LINKING SUSTAINABLE DRAINAGE SYSTEMS (SuDS) TOGETHER WITH ECOSYSTEM SERVICES AND DISSERVICES: NEW CONNECTIONS IN URBAN ECOLOGY

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Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, October 2015

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Acknowledgements

I am forever grateful to my main supervisor, Prof. Philip James, for his patience, understanding, forgiveness and expert supervision. I would also like to thank my co-supervisor, Prof. Miklas Scholz, for his expert advice and understanding. I would like to acknowledge the financial support from the Engineering and Physical Sciences Research Council (EPSRC) and thank the School of Environment and Life Sciences at the University of Salford for their excellent research facilities and resource access support. I would also like to thank the Red Rose Forest and the civil engineering undergraduate students for their provision of sample sites information.

I would like to thank Dr Tzoulas for his advice and method demonstration, Dr Gledhill for his advice on aquatic mesohabitat, Dr Armitage for his expert GIS guidance and Andjin for his sharing with me his statistics knowledge. I am also thankful for the PhD colleagues and the ecology undergraduate students who participated in the first and second trials of the two research methods. I must also thank Dr Bishop for organising the second trial in my absence.

I would like to thank Dr Hardman for giving me the opportunity to contribute to the UK NEA follow-on project and the Environment Agency for allowing me to participate in their inspirational Pollution Challenge competition and for giving me helpful advice.

I am grateful to both my former and current PhD colleagues for their assistance, inspiration and companionship. I offer my gratitude to Andjin, Barbara, Dr Bishop, Dr Chadwick, Dr Dennis, Dr Smith, Dr Gunawan, Enya, Hannah, Isabela, Lucy, Luiza, Rebecca, Ross, Vincent and Vinicius. I would also like to thank Dr Chadwick for proof-reading my thesis.

I am extremely grateful to my “brothers” (Alan, Azzy and Grant) who encouraged me to pursue this PhD, and the new friends I met in Manchester, in particular, Aleks and Jesus G., who motivated me to continue and supported me when I am most in need. Finally, I am forever indebted to my mum and dad for their unyielding love, and their continued emotional support.

Abbreviations

ANGST	-	Accessible Natural Greenspace Standard
AQ	-	Aquatic
BBC	-	British Broadcasting Corporation
BMP	-	Best Management Plan
BT	-	Built
BU	-	Bushes
BW	-	Bush (woody)
CBD	-	Convention of Biological Diversity
CDM	-	Construction, Design and Management
CIRIA	-	Construction Industry Research and Information Association
CMG	-	Cropped or Mowed Grass
CSO	-	Combined Sewerage Overflow
DAFOR	-	Dominant, Abundant, Frequent, Occasional, Rare
DF	-	Dog Faeces
EDINA	-	Edinburgh Data and Information Access
EDS	-	Ecosystem Disservices
EEU	-	Evidence of Educational Use
EH	-	Emergent Hydrophytes
EI	-	Educational Infrastructures
EofP	-	ease of parking
EofVM	-	evidence of vegetation management
EPA	-	Environmental Protection Agency
EPPS	-	Ecosystem Properties, Potentials and Services
ES	-	Educational Signs
EU	-	European Union
FH	-	Floating Hydrophytes
FL	-	Flowers
GF	-	Ground Flora
GPS	-	Global Positioning System
HGF	-	High grasses and forbs
HT	-	High Trees
IPCC	-	Intergovernmental Panel on Climate Change
IV	-	independent variables
LA	-	Legal Accessibility
LBLG	-	Low Bush and Long Grass
LC	-	Lower Canopy
LGF	-	Low grasses and forbs
LID	-	Low Impact Development
LT	-	Low Trees
MEA	-	Millennium Ecosystem Assessment
NA	-	Not applicable
NEA	-	National Ecosystem Assessment

NM	-	Not Managed
NPDES	-	National Pollutant Discharge Elimination System
OW	-	Open Water
P-value	-	The probability (P) of the likelihood that when observing two or more different events, any detectable difference between them is purely coincidental. P is from 0 to 1 (between 0% to 100% probabilities).
PA	-	Physical Accessibility
PEE	-	Proximity of the closest education establishment to sites / proximity of educational establishments
PM	-	Poorly Managed
PPT	-	Proximity to Public Transport
RC	-	Roman Catholic
RI	-	Recreational Infrastructures
RSPB	-	Royal Society for Protection of Birds
SEQ	-	South East Queensland
Sig.	-	Statistical significance, which is also know as the p-value
SL	-	Street Lights
SuDS	-	Sustainable Drainage Systems
TEEB ECOSYSTEMS AND BIODIVERSITY	-	The Economics of Ecosystems and Biodiversity
UC	-	Upper Canopy
UCIs	-	urban cooling islands
UHIM	-	Urban Heat Island Mitigation
UK	-	United Kingdom
US	-	United State
USA	-	United State of America
VOC	-	Volatile Organic Compound
WFD	-	Water Framework Directive
WM	-	Well Managed
WSUD	-	Water Sensitive Urban Design
WTP	-	Water Treatment Plant

Abstract

Increased flooding, urban diffuse pollution and habitat fragmentation are predicted as the climate changes and urbanisation increases; all will affect human and wildlife well-being negatively. Sustainable drainage systems (SuDS) have the potential to mitigate these effects and also provide additional amenity and biodiversity benefits. However, the current SuDS approach is site-specific and technically focused, hence, failing to generate anticipated amenity and biodiversity benefits. Therefore, a new SuDS approach is required.

A critical evaluation of the SuDS approach, the Ecosystem Approach, ecosystem services and disservices enabled an innovative SuDS Communication and Planning Framework to be created. The framework highlights key amenity and biodiversity related ecosystem services and disservices produced by vegetated SuDS systems, coupled with drivers affecting the production of these services and disservices.

This framework was validated by examining 49 representative sites within Greater Manchester using two ecosystem services and disservices variables assessment methods (vegetation structure cover-abundance and cultural ecosystem services and disservices appraisals). Resultant scores for five ecosystem services were calculated, where habitat for species and recreation ecosystem services were found to be synergistically linked to each other in a positive correlation. The result also enabled recommendations to be made that future vegetated SuDS development would benefit from involving local communities.

Overall the research produced practical Ecosystem Approach methods for SuDS development decision making, and the SuDS Communication and Planning Framework provides an innovative, easy to use tool to implement Ecosystem Approach compliant solutions for key SuDS stakeholders (planners, developers, designers, researchers and policy makers). Finally, the SuDS Communication and Planning Framework can now be found in the second part of the UK National Ecosystem Approach, UK NEA follow-on, as part of a series of Ecosystem Approach toolkits incorporated into the decision making processes for managing the urban environment in a sustainable way.

1. Introduction

Flooding and diffuse pollution have become worse, particularly in urban cities, due to climate change and increased urbanisation (Intergovernmental Panel on Climate Change, 2007; Pitt, 2007; Woods-Ballard *et al.*, 2007; Semadeni-Davies *et al.*, 2008; Defra, 2012). Similarly, habitat fragmentation (the disappearance, reduction in size and connectivity of natural wildlife habitats) has further intensified during the continuing growth of towns and cities (Millennium Ecosystem Assessment, 2005; UK National Ecosystem Assessment, 2011a, 2014).

Climate change modifies the water cycle, leading to changes in rainfall patterns (Astaraie-Imani *et al.*, 2012). This combined with increased urbanisation (reduction of porous surfaces and vegetation coverage) has led to increased surface runoff which, in turn, results in frequent breaching of the finite design capacity of the traditional containment and rapid transit drainage systems (Jones & Macdonald, 2007; Semadeni-Davies *et al.*, 2008; Defra, 2010; Willems *et al.*, 2012). These systems involving enclosed pipes that constrain and regulate surface runoff are no longer capable of protecting human health and wellbeing (Jones & Macdonald, 2007).

Concurrently, habitat fragmentation due to urbanisation places tremendous pressure on many animal species. Habitat fragmentation isolates wildlife populations, alters the conditions at habitat edges and triggers local species extinction (Millennium Ecosystem Assessment, 2005; Cain *et al.*, 2011; Dobbs *et al.*, 2014; Joint Nature Conservation Committee, 2014a). This can have a variety of negative effects on humans, such as increases in the populations of disease-carrying animals, more severe damage caused by flooding, and an increase in air pollution (Millennium Ecosystem Assessment, 2005; Cain *et al.*, 2011). Ultimately, our mental health is also negatively affected by loss of natural habitats (Millennium Ecosystem Assessment, 2005; Tzoulas *et al.*, 2007; Croucher *et al.*, 2008; Barton & Pretty, 2010, Konijnendijk, 2012; Maruthaveeran & Konijnendijk van den Bosch, 2014; Sandifer *et al.*, 2015). Overall, the three consequences of climate change and increased urbanisation (flooding, diffuse pollution and habitat fragmentation) bring about many negative consequences to biodiversity and human wellbeing.

In order to mitigate against floods, control diffuse pollution and reverse habitat fragmentation, less restrictive and more flexible drainage strategies that also serve with other Green Infrastructure elements (e.g. corridors) as wildlife buffer zones and connection for isolated wildlife habitats have been developed (Jones & Macdonald, 2007; Ellis, 2013). This is called the Sustainable Drainage System (SuDS) stormwater management approach.

The SuDS stormwater management approach has been shown to be a better solution to tackle excess flooding (through the effective use of the treatment train process – a series of processes applied in a sequence - to manage stormwater runoff) compared with traditional drainage methods (Woods-Ballard *et al.*, 2007; Ellis, 2013). However, the current SuDS design and planning practise is site-specific and, hence, limits the potential to provide amenity and biodiversity enhancements across the entire catchment ecosystem (Ellis, 2013). Consequently, this design and planning practise is unable to contribute to reversing habitat fragmentation.

In order to improve the amenity and biodiversity capacity of the SuDS stormwater management approach, a new SuDS design and planning practise based on the Ecosystem Approach has to be adopted. By integrating the Ecosystem Approach into SuDS via ecosystem services and disservices, the amenity and biodiversity across the catchment ecosystem will improve. This amenity and biodiversity improvement will in turn contribute to reversal of habitat fragmentation in urban areas.

The Ecosystem Approach recognises that humans are part of ecosystems, and their activities are subject to the natural limits and functioning of ecosystems (Maltby, 2010). The Ecosystem Approach gave rise to the use of ecosystem services (possible benefits from nature) and disservices (possible harm from nature) as the main tool in the management of nature.

The final product of this research will be the creation of the SuDS Communication and Planning Framework, which will benefit stakeholders such as planners, developers, designers, researchers and policy makers to plan SuDS developments using the Ecosystem Approach, taking account of the positive and negative aspects of nature. This new planning approach will enable SuDS to contribute to the effort to bring UK's water bodies to the “Good status” by 2021 or by 2027 at the latest, as required by the EU Water Framework Directive (WFD) deadlines (Environment Agency, 2014).

1.1. Aim and objectives

The overall purpose of the research is to enhance the SuDS stormwater management approach using the Ecosystem Approach and in particular the concepts of ecosystem services and disservices.

With this in mind, the aim of the research is to create a SuDS Communication and Planning Framework using both ecosystem services and disservices to facilitate the planning of new and retrofit SuDS developments. Accordingly, Table 1.1 details the objectives that will be carried out towards achieving the research aim.

Table 1.1 – Thesis objectives

Objective	**Action**	**Proposed method**
1. To conduct critical literature reviews to provide background and to establish the knowledge gap.	Critical analysis on issues (flooding, urban diffuse pollution and habitat fragmentation) caused by climate change and increased urbanisation. Critical examination of current stormwater drainage practises, the SuDS stormwater management approach, the Ecosystem Approach, of ecosystem services and disservices concepts in order to establish and fill in the knowledge gap – improve the existing SuDS approach so that it can better provide amenity and biodiversity benefits.	Critical literature review.
2. To establish links between the SuDS approach, ecosystem services and disservices.	Establish evidence for the creation of the SuDS Communication and Planning Framework to address the identified knowledge gap.	Critical literature review.
3. To develop and verify assessment methods for the SuDS Communication and Planning Framework validation.	Critical analysis to develop two new ecosystem services and disservices data collection methods (vegetation structure cover-abundance and cultural ecosystem services and disservices variables assessments) and verify them through two pilot studies (1: involves ecology students; 2: study involves ecology, geography, enginnering PhD researchers). Demonstrate the final version of the two methods via a case study at Castle Irwell. Collect the main research data (desk and site-based) in 49 green infrastructure sites (acting as proxies for vegetated SuDS sites) within Greater Manchester using the two methods. Develop weighted scoring procedures in order to calculate ecosystem services scores (habitat for species, urban heat island mitigation, carbon sequestration, recreation, education) based on collected data – forming evidence for the SuDS Communication and Planning Framework validation. Separate analysis for ecosystem disservices variables (bins, litter, dog faeces) data.	Critical literature review, two pilot studies, case study.

Continued…

Objective	Action	Proposed method
4. To analyse data collected from the two assessment methods in order to validate the SuDS Communication and Planning Framework.	Calculate ecosystem services scores using the scoring procedures developed as part of objective 3. Analyse scores statistically to validate the ecosystem services part of the framework. Analyse ecosystem disservices data collected for each sites statistically to validate the ecosystem disservices part of the framework.	Weighted ecosystem services scoring procedures, cross tabulation, independent samples T-test, Kruskal-Wallis and Pearson Chi-square tests.

According to Table 1.1, validation means to confirm whether the SuDS Communication and Planning Framework is scientifically robust and externally valid by statistically analysing the data collected using the vegetation structure cover-abundance surveys and the cultural ecosystem services and disservices variables appraisal methods. In contrast, verification means to confirm whether the two validation methods are workable and whether different researchers interpret the methods in the same way. In order to verify the two methods, a trial involving three researchers from different disciplines, together with a trial involving undergraduate students and a method demonstration case study will be performed.

1.2. Thesis structure

The entire research can be summed up using the flow diagram shown in Figure 1.1, which shows the logic behind the research, the research processes being carried out and the intended benefits of the research. The content of Figure 1.1 will be expanded and discussed in detail in subsequent chapters of the thesis (Figure 1.2).

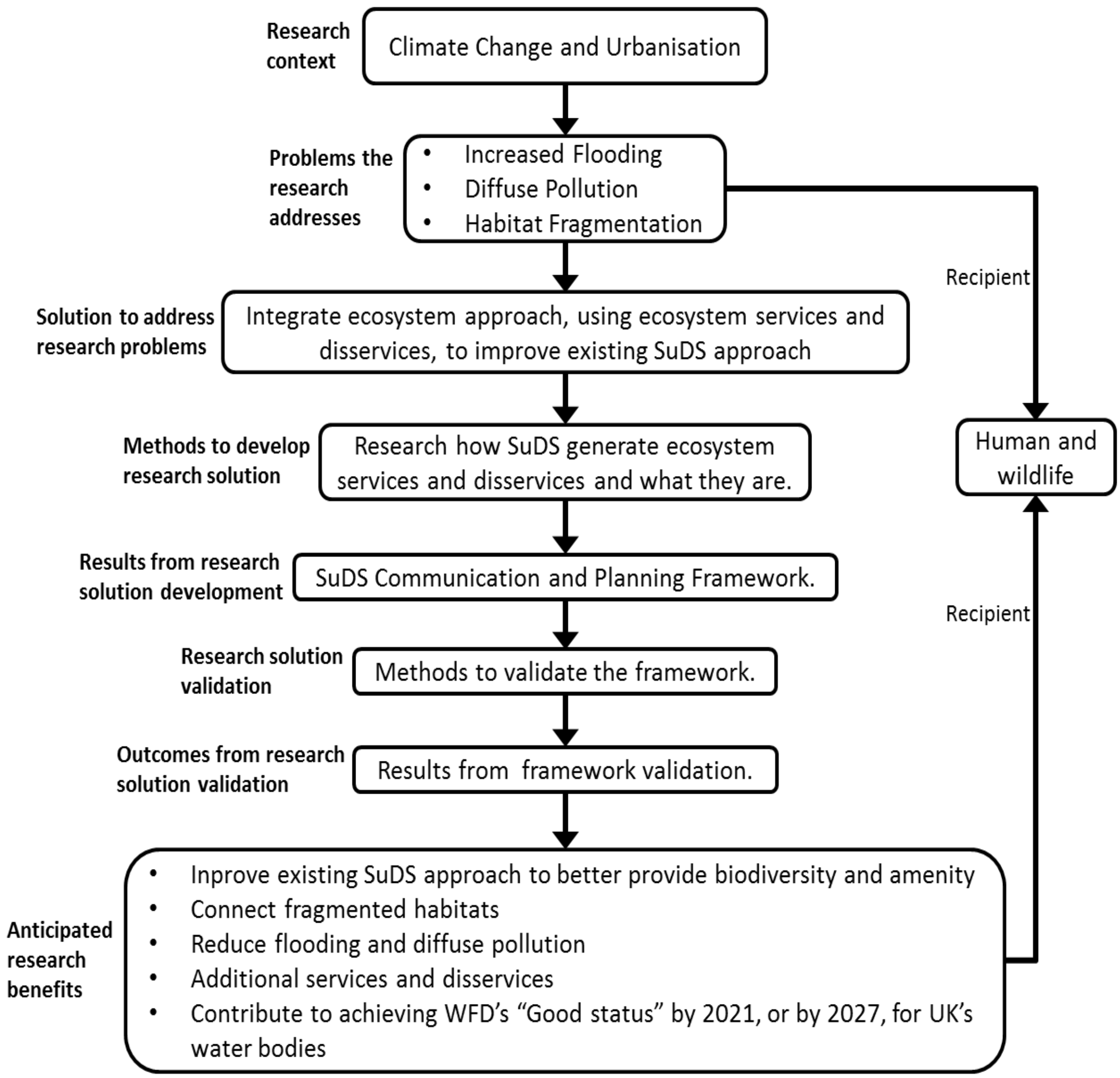

Figure 1.1– PhD research framework

Figure 1.2 shows the structure of the thesis, which aims to summarise the entire thesis and gives the reader a structured guide to follow.

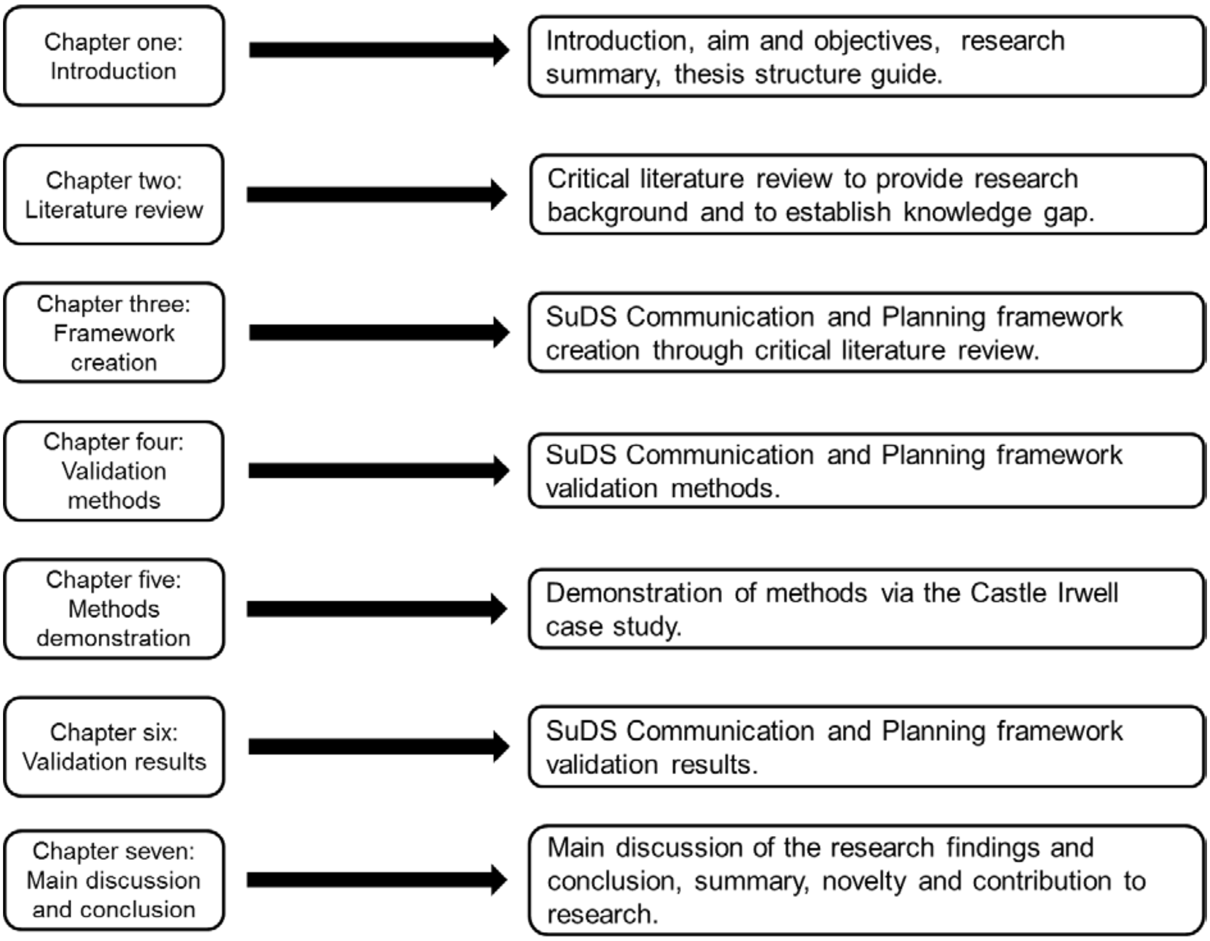

Figure 1.2 – Structure of thesis

Referring to Figure 1.2, chapter one of the thesis contains an introduction to the context of the research and a description of the problems this research is trying to solve – namely to produce a conceptual framework that will enhance the SuDS stormwater management approach by including ecosystem services and disservices that emerged from the Ecosystem Approach. The aim and the objectives of the research will also be stated in this chapter.

Chapter two contains critical literature reviews on how habitat fragmentation is worsening through increased urbanisation, how urbanisation and climate change cause increased flooding and diffuse pollution in the urban environment, and how the SuDS approach can be part of the solutions for tackling flooding and diffuse pollution in urban areas and contribute to reversing habitat fragmentation. The critical literature review will also cover the SuDS approach, the Ecosystem Approach, ecosystem services and ecosystem disservices.

Chapter three contains the critical literature review for the SuDS Communication and Planning Framework creation. This critical literature review establishes links between SuDS, ecosystem services and disservices, thereby allowing the creation of the SuDS Communication and Planning Framework.

Chapter four contains a detailed description of the methods involved in validating the SuDS Communication and Planning Framework. The methods being used are vegetation coverage abundance survey and cultural ecosystem services and disservices appraisals. Fourty nine sites within Greater Manchester were chosen for the validation of the framework.

Chapter five contains a case study that illustrates how the two validation methods detailed in Chapter four were used to gather data and produce ecosystem services scores. The site Castle Irwell was used as the method demonstration case study.

Chapter six contains the results of the SuDS Communication and Planning Framework validation. Ecosystem services scores (habitat for species, urban heat island mitigation, carbon sequestration, recreation and education) were produced for all 49 sites. These scores were analysed in accordance with different site area groups and different type of sites (aquatic or terrestrial). Analyses were also conducted to investigate the relationships between different ecosystem services (habitat for species versus recreation). Finally, the effects of ecosystem disservices variables (dog faeces and litter) were analysed to determine whether they influence the strength of the recreation ecosystem service.

