28	-29.428	43.409	-.678	.498	1.000
17-22	-53.176	45.671	-1.164	.244	1.000
17-26	-80.632	45.405	-1.776	.076	1.000
17-20	-129.823	44.667	-2.906	.004	.559
17-10	132.688	52.036	2.550	.011	1.000
17-15	135.367	47.174	2.870	.004	.629
17-14	139.088	50.928	2.731	.006	.966
13-28	-9.557	49.828	-.192	.848	1.000
13-22	-33.305	51.811	-.643	.520	1.000
13-26	-60.761	51.577	-1.178	.239	1.000
13-20	-109.952	50.928	-2.159	.031	1.000
13-10	112.817	57.500	1.962	.050	1.000
13-15	-115.496	53.140	-2.173	.030	1.000
13-14	-119.217	56.500	-2.110	.035	1.000
28-22	23.748	44.441	.534	.593	1.000
28-26	51.204	44.168	1.159	.246	1.000
28-20	100.395	43.409	2.313	.021	1.000
28-10	103.259	50.959	2.026	.043	1.000
28-15	105.939	45.984	2.304	.021	1.000
28-14	109.659	49.828	2.201	.028	1.000
22-26	-27.456	46.393	-.592	.554	1.000
22-20	76.647	45.671	1.678	.093	1.000
22-10	79.511	52.900	1.503	.133	1.000
22-15	82.191	48.125	1.708	.088	1.000
22-14	85.911	51.811	1.658	.097	1.000
26-20	49.191	45.405	1.083	.279	1.000
26-10	52.056	52.671	.988	.323	1.000
26-15	54.735	47.873	1.143	.253	1.000
26-14	58.456	51.577	1.133	.257	1.000
20-10	2.865	52.036	.055	.956	1.000
20-15	5.544	47.174	.118	.906	1.000
20-14	9.265	50.928	.182	.856	1.000
10-15	-2.679	54.202	-.049	.961	1.000
10-14	-6.400	57.500	-.111	.911	1.000
15-14	3.721	53.140	.070	.944	1.000

Appendix J Post-hoc analysis for overall scores for wildlife and wellbeing with image 21 removed

Pairwise Comparisons of Photo Number

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests. Images without a hedge are coloured red. Significant differences are highlighted in yellow.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
19-16	25.573	44.109	.580	.562	1.000
19-23	-25.934	40.199	-.645	.519	1.000
19-27	-69.256	40.633	-1.704	.088	1.000
19-25	-174.191	41.347	-4.213	.000	.003
19-18	200.384	41.100	4.876	.000	. 000
19-24	-227.780	41.604	-5.475	.000	.000
19-12	232.355	46.736	4.972	.000	.000
19-17	251.373	40.412	6.220	.000	.000
19-13	269.956	46.237	5.838	.000	.000
19-28	-278.558	39.238	-7.099	.000	.000
19-22	-300.054	41.347	-7.257	.000	.000
19-26	-325.884	41.100	-7.929	.000	.000
19-20	-369.831	40.412	-9.152	.000	.000
19-10	372.373	47.265	7.878	.000	.000
19-15	375.232	42.746	8.778	.000	.000
19-14	378.939	46.237	8.196	.000	.000
16-23	-.361	44.474	-.008	.994	1.000
16-27	-43.683	44.866	-.974	.330	1.000
16-25	-148.618	45.514	-3.265	.001	.149
16-18	-174.811	45.290	-3.860	.000	.015
16-24	-202.207	45.748	-4.420	.000	.001
16-12	206.783	50.461	4.098	.000	.006
16-17	-225.800	44.666	-5.055	.000	.000
16-13	244.383	49.998	4.888	.000	.000
16-28	-252.985	43.607	-5.801	.000	.000
16-22	-274.482	45.514	-6.031	.000	.000
16-26	-300.311	45.290	-6.631	.000	.000
16-20	-344.258	44.666	-7.707	.000	.000
16-10	346.800	50.951	6.807	.000	.000
16-15	349.659	46.789	7.473	.000	.000
16-14	353.367	49.998	7.068	.000	.000
23-27	-43.322	41.028	-1.056	.291	1.000
23-25	-148.257	41.736	-3.552	.000	.052
23-18	174.450	41.491	4.205	.000	.004
23-24	-201.846	41.991	-4.807	.000	.000
23-12	206.422	47.081	4.384	.000	.002
23-17	225.439	40.810	5.524	.000	.000
23-13	244.022	46.585	5.238	.000	.000
23-28	-252.624	39.648	-6.372	.000	.000
23-22	274.121	41.736	6.568	.000	.000
23-26	-299.950	41.491	-7.229	.000	.000
23-20	343.897	40.810	8.427	.000	.000
23-10	346.439	47.606	7.277	.000	.000
23-15	349.298	43.123	8.100	.000	.000
23-14	353.005	46.585	7.578	.000	.000
27-25	104.935	42.154	2.489	.013	1.000
27-18	131.128	41.912	3.129	.002	.239