Chapter seven of the thesis contains the overall discussions. The discussions include commentary on research limitations, the significance of the results have on biodiversity and amenity of vegetation SuDS systems, and on the merit of integrating the Ecosystem Approach, using ecosystem services and disservices, to enhance the existing SuDS approach. The main findings are: (1) vegetated SuDS types, especially stormwater wetlands, have the potential to generate the most habitat for species, urban heat island mitigation and carbon sequestration ecosystem services; (2) new vegetated SuDS developments should ensure the highest habitat for species ecosystem service possible (by providing permanent aquatic features and ensure the site is larger than 5500m^2) in order to also obtain the highest recreation ecosystem service; (3) new vegetated SuDS developments should have bins on-site because they can help reduce dog faeces and litter coverage; (4) new vegetated SuDS developments should ensure long term and sustained local community groups involvement to ensure proper site maintenance, maximise education opportunities, encourage community acceptance and enhance social integration. The chapter also describe the novelty and contribution of the research.

2. Literature review

2.1. Introduction

Chapter one contained the introduction to the thesis (Section 1), the aim and objectives of the research (Section 1.1), summary of the research (Figure 1.1) and the structure of the thesis (Figure 1.2).

In accordance with Figure 1.1, this chapter presents a critical review of the reasons behind the adoption of the SuDS stormwater management approach in urban environments in order to achieve the following objectives:

1. To highlight the research context (climate change and urbanisation).
2. To justify the problems the research addresses (increased flooding, diffuse pollution and habitat fragmentation)
3. To frame the solution to address the research problems (integrate Ecosystem Approach, using ecosystem services and disservices, to improve existing SuDS approach).

With regards to the first objective, the literature documenting the effects of increased urbanisation and climate change on flooding, diffuse pollution and habitat fragmentation is critically analysed in section 2.2. This section also contains the critical examination of the literature in order to establish how these three issues in turn affect urban drainage. This section concludes with formulating the case for changing the traditional, unsustainable, drainage approach to the SuDS stormwater management approach in order to mitigate the negative consequences (flooding, diffuse pollution and habitat fragmentation) triggered by climate change and increased urbanisation.

With regards to the second objective, critical analysis of the literature relating to the Sustainable Drainage Systems (SuDS) stormwater management approach is conducted in section 2.3, with the following sub-sections illustrating the details of the critical analysis:

- 2.3.1 – A breakdown of traditional drainage approach and the SuDS approach was conducted, to determine the advantages of the SuDS approach over the traditional approach.
- 2.3.2 – A critical appraisal of similar stormwater management approaches from other parts of the world, justifying the use of the SuDS approach in the UK based on legislative and climatic differences.
- 2.3.3 – A critical examination of the philosophy of the SuDS approach , differentiating the three main SuDS objectives in order to justify the observation that current SuDS planning and design practises fail to sufficiently achieve the amenity and biodiversity objective.
- 2.3.4 – A critical examination of the process behind the SuDS treatment train, justifying the Ecosystem Approach to be the natural way to improve SuDS decision making as a means of achieving the amenity and biodiversity objective.
- 2.3.5 – A critical analysis of the SuDS techniques, proving that vegetated SuDS techniques are the best at promoting amenity and biodiversity.

Section 2.3 is concluded by identifying the gaps present in current SuDS approach that prevent it from achieving the amenity and biodiversity objective.

Finally, with regards to the third objective, the chapter is concluded in section 2.4, by formulating the case to extend the current SuDS approach by integrating the Ecosystem Approach to enhance amenity and biodiversity of new and retrofit SuDS schemes.

2.2. Context

This section critically examines the literature-based evidence on how increased urbanisation and climate change affect urban drainage through increased flooding, amplified diffuse pollution in urban areas and the worsening of habitat fragmentation.

This section also critically assesses the existing SuDS literature to differentiate how the SuDS approach is better than traditional drainage practises at mitigatingthe negative consequences (flooding, diffuse pollution and habitat fragmentation) triggered by climate change and increased urbanisation.

2.2.1. Flooding due to increased urbanisation

Increasingly, flooding is problematic because of ever expanding cities (Intergovernmental Panel on Climate Change, 2007; Pitt, 2007; Woods-Ballard *et al.*, 2007; Defra, 2010). Urbanisation affects the natural hydrological processes (evaporation, evapotranspiration, groundwater recharge, infiltration and surface runoff) by altering the distribution of rainwater once it hits the ground (Konrad & Booth, 2005).

Prior to urbanisation, permeable topsoil and vegetation absorb the rainwater once it falls onto the ground. Vegetation takes up rainwater through roots and eventually evapotranspires the water back into the atmosphere (Begon *et al.*, 2009). Topsoil holds onto the remaining rainwater, from which it evaporates, or slowly infiltrates it into the ground below and recharges the groundwater systems, such as aquifers (Butler & Davies, 2011). At this stage, rainwater will flow slowly through the below ground waterbodies towards a receiving river, where it will contribute to the river's baseflow (Hamel *et al.*, 2013). Once the topsoil is eventually saturated, water will amass on the ground surface (ponds or puddles), where it will undergo evaporation or flow slowly into a receiving river (slowed down by the dense vegetation and the naturally uneven, permeable ground) (Woods-Ballard *et al.*, 2007; Butler & Davies, 2011). Pre-urbanisation's water balance is, overall, groundwater flow dominant.

In contrast, vegetated grounds post-urbanisation are transformed into a series of impermeable areas (covered by roads and buildings), and, with little or no vegetation, there is reduced evapotranspiration (Jones & Macdonald, 2007; Woods-Ballard *et al.*, 2007; Butler & Davies, 2011). Impermeable surfaces also severely reduce rainwater infiltration and groundwater recharge by blocking infiltration pathways previously provided by permeable soils (Konrad & Booth, 2005). Reduced infiltration and groundwater recharge subsequently lowers the baseflow (or lowflow during dry seasons) to rivers, which will have significant negative impacts on water pollution and aquatic habitats (Hamel *et al.*, 2013). With the infiltration pathway blocked by impermeable surfaces, the majority of rainwater will amass on the ground surface. This water will then flow into adjacent waterbodies, such as a river either directly or through shortened flow paths provided by urban drainage (Jones & Macdonald, 2007; Woods-Ballard *et al.*, 2007; Butler & Davies, 2011). The water going into the river, therefore, will be at a much accelerated rate compared to water arriving at the same river after the natural infiltration process, groundwater systems and through dense surface vegetation (Jones & Macdonald, 2007; Woods-Ballard *et al.*, 2007; Butler & Davies, 2011; Hamel *et al.*, 2013). Post-urbanisation's water balance is therefore surface water flow dominant.

Overall, the change of water balance redistribution from groundwater flow dominant to surface water flow dominant due to urbanisation has negative consequences to the receiving river. These negative consequences are most clearly illustrated by the rain storm hydrographs for pre and post-development scenarios (Figure 2.1).

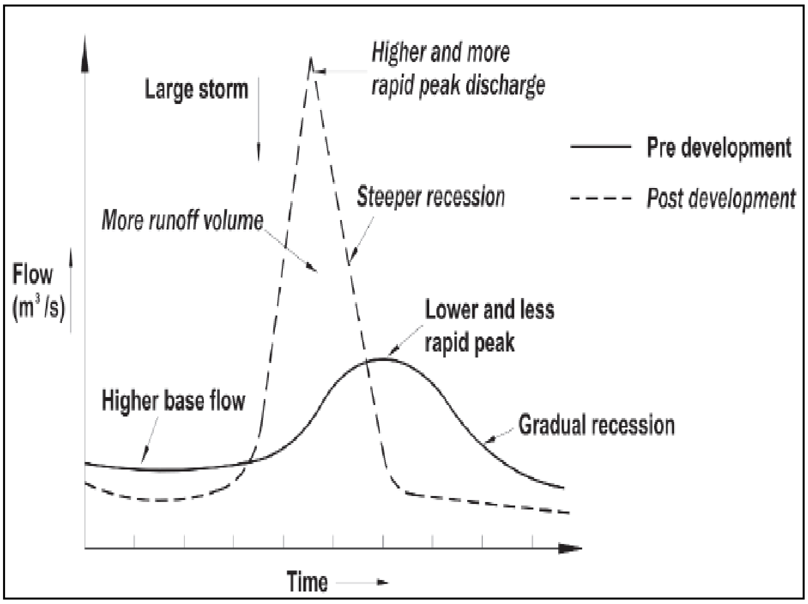

Figure 2.1 - The effect of urbanisation on the runoff hydrographs after a rain storm (Woods-Ballard et al., 2007, p.1-5, Figure 1.3)

After critically examining the runoff hydrographs shown in Figure 2.1, it is clear that in the pre-development scenario (solid line in Figure 2.1) water from the rain storm will be mostly absorbed into the high base flow as result of permeable soil allowing greater amount of water to percolate through and infiltrate into the ground (Woods-Ballard *et al.*, 2007). With the combination of evapotranspiration by dense vegetation and water retention by porous top-soil, the quantity and rate of peak discharge into the river is reduced. Consequently, water flow from the rainstorm is allowed to gradually and gently recede.

The opposite effect is realised after critically examining the runoff hydrograph for the post development scenario (dotted line in Figure 2.1). The water from the rain storm cannot contribute to the river's base flow because infiltration pathways are blocked by impermeable surfaces. The water instead accumulates on the ground surface, resulting in high runoff volume (Woods-Ballard *et al.*, 2007). However, this huge amount of water does not stay on the ground surface for long. The water, aided by smooth and compacted grounds and unhindered by vegetation, flows rapidly into the river. The large quantity and the increased discharge rate of the stormwater result in erosion of the river channel, river pollution and downstream flooding.

Overall, the SuDS stormwater management approach, in terms of flooding, can be used to compensate the loss of pre-development, permeable lands by providing extra capacity to temporarily store stormwater runoff and release the water gradually in a controlled manner (Woods-Ballard *et al.*, 2007; Dickie *et al.*, 2010; Moore & Hunt, 2012; Scholz *et al.*, 2013). The SuDS approach, if implemented correctly, can potentially reduce flooding and erosion of the receiving natural water bodies, and protect wildlife habitats (Jones & Macdonald, 2007; Butler & Davies, 2011; Defra, 2011).

2.2.2. Water Framework Directive

The Water Framework Directive (WFD) is an European Union (EU) legislation introduced in the year 2000, which was incorporated into UK law in 2003 (Environment Agency, 2014). The main objective of the WFD is to allow all the water bodies, surface and sub-surface, to improve in quality ecologically and chemically, within the entire EU (Joint Nature Conservation Committee, 2010). In order to achieve this objective, a series of deadlines are written into the WFD which all EU Member States (including the UK) must meet.

For the UK, the first deadline is that all the inland and coastal surface water bodies have to be at the "good surface water status" by 2015, allowing for some special cases, where revised deadlines will be activated (Parliamentary Archives, 2012).

To achieve the "good surface water status", inland water bodies must achieve the "good ecological status" by, firstly, having all of the biological aspects concerning the status (fish fauna, benthic invertebrates, aquatic flora) to be rated as good; secondly, the values for general conditions, such as temperature, oxygen, pH, nutrient conditions, and hydromorphology must be inside a specific good ecosystem functionality spectrum; thirdly, it must not exceed the environmental quality standards for river basin-specific pollutants (Richter et al., 2013). For artificial and heavily modified water bodies, the "good ecological potential" concept is applied instead of the "good ecological status". This allows continued human usage and the hydromorphological standard that must be achieved is thus lowered. Applying the "good ecological potential" concept instead of the good ecological status makes sense because naturalising these heavily altered water bodies would incur costs that far outweight the potential benefits that naturalisation can achieve (Richter et al., 2013).

Alongside the good ecological status or potential concepts, the water body must also achieve the good chemical status by satisfying the EU quality standards for 33 priority substances as set out in Annex X of the directive 2008/105/EC (European Parliament and Council, 2000 in Richter et al., 2013); some pollutants that are detailed within the directive 2006/11/EC (European Parliament and Council, 2006a in Richter et al., 2013); and nitrate in accordance with the EU Nitrate Directive 91/676/EEC (European Council 1991 in Richter et al., 2013).

Unfortunately, the “good status” was not anticipated to be achieved by 2015 for many cases. This is because many rivers in the UK are highly modified due to past industrialisation legacy and continue to suffer from diffuse pollution, also due to past industrial activities and ongoing urbanisation. Therefore, the natural conditons (e.g. temperature, oxygen, pH, nutrient conditions, hydromorphology) of the water bodies are either technically unfeasible improve or cannot do so without incurring disproportionate costs. The revised deadline was thus activated and water bodies will have to reach the “good status” by 2021 for interim targets or 2027 for full compliance (Environment Agency, 2014).

2.2.3. Diffuse pollution due to increased urbanisation

Urban diffuse pollution, according to Defra (2012), is water pollution associated with urban settlements (including motorway runoff and mine waters). It is released unintentionally by non-point sources within towns and cities and is often unlicensed. It is very difficult to identify who is responsible for and who is best placed to improve the situation, because there are many sources, and they are highly varied. Examples of the sources include:

- Road run-off,
- Discharges from surface water drains, and
- Foul waste pipes wrongly connected with surface water drains.

These three sources contribute to urban runoff. According to Defra's 2012 consultation, urban runoff is a high priority urban diffuse pollution source. Figure 2.2 contains a map showing the areas most affected by activities contributing to urban runoff in the North of England.

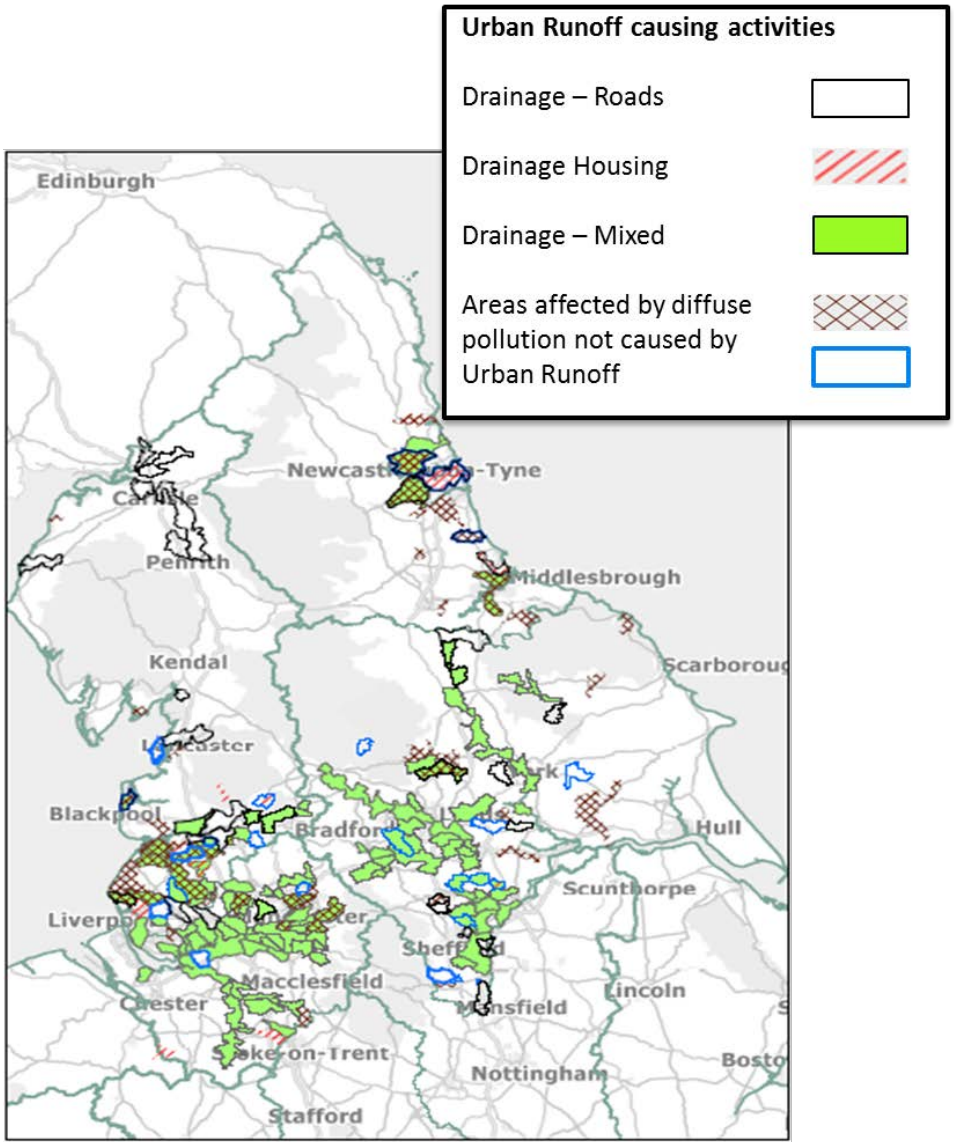

Figure 2.2 - Areas most affected by activities contributing to Urban Runoff (Environment Agency, 2013a)

By examining the map shown in Figure 2.2, it is clear that the areas most affected by urban runoff causing activities are major cities in the North of England, such as Manchester, Liverpool, Sheffield, Leeds and Newcastle, and their surrounding urban regions. Figure 2.3 contains data showing surface water bodies in the North of

England currently failing the EU Water Framework Directive's (WFD) "good surface water status" due to various urban diffuse pollution activities.

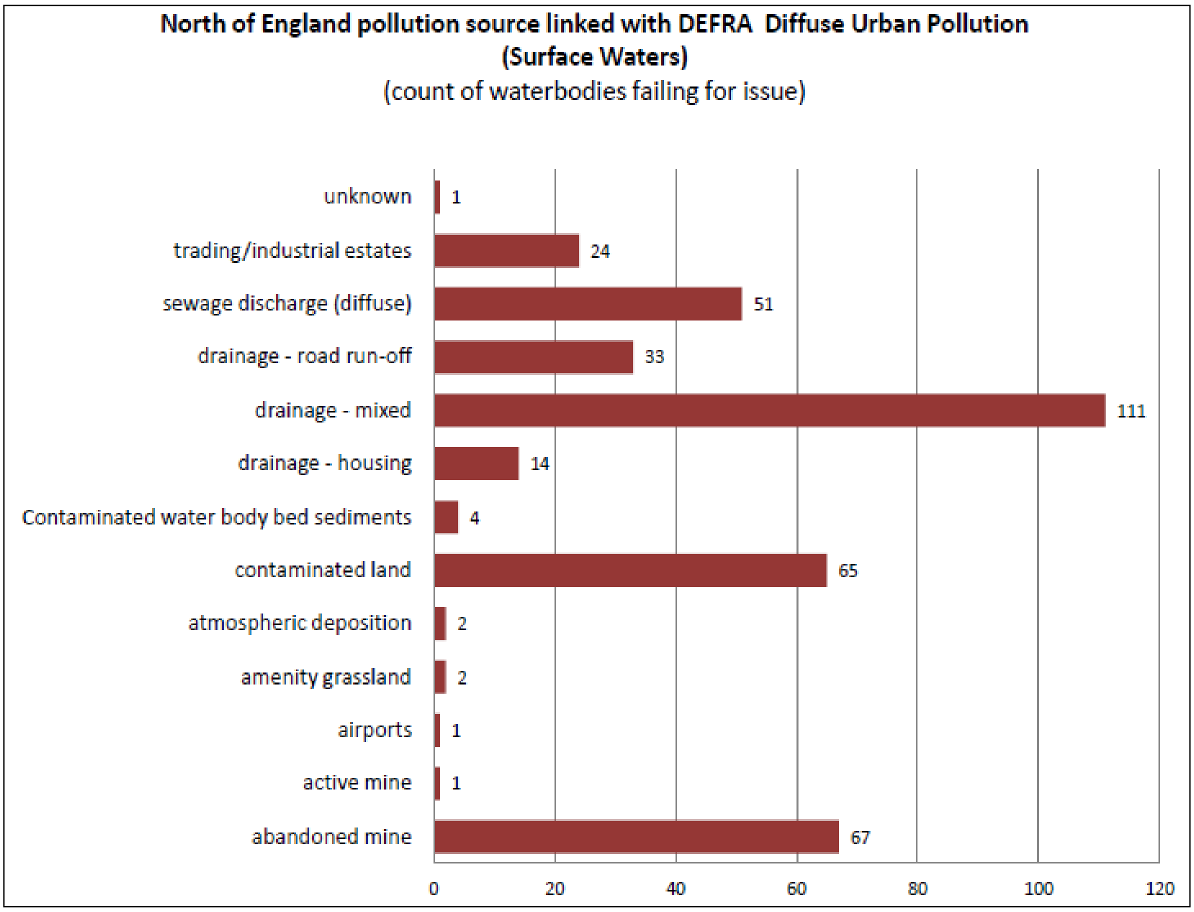

Figure 2.3 - North of England pollution source linked with Defra Diffuse Urban Pollution (Environment Agency, 2013b).

Please note that only "drainage – road run-off", "drainage – mixed" and "drainage – housing" are activities the SuDS approach is designed to tackle. Therefore focus is put on these three activities in this research.

By critically analysing the data within Figure 2.3 it is calculated that 376 surface water bodies in the North of England are currently failing the 2015 WFD deadline due to various urban diffuse pollution activities. The SuDS approach is designed to tackle three activities in particular:

- Drainage – road run-off, which contributes to 33 failing surface water bodies, according to Figure 2.3.
- Drainage – mixed, which contributes to 111 failing surface water bodies, according to the data in Figure 2.3.
- Drainage – housing, which contributes to 14 failing surface water bodies, according to the data in Figure 2.3.

These three urban diffuse pollution activities contribute to the pollution of 158 surface water bodies, according to Figure 2.3. Therefore, the SuDS stormwater management approach can potentially improve 42% of the surface water bodies in the North of England (Figure 2.3). The situation in the North of England is broadly similar to the rest of England outside London due to similar climate, geography, geology, development history, and population size. Therefore, similar improvement to the surface water bodies for the rest of England, aside from London, can potentially be achieved through the adoption of the SuDS stormwater management approach.

2.2.4. Habitat fragmentation due to urbanisation

The definition of habitat fragmentation for this research is the partitioning of areas with natural land cover into smaller, separate and isolated patches (within a matrix of dissimilar habitats) through urbanisation, which is the replacement of vegetated land cover by impermeable surfaces (Collinge, 1996; Fahrig, 2003; Fischer & Lindenmayer, 2007; Douglas & James, 2015; Mitchell *et al.*, 2015).

Habitat fragmentation is a major problem worldwide, leading to the decrease of habitat area, isolation of populations, alteration of the conditions at habitat edges, and loss of biodiversity (Bierregaard Jr *et al.*, 1992; Collinge, 1996; Millennium Ecosystem Assessment, 2005; Cain *et al.*, 2011; Joint Nature Conservation Committee, 2014a).

There are two types of approach to the study of habitat fragmentation: the species-oriented and pattern-oriented approaches (Fischer & Lindenmayer, 2007). The study of habitat fragmentation (the pattern-oriented approach) started with the island biogeography theory (MacArthur & Wilson, 1967). This influenced seminal ecological projects such as the fragmentation of tropical rainforest project started by Thomas Lovejoy in 1979. This project examined the biodiversity within intentionally divided and separated small patches of forests (Bierregaard Jr *et al.*, 1992), and documented the effects of the distance between fragments, the size of fragments, and the physical and biological effects at fragment edges. This and other equally important research contributed to habitat fragmentation becoming a major research theme in conservation and restoration ecology (Bierregaard Jr *et al.*, 1992; Fischer & Lindenmayer, 2007; Cain *et al.*, 2011; Mitchell *et al.*, 2015).

A critical review of the literature indicates that habitat fragmentation due to urbanisation can have the following detrimental effects on biodiversity (Bierregaard Jr *et al.*, 1992; Millennium Ecosystem Assessment, 2005; Laurance, 2008; Cain *et al.*, 2011; Joint Nature Conservation Committee, 2014a; Mitchell *et al.*, 2015):

- Loss of habitat area;
- Loss of top predators, which indirectly results in the loss of a population control mechanism;
- Small patches of habitats are susceptible to edge effects, which lead to the increase of invasive species abundance, increased rates of inbreeding and genetic drift;
- Spatial isolation of population, which increases the risk of local native species extinction.

Habitat loss can have a variety of negative effects on humans (Millennium Ecosystem Assessment, 2005; Cardinale *et al.*, 2012; Gottdenker *et al.*, 2014). For example, Lyme disease carrying ticks (*Acarina*) population can expand due to loss of predators (Sol *et al.*, 2013; Uspensky, 2014; Mitchell *et al.*, 2015). The replacement of natural habitat with impervious surfaces can increase damage caused by flooding due to the loss of vegetation which previously slowed down stormwater runoff rate (Millennium Ecosystem Assessment, 2005; Woods-Ballard *et al.*, 2007). The loss of vegetation coverage also increases air and water pollution (Maiti & Agrawal, 2005; Millennium Ecosystem Assessment, 2005; Qadir *et al.*, 2013; Räsänen *et al.*, 2013; Cohen *et al.*, 2014; Baró *et al.*, 2015; Paul & Nagendra, 2015). Our mental health is negatively affected due to loss of natural green spaces (Millennium Ecosystem

Assessment, 2005; Tzoulas *et al.*, 2007; Croucher *et al.*, 2008; Barton & Pretty, 2010; Konijnendijk, 2012; Maruthaveeran & Konijnendijk van den Bosch, 2014; Sandifer *et al.*, 2015).

Habitat fragmentation can be reversed by employing techniques from ecological restoration, the study of which was founded by Anthony Bradshaw (Bradshaw, 1987 in Bradshaw, 1996). However, the term "ecological restoration" was first introduced in the late 1980s by John Aber and William Jordan (Douglas & James, 2015). It stems from conservation ecology, and its main aim is to reverse the effects of fragmentation by increasing habitat connectivity (Hilderbrand *et al.*, 2005; Vaughn *et al.*, 2010; Cain *et al.*, 2011; Sudduth *et al.*, 2011; Douglas & James, 2015). The ecological concepts concerning restoration ecology are disturbance, genetic diversity, succession (biological community composition recovers over time following a disturbance event), community assembly theory (similar sites can develop different biological communities depending on order of arrival of different species) and habitat fragmentation (Vaughn *et al.*, 2010; Douglas & James, 2015). Finally, ecological restoration has a botanical bias (Douglas & James, 2015). Therefore, planting vegetation to create links (habitat corridors) and buffer zones is an effective technique that connects and protects fragmented habitats, thus allowing opportunities for wildlife to move around and utilise previously isolated, broken habitats.

Habitat corridors can help maintain biodiversity in a fragmented landscape. They are areas that connect two or more separated habitats, thus allowing organisms and matter to move around (Cain *et al.*, 2011; Mitchell *et al.*, 2015). Buffer zones (areas with less stringent controls on land use, yet which are at least partially compatible with many species resource requirements) can also help maintain biodiversity in a fragmented landscape (Marshall & Moonen, 2002; Cain *et al.*, 2011; Mitchell *et al.*, 2015; Street *et al.*, 2015). Creating habitat corridors and buffer zones is part of the overall ecological restoration solution in urban areas (Collinge, 1996; Vaughn *et al.*, 2010; Sudduth *et al.*, 2011; Douglas & James, 2015)

Throughout the majority of the last century there was a significant decline in pond and wetland numbers in the UK, caused by urbanisation (Brown *et al.*, 2010; UK

National Ecosystem Assessment, 2011a; Janse *et al.*, 2015), which led to habitat loss and fragmentation for many of the UK's aquatic ecosystems.

SuDS schemes have the potential to support and enhance freshwater biodiversity in urban areas. For example, in Dunfermline, Scotland, research found that SuDS ponds can support up to 47 invertebrate species (Briers, 2014). Jackson & Boutle (2008) showed that colonisation by aquatic fauna occurred at newly constructed SuDS swales and ponds at Upton, Northampton, UK. Therefore, detached River Nene Valley aquatic and semi-aquatic species can use these new SuDS features as places of refuge (Jackson & Boutle, 2008). Viol *et al.* (2009) observed that similarly rich and varied aquatic macroinvertebrate communities (displaying comparable composition and structure at the family level) can be supported by highway stormwater ponds, despite their poor water quality due to their pollutant retention function, compared with surrounding natural ponds (Viol *et al.*, 2009). This makes the highway stormwater ponds being studied ideal wildlife refuges and connections to fragmented aquatic habitats (Viol *et al.*, 2009). Moore and Hunt (2012) examined the richness and diversity of vegetated and aquatic macroinvertebrate communities in stormwater wetlands and ponds in the US. They found more than 50 vegetation species and 31 macroinvertebrate families are present in the stormwater ponds and wetlands surveyed (Moore & Hunt, 2012). They also noted that emergent vegetation plays a vital role in attracting some insect families (Odonatae) and provide a link to the vegetation at the littoral zones (or fringed wetlands), so that more diverse groups of macroinvertebrates can colonise, which helps provide different trophic functions to the ecosystem (Moore & Hunt, 2012).

Aside from ground level, vegetated SuDS systems, green roofs can also act as connections to fragmented habitats. For example, Kim (2004) examined how the Ecosystem Approach green roofs can reconnect fragmented habitats by studying the case of using different green roof designs (wetland, meadow, scrub, woodland, vegetable field) to form an urban eco-network in Seoul. Oberndorfer *et al.* (2007) reviewed ecosystem services that can be provided by green roofs, and found that they can support a variety of invertebrate and avian communities in several countries. Rare and uncommon species of insects such as beetles, ants, bugs, flies, bees, spiders, and leafhoppers have been recorded on green roofs around the world, which are positively linked to vegetation species richness (Brenneisen, 2006; Oberndorfer *et al.*, 2007). Bates *et al.* (2013) observed that green roofs with a range of substrate types can support a variety of species because they can act as different types of microhabitats, offering "disturbance refugia" for challenging environmental conditions, such as droughts (Bates *et al.*, 2013). When looking at habitat connectivity in terms of pollination, green roofs are comparable with ground-based green infrastructures, such as parks and prairies (Tonietto *et al.*, 2011), even though they contain smaller and less diverse pollinators (Ksiazek *et al.*, 2012).

Finally, various studies have shown the SuDS approach (especially when using vegetated SuDS techniques) can contribute to reversing habitat fragmentation by acting as wildlife corridors and buffer zones to connect and protect separated and isolated habitats due to urbanisation (Kim, 2004; Brenneisen, 2006; Oberndorfer *et al.*, 2007; Jackson & Boutle, 2008; Viol *et al.*, 2009; Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012; Moore & Hunt, 2012; Bates *et al.*, 2013; Briers, 2014). Nevertheless, stand-alone SuDS systems are not adequate in contributing to the efforts to reverse habitat fragmentation. SuDS sites (in particular sites that contain "micro-and meso-vegetative SuDS systems") should work with existing urban green infrastructures (parks and gardens) as together they can provide not only a fully sustainable surface water management system, but also connectivity to habitats fragmented by urbanisation, in order to recover previously lost urban biodiversity (Ashton *et al.*, 2010; Wise *et al.*, 2010; Natural England, 2011; Ellis, 2013; Graham *et al.*, 2013).

2.2.5. The effects of climate change on urban drainage

The natural water cycle is currently being altered by the effect of increasing global mean temperature caused by climate change (Intergovernmental Panel on Climate Change, 2007; US Environmental Protection Agency, 2014). There are many consequences, and one is the modification of earth's precipitation patterns (Astaraie-Imani *et al.*, 2012). One of the effects of this will be the increase in risk of flooding and diffuse pollution in urban areas. The effects of climate change on urban drainage include:

- The rise of inland flash floods due to storminess and sea level rise put extra pressure on existing drainage infrastructure (Intergovernmental Panel on Climate Change, 2007);
- Increased frequencies of heavy rainstorms produce more severe floods, which cause disruption to transport, businesses and residents of the affected areas (Intergovernmental Panel on Climate Change, 2007);
- Traditional sewer systems are designed with limits on how much stormwater they can handle, therefore they are vulnerable to rainfall extremes, as the design did not take account of what will happen when the limits are exceeded (Willems *et al.*, 2012);
- For cities that have a substantial combined sewer system, increased rainfall can worsen the problem of overflows of untreated wastewater flowing into receiving natural waterbodies (Semadeni-Davies *et al.*, 2008);
- Increased rainfall can raise the peak flow volume and increase flood risk (Semadeni-Davies *et al.*, 2008).

The SuDS stormwater management approach is deemed to be part of the solutions in combating the changing rainfall patterns caused by climate change (Carter *et al.*, 2015). With the promotion of a more natural way of draining surface runoff, the worst effects of climate change that affect the urban environment can be mitigated.

2.3. The Sustainable Drainage Systems stormwater management approach

Section 2.2 contains detailed reasons for adopting the SuDS stormwater management approach. In section 2.3, a critical analysis of the SuDS stormwater management approach is presented. Table 2.1 illustrates the summary of the six issues discussed in this section.

Table 2.1 – Summary of issues in section 2.3

Issues	**Summary**
1	A comparison is made of the traditional drainage approach with the SuDS approach, highlighting the advantages of the SuDS approach over the traditional approach in combating the issues relating to climate change and increased urbanisation.
2	An appraisal of similar stormwater management approaches from other parts of the world is performed and the legislative and climatic differences which enable the SuDS approach to be used in the UK are made clear.
3	An analysis is made of the philosophy of the SuDS approach by discussing the three main SuDS objectives in order to highlight the fact that current SuDS planning and design practises fails to sufficiently achieve the amenity and biodiversity objective.
4	An analysis of the SuDS treatment train is performed, highlighting how the Ecosystem Approach is the natural way to improve SuDS decision making in order to achieve the amenity and biodiversity objective.
5	An introduction to the biodiversity concept is made, linking biodiversity with the Ecosystem Approach and presenting the case for enhancing biodiversity in SuDS planning and design which will in turn increase amenity of the concerned area.
6	A critical analysis the SuDS techniques is performed and the conclusion that vegetated SuDS techniques are the best at promoting amenity and biodiversity is made clear.

Section 2.3 concludes by highlighting the gaps present in current SuDS approach that prevents it from achieving the amenity and biodiversity objective.

2.3.1. Traditional drainage strategies

Water is essential to life on earth, and the hydrologic cycle (Figure 2.4) is one of the main continuous process cycles that govern the natural environment.

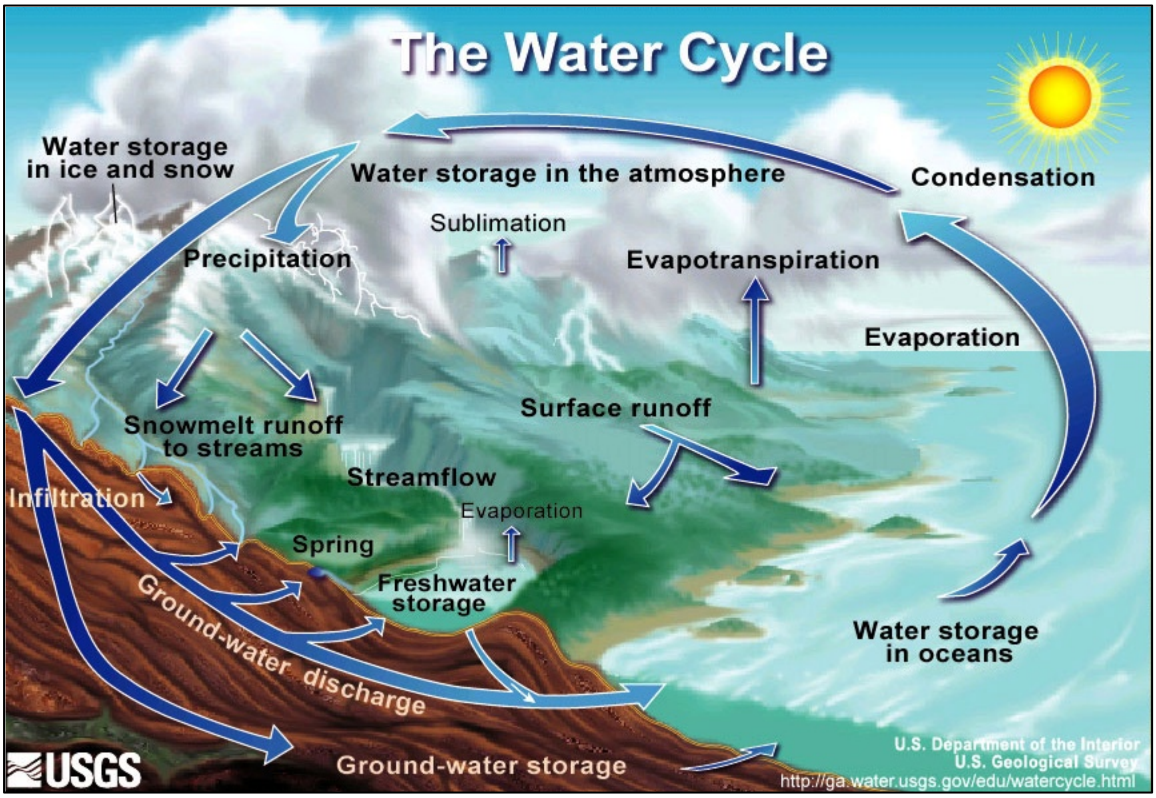

Figure 2.4 – The water cycle (U.S. Geological Survey, 2014)

As shown in Figure 2.4, water is always moving and changing between vapour, liquid and ice repeatedly through natural processes such as evaporation, condensation and precipitation. Humans interact with the natural water cycle mainly in two ways: first, water abstraction for personal and industrial usages; second, impermeable surfaces (buildings, roads, car parks) land coverage alters and prevents natural drainage processes such as infiltration and evapotranspiration, putting pressure on other processes, such as surface run-off and groundwater recharge (Chocat *et al.*, 2004; Butler & Davies, 2011).

Due to human interaction with the water cycle, two types of water are formed that require drainage (Chocat *et al.*, 2004; Butler & Davies, 2011):

- Wastewater from personal and industrial uses. This type of water will cause pollution and health risks if not drained properly.
- Stormwater from precipitation of any kind that falls on built-up areas. Often this type of water is contaminated with certain pollutants, which if not

drained properly, can cause health risks as well as inconvenience, damage and flooding.

Overall, adequate drainage is an essential element of human settlements. The second type of interaction between human and the water cycle (stormwater drainage) is the area of the research focus.

Heavily designed and engineered drainage systems form an important aspect of the urban water cycle (Figure 2.5), allowing control and management of rainwater so that human beings are able to live in healthy and safe settings (Chocat *et al.*, 2004; Butler & Davies, 2011).

Figure 2.5 - The urban water cycle (SEQ Healthy Waterways Partnership, 2009)

For this research, the focus is on the treatment of stormwater runoff in urban areas, as highlighted in Figure 2.6.

Traditionally, stormwater runoff is treated by society in a very repressive way by constraining and regulating it as much as possible (Jones & Macdonald, 2007). In urban areas, the aim has been to dispose of stormwater that built up on the impermeable surfaces, such as roads and car parks, as quickly as possible by directing it in underground enclosed pipes, such as the combined and separated sewer systems found in most cities in the UK. The combined systems mix wastewater and stormwater together to be directed, eventually, to the nearest natural water body (Figure 2.9).

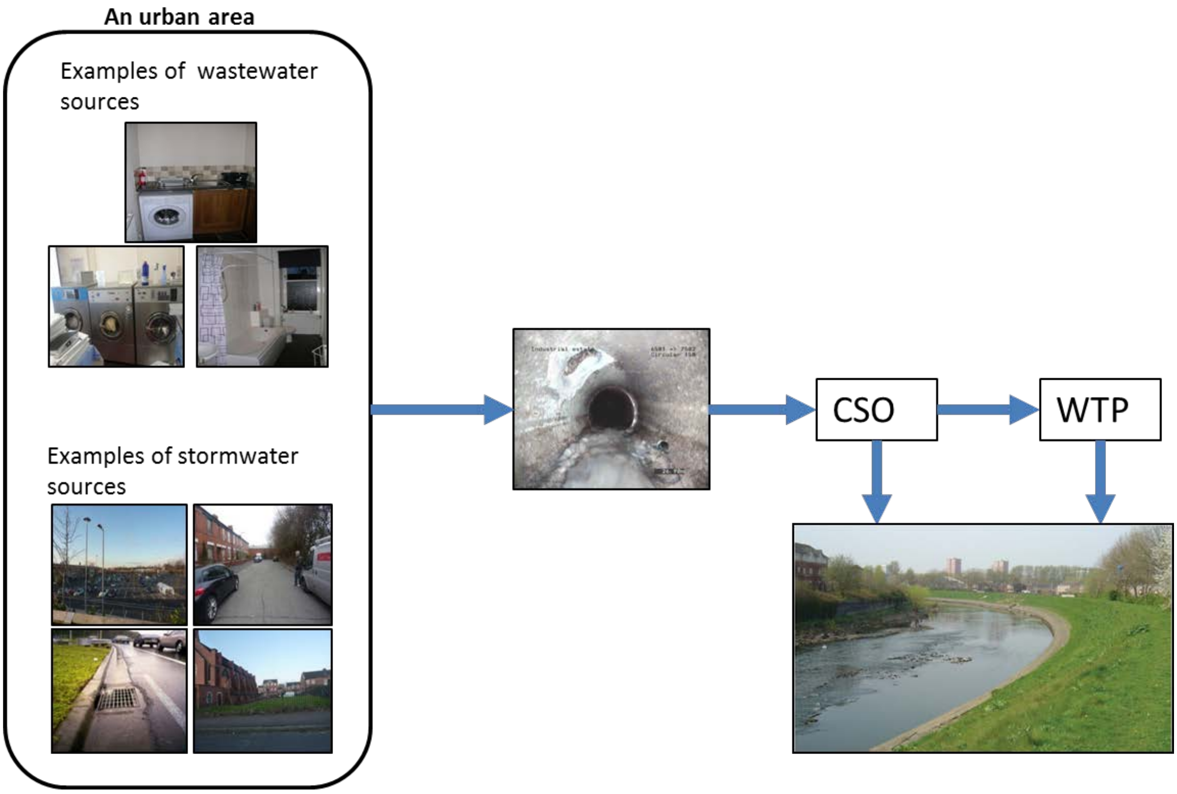

Figure 2.6 - An illustration of a combined waste and storm water system (adapted from Butler & Davies, 2011).

Note: CSO = Combined Sewerage Overflow. WTP = Wastewater Treatment Plant. James et al. (2012) provided the road drain and river photos within the figure, otherwise, the photos are original.

The system shown in Figure 2.6 is not adequate because when heavy rainstorm events occur due to the effects of urbanisation and climate change, as discussed in section 2.2, the system is easily overwhelmed by the surface stormwater runoff. The result is wastewater overflowing into urban areas.

With the issue of wastewater overflowing in mind, the separated systems approach was invented to keep waste and stormwater apart by directing wastewater firstly to wastewater treatment plants using a network of pipes, whilst separately directing stormwater to the nearest natural water body using another network of pipes (Figure 2.7).

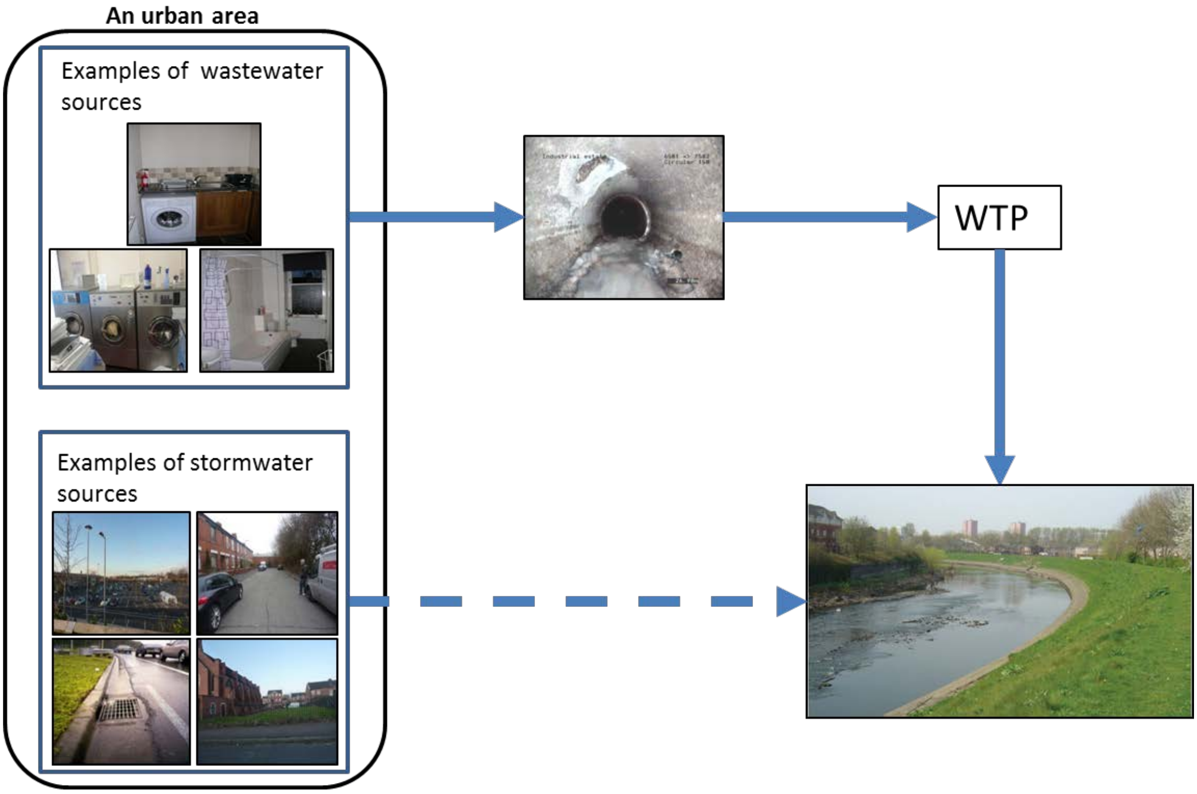

Figure 2.7 - An illustration of a separated waste and stormwater system (adapted from Butler & Davis, 2011).

Note: James et al. (2012) provided the road drain and river photos within the figure, otherwise, the photos are original.