27-24	158.524	42.407	3.738	.000	.025
27-12	163.100	47.452	3.437	.001	.080
27-17	182.117	41.237	4.416	.000	.001
27-13	200.700	46.960	4.274	.000	.003
27-28	-209.302	40.088	-5.221	.000	.000
27-22	230.799	42.154	5.475	.000	.000
27-26	256.628	41.912	6.123	.000	.000
27-20	300.575	41.237	7.289	.000	.000
27-10	303.117	47.973	6.318	.000	.000
27-15	305.976	43.527	7.030	.000	.000
27-14	309.684	46.960	6.595	.000	.000
25-18	26.193	42.605	.615	.539	1.000
25-24	53.589	43.092	1.244	.214	1.000
25-12	58.165	48.065	1.210	.226	1.000
25-17	77.182	41.941	1.840	.066	1.000
25-13	95.765	47.580	2.013	.044	1.000
25-28	-104.367	40.812	-2.557	.011	1.000
25-22	125.864	42.843	2.938	.003	.450
25-26	-151.693	42.605	-3.560	.000	.050
25-20	195.640	41.941	4.665	.000	.000
25-10	198.182	48.580	4.080	.000	.006
25-15	201.041	44.195	4.549	.000	.001
25-14	204.748	47.580	4.303	.000	.002
18-24	-27.396	42.854	-.639	.523	1.000
18-12	31.972	47.853	.668	.504	1.000
18-17	50.989	41.697	1.223	.221	1.000
18-13	69.572	47.365	1.469	.142	1.000
18-28	-78.174	40.561	-1.927	.054	1.000
18-22	-99.671	42.605	-2.339	.019	1.000
18-26	-125.500	42.365	-2.962	.003	.415
18-20	-169.447	41.697	-4.064	.000	.007
18-10	171.989	48.369	3.556	.000	.051
18-15	174.848	43.964	3.977	.000	.009
18-14	178.556	47.365	3.770	.000	.022
24-12	4.576	48.287	.095	.925	1.000
24-17	23.593	42.195	.559	.576	1.000
24-13	42.176	47.804	.882	.378	1.000
24-28	-50.778	41.072	-1.236	.216	1.000
24-22	72.275	43.092	1.677	.093	1.000
24-26	-98.104	42.854	-2.289	.022	1.000
24-20	142.051	42.195	3.367	.001	.104
24-10	144.593	48.799	2.963	.003	.414
24-15	147.452	44.436	3.318	.001	.123
24-14	151.160	47.804	3.162	.002	.213
12-17	-19.017	47.263	-.402	.687	1.000
12-13	-37.601	52.331	-.719	.472	1.000
12-28	-46.202	46.263	-.999	.318	1.000
12-22	-67.699	48.065	-1.408	.159	1.000
12-26	-93.528	47.853	-1.955	.051	1.000
12-20	-137.476	47.263	-2.909	.004	.494
12-10	140.017	53.242	2.630	.009	1.000
12-15	-142.876	49.274	-2.900	.004	.508
12-14	-146.584	52.331	-2.801	.005	.693
17-13	18.583	46.769	.397	.691	1.000
17-28	-27.185	39.864	-.682	.495	1.000
17-22	-48.682	41.941	-1.161	.246	1.000
17-26	-74.511	41.697	-1.787	.074	1.000

17-20	-118.458	41.019	-2.888	.004	.528
17-10	121.000	47.786	2.532	.011	1.000
17-15	123.859	43.321	2.859	.004	.578
17-14	127.567	46.769	2.728	.006	.868
13-28	-8.602	45.759	-.188	.851	1.000
13-22	-30.098	47.580	-.633	.527	1.000
13-26	-55.928	47.365	-1.181	.238	1.000
13-20	-99.875	46.769	-2.135	.033	1.000
13-10	102.417	52.804	1.940	.052	1.000
13-15	-105.276	48.801	-2.157	.031	1.000
13-14	-108.983	51.886	-2.100	.036	1.000
28-22	21.497	40.812	.527	.598	1.000
28-26	47.326	40.561	1.167	.243	1.000
28-20	91.273	39.864	2.290	.022	1.000
28-10	93.815	46.798	2.005	.045	1.000
28-15	96.674	42.229	2.289	.022	1.000
28-14	100.381	45.759	2.194	.028	1.000
22-26	-25.829	42.605	-.606	.544	1.000
22-20	69.777	41.941	1.664	.096	1.000
22-10	72.318	48.580	1.489	.137	1.000
22-15	75.177	44.195	1.701	.089	1.000
22-14	78.885	47.580	1.658	.097	1.000
26-20	43.947	41.697	1.054	.292	1.000
26-10	46.489	48.369	.961	.336	1.000
26-15	49.348	43.964	1.122	.262	1.000
26-14	53.056	47.365	1.120	.263	1.000
20-10	2.542	47.786	.053	.958	1.000
20-15	5.401	43.321	.125	.901	1.000
20-14	9.108	46.769	.195	.846	1.000
10-15	-2.859	49.776	-.057	.954	1.000
10-14	-6.567	52.804	-.124	.901	1.000
15-14	3.708	48.801	.076	.939	1.000