The two systems illustrated in Figures 2.6 and 2.7 are restraining the naturally free-flowing characteristic of water. This is because the predominantly pollution free stormwater is forced to go into prearranged paths (drainage pipes) buried underneath streets, which only suits the way water managers intend it to behave (Jones & Macdonald, 2007). This has led to stormwater drainage designs that focus predominantly on heavily engineered solutions, such as concrete pipes and manholes. These systems lead the water to the nearest natural water bodies as quickly as possible, hence removing the risk of flooding and diffuse pollution in the affected areas. However, with water being diverted into the nearest water course, the problems of flooding and diffuse pollution due to increased urbanisation and climate change (as discussed in section 2.2) were only moved downstream, and this has led to severe pollution of rivers and costal water bodies (Chocat *et al.*, 2004; Brown *et al.*, 2010; Defra, 2010; Butler & Davies, 2011; Marine Conservation Society, 2011; Newton, 2013; Carter *et al.*, 2015). A solution must be found so that stormwater can be controlled, managed and treated in a way that mimics how nature treats rainwater. With this in mind, the SuDS stormwater management approach was developed.

2.3.2. Sustainable Drainage Systems (SuDS)

The Sustainable Drainage Systems (SuDS) stormwater management approach is an engineering concept, replacing traditional drainage strategies, to mitigate flooding in urban areas. Traditionally, its purpose is to manage stormwater runoff from impermeable surfaces so that the risks posed to the natural environment are eliminated, minimised or mitigated (Woods-Ballard *et al.*, 2007). The SuDS stormwater management approach also aims to enhance the natural environment, for the benefits of both human and wildlife, as far as possible (Woods-Ballard *et al.*, 2007).

Aside from flood prevention, the SuDS approach can treat stormwater at source, on site and regionally, to ensure better water quality upon its eventual release, thus reducing diffuse pollution from entering into natural waterbodies (Woods-Ballard *et al.*, 2007; Ellis, 2013). The SuDS approach can prevent, reduce or mitigate flooding and improve water quality using naturally occurring methods such as attenuation, evapotranspiration, infiltration and retention (Woods-Ballard *et al.*, 2007; Ellis, 2013; Uzomah *et al.*, 2014).

The SuDS approach has three main objectives: to manage the quantity of urban run-off, to control the quality of urban run-off, and to enhance amenity and biodiversity of the concerned area (Woods-Ballard *et al.*, 2007; Ellis 2013; Scholz *et al.*, 2013; Department for Environment, Food and Rural Affairs, 2014; Uzomah *et al.*, 2014). Overall, quantity, quality, amenity and biodiversity govern all SuDS designs and implementations.

The key documentations on the SuDS approach are all published by an umbrella organization, the Construction Industry Research and Information Association (CIRIA), and they are widely used in the industry as standard SuDS design practises. The following are some of the key CIRIA SuDS documents:

- R156 – Infiltration drainage: manual of good practice (Bettes, 1996),
- C521 – Sustainable urban drainage systems: design manual for Scotland and Northern Ireland (CIRIA, 2000),
- C582 – Source control using constructed pervious surfaces: hydraulic, structural and water quality performance issues (Pratt *et al.*, 2002),
- C609 – Sustainable drainage systems – hydraulic, structural and water quality advice (Wilson *et al.*, 2004),
- C625 – Model agreements for sustainable water management systems (Shaffer *et al.*, 2004),
- C635 – Designing for exceedance in urban drainage, good practice (Balmforth *et al.*, 2006),
- C697 – The SuDS manual (Woods-Ballard *et al.*, 2007),
- C687 – Planning for SuDS, making it happen (Dickie *et al.*, 2010),
- C712 – The benefits of large species trees in urban landscapes: a costing, design and management guide (Armour *et al.*, 2012),
- C713 – Retrofitting to manage surface water (Digman *et al.*, 2012).

The document "C697 – The SuDS manual" (Woods-Ballard *et al.*, 2007) sets out all the key SuDS issues and it is often used as the industry standard source of information in any SuDS design works. Therefore, details of the SuDS approach in this section are mostly provided by the SuDS manual.

There are other similar concepts of stormwater management in existence. The three most familiar are Best Management Practises, also known as BMP, Low-Impact Development, also known as LID, and Water-Sensitive Urban Design, also known as WSUD. Both Best Management Practises (more recently it is being referred to as stormwater control measures (Uzomah *et al.*, 2014)) and Low-Impact Development are concepts developed in USA, whereas Water-Sensitive Urban Design is used in Australia and Netherlands predominately (Rijke *et al.*, 2008).

In the United States, the main driver for stormwater management is the Clean Water Act. It was created in 1972 and modified in 1987 to take account of stormwater runoff (Carey *et al.*, 2012). This is where the term Best Management Practices was first mentioned (Carey *et al.*, 2012). Initially, BMPs are techniques created to tackle point source industrial wastewater discharges (Carey *et al.*, 2012) but since stormwater runoff was understood to carry substantial environmental threats, BMPs were incorporated within the National Pollutant Discharge Elimination System (NPDES) Stormwater Program, which was derived after the amendment to the Clean Water Act in 1987 (Carey *et al.*, 2012).

The Best Management Practises stormwater management techniques cover non-structural and structural practises and processes which aim to minimise, eradicate or prevent pollutants from stormwater runoff reaching the receiving waters (Fletcher *et al.*, 2014) and focuse on water quality and flood improvements. Overall, they are techniques designed to manage stormwater sustainably.

The Low-Impact Development stormwater management approach details planning and design management concepts that aim to sustainably control and manage stormwater using Best Management Practices techniques (Hoyer *et al.*, 2011). The Low-Impact Development concept was derived prior to the SuDS approach, but both are similar because they aim to manage surface stormwater runoff using spatially distributed Best Management Practises techniques, such as stormwater wetlands, permeable pavements and ponds. The aim for both LID and SuDS is to utilise these BMP techniques in order to mimic the natural drainage pattern and return the hydrology of the site to as close to its natural hydrology as possible (Young *et al.*, 2009; Fletcher *et al.*, 2014; US Environmental Protection Agency, 2014).

The Water-Sensitive Urban Design water management approach is broader than SuDS because it deals with the entire water cycle and integrates the management of it into urban design and planning, whereas the SuDS approach only looks at the management of predominately surface stormwater (Ashley *et al.*, 2013). Water-Sensitive Urban Design has three main objectives: firstly, with regards to potable water – it aims to ensure a sustainable supply; secondly, with regards to wastewater – it aims to work to improve the treatment; and thirdly, with regards to stormwater – it aims to ensure the recycling and reuse of stormwater as much as possible (Rijke *et al.*, 2008; Hoyer *et al.*, 2011; Ashley *et al.*, 2013).

In the UK, the management of wastewater and stormwater are directed by the Water Framework Directive (Xenarios & Bithas, 2007; Joint Nature Conservation Committee, 2010). Groundwater management is also governed by the Water Framework Directive (Joint Nature Conservation Committee, 2010). The focus of this research is solely on surface stormwater management; therefore, only the surface stormwater management capacity of the Water-Sensitive Urban Design approach was examined.

Australia is prone to severe droughts (Coutts *et al.*, 2012). Consequently, the Water-Sensitive Urban Design approach has a strong emphasis on minimising the use of treated drinking water imported into urban areas by capturing and reusing rainwater as much as possible (Rijke *et al.*, 2008; Healthy Waterways, 2011; Coutts *et al.*, 2012; Stephenson, 2013). As for the Netherlands, the emphasis in implementing Water-Sensitive Urban Design is to mitigate flooding caused by increased urbanisation and climate change, and improve the country's water quality, as demanded by European legislation (Rijke *et al.*, 2008).

European legislation, especially the Water Framework Directive, drive the UK's approach to stormwater management (Joint Nature Conservation Committee, 2010). Additionally, the SuDS approach was introduced into the existing planning regime in England in early 2015 (Milne, 2014; Johnston, 2015). This was in response to requirements documented in the Schedule three of the Flood and Water Management Act 2010 (Flood and Water Management Act, 2010). The 2010 Act came about after Sir Michael Pitt's 2007 flood review (Pitt, 2007).

Overall, SuDS, BMP, LID and WSUD are very similar in many aspects. Technological advances and lessons learned can be applied across all four approaches but the environmental legislation and climate in the UK are different from USA, Australia and Netherlands. Therefore, the SuDS approach is the preferable stormwater management approach to be employed in this country to enable its waterbodies to achieve the WFD's "good surface water status" by 2027 (Joint Nature Conservation Committee, 2010).

2.3.3. SuDS objectives

Referring back to the SuDS objectives mentioned in section 2.3.2, there are general principles illustrated in the SuDS manual (Woods-Ballard *et al.,* 2007) for ensuring these objectives are met, and they are summarised in Table 2.2.

Table 2.2 – The principles for ensuring that the SuDS objectives are met (Woods-Ballard et al., 2007, p3-2, 10, 13 and 15)

SuDS objectives	**Principles**
Quantity	Ensure that the flood protection provided by the SuDS scheme truly defends the people and the property it is designed to protect. Ensure that the SuDS scheme does not make flooding of the natural waterbody it is connected to, and at any point (upstream or downstream) within the associated catchment, worse than at present.
Quality	Ensure the SuDS treatment train is applied, with the proper SuDS techniques, to tackle water pollution arising from various users and activities.

Continued…

Amenity	Three principles must be adhered to in order to successfully achieve the amenity aspect of the third SuDS objective. They are health and safety, visual impact and amenity benefits. Health and safety Ensure appropriate SuDS design practises (e.g. ensure ponds have shallow side slopes, shallow shelving edges and strategically placed vegetation, and ensure swales do not have a side slope ratio that is steeper than 1 in 3) are followed to prevent risks of drowning and vehicles overturning into swales. Ensure risk assessments are performed for all SuDS sites and are appropriate to meet the requirements of the Construction, Design and Management (CDM) Regulations 2015. Visual impact and amenity benefit Ensure the SuDS site is aesthetically pleasing by using vegetation and appropriate landscaping. Ensure open water areas are connected to recreational areas. Ensure the SuDS site is aesthetically pleasing all year round by employing appropriate maintenance techniques and plan. Ensure the local people are informed and educated about how the SuDS systems can drain the site and offer environmental protections. This especially applies to local homeowners.
Biodiversity	Ensure native plants are used in SuDS constructions. Ensure SuDS sites are located either in or near natural or semi natural sites, such as natural ponds and wetland habitats. Ensure that natural drainage systems are either retained or enhanced. Ensure a range of wildlife habitat types are created. In pond designs, ensure a shallow, aquatic bench is built-in. This aquatic bench should lie no more than 0.45m below the permanent water level, and it should be at least 1m wide. Ensure the appropriate maintenance and management plan is implemented.

With regards to the health and safety aspects of the SuDS objective principles detailed in Table 2.2, there is no mention of the risk of mosquitos accumulating in SuDS sites. This is because, within the SuDS manual, mosquito accumulation is simply dismissed as not to be a concern because they do not pose West Nile or malaria risks (Woods-Ballard *et al.*, 2007, p3-13). However, invasive mosquitos are becoming an increasing threat to the UK due to climate change (Medlock & Leach, 2015). Therefore, better mosquito prevention measures should be adopted in new SuDS planning and designs. Stating mosquito accumulation as an ecosystem disservice is a good starting point to address this potential public health concern.

Lyme disease is not mentioned anywhere in the SuDS manual, although is a well-known public health issue, especially due to habitat fragmentation via urbanisation (Gottdenker *et al.*, 2014; Uspensky, 2014; Vlachopoulou, 2014; Donohoe *et al.*, 2015; Medlock & Leach, 2015; Mitchell *et al.*, 2015). Consequently, improvement to the existing SuDS approach needs to be made in order to militate against the risk of Lyme disease spreading via the increase in tick population due to the provision of natural habitats via the use of SuDS schemes in urban areas.

The SuDS manual listed five other health and safety risks that SuDS sites can pose to the public (Woods-Ballard *et al.*, 2007, p3-14): sudden inflow of water; drowning; falling from inlet or outlet structure; entering inlet or outlet pipes; contact with contaminated sediments. Various risk lowering procedures are recommended in the SuDS manual, with the aim to avoid, to reduce or to mitigate against the five risks (Woods-Ballard *et al.*, 2007). Particular risk lowering procedures concerning open waterbodies are also detailed in the SuDS manual, for example, the provision of safe access, fencing around open waterbodies, avoiding the use of slopes steeper than 1:3, providing education boards for public information, providing lifesaving equipment and so on (Woods-Ballard *et al.*, 2007, p3-14).

However, the health and safety risks covered in the SuDS manual are not enough to cover all the issues associated with human interaction with SuDS sites, as these sites are a form of urban green infrastructure, or green space (US Environmental Protection Agency., 2007; Ashton *et al.*, 2010; Wise *et al.*, 2010; Natural England, 2011; Odefey *et al.*, 2012; Ellis, 2013; Graham *et al.*, 2013; Struck *et al.*, 2010 cited in Fletcher *et al.*, 2014; Wolf, 2015). Aside from physical health and safety risks, there are also psychological factors that have not been discussed within the SuDS manual (Millennium Ecosystem Assessment. 2005; Tzoulas *et al.*, 2007; Croucher *et al.*, 2008; Barton & Pretty, 2010; Konijnendijk, 2012). These psychological issues are illustrated in the following list:

- The link between attractiveness of green space and motivation for exercise (English Nature, 2003; Croucher *et al.*, 2008);
- The effects of urban green space on social integration (Germann-Chiari & Seeland, 2004);

- The association of the fear of crime and antisocial behaviours with green space and environmental design (Petherick, 2001; Maruthaveeran & Konijnendijk van den Bosch, 2014);
- Human being's interaction with nature and the effects it has on mental health of humans, such as biophilia, stress reduction and attention restoration (Croucher *et al.*, 2008; Konijnendijk, 2012; Sandifer *et al.*, 2015).

Overall, there is a need to improve current SuDS planning and design practises in order to address the health and safety risks and psychological issues identified with regards to SuDS development.

In terms of sites that utilise the SuDS stormwater management approach, there are many potential benefits to local people that SuDS can offer. These potential benefits include:

- Lowering of local air temperature due to the reduction of the urban heat island effects (Oberndorfer *et al.*, 2007; Woods-Ballard *et al.*, 2007; Scholz & Uzomah, 2013);
- Access to fresh water if the site utilises rainwater harvesting techniques (Costanza et al., 1998; Woods-Ballard *et al.*, 2007; The Economics of Ecosystems and Biodiversity, 2010; Liebman *et al.*, 2011; Burkhard *et al.*, 2012; Scholz & Uzomah, 2013);
- Providing opportunities for growing food as part of urban horticulture (Madaleno, 2002; Woods-Ballard *et al.*, 2007; Freshwater Society & Mississippi Watershed Management Organization, 2011; Liebman *et al.*, 2011; Moore & Hunt, 2011; Uzomah *et al.*, 2014); and
- Providing recreation opportunities for local residents and education opportunities for students from local educational establishments (Loughner, 2004; Grehl & Kauffman, 2007; UK National Ecosystem Assessment, 2011a; Moore & Hunt, 2012).

Although the SuDS manual mentioned recreation as a potential benefit from SuDS schemes, it did not provide design and planning guidelines as to how to ensure

SuDS schemes provide recreational opportunities for local people. Consequently, there is a need to detail how recreational opportunities can be introduced in new SuDS sites by examining other urban green spaces and green infrastructure design guidelines (English Nature, 2003; Fields in Trust / National Playing Fields Association, 2008; Ellis, 2013).

Sites that utilise the SuDS approach can also make a difference to the well-being of the wider population and contribute to the benefits of global humanity. The potential national and global benefits of SuDS include:

- Improvements to global climate due to biological carbon sequestration provided by the vegetation grown on the SuDS sites (Alonso *et al.*, 2012; Moore & Hunt, 2013; Uzomah *et al.*, 2014);
- Improved food security due to increased pollination opportunities (Tonietto *et al.*, 2011; UK National Ecosystem Assessment, 2011a; Ksiazek *et al.*, 2012; Uzomah *et al.*, 2014); and
- Enhanced biodiversity due to the improvements in habitats for wild animals and improvements on water quality of natural water bodies (Millennium Ecosystem Assessment, 2005; Woods-Ballard *et al.*, 2007; UK National Ecosystem Assessment, 2011a; Moore & Hunt, 2012; Uzomah *et al.*, 2014).

Overall, a new approach to SuDS planning and design is required to address issues not being dealt with in current SuDS design and planning practises.

2.3.4. The SuDS treatment train

The SuDS approach, as well as being a water management concept, is also a water treatment concept. It treats stormwater via the SuDS treatment train (Figure 2.12). There are four stages to the treatment train: one, prevent stormwater runoff (prevention); two, manage stormwater runoff at source (source control); three, manage stormwater in a local area (site control); four, manage stormwater from several sites (regional control). Figure 2.8 shows the SuDS treatment train diagrammatically in a simplified urban water cycle.

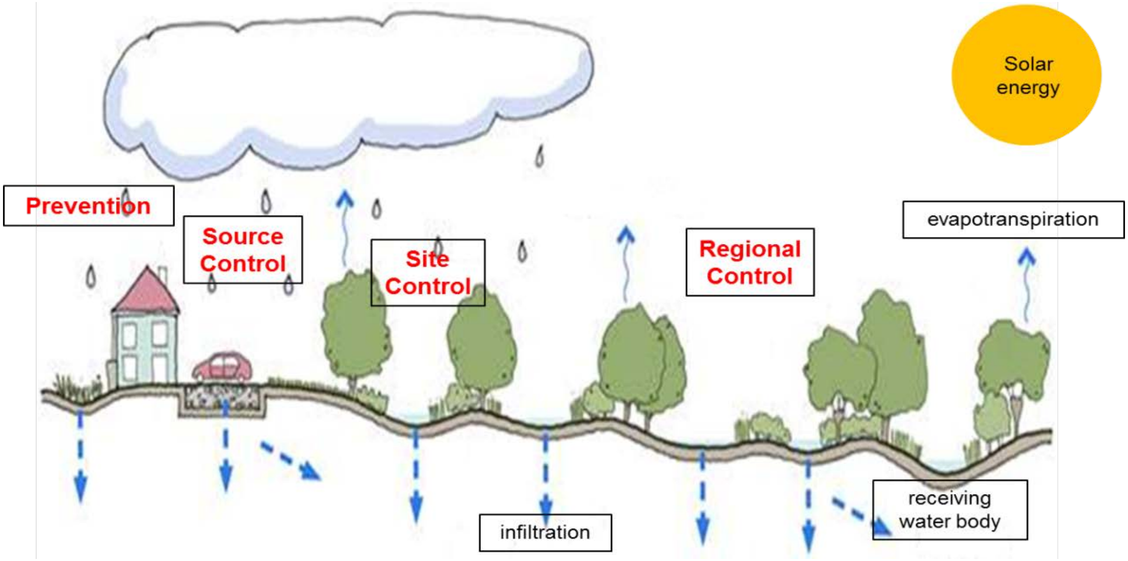

Figure 2.8: The SuDS treatment train in a simplified urban water cycle (Susdrain, 2012)

As can be seen in this simplified urban water cycle in Figure 2.8, the SuDS treatment train fits perfectly within it. The water cycle, as shown in Figure 2.8, is a natural ecosystem process that supports ecosystem biodiversity and generates many ecosystem services and disservices that can directly and indirectly affect human well-being and the health of the natural environment (de Groot *et al.*, 2002; Brauman *et al.*, 2007; The Economics of Ecosystems and Biodiversity, 2011; UK National Ecosystem Assessment, 2011b). The water cycle can also affect a vast spatial area. For example, the water that arrives at the receiving water body in Figure 2.8 will eventually make its way out to the sea, crossing multiple catchment areas. Therefore, the SuDS stormwater management approach has the potential to affect the biodiversity and amenity of areas that are out with its designed spatial coverage, subsequently contributing to the connection of previously fragmented natural habitats (Kim, 2004; Oberndorfer *et al.*, 2007; Jackson & Boutle, 2008; Viol *et al.*, 2009; Natural England, 2011; Moore & Hunt, 2012; Ellis, 2013; Graham *et al.*, 2013). However, current SuDS design and practise is too site oriented and engineering focused (Ellis, 2013), therefore, failing to consider the impact on the ecosystem. Consequently, the current SuDS approach must be improved in order to tackle challenges in the ecosystem.

2.3.5. Outline of SuDS techniques

In order to realise the SuDS treatment train concept, as shown in Figure 2.8, ten standard Best Management Practises techniques were employed : rainwater harvesting; pervious pavements; filter strips; swales; green roofs; ponds; infiltration devices; wetlands; underground storage; bioretention. These techniques were originally developed in the United States (Carey *et al.*, 2012) and are now adopted as standard stormwater management techniques which are outlined in SuDS literatures (Woods-Ballard *et al.*, 2007). Similar techniques, albeit with different names, are found in standard Low-Impact Development and Water-Sensitive Urban Designs literatures (Rijke *et al.*, 2008; Department of Planning and Local Government, 2010; Hoyer *et al.*, 2011; Fletcher *et al.*, 2014; United States Environmental Protection Agency, 2014; Jia *et al.*, 2015).

In Appendix A there are outline, brief descriptions of each SuDS technique, the treatment train stages each belongs to, and their water treatment processes. The main source of information is from CIRIA's SuDS Manual (Woods-Ballard *et al.*, 2007), with amendments. Other sources are stated within Appendix A.

The water treatment processes stated in Appendix A are naturally occurring phenomena, with additional manufactured components added in to mimic the functions of missing components. For example, a geomembrane is added in to mimic natural porous soils (Woods-Ballard *et al.*, 2007). Table 2.3 detailed examples of plants to be planted on sites employing vegetated SuDS techniques in the UK.

Table 2.3 – Examples of plants that are recommended for planting on sites that employ vegetated SuDS techniques (Graham et al., 2013)

SuDS techniques	**Examples of recommended plants**
Green roof	Shrubs Californian lilac (*Ceanothus*), Broom (*Cytisus scoparius*), Dogwood (*Cornus sanguinea*) Herbaceous perennials and grasses Yarrow (*Achillea millefolium*), Bent grasses (*Agrostis* spp.), Bugle (*Ajuga reptans*)
Filter strip	Herbaceous perennials and grasses Yarrow (*Achillea millefolium*), Bent grasses (*Agrostis* spp.), Black knapweed (*Centaurea nigra*)
Swale	Herbaceous perennials and grasses Crested dogs tail (*Cynosurus cristatus*), Bent grasses (*Agrostis* spp.), Viper's bugloss (*Echium vulgare*)
Ponds and Wetlands	Trees Alder (*Alnus glutinosa*), Downy birch (*Betula pubescens*), Bird cherry (*Prunus padus*) Shrubs Hazel (*Corylus avellana*), Hawthorn (*Crataegus monogyna*), Dogwood (*Cornus sanguinea*) Herbaceous perennials and grasses Yarrow (*Achillea millefolium*), Bent grasses (*Agrostis* spp.), Black knapweed (*Centaurea nigra*) Erect marginal plants Yellow iris (*Iris pseudacorus*), Gipsywort (*Lycopus europaeus*), Various species of rush (*Juncus* spp.), Marsh woundwort (*Stachys palustris*) Low growing marginal plants Amphibious bistort (*Persicaria amphibia*), Brooklime (*Veronica beccabunga*), Fleabane (*Pulicaria dysenterica*), Marsh-marigold (*Caltha palustris*)
Bioretention	Trees Downy birch (*Betula pubescens*), Bird cherry (*Prunus padus*), Rowan (*Sorbus aucuparia*) Shrubs Hazel (*Corylus avellana*), Hawthorn (*Crataegus monogyna*), Dogwood (*Cornus sanguinea*) Herbaceous perennials and grasses Bugle (*Ajuga reptans*), Columbine (*Aquilegia* sp.), Aster (*Aster* sp.)

The plants listed in Table 2.3 are only examples of the vegetation that SuDS techniques can support. They also promote various different animal species, support different types of habitats and provide ecological niches to serve their needs (Millennium Ecosystem Assessment, 2005; Oberndorfer *et al.*, 2007; Woods-Ballard *et al.*, 2007; Tonietto *et al.*, 2011; UK National Ecosystem Assessment, 2011a; Moore & Hunt, 2012; Briers, 2014; Uzomah *et al.*, 2014). Overall, vegetated SuDS techniques are most suited to promoting amenity and biodiversity; therefore, the new SuDS approach that incorporates the Ecosystem Approach should be built around vegetated SuDS techniques.

2.4. Conclusion

Summarising section 2.2.3, habitat fragmentation due to urbanisation can be reversed using tools such as habitat corridors and buffer zones from restoration ecology. Also illustrated in section 2.2.3, vegetated SuDS techniques such as stormwater wetlands and ponds can act as corridors and buffer zones for wildlife. Therefore, integrating the Ecosystem Approach to the existing SuDS approach should focus solely on vegetated SuDS techniques in order to effectively connect fragmented habitats, and enhance amenity and biodiversity for the concerned area and also for the entire catchment ecosystem.

As mentioned in section 2.3.3, the SuDS approach can enhance the amenity and biodiversity of the whole catchment ecosystem by acting as wildlife corridors and buffer zones. One suggestion is that vegetated SuDS sites should be incorporated as part of urban green infrastructures (for example, stormwater retention ponds can be integrated into urban parks, stormwater wetlands can be linked to local nature reserves). Therefore, vegetated SuDS sites can act as connections for divided habitats and hence reverse habitat fragmentation caused by urbanisation and amplified through climate change (Ellis, 2013). In order to integrate vegetated SuDS sites into existing urban green infrastructures, analysis should be performed so that common biodiversity elements can be identified, features beneficial to people using the sites should be recognised, and traits that may prevent site usage should also be acknowledged.

Current SuDS design and practice is too engineering focused, therefore, it cannot realise its biodiversity enhancement potential. A new planning approach must be found to incorporate into the existing SuDS approach in order to enable it to fulfil its amenity and biodiversity objective. Consequently, efforts are being made to incorporate the Ecosystem Approach, through the use of ecosystem services, into SuDS (Mak *et al.*, 2012; Scholz *et al.*, 2013; Uzomah *et al.*, 2014), and linking vegetated SuDS with existing urban green infrastructures (Ashton *et al.*, 2010; Wise *et al.*, 2010; Natural England, 2011; Ellis, 2013; Graham *et al.*, 2013).

The Ecosystem Approach is a landscape management and planning strategy that aims to provide an "integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (Joint Nature Conservation Committee, 2014b). Ecosystem Services are provisions from the natural environment that are beneficial to human beings (Costanza et al., 1998; Daily, 1997; de Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2005; Boyd & Banzhaf, 2006; The Economics of Ecosystems and Biodiversity, 2010; UK National Ecosystem Assessment, 2011b; Hanson *et al.*, 2012; Gómez-Baggethun & Barton, 2013), such as habitat for species and water purification (Costanza et al., 1998; Daily, 1997; de Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2005; The Economics of Ecosystems and Biodiversity, 2010; UK National Ecosystem Assessment, 2011b).

Overall, the SuDS stormwater management approach can do much more than merely manage and control the quantity and quality of stormwater. It can enhance biodiversity and amenity across a wide geographical area, such as a whole catchment ecosystem. Therefore, improving the current SuDS approach by incorporating the Ecosystem Approach using the ecosystem services framework, and integrating vegetated SuDS with existing urban green infrastructures, will enable SuDS development decision making to take account of ecosystems it will affect.

3. SuDS Communication and Planning Framework creation

3.1. Introduction

Chapter 2 contained a justification for why the SuDS approach is better than traditional drainage strategies in combating flooding and diffuse pollution in urban environments caused by the increased urbanisation and climate change. The chapter also contained an introduction to the Ecosystem Approach, and ecosystem services and disservices, and hypothesised how the Ecosystem Approach is the best way to analyse and communicate the effectiveness of SuDS. This formed the solution to address research problems component of the PhD research framework (Figure 1.1).

In this chapter a more detailed critical analysis of the Ecosystem Approach, ecosystem services and disservices is presented. This is related to the aim of identifying the ecosystem services and disservices best suited for the analysis of vegetated SuDS techniques (forming the method to develop research solution and the research solution verification components of the PhD research framework; Figure 1.1). This aim is achieved through critically examining evidence in the literature on how the vegetated SuDS techniques can generate these services and disservices. The literature evidence is then transformed to create the SuDS Communication and Planning Framework.

The critical literature examination is split into three parts. Firstly, the critical examination of the Ecosystem Approach is in section 3.2. This section also contains analysis of the three main objectives and the 12 principles of the Ecosystem Approach, together with a critical consideration of the ecosystem service and disservice concepts. Secondly, local and global examples of how the Ecosystem Approach is being and can be applied are critically appraised, focusing on the management of water in the urban environment. Finally, the need to create a framework to allow the Ecosystem Approach to be applied more efficiently in urban water cycle management is justified, focusing on the management of stormwater in the urban environment.

3.2. The Ecosystem Approach

The Ecosystem Approach links economic development, social development and environmental protection together (Secretariat of the Convention on Biological Diversity, 2004). The three objectives of the Ecosystem Approach, according to the Convention on Biological Diversity (CBD), are shown in Figure 3.1.

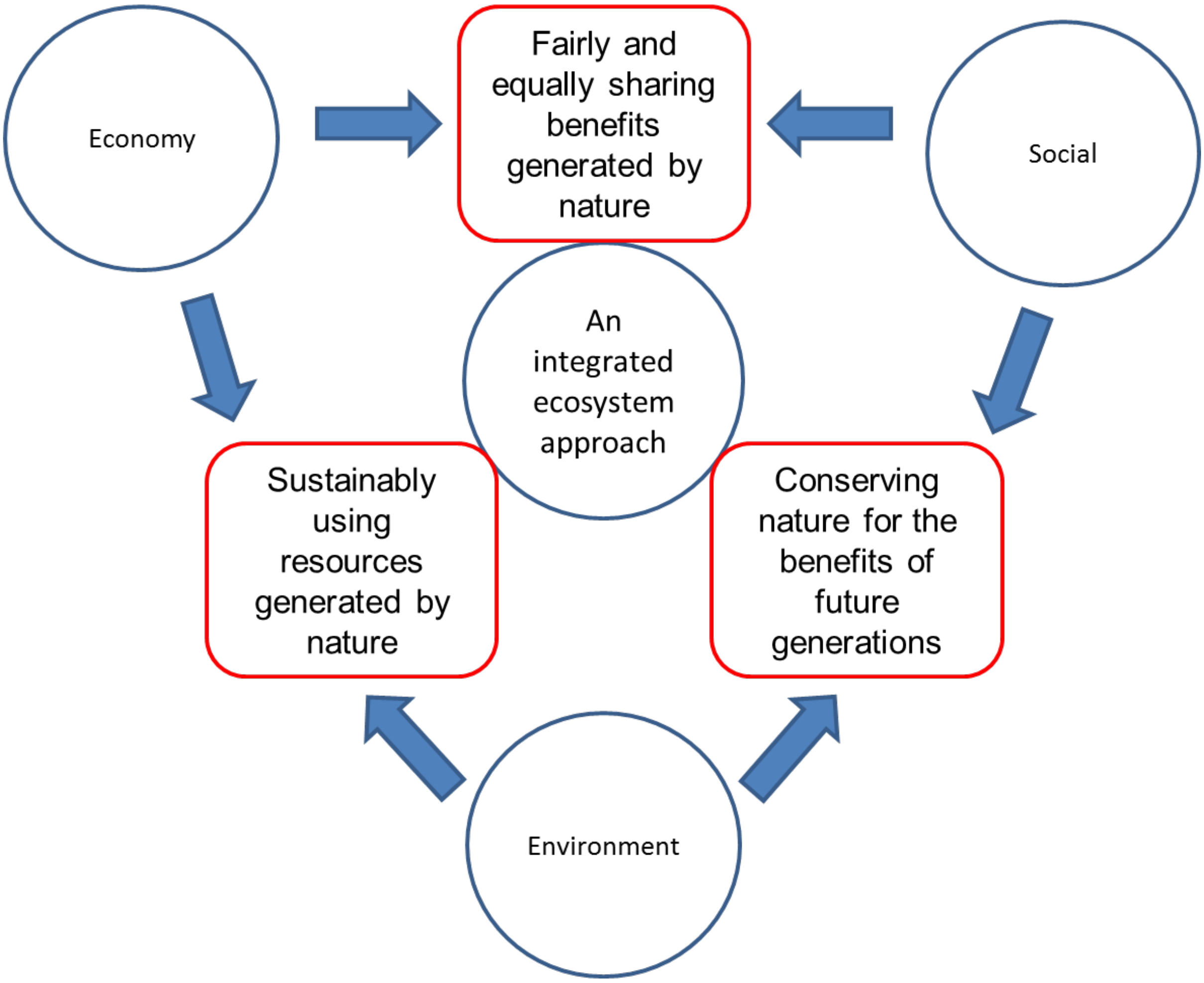

Figure 3.1 - CBD's three main objectives (red boxes) for the Ecosystem Approach (Secretariat of the Convention on Biological Diversity, 2004)

Judging by the anthropogenic wordings of the three main objectives shown in Figure 3.1 and the links they have with the environment, economy and society, it can be concluded that the Ecosystem Approach recognises the fact that humans are part of ecosystems, and their activities are subject to the natural limits and functioning of ecosystems (Maltby, 2010). Following on from this acknowledgment, and in order to give clarity to the three Ecosystem Approach objectives mentioned in Figure 3.1, 12 principles of the Ecosystem Approach were agreed (Secretariat of the Convention on Biological Diversity, 2004). They are categorised in Table 3.1.

Table 3.1 - The 12 principles of the Ecosystem Approach (Secretariat of the Convention on Biological Diversity, 2004)

Principle	**Details**
1	The objectives of management of land, water and living resources are a matter of societal choice.
2	Management should be decentralised to the lowest appropriate level.
3	Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4	Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should (a) Reduce those market distortions that adversely affect biological diversity; (b) Align incentives to promote biodiversity conservation and sustainable use; and (c) Internalise costs and benefits in the given ecosystem to the extent feasible
5	Safeguard ecosystem structures and functions so that the corresponding ecosystem services can be maintained.
6	Ecosystem management needs to ensure the ecosystem functions within its limit.
7	The Ecosystem Approach should be undertaken at the appropriate spatial and temporal scales.
8	Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term.
9	Management must recognise that change is inevitable.
10	The Ecosystem Approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11	The Ecosystem Approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practises.
12	The Ecosystem Approach should involve all relevant sectors of society and scientific disciplines.

The 12 principles of the Ecosystem Approach listed in Table 3.1 justified the use of ecosystem services as one of many tools in the management of nature.Examples of the Ecosystem Approach include the Millennium Ecosystem Assessment (MEA), The Economics of Ecosystems and Biodiversity (TEEB), and the UK National Ecosystem Assessments (UK NEA). They all provide much necessary scientific data to aid the understanding of different ecosystem structures and functions, in order to safeguard the ecosystem services they provide.

Across Europe, the Ecosystem Approach is being advocated for use as an aid to carry out the Water Framework Directive (WFD) in each participant state, particularly in the urban environment (Vlachopoulou *et al.*, 2014). One advantage of using the Ecosystem Approach is that it enables the WFD to be carried out on a wider, catchment ecosystem basis (Vlachopoulou *et al.*, 2014). Ecosystem ApproachAnother potential advantage of using the Ecosystem Approach is that the WFD enactment process can finally move away from enforcing strict legislation with which member states need to comply, by including more people from different levels of society and highlighting the societal benefits for improving the water bodies to the WFD standards (Vlachopoulou *et al.*, 2014).Ecosystem Approach

Although the management of land, water and living resources now widely adopts the Ecosystem Approach, a common and persistent criticism of this approach is that there is a lack of specific tools to implement solutions (Maltby, 2010). Therefore, this research aims to devise an Ecosystem Approach based framework for use in SuDS decision making by combining the ecosystem service and disservice concepts to justify SuDS development decisions, in order to manage the stormwater runoff within the urban water cycle in a more holistic way. Ecosystem disservices emerge from the work on ecosystem services (von Döhren & Haase, 2015) and, as such, are intrinsically linked with, and are the direct opposite, of ecosystem services (von Döhren & Haase, 2015). Ecosystem disservices will be critically examined in more detail in section 3.3.6.

Referring back to Table 3.1, the Ecosystem Approach principles being examined in this research that can be incorporated into SuDS decision making are principles one, two, eleven and twelve. The reason for examining principle one is because SuDS systems are being retrofitted adjacent to local communities (Stovin, *et al.*, 2007; Digman *et al.*, 2012; Uzomah *et al.*, 2014). Therefore they should be able to decide how their local SuDS system is managed. This is because local communities can either suffer or stand to gain environmental, economic and social benefits from their local SuDS systems depending on how involved they are in the management of these systems (Arendt, 2004; Ellis *et al.*, 2004; Woods-Ballard *et al.*, 2007; Croucher *et al.*, 2008; Jackson & Boutle, 2008; Allen *et al.*, 2012; Byrne, 2012; Graham *et al.*, 2013; Krasny *et al.*, 2014; Safransky, 2014; Wolch *et al.*, 2014; Bell, 2015; Church, 2015; von Döhren & Haase, 2015). The only way to ensure proper management of SuDS systems is if the local communities have the freedom to choose how they are managed (Woods-Ballard *et al.*, 2007; Allen *et al.*, 2012; Krasny *et al.*, 2014; Church, 2015).

The reason for examining principle two is because there are currently issues with regards to SuDS schemes to ownership and maintenance of sites (Bell, 2015). Therefore, if local people are involved in the management of their SuDS systems, the situation of inappropriate management techniques that create socio-economic divide amongst local communities can be avoid (Woods-Ballard *et al.*, 2007; Croucher *et al.*, 2008; Allen *et al.*, 2012; Byrne, 2012; Krasny *et al.*, 2014; Safransky, 2014; Wolch *et al.*, 2014; Church, 2015).

The reason for examining principle eleven is because there are many local community groups involved in the management of parks and gardens (elements of urban green infrastructures) (Allen *et al.*, 2012; James *et al.*, 2012; Church, 2015). Even though their work often are not publicised, they have many specific local knowledge which aid the management of these sites (James *et al.*, 2012). Management of SuDS systems can, therefore, adopt similar arrangements so that these systems are managed in accordance with local needs (Allen *et al.*, 2012; Church, 2015).

The reason for examining principle twelve is because even though SuDS is primarily an engineering concept (designed to tackle increased flooding and diffuse pollution through climate change and increased urbanisation), it can enhance the environment ecologically and the society socially (Woods-Ballard *et al.*, 2007; Graham *et al.*, 2013). Therefore, a multi-disciplinary approach, coupled with heavy involvement of local communities, in the SuDS design and planning stages, and future maintenance of SuDS sites, should be made compulsory.

The research critically examines the ecosystem service and disservice concepts in order to generate the SuDS Communication and Planning Framework. This will aid SuDS development decisions making in urban areas and justifying every decisions made are Ecosystem Approach compliant to principles one, two, eleven and twelve in particular (Table 3.1).

3.3. Critically appraise the ecosystem services and disservices for the SuDS Communication and Planning Framework

This section contains a detailed critical analysis of the ecosystem service and disservice concepts, with the aim of identifying the ecosystem services and disservices best suited to justify each vegetated SuDS system.

By the end of the section, a list of ecosystem services and disservices will be generated for the creation of the SuDS Communication and Planning Framework.

3.3.1. The beginning and the emergence of ecosystem services

As hypothesised in Chapter 2, the SuDS treatment train lies perfectly within the urban water cycle. Therefore the Ecosystem Approach is appropriate to appraise SuDS, and one of the main tools used to justify this approach, as mentioned in the fifth principle of the Ecosystem Approach, is ecosystem services. Recognition of the importance of ecosystems to the health and well-being of human beings is not new and can be traced back more than 2000 years, when Plato hypothesised the importance of soil in retaining water and the importance of trees in retaining the nutrients within the soils by bemoaning the loss of natural vegetation cover due to deforestation (Daily *et al.*, 1997). Less far back into history, George Perkins Marsh (1864) theorised the importance of microorganisms within soils and appreciated their qualities that allows them to support the natural environment and benefit human beings. Westman (1977) explained the social benefits nature can bring to humans, which formed the early basis for cultural ecosystem services. With the recognition of various benefits natural ecosystems can generate for people, Ehrlich and Ehrlich (1981) gathered evidence together and created the term "ecosystem services". This term has since been adopted in the literature right up to present time, with some alterations to the definitions (Costanza et al., 1998; Daily *et al.*, 1997; de Groot *et al.*, 2002; MEAa, 2005; Boyd & Banzhaf, 2007; Wallace, 2007; Fisher *et al.*, 2009; The Economics of Ecosystems and Biodiversity, 2011; UK National Ecosystem Assessment, 2011a; Hanson *et al.*, 2012; Bastian *et al.*, 2013; Haines-Young & Potschin, 2013; Scholz, 2013a; UK NEA, 2014; Douglas & James, 2015; Mitchell *et al.*, 2015). Conversely, ecosystem disservices are directly opposite to ecosystem services because they are end-products generated by the natural environment that have negative effects, or costs, to human beings, and include examples such as disease carrying animals and plant pollens triggering allergies (Lyytimaki *et al.*, 2008; Lyytimaki & Sipila, 2009; Dunn, 2010; Limburg *et al.*, 2010; Escobedo *et al.*, 2011; Gómez-Baggethun & Barton, 2013).

3.3.2. Critical analysis of ecosystem services for the generation of the SuDS Communication and Planning Framework

The definition of ecosystem services should be suitable for the urban environment, where the SuDS approach is to be applied. The three main SuDS objectives are to mitigate flooding, minimise pollution of natural water bodies from stormwater runoff, and improve the amenity and biodiversity of the area concerned (Woods-Ballard *et al.*, 2007). As concluded in chapter two, the focus of the research is on vegetated SuDS techniques because they are the best approach to achieving the amenity and biodiversity objective.

Judging from the first two objectives and existing SuDS planning and design standards (Woods-Ballard *et al.*, 2007; Dickie *et al.*, 2010; Digman *et al.*, 2012), sites with vegetated SuDS infrastructures installed require high maintenance and need to be engineered to ensure that all the intended technical aims are satisfied, such as the ability to:

- handle a minimum storm event magnitude,
- control the discharge rate to a pre-determined figure,

- treat properly the pollution carried by the “first flush” of the stormwater runoff.

There are issues with regards to ownership and maintenance of sites associated with SuDS schemes (Bell, 2015). SuDS schemes are also investments because developers need incentives to attract them to invest in better drainage solutions (Bell, 2015).

Judging by the factors above, the definition of ecosystem services used to appraise vegetated SuDS techniques should also reflect the urban environment, be suitable to the highly engineered nature of any SuDS sites, and be able to be properly valued in order to balance out the investments put into SuDS. Table 3.2 contains information of the definitions and classification systems used for describing the ecosystem service concept. The definitions and classifications systems were chronologically analysed in order to examine the changes of definitions and classifications over the years.

Table 3.2- Ecosystem services definitions and classification

Sources	**Ecosystem services definition**	**Ecosystem services classification**
Daily *et al.*, 1997	Conditions and processes from nature that sustain and fulfill human beings.	Production inputs. Sustenance of plant and animal life. Provision of existence and option values (Ojea *et al.*, 2012, p.3).
Costanza et al., 1998	The direct or indirect benefits ecosystem functions generate for the human populations.	Seventeen ecosystem services, which include ecosystem goods.
de Groot *et al.*, 2002	The capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (de Groot et al, 2002, p.394). This definition is for ecosystem functions.	Production functions, regulation functions, habitat functions, information functions
MEA, 2005b	Benefits people obtain from ecosystems.	Cultural, provisioning, regulating, supporting
Boyd & Banzhaf, 2006	Ecological components directly consumed or enjoyed to produce human well-being (Fisher *et al.*, 2009, p.645).	Intermediate components, services, benefits (Ojea *et al.*, 2012, p.3)

Continued…

Wallace, 2007	Benefits people obtain from natural ecosystems, but only end services should be considered in valuation. (Ojea *et al.*, 2012).	Adequate resources, protection from predators/disease/parasites, benign physical and chemical environment, socio-cultural fulfilment.
Fisher *et al.*, 2009	Aspects of ecosystems utilised (actively or passively) to produce human well-being. Benefits are valued in economic terms and are always derived from intermediate or final services (Ojea *et al.*, 2012).	Abiotic inputs, intermediate services, final services, benefits
TEEB, 2011	The benefits that humans derive from nature.	Habitat services, regulating services, provisioning services, cultural and amenity services
UK National Ecosystem Assessment, 2011b	The benefits people obtain from ecosystems.	Provisioning, regulating, and cultural
Bastian *et al.*, 2013	The actually used or demanded contributions of ecosystems and landscapes to human benefits and the human well-being.	Ecosystem properties, potentials, services, benefits/values, beneficiaries
Haines-Young & Potschin, 2013	Outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the well-being of people. They retain a connection to the underlying ecosystem functions, processes and structures that generate them.	Provisioning, regulation & maintenance, cultural

The information in Table 3.2 allows the conclusion to be made that the definition of an ecosystem service and its classification has progressed over time from only concentrating on the ecological aspects of the ecosystems to a more human benefit orientated definition and classification. This is best demonstrated when Boyd and Banzhaf (2006), Wallace (2007), The Economics of Ecosystems and Biodiversity (2011) and Bastian *et al.* (2013) differentiated the final products or services human beings truly consume and demand that are generated by the natural ecosystems, from the intermediate services generated by inherent ecosystem processes, within their ecosystem services categories.

The diversion from purely ecological to a more human well-being led ecosystem services analysis was justified in the landmark Millennium Ecosystem Assessment (MEA), published in 2005. The MEA theorised ecosystem services as benefits people obtain from ecosystems (MEA, 2005b), and established four categories of ecosystem services: supporting, provisioning, regulating, and cultural. Supporting services are “services necessary for the production of all other ecosystem services” (MEA, 2005a, p.59). Provisioning services are “products obtained from ecosystems” (MEA, 2005a, p.56). Regulating services are “benefits obtained from regulation of ecosystem processes” (MEA, 2005a, p.57). Cultural services are “nonmaterial benefits obtained from ecosystems” (MEA, 2005a, p.58). The categorisation prioritises the supporting services as the service category that governs the other three categories, as shown in Figure 3.2.

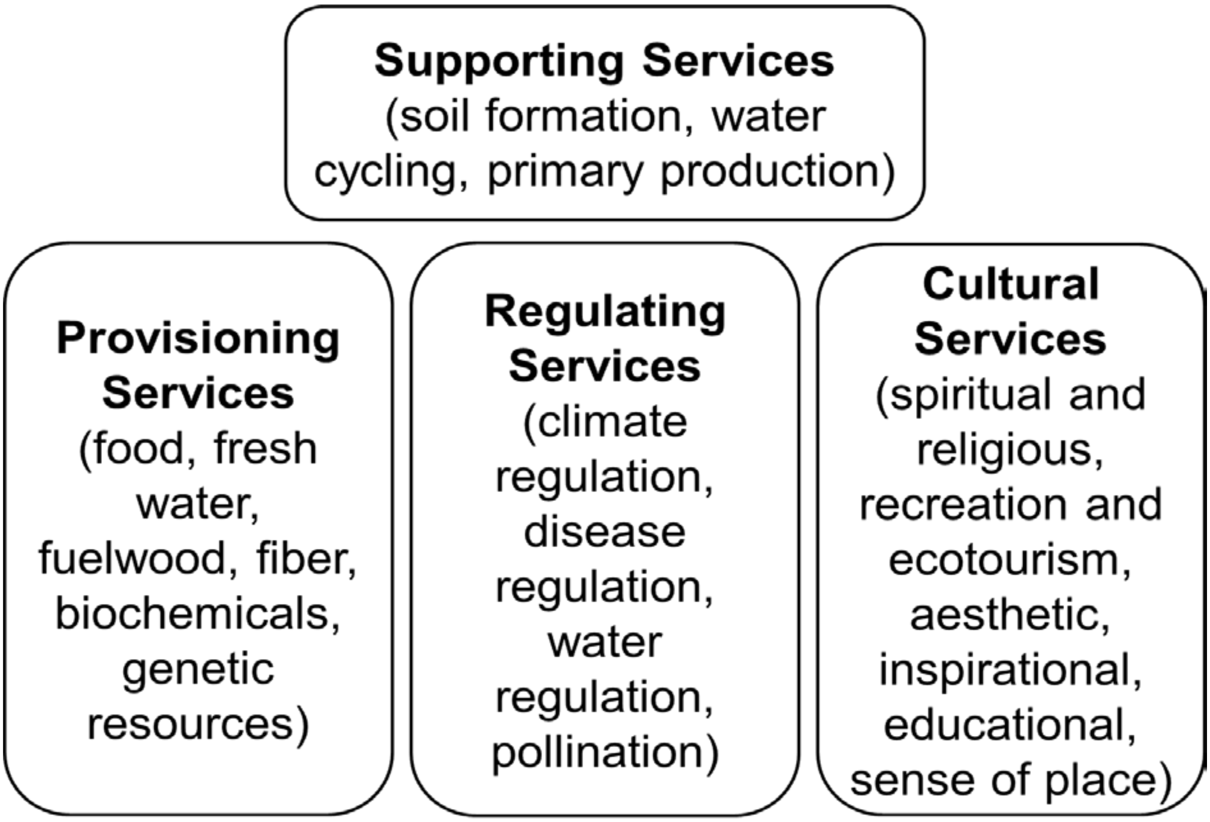

Figure 3.2 – Ecosystem services (adapted from MEA, 2005a)

The categories – indeed the prioritisation of the supporting services as the dominant service category that gives birth to all other services – as shown in Figure 3.2 justify the argument that double-counting of ecosystem services can easily occur. This is because counting an individual supporting service (e.g. water cycling) will automatically count the sub-services the individual supporting service can generate (e.g. water regulation, fresh water provision, recreation) (Kandulu *et al.*, 2014). Consequently, this will exaggerate the economic benefits to the society an ecosystem service can provide or economic costs to the society when an ecosystem service is disrupted (Fu *et al.*, 2011; Keeler *et al.*, 2012; Kandulu *et al.*, 2014).

In order to avoid double counting of the ecosystem services, more efforts have been made to distinguish services from processes (Boyd and Banzhaf, 2007; The Economics of Ecosystems and Biodiversity, 2010; Bastian *et al.*, 2011; Fu *et al.*, 2011; Keeler *et al.*, 2012; Kandulu *et al.*, 2014). Ecosystem processes are, according to Brown *et al.*, (2007, p.332) “the complex physical and biological cycles and interactions that underlie what we observe in the natural world.” Ecosystem processes are driven by the cycling of matter and the flow of energy. Examples of ecosystem processes are primary production, and the water nutrient cycles. Consequently, it can be concluded that the distinction made to separate ecosystem services from ecosystem processes prioritises the benefits individual human beings can get from ecosystems.

The Economics of Ecosystems and Biodiversity (TEEB) is a world-wide analysis and examination of the role of economics on resulting ecosystems and biodiversity. This study of ecosystems and biodiversity economics was a result of proposals put forward during the Potsdam G8+5 meeting in 2007. At that meeting there was a request issued to member states, urging them to conduct climate change analysis in order to evaluate how it can lead to global biodiversity loss and the consequent economic effects. The results of this analysis are currently being used to support the economic case for conservation activities (Ring *et al.*, 2010). After analysing the proposal raised at the G8+5 meeting, in particular the call to examine ways to monetarise conservation activities (Ring *et al.*, 2010), it can be concluded that The Economics of Ecosystems and Biodiversity is a study aimed at getting environmental economists more involved in environmental policy making, impacting more on decisions made.

Within the The Economics of Ecosystems and Biodiversity project ecosystem services are placed in four categories – provisioning, regulating, habitat or supporting, and cultural (The Economics of Ecosystems and Biodiversity, 2011). After examining MEA and TEEB publications, it can be concluded that the main difference between TEEB and MEA lies with their treatment for the supporting ecosystem services. For supporting services, TEEB excluded ecosystem processes such as primary production, water cycling, soil formation and nutrient cycling, whereas, MEA included these processes within their supporting services category. According to TEEB, these processes are the natural ecosystem functions. They are important but do not directly benefit human beings.

The UK National Ecosystem Assessment (UK NEA) created another ecosystem services classification (UK National Ecosystem Assessment, 2011b). In this classification supporting services were completely excluded, for the same reason as TEEB. Therefore they only have three categories – provisioning, regulating, and cultural.

In 2011 a paper was published which further categorised ecosystem services as properties, potentials and services, and the authors called it the Ecosystem Properties, Potentials and Services (EPPS) three pillars conceptual framework (Bastian *et al.*, 2011). Their justification for setting up this new conceptual framework was to illustrate the "difference between the capacity of ecosystems and landscapes to supply goods and services on the one hand, and of the actual use of these services on the other hand" (Bastian *et al.*, 2011, p.14). Recently, the same authors updated their three pillars EPPS framework into five pillars by adding in "benefits and values" and "users or beneficiaries" (Bastian, *et al.*, 2013) to add more focus on benefits nature can bring to the individual human level.

Baró *et al.* (2015) proposed an innovative approach to examine the differences between ecosystem services supply (through green infrastructures) and demand (environmental quality standards threshold values) through analysing regulating ecosystem services in five European cities (Barcelona, Berlin, Stockholm, Rotterdam, and Salzburg). They examined whether the services supplied by green infrastructures (which are benefits individual user can experience) are able to contribute to meeting the environmental quality standards threshold values (which are the minimum amount of benefits the user actually needs). An example of environmental quality standards threshold values include the World Health Organisation's air quality guidelines reference values for pollutants PM_{10} (20µgm^{-3} (year)), NO_2 (40µgm^{-3} (year)) and O_3 (100µgm^{-3} (8-h)) (Baró *et al*., 2015).

The approach developed by Baró *et al*. (2015) proved suitable for both the air purification and global climate regulation services because well-established standards threshold values are available at the spatial scale (city) at which they undertook their research. However, they also discovered that the air purification and global climate regulation services provided by urban green infrastructure made only very small contributions towards complying with the environmental quality standards threshold values compared with other urban policies designed to tackle air pollution and greenhouse gas emissions (Baró et al., 2015). Nonethless, the research performed by Baró *et al.* (2015) is a good example of applying the ecosystem service framework in the urban setting (through green infrastructures) to improve existing planning tools (in this case, the environmental quality standards). This is similar to the aim of this research, which is to integrate the Ecosystem Approach into SuDS stormwater management approach to improve existing SuDS development decision making processes.

The changes in the focus of ecosystem services classification from ecology-led to more society and individual human orientated can be seen in Figure 3.3, where two ecosystem services – water purification and flood mitigation – were isolated and the changes of what they stand for chronologically analysed.

Daily (1997)

A list of ecosystem services that include "purification of air and water" and "mitigation of droughts and floods".

Costanza et. al (1998)

Ecosystem service	Ecosystem function
Water regulation	Regulation of hydrological flows
Disturbance regulation	Capacity and integrity of ecosystem response to environmental fluctuations.

Groot et. al (2002)

Ecosystem processes and components	Ecosystem functions		Goods and services (examples)
	Regulation Functions	Water regulation	• Drainage and natural irrigation. • Medium for transport
		Disturbance prevention	• Storm protection • Flood prevention

MEA (2005)

Ecosystem service	
Regulating Services	Water regulation
	Storm protection
Supporting Services	Water cycling

Wallace (2007)

Category	Ecosystem services (selected) – experienced at the individual human level		Ecosystem processes and assets
Adequate resources	• Food • Water • Transport • Disease protection	• Access to mates and being loved • Recreation • Meaningful occupation	Processes – Disturbance regimes (e.g. flooding) Assets – Water assets

Continued...

Brauman (2007)

Eco-hydrologic process	Attribute	Hydrologic service (selected)	
	Quantity, Quality, Location, Timing	Diverted water supply	water for municipal, agricultural
		In situ water supply	water for hydropower, recreation
		Water damage mitigation	reduction of flood damage
		Spiritual and aesthetic	provision of religious, educational
		Supporting	Habitats support.

Fisher (2008)

Abiotic inputs	Intermediate services	Final services	Benefits
Sunlight, rainfall, nutrients, etc.	Soil formation, primary productivity, nutrient cycling	Water regulation	Water for irrigation, drinking water, electricity from hydro-power

TEEB (2011)

Ecosystem service	
Regulating services	Moderation of extreme events
Provisioning services	Fresh water

UK NEA (2011)

Final ecosystem services		Goods (selected)	Well-being value
Provisioning	Water supply	Food, fibre, energy, drinking water, flood control, aesthetic, spiritual	Economic, health, shared social
Regulating	Hazard regulation		

CICES (2013)

Section	Division	Group
Regulation and Maintenance	Mediation of flows	Liquid flows

Figure 3.3 – The changes in the focus of ecosystem services classification through looking at "water purification" and "flood mitigation" (the underlined texts highlights the ecosystem services)

According to the analysis shown in Figure 3.3, the meaning of “purification of air and water” and “mitigation of droughts and floods” was elaborated from the simple phrases in 1997 to the kind of benefits individual human beings will experience when these two services were adequately cultivated. This is best demonstrated by Wallace (2007) when he devised the ecosystem services as experienced by individuals. Although conflicts of viewpoints persisted in subsequent years, leading to ideas going back to a more ecologically orientated ecosystem services classification, the human level experience was recognised as an important consideration when defining and classifying ecosystem services.

3.3.3. Biodiversity in the Ecosystem Approach, ecosystem services and disservices, and SuDS

Biological diversity, or biodiversity, is a term first introduced by Lovejoy (1980) to describe the variability among living organisms from all sources within the earth’s biosphere. Since then, extensive work has been done to expand on this simple definition. Figure 3.4 details the analysis of development of the term biodiversity.

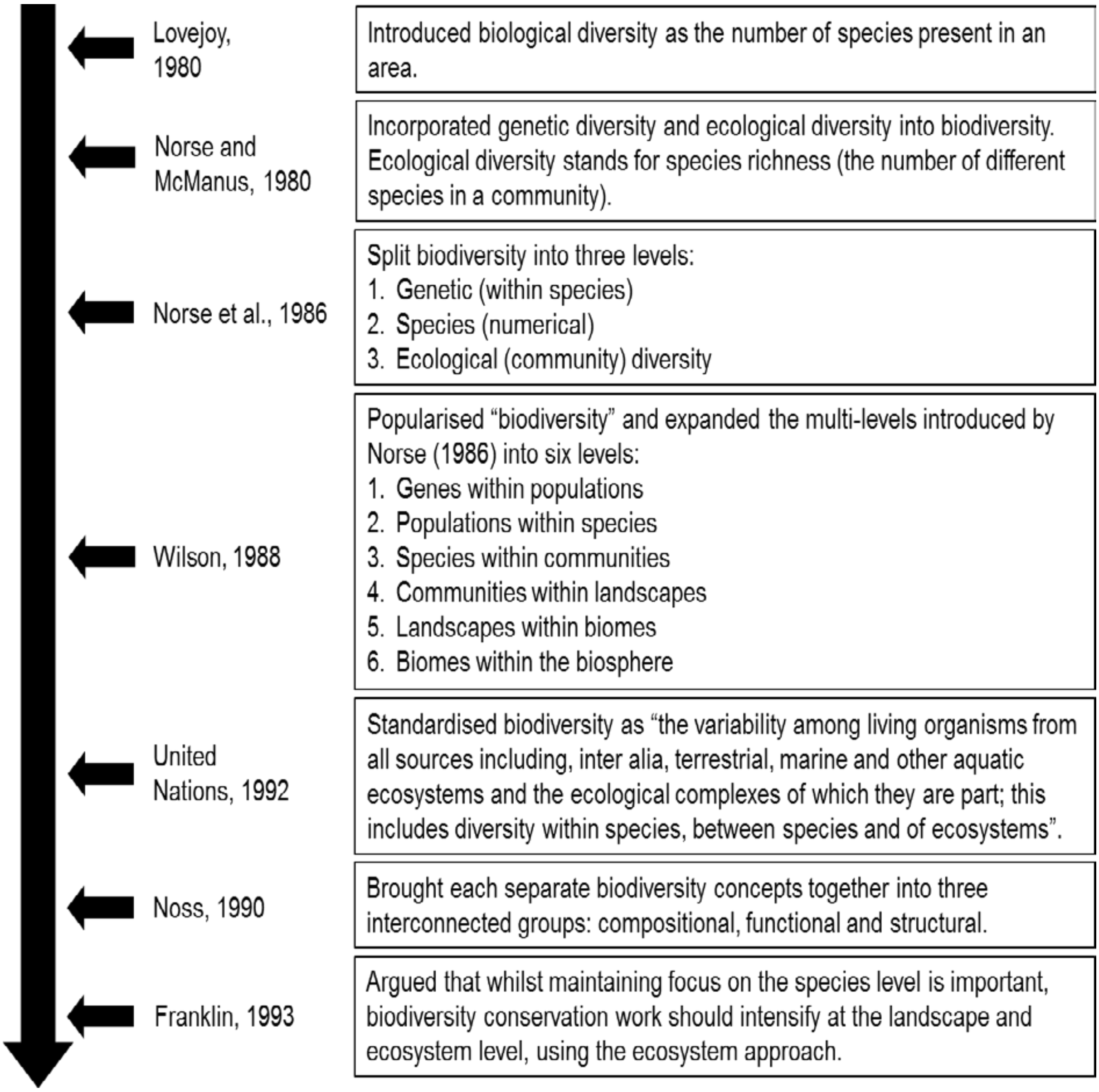

Figure 3.4 – The biodiversity concept development timeline and definitions. Please note that the reference Norse and McManus (1980) is cited within Norse (1986).

As shown in the analysis of biodiversity in Figure 3.4, using the Ecosystem Approach to preserve biodiversity was introduced by Franklin (1993), which was later incorporated in the work on ecosystem services as detailed in section 3.3.2.

In section 3.3.2, it was concluded that human beings depend on healthy ecosystems in order to thrive, because they provide many services beneficial to us (MEA, 2005). Biodiversity is an important measure in the Ecosystem Approach and ecosystem services. In terms of policy, according to principle ten of the Ecosystem Approach, it is important to maintain biodiversity of an ecosystem so that it can be used sustainably by human beings (Secretariat of the Convention on Biological Diversity, 2004). Therefore, a balance must be achieved between conserving biological diversity and using the biodiversity for the benefits of humans.

At the same time as biodiversity is able to provide benefits to humans, it can also cause us harm because of human interactions with nature, ecological processes such as disturbances, predation, competition between and within species, stress and mutually beneficial positive interactions between different species (facilitation) can potentially have negative effects on us, both physically and emotionally (Cain *et al.*, 2011).

From the critical analysis of publications on biodiversity in SuDS systems it can be hypothesised that SuDS systems have the potential to enhance or protect the biodiversity of local areas (Ackerman, 2003; Sparling *et al.*, 2004; Scher & Thièry, 2005; Viol *et al.*, 2009; Angelibert *et al.*, 2010; Coffman & Waite, 2011; Editorial, 2011; Briers, 2014; Van Mechelen *et al.*, 2015). For example, Viol *et al.* (2009) discovered that SuDS sites can act as refuges for native flora and fauna. Briers (2014) discovered that these sites have the potential to support and enhance freshwater biodiversity in urban areas. Constructed wetlands have also been shown to be an adequate substitute for natural wetlands by reviving lost biodiversity in local areas (Vymazal, 2011). Green roofs can also enhance biodiversity of the surrounding area, but the roofs themselves need to be designed with high functional diversity so that wildlife species will occupy theses roofs. Van Mechelen *et al.* (2015) discovered that lower functional diversity negatively affects the green roof’s ability to generate ecosystem services, including habitat for species. Functional diversity is one aspect of biodiversity that has to do with the traits that an organism offers to the community it is occupying and to the ecosystem it is a part of (Petchey & Gaston, 2006). Examples of functional diversity traits for plants include flower colour, lateral spread, leaf area, photosynthetic pathway, plant height, seed bank index, succulence and woodiness (Van Mechelen *et al.*, 2015). Contrary to the above green roof example, there are instances that green roofs not especially designed to be habitats for species are occupied by wild animals, such as birds, spiders and a variety of insects (Coffman & Waite, 2011).

All the above examples are justifications that SuDS systems enhance biodiversity of the local area. Vegetated SuDS systems such as green roofs, retention ponds and stormwater wetlands are the most likely SuDS techniques to contribute to the enhancement or protection of biodiversity for a local area, as evidenced by the above examples.

Retention ponds and stormwater wetlands cannot be compared with natural ponds, which are more biologically diverse, but they support many species and the biodiversity of these aquatic bodies compares favourably with rivers or lakes (Grillas *et al.*, 2004; Nicolet *et al.*, 2004; Oertli *et al.*, 2004; Williams *et al.*, 2004; Angelibert *et al.*, 2006 in Angelibert *et al.*, 2010). On the other hand, SuDS ponds often contain water contaminated with heavy metals, organic debris and chemical residues (Glassey, 1991; Pitt *et al.*, 1995 in Ackerman, 2003) because they are either designed as end-of-pipe drainage solutions for local source control SuDS systems (Scholz, 2004) or they receive surface runoff from roads and car parks. Nonetheless, SuDS ponds can sustain a decent level of biodiversity and are found to be important habitat for species such as Odonata, Amphibians and other aquatic macroinvertebrates (Ackerman, 2003; Scher & Thièry, 2005; Viol *et al.*, 2009; Briers, 2014). Sparling *et al.* (2004) working in the United States discovered that stormwater wetlands are attractive habitats for wetland associated wildlife such as Red-winged blackbird (*Agelaius phoeniceus*), despite all the polluted water they receive. Overall, after critical analysis of publications on biodiversity in SuDS systems, it can be concluded that both retention ponds and stormwater wetlands act as refuges for local wildlife and hence can contribute to landscape connectivity.

As concluded in section 2.3.2, enhancing the amenity and biodiversity value of the local areas is one of the three main objectives of SuDS. Therefore, SuDS planning and design should take biodiversity into account, with the aim of improving the biological diversity of the areas concerned. However, biodiversity considerations are still lacking in most SuDS planning and design. Consequently, it is hypothesised that research on the biodiversity benefits of SuDS drives efforts to incorporate biodiversity in SuDS planning and design, and subsequently, enhances the ecosystem services SuDS can produce.

3.3.4 The interactions between different ecosystem services

Ecosystem services are often inter-linked by drivers or directly with each other (Bennett *et al.*, 2009). Some drivers can change an ecosystem service for the better, which in turn worsens another ecosystem service. This situation is termed trade-offs (Bennett *et al.*, 2009). To demonstrate the trade-off effect that land use change (an ecosystem service driver) has on ecosystem services, Eigenbrod *et al.* (2011) compared flood mitigation and carbon storage in their model for two scenarios: urbanisation through densification and urbanisation through urban sprawl. In terms of flood mitigation, Eigenbrod *et al.* (2011) argued that in the urbanisation through densification scenario, the population will rise and there will be an increase in impermeable surface coverage. This is because as population rises, people will be driven to live closer to rivers and houses will also be built nearer rivers with a consequent rise in impermeable surface coverage. This will result in increased surface runoff, which elevates the peak flows of the river (Figure 2.1). Overall, the combination of more people living nearer rivers and peak flow increase will make flooding more likely and more damaging. Hence the flood mitigation ecosystem service will worsen.

However, the situation is different in the urbanisation through urban sprawl scenario: flood mitigation will be unaffected. This is because people are no longer being driven to live closer to rivers (people move to rural lands, away from rivers running through over-populated urban areas) (Eigenbrod *et al.*, 2011). Consequently, when flooding occurs after a heavy rainstorm, people will be less affected. That is the reason why there is no change in flood mitigation (Eigenbrod *et al.*, 2011).

In terms of carbon storage, Eigenbrod *et al.*, (2011) argue that in the urbanisation through densification scenario, carbon storage will be unaffected. This is because land take does not increase significantly in the urbanisation through densification scenario because new buildings are built closer together and built higher (Eigenbrod *et al.*, 2011). Previously developed land is also reused instead of land from the countryside. Therefore, carbon storage via already existing vegetation remains unchanged (Eigenbrod *et al.*, 2011).

However, the situation is again different in the urbanisation through urban sprawl scenario.   Eigenbrod *et al.* (2011) explained that as the ever expanding urban area encroached into previous rural areas, so much of the rural lands will be converted into urban land. Therefore, land previously that stored carbon will be lost (trees will be cut down, grass will be dug up). Consequently, carbon storage will worsen. Overall, densification style urbanisation will degrade flood mitigation (lost of permeable surfaces degrade natural infiltration), but it has no effect on carbon storage. On the other hand, urban sprawl style urbanisation will degrade carbon storage, but it has no effect on flood mitigation (more permeable surfaces is kept therefore preserving natural infiltration). On the whole, Eigenbrod *et al.* (2011) demonstrated that land use change (either densification style urbanisation or urban sprawl style urbanisation) will have different effects on ecosystem services, as illustrated by the flood mitigation and carbon sequestration comparisons.

Multiple ecosystem services can be improved or worsened at the same time either due to their interactions with the shared driver, or with each other. This situation is termed synergies (Bennett *et al.*, 2009).   In the case of urban green infrastructures, vegetation (a driver) provides habitat for species and carbon sequestration, and at the same time offer recreation (horticulture), and education opportunities (Haase *et al.*, 2012). The direct synergy between habitat for species and recreation is also realised through research that shows specific amount of exercises performed on green spaces can improve mental health of a person (Barton & Pretty, 2010).

In terms of stormwater retention ponds, they can provide places of refuge for aquatic macroinvertebrates by providing them with conditions to establish habitats (Viol *et al.*, 2009). This is despite the stormwater runoff purification function of the ponds, which results in lower water quality in relation to the adjacent rivers. Therefore the two ecosystem services (habitat for species and water purification) work in synergy to provide sanctuaries for aquatic macroinvertebrates. But the issue of water quality acts as a driver that either improves or worsens these two ecosystem services. Overall, the SuDS approach produces many different ecosystem services. Each of these services is either interlinked with drivers or are directly linked with each other. For example, by allowing vegetation in a stormwater wetland to grow and cut only periodically, complex plant structures can provide a better habitat for species ecosystem service, but can also change the flow of stormwater from laminar to turbulent (HR Wallingford, 2004; Woods-Ballard *et al.*, 2007). Turbulent water flow disrupts processes such as attenuation and infiltration (HR Wallingford, 2004; Woods-Ballard *et al.*, 2007), which has a negative effect on flood mitigation and water purification ecosystem services.

The interactions between different ecosystem services is further complicated when ecosystem services are split into supply and flow. Landscape fragmentation is a key driver that influences the supply and flow of multiple ecosystem services (Mitchell *et al.*, 2015), such as pollination, habitat for species, carbon sequestration. Although landscape fragmentation is generally detrimental to the supply of ecosystem services, it can improve the flow of ecosystem services, depending on the type of services (Mitchell *et al.*, 2015). For example, areas that offer ecosystem services (supply) and areas that demand the services (demand) can become spatially closer together due to urban expansion, a process that also leads to landscape fragmentation (Mitchell *et al.*, 2015). The result is an improvement in ecosystem service flow, such as increased pollination and access to green spaces for recreation (Mitchell *et al.*, 2015). Patterns of human movement altered by fragmentation can also improve or undermine the flow of ecosystem services (Mitchell *et al.*, 2015).

The strength of ecosystem services and disservices can also be predicted via examination of their common drivers, such as terrestrial vegetation structure and aquatic mesohabitat structures. In fact, the increase in strength of two different ecosystem services (habitat for species and carbon sequestration) via their common driver (terrestrial vegetation structure) can generate ecosystem disservices (disease carrying animals) (Mitchell *et al.*, 2015).

3.3.5 The ecosystem services to be used in the SuDS Communication and Planning Framework

As identified from the critical analysis of the current SuDS approach in Chapter 2, the amenity and biodiversity enhancement objective is not adequately addressed. The Ecosystem Approach addresses this objective and hence, with this in mind, the ecosystem services chosen to feature in the SuDS Communication and Planning Framework, which is being developed as part of the current study, should be selected to make SuDS sites more comfortable, attractive and friendly to people and wildlife. Also, as identified in Chapter 2, vegetated SuDS systems are better at promoting biodiversity compared with non-vegetated SuDS systems and are also better at generating the ecosystem services that can enhance the amenity and biodiversity of the associated areas.

In order to address the amenity and biodiversity gap within existing SuDS approach and practises, the ecosystem services for the SuDS Communication and Planning Tool were chosen following a critical review of three key literature sources:

- The Millennium Ecosystem Assessment (MEA, 2005),
- The Economics of Ecosystems and Biodiversity (TEEB, 2011), and
- The UK National Ecosystem Assessment (UK NEA, 2011; 2014).

The ecosystem services were further modified in order, firstly, to satisfy the philosophy that they should be directly beneficial to human beings, and secondly, to reflect the fact that the research only deals with issues arising from urban environments. All the other literature mentioned in section 3.3.2 that detail different ecosystem services characterisations were also consulted in the process of identifying the ecosystem services for the Framework.

The three documents mentioned above are referenced in the UK government's official documents detailing adoption of the Ecosystem Approach in managing urban environments (Defra, 2011). The UK National Ecosystem Assessment, in particular, has now completed its second phase development, titled the UK NEA-follow on (UK NEA, 2014), which further enhanced the excellent work already completed on

Ecosystem Approach and ecosystem services in the UK. The ecosystem services for the SuDS Communication and Planning Framework are described in Table 3.3.

Table 3.3 – Definition of individual ecosystem services, their relationship with the three main SuDS objectives and vegetated SuDS examples

Ecosystem service categories	**Ecosystem services**	**Ecosystem services explanations and specific vegetated SuDS examples**	**Ecosystem Services drivers**
Supporting			
	Habitat for species	<u>Definition</u> Habitat for species is the ecosystem service that supports all the other subsequent services an ecosystem can generate (The Economics of Ecosystems and Biodiversity, 2011). This is because for an ecological or environmental area to be able to support a particular animal or plant species, it must be able to provide everything the animal or plant needs to survive (UK NEA, 2011; The Economics of Ecosystems and Biodiversity, 2011). The factors that the animal or plant needs to survive ranges from food, water and shelter, to the maintenance of biological and genetic diversity, and the provisions of multiple ecological niche (The Economics of Ecosystems and Biodiversity, 2011; Moore, 2011; Burkhard *et al.*, 2012). Vegetated SuDS systems can be ideal places of habitats for many animal and plant species, and they in turn contribute to the overall biodiversity of the urban environment (Moore, 2011).	Vegetation, insect and animal species richness, abundance and diversity. Habitat size, location, structure and diversity. Vegetation species growth and survival rate. Functional diversity of vegetation. Abotic characteristics. Maintenance techniques.

Continued…

	Habitat for species	<u>Vegetated SuDS examples</u> Jackson & Boutle (2008) showed that colonisation of aquatic fauna occurred at newly constructed SuDS swales and ponds at Upton, Northhampton, UK. These new SuDS features can also act as "backwater habitats for aquatic and wetland species that have dispersed from the River Nene Valley" (Jackson & Boutle, 2008, p.1). Viol *et al.* (2009) observed that highway stormwater ponds, despite their poor water quality due to their pollutant retention function, can act as refuges to native plants and animals. This is supported through the biodiversity comparison between these ponds and natural ponds nearby, using aquatic macroinvertebrate communities as proxy. It was found that the aquatic macroinvertebrate communities in the highway stormwater ponds were similarly abundant and diverse, displaying a comparable spread of "family community composition and structure" compared with the surrounding natural ponds (Viol *et al.*, 2009, p.3163). Moore and Hunt (2012) analysed 20 ponds and 20 constructed stormwater wetlands in North Carolina, USA, in order to quantify their habitat for species service value. They examined the richness and diversity of plants and aquatic invertebrates found within these ponds and wetlands. In terms of aquatic invertebrates, they discovered that these two SuDS systems support different community composition, but the level of diversity is similar (Moore and Hunt, 2012). In terms of plants, they discovered that wetlands support a higher plants diversity compared with ponds (Moore and Hunt, 2012). The SuDS ponds in Dunfermline, Scotland, was found to be able to support communities of between 10 and 47 invertebrate species (Briers, 2014) Green roofs can support a variety of plant, insect and animal species, although they are deemed not to be as biodiverse as ground based natural systems (Moore, 2011). Dvorak & Volder (2010) conducted a review of green roofs across North America. They found that green roofs can support a variety of succulent plant species (shallow root systems, efficient use of water). The most	

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	Habitat for species	commonly found plants on green roofs in North America are species from the *Sedum* genus, but there are also species from the *Delosperma*, *Opuntia*, *Rhodiola*, *Portulaca*, *Aloe* and *Sempervivum* genera (Dvorak & Volder, 2010). However, green roofs that only consist of succulent plants have lower functional diversity than green roofs that consist of more diverse plant species (Van Mechelen *et al.*, 2015). Lower functional diversity negatively affects the green roof's ability to generate ecosystem services, including habitat for species (Van Mechelen *et al.*, 2015). In terms animal diversity, Coffman & Waite (2011) discovered different bird, spider and insect species on two different green roof types (one extensive and one intensive). They also discovered that wild animals occupied the green roofs even though the roofs were not designed to be habitats for these animals (Coffman & Waite, 2011). Green roof substrate depth and composition are important factor in promoting biodiversity because they influence soil properties such as water holding capacity, soil organic matters, nutrient availability and cation-exchange capacity (Rowe *et al.*, 2012; Cao *et al.*, 2014). Green roof substrates condition, therefore, is the key variable that affects the roof's habitat for species potential. As mentioned in Chapter 2, vegetated SuDS sites can act as wildlife refuges and connections to fragmented habitats. If the planning and design of SuDS developments can incorporate existing urban green infrastructures, they can contribute to the recovery of previously lost urban biodiversity (Natural England, 2011; Ellis, 2013; Graham *et al.*, 2013).	

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Provisioning			
	Food and Raw material	<u>Definition</u> Food and raw materials are ecosystem services that can be produced on sites utilising vegetated SuDS techniques because: • They are lands that either allow eatable vegetation to grow or areas that allow eatable animals to live (Costanza et al., 1998; Burkhard *et al.*, 2012; The Economics of Ecosystems and Biodiversity, 2011; Scholz & Uzomah, 2013). • They are lands that plants (e.g. trees, grasses) can grow which can be turned into materials used for constructions and fuel, such as wood, biofuels and plant oils (The Economics of Ecosystems and Biodiversity , 2011; Scholz & Uzomah, 2013).	Community engagement and public participation Amount of harvested above ground biomass Amount of yield

Continued…

	Food and Raw material	<u>Vegetated SuDS examples</u> Vegetated SuDS sites have great potential as land for growing food for urban consumptions (Moore & Hunt, 2011). Food such as berries and mushrooms can be harvested from these sites (Niemelä *et al.*, 2010). Green roofs are being utilised for growing food, such as cucumbers and peppers, as part of the urban agriculture movement (Veenhuizen, 2007; Ackerman, 2012; Eksi *et al.*, 2015). In relation to the urban agriculture movement, Pedersen (2015) examined food production in Wellington city, New Zealand, and predicted that 100% of food production for the city's population can be achieved by growing food around domestic dwellings. Vegetated SuDS sites can also achieve high food productivity if the design is with food production in mind. Their food provisioning potential can be similar to allotment gardens (Groenewegen *et al.*, 2006). If vegetated SuDS design, construction and maintenance can adopt practises from civic ecology, these sites can contribute to food production in urban areas because local communities are encouraged to be involved, care for the sites and grow food for the local community (Krasny *et al.* 2014). Moore (2011) documented via her literature review that above ground biomass from vegetated SuDS sites can harvested and then dried to form raw materials. Raw materials can be in the form of legumes, which can be used as animal feeds and feedstock for biofuels (Oelmann *et al.*, 2007; Jensen *et al.*, 2011). Trees can potentially be harvested from large vegetated SuDS sites, such as stormwater wetlands for their timber (Niemela *et al.*, 2010; Moore & Hunt, 2011; Uzomah *et al.*, 2014; Hansen *et al.*, 2015), although the urban locations of these vegetated SuDS sites and the stormwater management capacity of these sites make harvesting trees for timber impractical.	

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Regulating			
	Urban Heat Island Mitigation	<u>Definition</u> Urban heat islands occur when built areas are observed to give rise to higher temperatures compared with the surrounding natural landscapes (US EPA, 2012). There are various reasons contributing to this occurrence. Firstly, these built areas are dominated by paved surfaces and buildings, which replace the vegetation previously occupying the space. Because vegetation has the ability to provide shading, absorb and evaporate moisture, they keep the air and surface temperature low (US EPA, 2008). Whereas, removing the vegetation from the land will result in a rise in air and surface temperature (US EPA, 2008). Secondly, paved surfaces and buildings usually come in dark-colours and are made up of impervious materials (e.g. asphalt and slated roofs). These materials absorb radiation from the sun and emit heat. They can also transfer the radiation downward into the subsurface, where during night time the heat will escape back into the air (US EPA, 2008). The temperature of stormwater runoff can increase whilst it flows over heated impervious surfaces, and carrying the heat into receiving natural waterbodies (US EPA, 2012), damaging the aquatic ecosystems. Urban heat island are also linked to changes in rainfall patterns in urban areas, with evidence indicating that significant increase of extreme rainfall are triggered by urban heat island effects (Pathirana *et al.*, 2014). Urban heat island can be mitigated by installing vegetated SuDS sites because: • Vegetation is reintroduced into areas dominated by dark and impervious surfaces, such as asphalt roads and roofs. • Vegetation introduces evapotranspiration to cool down the surrounding air. It can increase albedo (the reflection of incoming radiation away from ground surface). • Vegetation can provide shading, which keeps the ground surface temperature low.	Amount of plants Coverage of plants Solar reflectivity Amount of shades provided by vegetation Evapotranspirative rate Amount of water available to plants Leaf area index Plant heights Sun-path and overshadowing of buildings Land availability Sunlight

Continued…

	Urban Heat Island Mitigation	<u>Vegetated SuDS examples</u> Sites with vegetated SuDS techniques, such as wetlands, ponds, green roofs, swales, are part of the urban Green Infrastructures (Matthews *et al.*, 2015). Green Infrastructures can mitigate the urban heat islands by reducing ambient temperature and increasing vegetated ground covers, which increase evaporative cooling, of towns and cities (Matthews *et al.*, 2015). Urban heat island effects at night time can also be mitigated by increasing the amount of vegetation coverage and permeable surfaces (Holmer *et al.*, 2007; 2012 in Andersson-Sköld *et al.*, 2015). Norton *et al.* (2015) created a framework using thermal mapping for prioritisation and selection of urban Green Infrastructures, including green roofs, for cooling. This framework considers various cooling benefits (shading by canyon surfaces, shading of people by trees, solar reflectivity, evapotranpsirative cooling and priority locations) that are provided by different urban green infrastructures to mitigate the urban heat island effects (Norton *et al.*, 2015). Remote sensing technology has been used to investigate the effects of green infrastructures, in particular urban wetlands, for their urban heat island mitigation capability. For example, Wang and Zhu (2011) used Landsat Thematic Mapper remote sensing imagery to analyse the temperature regulating effects of urban wetlands on the city of Hangzhou, China. They found that urban wetland can mitgated the urban heat island effects, and the key factors are the type of wetlands and the difference of them from built up areas (Wang and Zhu, 2011). Urban wetlands can form urban cooling islands (UCIs), which offer cooling effects to their associated towns and cities (Sun *et al.*, 2012). The wetlands within the city of Beijing were investigated for their UCI intensity using a high resolution imaging instrument called Advanced Spaceborne Thermal Emission and Reflection Radiometer images. It was found that the shape and the location of the wetlands within the urban areas are significant indicators of their urban heat island mitigation capability (Sun *et al.*, 2012).	exposure to support the plants Industry and public appreciation Cost effectiveness

Continued…

	Urban Heat Island Mitigation	Green roofs can also be used to mitigate the urban heat island effects in towns and cities. Baik *et al.* (2012) examined the effects of green roofs on lowering the local air temperature using a thermodynamic based computation model and tested the model in Seoul, Korea. They managed to show that green roofs improves local air quality and reduces air temperature. The factors of the improvement depends on the amount of vegetative shading, evapotranspiration rate, albedo, leaf area index and local wind direction (Baik et al, 2012). Wong and Lau (2013) conducted a qualitative (focus group discussions) and quantitative (virtual 3D sun-path and shading models development) research into the potential mitigating effects of green roofs in Hong Kong. The factors influencing green roofs urban heat mitigation capability, according the Wong and Lau (2013), are the amount of vegetation coverage, sun-path and overshadowing of buildings on the green roofs, availability of rooftop spaces, longevity of the rooftop structures of existing buildings, sunlight exposure to support the vegetation on the green roofs, and industry and public appreciation of green roofs benefits towards mitigating the urban heat island effects.	

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	Carbon sequestrati on	<u>Definition</u> Plants take in carbon dioxide from the atmosphere through the photosynthesis process. They then extract carbon from the carbon dioxide molecules and fix them in cell tissues as they grow, thereby transforming carbon from the atmosphere to the biotic system. Plants store carbon for as long as they live, in the form of living biomass. When they die, two things will happen. First, the carbon is re-released back to the atmosphere in the form of carbon dioxide through soil microorganisms decomposing the dead biomass, a soil organic matter, using oxygen in order to obtain energy for their growth and functioning. Second, the dead biomass becomes a part of the food chain and eventually the carbon from the dead biomass is stored through burial to form soil carbon. Sediment accretion (slow addition to land by deposition of water-borne sediment) will also occur, eventually to bury and lock away the soil carbon for a long time (Costanza et. al, 1998; Perry, 1998; Waran, 2001; Da Silva *et al.*, 2010; The Economics of Ecosystems and Biodiversity , 2011; Burkhard *et al.*, 2012; Moore & Hunt, 2012; Scholz & Uzomah, 2013).	Amount of aboveground belowground biomass Annual net photosynthesis rate of plants Difference of CO_2 concentration of site compared with surrounding area CO_2 absorption velocity and emission rate of plants grown on site Amount of soil organic carbon Type of vegetation Type of soil substrate

Continued…

	Carbon sequestration	<u>Vegetated SuDS examples</u> Vegetated SuDS sites can contribute to carbon sequestration by acting as sinks that store up carbon as above and below ground biomass. However, as Perry (1998) and Waran (2001) explained, “old-growth forests have the ability to sequester carbon for decades, stored in the wood and other organic matter”. Therefore, SuDS sites with plenty of mature trees are good carbon sequestration sites, as mature trees have plenty of biomass accumulated and experience little net growth, making the changes in that stock (flux) very small or zero. SuDS sites dominated by grasses have limited carbon sequestration ability, as grasses tend to be short living therefore biomass does not accumulate, and changes in that stock (fluxes) are rapid. Moore and Hunt (2013) constructed a framework to predict carbon emission of vegetated SuDS techniques. As part of their work, they critically analysed existing literatures and generated the carbon sequestration rates for several vegetated SuDS systems. For grassed filter strips and swales, the carbon sequestration rate is 34 gCm^{-2} $year^{-1}$ (Milesi *et al.*, 2005; Qian *et al.*, 2010; Bouchard *et al.*, 2013 in Moore & Hunt, 2013). For green roofs, the carbon sequestration rate is 190 gCm^{-2} $year^{-1}$ (Getter & Rowe, 2009 in Moore & Hunt, 2013). For wetlands and ponds, the carbon sequestration rate is 125 gCm^{-2} $year^{-1}$ (Anderson & Mitsch, 2006; Moore & Hung, 2011 in Moore & Hunt, 2013). However, after they analysed the construction, transport and maintenance carbon emission data for all the vegetated SuDS systems, only wetlands and ponds are found to be carbon sinks. They rest are carbon source, potentially contributing to the global carbon emission (Moore & Hunt, 2013). Ponds sequester carbon through organic matters accumulating and getting buried in sediments (Downing *et al.* 2008; Boyd *et al.*, 2010; Downing, 2010; Adhikari *et al.*, 2012; Moore & Hunt, 2013; Pittman *et al.*, 2013). Sediment organic matters are made up of different forms of carbon and nutrients, such as carbohydrates, proteins, fats and nucleic acids (Logan & Longmore, 2011).	Annual energy savings Avoided greenhouse gas emissions

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	Carbon sequestration	There are several sources of the sediment organic matters in ponds. They include dead and decomposed plants and animals, bacteria or plankton within the pond, natural and human generated environmental pollutants within the catchment (Downing, 2010; Logan & Longmore, 2011). Sources of anthropogenic sediment organic matter include sewage discharge, road runoff, residential runoff, runoff from contaminated land, amenity grassland runoff, industrial runoff and so on (Environment Agency, 2013b). In order for green roofs to sequester carbon effectively, the soil substrate type and composition are important factors. This is justified through the experiment conducted by Luo et al (2015). They constructed a green roof using sewage sludge and native plants in DuJiangyan City, China. They then analysed carbon sequestration and carbon storage of the green roof via periodic substrate sampling, and periodic sampling of the above ground and below ground components of plants, and compared the amount of carbon sequester and stored with local natural soil Luo *et al.* (2015). The results showed that the sewage sludge mixed substrate sequestered and stored more carbon then the local natural soil, thus justifying the hypothesis that substrate is an important factor in green roof carbon sequestration Luo *et al.* (2015). Carbon sequestration potential of vegetated SuDS systems can also be examined through life cycle assessment. Spatari & Montalto, 2011) conducted life cycle assessment (avoided energy use and greenhouse gas emissions, which translate to avoided carbon dioxide emissions) of selected Low Impact Development strategies (SuDS systems in America) in New York, USA. Their research concluded that the Low Impact Development strategies being analysed can save 7.3GJ of energy annually and can result in 0.4 metric tons of avoided greenhouse gas emissions (Spatari & Montalto, 2011). This justified the hypothesis that vegetated SuDS systems can sequester carbon by examining the annual energy savings and avoided greenhouse gas emissions.	

Continued…

	Pollination	<u>Definition</u> Pollination in this case refers to animal pollination only, and is mainly provided by insects, and to some extent, by birds and bats (The Economics of Ecosystems and Biodiversity, 2011). Bumble bees are one of the main type of pollinators and are responsible for the pollination of many fruits, vegetables, and other culture plants human beings depend on (The Economics of Ecosystems and Biodiversity, 2011; Burkhard, 2012). Changes in the ecosystem, caused by increased urbanisation and climate change, affects the "distribution, abundance and effectiveness of pollinators" (Burkhard *et al.*, 2012, p. 20). A biodiverse environment will provide habitats for pollinators, and flowering plants of different sizes and species to attract the pollinators (Cain *et al.*, 2011).	Flowering plants abundance, richness and diversity Number of flowering plant visits by pollinating insects Pollinator species diversity Presence of natural vegetation that act as habitats for pollinators Proximity of site to natural habitats Pollinators nesting densities

Continued…

	Pollination	<u>Vegetated SuDS examples</u> Vegetated SuDS systems can generate pollination services because they promote biodiversity, hence can support plenty of flowering plants and provide habitats for pollinators (Jackson & Boutle, 2008; Dvorak & Volder, 2010; Coffman & Waite, 2011; Moore, 2011; Van Mechelen *et al.*, 2015). Hoffmann (2005) conducted a study on road verges (can be seen as bioretention) in Netherlands. He found that the higher the amount and the more diverse the flowering plants species, the more pollinator species there are at the site. Tonietto *et al.* (2011) and Ksiazek *et al.* (2012) analysed green roofs across Chicago, USA and compared them with nearby natural ground based green spaces. Both studies found that smaller amounts of pollinators are present at the green roofs, but they are able to sustain the native plants grown on the roofs in their study without additional pollination measures. However, both studies also confirmed that more diverse native vegetation needs to be planted in order for vegetated SuDS systems, such as green roofs, to generate more pollination services (Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012). Rooney *et al.* (2015) found that event though stormwater wetlands are not as biodiverse as natural or agricultural wetlands, they can still potentially provide habitats for pollinators. Therefore, vegetated SuDS systems can potentially benefit the urban agriculture movement because they can be habitats for pollinators, which then allow the pollinators to pollinate the food crops grown on the urban agricultural sites (Lin *et al.*, 2015).	

Continued…

Cultural			
	Recreation, Education and Positive Aesthetic	<u>Definition</u> Vegetated SuDS systems are part of urban green infrastructures. Green infrastructures are known to be able to provide various cultural services (recreation, education and positive aesthetics) for people living within towns and cities, thus offering them mental and physical health benefits (Costanza et al., 1998; MEA, 2005; The Economics of Ecosystems and Biodiversity ; 2011; UK NEA, 2011; 2014). MEA (2005), The Economics of Ecosystems and Biodiversity (2011) and UK NEA (2011, 2014) acknowledge that benefits from cultural services, such as opportunities to engage in sports, relaxation and a sense of inspiration, offered by urban green infrastructures are increasingly being recognised but can be difficult to measure. However, there are researches that attempted to measure these benefits both qualitatively and quantitatively.	Public perception Naturalness and colour diversity Recreational facilities Dissemination of research work Exposure of site to public Location of site Public participation in planting, maintaining, monitoring and caring of the site. Distance of site from education establishment History of use for

Continued…

	Recreation, Education and Positive Aesthetic	<u>Vegetated SuDS examples</u> Moore and Hunt (2012) analysed the recreational and educational potential of stormwater wetlands and ponds via visual assessment using a qualitative rubric. This qualitative rubic contains variables such as legal accessibility, recreational infrastructure, history of educational use and educational infrastructure to aid the qualitative analysis of the cultural services these stormwater wetland and ponds can produce (Moore & Hunt, 2012). Loder (2014) conducted semi-structured interviews in Toronto and Chicago to analyse office worker's perception of the aesthetic values of green roofs. Her research showed that the naturalness of the green roof is an important factor in the office worker's perception of the aesthetic values of the roofs (Loder, 2014). This is because the naturalness of the green roofs are linked to fascination, creative thinking, calmness, caring of self and respite from urban living, according to the office workers interviewed for the research (Loder, 2014). Vegetated SuDS systems can be used to educate the public about nature and what the systems is trying to achieve in terms of stormwater management. Church (2015) conducted semi-structured interviews in Oregon, USA, to examine the educational capacity of bioretention swales and rain gardens. She discovered that just by exposing the public to these stormwater management devices enables people to appreciate the processes involved (Church, 2015). She also concluded that adding educational information signs at these stormwater management sites can enhance the educational services they provide (Church, 2015). The addition of information signage as a useful tool to enhance the educational value of vegetated SuDS sites is further justified by the survey and interviews conducted by Feinberg (2015). However, Feinberg (2015) also discovered that long term funding is required in order to maintain properly these signs, which can be difficult to find. Hansen *et al.* (2015) concluded that cultural services of vegetated SuDS systems are best appreciated if they are exposed to the public, via cross-case comparative analysis of planning documents from Berlin, New York, Salzburg, Seattle and Stockholm. They also	educational purpose Presence and condition of educational infrastructure Size of site

Continued…

	Recreation, Education and Positive Aesthetic	concluded that the ease of access to these vegetated SuDS sites is a very important factor in the appreciation of cultural services (Hansen, 2015). Ultimately, public participation in the maintenance of vegetated SuDS sites will enable people to directly experience the cultural services these sites can generate, as proven by the civic ecological practices review and assessment performed by Krasny *et al.* (2014).	

3.3.6 The emergence of ecosystem disservices

Ecosystems, as well as providing services beneficial to human beings, also have by-products that are detrimental to our way of life. As stated in Section 2.3, ecosystem disservices are end-products generated by the natural environment that have negative effects, or costs, to human beings (Lyytimaki *et al.*, 2008; Lyytimaki & Sipila, 2009; Dunn, 2010; Limburg *et al.*, 2010; Escobedo *et al.*, 2011; Gómez-Baggethun & Barton, 2013; Gómez-Baggethun *et al.*, 2013; Shapiro & Báldi, 2014; von Döhren & Haase, 2015). For example, forests provide various ecosystem services such as carbon sequestration and recreation; but can also generate fear and stress for people, especially at night time, when there are no street lights to light up the place (Lyytimaki & Sipila, 2009; Maruthaveeran & Bosch, 2014).

The SuDS approach is a water management system designed to tackle stormwater in urban areas. Increased urbanization not only intensified diffuse pollution (as outlined in section 2.2.2), it also brought humans closer to wildlife species because cities are expanding into rural areas, creating unplanned and uncontrolled urban sprawl areas that are attached to the edge of the city. Urban environments are designed to be suitable for human lifestyles, therefore with the continued expansion of urban sprawl, “more wild or semi-wild species face the need to adapt and find niches in human-oriented urban areas” (Lyytimaki & Sipila, 2009, p.310; Garroway & Sheldon, 2013). This will inevitably affect humans’ way of life, as wild animals try to adapt to urban environments (Garroway & Sheldon, 2013), leading to animals building up their habitats in people’s living and working spaces and foraging in bins in order to find food (Garroway & Sheldon, 2013). Wild species can also carry with them parasites and diseases that can pass on to human beings, pets and domestic animals (Polley, 2005).

As discussed in section 2.3.3, many SuDS sites use vegetation to control stormwater flow. Some, such as retention ponds, even retain water on site for treatment. SuDS sites can also be considered as patches of natural environments within over populated urban areas, providing habitats for a variety of wildlife species. Therefore, SuDS sites can have associated negative effects. They are listed as follows:

- Provision of habitats for disease carrying animals such as rats and mosquitoes (Hunt *et al.*, 2005; Woods-Ballard *et al.*, 2007; Gómez-Baggethun & Barton, 2013),
- The risks of accidents due to the ease of access to open water bodies for local people, particularly concerning retentions ponds and wetlands (Kemp & Sibert, 1992; Jones *et al.*, 2006; Sustainable Cities Institute, 2012),
- Because SuDS sites have to deal with the initially high pollution level stormwater runoff (the first flush) (Woods-Ballard *et al.*, 2007), children can be exposed to contaminants when playing in and around these sites, especially immediately after the first flush (Sparling *et al.*, 2004; Grimm, 2007; DeLorenzo *et al.*, 2012),
- Plants and microbial activity on SuDS sites are designed to treat stormwater through plant uptake of pollutants, adsorption, biodegradation of contaminants and nutrient removal (Woods-Ballard *et al.*, 2007), the soil is therefore full of contaminated sediments. Certain contaminants (e.g. many toxic heavy metals and organic compounds such as polychlorinated biphenyls (PCBs) and benzo (a) pyrene) will indirectly affect human health due to bioaccumulation in the food chain because wildlife species uses vegetated SuDS systems as habitats and a source for food (Torno et al., 1986; Begon *et al.*, 2009), and
- The sense of fear and unrest associated with unmanaged natural environments, especially at night-time where visibility is poor (Jones *et al.*, 2006; Lyytimaki *et al.*, 2008; Sustainable Cities Institute, 2012).

Overall, these issues cannot be ignored and have to be assessed properly. SuDS developments are located near people's homes and places of work. Whilst people are encouraged to use these sites to enjoy the services they provide, they are also likely to be exposed to the disservice these sites can generate. Hence, there is a need for this research to analyse the positive and negative contributions sites with the SuDS stormwater management approach have on human well-being.

There are wide variations in how the term "ecosystem services" is defined and how the services are classified. As discussed in section 3.3.5, the definition used in this thesis is that ecosystem services are benefits generated by nature that are beneficial to human well being – physically, mentally and socially (Daily *et al.*, 1997; Costanza et al., 1998; de Groot *et al.*, 2002; MEA, 2005; Boyd & Banzhaf, 2007; Wallace *et al.*, 2007; Fisher *et al.*, 2009; The Economics of Ecosystems and Biodiversity, 2010; UK NEA, 2011; Haines-Young *et al.*, 2012; Hanson *et al.*, 2012; Bastian *et al.*, 2013; Scholz & Uzomah, 2013). Therefore, the ecosystem services chosen to form the SuDS Communication and Planning Framework adhere to this definition.

3.3.7 The ecosystem disservices to be used in the SuDS Communication and Planning Framework

The ecosystem disservices to be used in the SuDS Communication and Planning Framework are listed in Table 3.4. The ecosystem disservices category is based on the conceptual framework linking green infrastructure, and ecosystem and human health, created by Tzoulas *et al.* (2007). The reason to justify using this particular framework to categorise the ecosystem disservices is because the disservices critically analysed in section 3.3.6 are highly anthropogenic, and concern many social, ecosystem and human health issues which were discussed by Tzoulas *et al.* (2007). The framework presented by Tzoulas *et al.* (2007) also shares the multi-disciplinary nature of the ecosystem disservices critically examined in section 3.3.6. Therefore, the categorisation adopted for the ecosystem disservices in the new SuDS Communication and Planning Framework will be able to communicate with a variety of disciplines.

The ecosystem disservices chosen are based on the work done by von Döhren & Haase (2015). They conducted a comprehensive review of existing ecosystem disservices research in urban areas, and summarised them by producing a list of urban ecosystem disservices. This list of disservices were then further modified, based on SuDS literature and literature related to issues mentioned in the SuDS literature, to suit the SuDS Communication and Planning Framework.

Table 3.4 – The ecosystem disservices for the SuDS Communication and Planning Framework (Woods-Ballard et al., 2007; Tzoulas et al., 2007; von Döhren & Haase, 2015)

Ecosystem disservices categories	**Ecosystem disservices**	**Ecosystem disservice generated by vegetated SuDS**	**References**	**Driver that can be used to overcome Ecosystem Disservices**
Community and social impact				
	Community acceptance	Local community may not accept the SuDS schemes situated close to their home and work place due to health and safety, and water borne diseases and water contamination concerns (Eliis *et al.*, 2004; Woods-Ballard *et al.*, 2007). This is especially concerned with techniques such as retention ponds, stormwater wetlands and bioretention devices.	Ellis *et al.*, 2004; Woods-Ballard *et al.*, 2007; Allen *et al.*, 2012 ; Church, 2015	Communication, public awareness, and education (Woods-Ballard *et al.*, 2007 ; Allen *et al.*, 2012; Church, 2015)
	Socio-economic divide	Various research studies highlighted the fact that people in a lower socio-economic group are less inclined to accept environmentally sound practices, such as the SuDS stormwater approach. People in a lower socio-economic group are less likely to visit green spaces. There is also a perception that green spaces benefit predominantly affluent, Caucasian communities (Allen *et al.*, 2012; Byrne, 2012; Safransky, 2014; Wolch *et al.*, 2014). Therefore, socio-economic divides can occur due to the introduction of SuDS schemes in local areas.	Woods-Ballard *et al.*, 2007; Croucher *et al.*, 2008; Allen *et al.*, 2012; Byrne, 2012; Krasny *et al.*, 2014; Safransky, 2014; Wolch *et al.*, 2014	Public participation and integration through civic ecology practises (Krasny *et al.*, 2014)

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Economic impact				
	Damage to properties	Certain SuDS techniques, such as green roofs, are particularly susceptible to damage if not designed properly. Examples of damage include plant roots growing into and through the roof, causing structural damage. All these result in economic loss. The water accumulated on green roofs can also seep into and through the roof. Plants grown on green roofs can catch fire, which can then cause structural damage, resulting in economic cost.	Woods-Ballard *et al.*, 2007; Breuning, 2008; Department of Communities and Local Government, 2013	Proper design practices and maintenance regime (Woods-Ballard *et al.*, 2007; Department of Communities and Local Government, 2013).
	Land use conflicts	Large SuDS sites, such as stormwater wetlands, can hinder fast and smooth transportation by not enabling linear roads to be built. This results in economic cost. Using valuable lands for stormwater management can be viewed as a waste of land resources, especially if the land can be used in a more profitable way (for construction). This can apply to retention ponds, stormwater wetlands, swales and bioretention devices such as rain gardens. If the planning and designed for new SuDS schemes are too focused on enhancing the amenity and biodiversity of the local areas, these new SuDS sites may have to compromise on their hydraulic performance. This can exacerbate flooding and diffuse pollution, which has a long term economic cost.	Woods-Ballard *et al.*, 2007; Lyytimaki *et al.*, 2008; Allen *et al.*, 2012; Bell, 2015; von Döhren & Haase, 2015	Stakeholder (developers and landowners) communication (Woods-Ballard *et al.*, 2007; Allen *et al.*, 2012). Compensation (Bell, 2015). Proper maintenance regimes (Woods-Ballard *et al.*, 2007).

Continued…

	Maintenance cost	Effective sediment management and vegetation maintenance (e.g. mowing, trimming, litter clearance) are essential for achieving the three main SuDS objectives and maintaining the effectiveness of the SuDS techniques employed to achieve these objectives. Examples of SuDS maintenance work include: 1) removal of vegetation contaminated by stormwater pollutants (mowing, pruning), which is part of the stormwater purification process; 2) removal of invasive vegetation; 3) removal of excessive leaf litter to prevent inlet and outlet blockages; 4) removal of human generated litters; 5) removal of sediments via de-silting. SuDS sediments are treated as contaminated waste; 6) removal and disposal of oils or petrol residues safely by following established health and safety standards (in the UK, permits for oil and petrol residues disposal are issued by the Environment Agency (Environment Agency, 2015)); 7) irrigation and feeding plants during their establishment; 8) checking fire breaks; 9) inspecting bare patches and replanting if necessary; 10) stabilising erosion banks and channels; 11) repairing broken inlets and outlets. All these maintenance works require personnel and funding to achieve. This is a particular concern, especially if the ownership of SuDS schemes is not clear (Bell, 2015).	Arendt, 2004; Woods-Ballard *et al.*, 2007; Hale & Sadler, 2011; Allen, 2012; Krasny *et al.*, 2014; Bell, 2015; von Döhren & Haase, 2015	Maintenance or endowment funds establishment (Hale & Sadler, 2011). Environmental stewardships (Krasny *et al.*, 2014). Stakeholder communication and education (Allen, 2012).

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Physical health Impact				
	Accidents	Tree branches in SuDS sites can break up and fall onto people walking onsite. People can drown in SuDS ponds. Cars can overturn and fall into swales. Children using SuDS sites as play areas can encounter sudden inflow of water. People can fall from inlet or outlet structures.	Woods-Ballard *et al.*, 2007; von Döhren & Haase, 2015	Proper risk assessment, prevention and mitigation measures (Woods-Ballard *et al.*, 2007).
	Disease carrying animals	Because animals, such as mosquitos, rodents and ticks can be disease vectors (West Nile, malaria Well's disease and Lymes disease), when they use SuDS sites as habitats or points of feeding, they can transmit disease to humans due to direct or indirect interactions.	Hunt *et al.*, 2005; Woods-Ballard *et al.*, 2007; Gottdenker *et al.*, 2014; Vlachopoulou, 2014; Uspensky, 2014; Centers for Disease Control and Prevention, 2015; Donohoe *et al.*, 2015; Medlock & Leach, 2015; Mitchell *et al.*, 2015; von Döhren & Haase, 2015	Proper maintenance regime, such as mowing, rake leaves and clear tall grasses (Centers for Disease Control and Prevention, 2015). Ensure deep ponds and constant water flow (Hunt *et al.*, 2005). Regularly practise water-level drawdown (Hunt *et al.*, 2005). Consider vegetation species selection and amount of woody vegetation (Hunt *et al.*, 2005). Litter management and rodent control (Woods-Ballard *et al.*, 2007).

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	Contaminant exposure	Food and water harvested in and around SuDS sites maybe contaminated due the initial flow of stormwater from impermeable surface, which carries the most pollutants. This is especially concerning for techniques such as stormwater wetlands, retention ponds and bioretention devices such as rain gardens. People can also be exposed to contaminants by coming into contact with sediments accumulated on site and disease carrying wild animals in SuDS sites. Certain contaminants will indirectly affect human health due to bioaccumulation in food chain because wildlife species uses vegetated SuDS systems as habitats and a source for food.	Sparling *et al.*, 2004; Begon *et al.*, 2009; B. Woods-Ballard et al, 2007; DeLorenzo *et al.*, 2012; Weirich & Miller, 2014	Source, pathway, receptor identification and risk assessment (Woods-Ballard *et al.*, 2007). Control the growth of algae (Woods-Ballard *et al.*, 2007). Fencing around SuDS sites. Access permits. Public education (Weirich & Miller, 2014).
	Plant pollen allergies	The vegetation grown on SuDS sites can produce pollens which can cause allergic reactions or intoxication. For example, Mugwort (*Artemisia vulgaris*) pollen can trigger life threatening symptoms for people with asthma related respiratory issues.	Carinanos & Casares-Porcel, 2011; Konijnendijk 2012; von Döhren & Haase, 2015	Increase vegetation species diversity. Careful control when planting exotic species (Carinanos & Casares-Porcel, 2011). Use low pollen producing species (Carinanos & Casares-Porcel, 2011).

Continued…

	Biogenic Volatile Organic Compound (BVOC) emissions	Air quality can be depleted due to vegetation planted in stormwater wetlands and bioretention devices, such as rain gardens, emitting Biogenic Volatile Organic Compounds, which react with man-made atmospheric oxidants (O_3, OH, NO_3) to produce Biogenic Secondary Aerosols (BSOA). These BSOAs are fine particle pollutants and can negatively affect human's respiratory system. BVOCs are also an important precursor to enhanced ozone (O_3) in the lower atmosphere, which also damages the human respiratory system. The BVOCs most commonly emitted by plants are isoprene and monoterpene.	Laothawornkitkul et al., 2009; Carlton *et al.*, 2010; Escobedo *et al.*, 2011; Pataki *et al.*, 2011; Wang *et al.*, 2014; von Döhren & Haase, 2015; US EPA, 2015	Reduce man-made atmospheric pollutant emissions (Carlton *et al.*, 2010). Refer to existing databases (e.g. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) (Guenther et al., 2006) and a database featuring standard emission potential of European tree species and general land use classes (Steinbrecher et al., 2009)) in order to select plants that have low BVOC emission potential for planting in SuDS sites (Pataki et al., 2011) Consideration of temperature and light exposure must also be taken because they are the key control factors for the plants' BVOC emissions (Laothawornkitkul et al., 2008)

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Psychological health impact				
	Fear and stress	SuDS sites, especially stormwater wetlands, are similar to other urban green spaces such as parks. They can be associated with fear of crime and antisocial behaviours.	Petherick, 2001; Maruthaveeran, & Konijnendijk van den Bosch, 2014	Modify design practises to increases prospect (escape route and open view) and decreases refuge (hiding places) of SuDS sites (Petherick, 2001). Reduce areas of non-illumination.
	Habitat competition with humans	SuDS sites can play hosts to wild animals or insects that are cause fear and stress, and are physically dangerous. Therefore, they prevent humans from accessing the SuDS sites.	Leite *et al.*, 2011; Konijnendijk, 2012; Sol, *et al.*, 2013; von Döhren & Haase, 2015	Proper site management. Public education with regards to feeding wild animals.
	Negative aesthetic	Many species, such as squirrels, foxes and birds searching for food from rubbish bins located in and around SuDS sites can litter the environment. Bird and dog excrement in and around SuDS sites can be considered as aesthetic and hygiene problem.	Lyytimaki *et al.*, 2008	Public education. Proper maintenance regime.

After presenting all the information regarding SuDS, ecosystem services and disservices, the links between services and disservices with SuDS needs to be established. These will be detailed in section 3.4.

3.4. Integrating the Ecosystem Approach into the SuDS approach, using ecosystem services and disservices, to create a new SuDS Communication and Planning Framework

As discussed in previous sections, ecosystem services and disservices are used to integrate the Ecosystem Approach into the SuDS approach.

Referring back to section 2.3.3, the SuDS stormwater management approach is governed by three main objectives:

- To control the quality of stormwater runoff,
- To manage the quantity of stormwater runoff, and
- To enhance the amenity and biodiversity of the concerned area.

Sections 2.3.3 and 3.3.6 contain discussion of the many issues concerning human being's interaction with natural environments within urban areas generated by utilising the SuDS approach to managing stormwater in urban settings. They are collectively termed ecosystem disservices.

Referring back to the conclusion of Chapter 2, the current SuDS approach is not sufficient in tackling the catchment wide human and wildlife well-being issues triggered by new SuDS developments. Therefore, the Ecosystem Approach is being integrated into the current SuDS approach in order to improve SuDS planning and design to address ecosystem wide issues.

Having critically analysed the Ecosystem Approach (section 3.2), ecosystem services (section 3.3.2 to 3.3.5) and ecosystem disservices (section 3.3.6 and 3.3.7), the Ecosystem Approach can now be combined with the SuDS approach, using ecosystem services and disservices to create the SuDS Communication and Planning Framework (see Figure 3.5, 3.6 and 3.7), focusing on vegetated SuDS techniques, in order to satisfy the amenity and biodiversity objective of the SuDS approach.

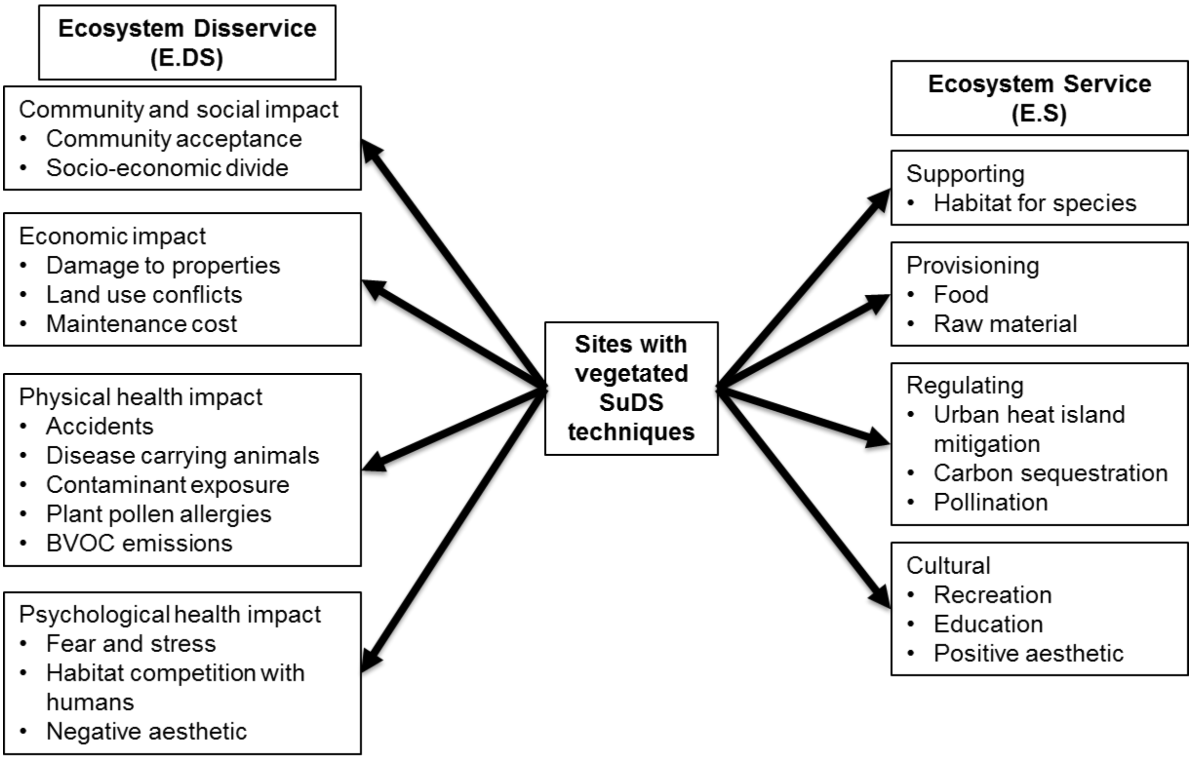

Figure 3.5 – The first part of the SuDS Communication and Planning Framework.

The first part of the SuDS Communication and Planning Framework in Figure 3.5 shows the ecosystem services and disservices that can be generated by sites with vegetated SuDS techniques, which will affect the amenity and biodiversity objective of the SuDS approach. The ecosystem services on the right hand side of the framework in Figure 3.5 are split into four categories, as justified by the critical analysis performed in section 3.3.5.

As concluded in section 2.3.3, vegetated SuDS techniques offer the most biodiversity and amenity benefits. Therefore, only vegetated SuDS techniques are included in the SuDS Planning and Communication Tool (see Figure 3.6, 3.6 and 3.7) in order to address the amenity and biodiversity gap currently exist in the SuDS approach.

The ecosystem disservices on the left hand side of the framework are split into four categories in accordance with Tzoulas *et al.* (2007). The choice of ecosystem disservices featured in the framework was justified by the critical analysis performed in section 3.3.7. Figure 3.6 contains the second part of the SuDS Communication and Planning Framework.

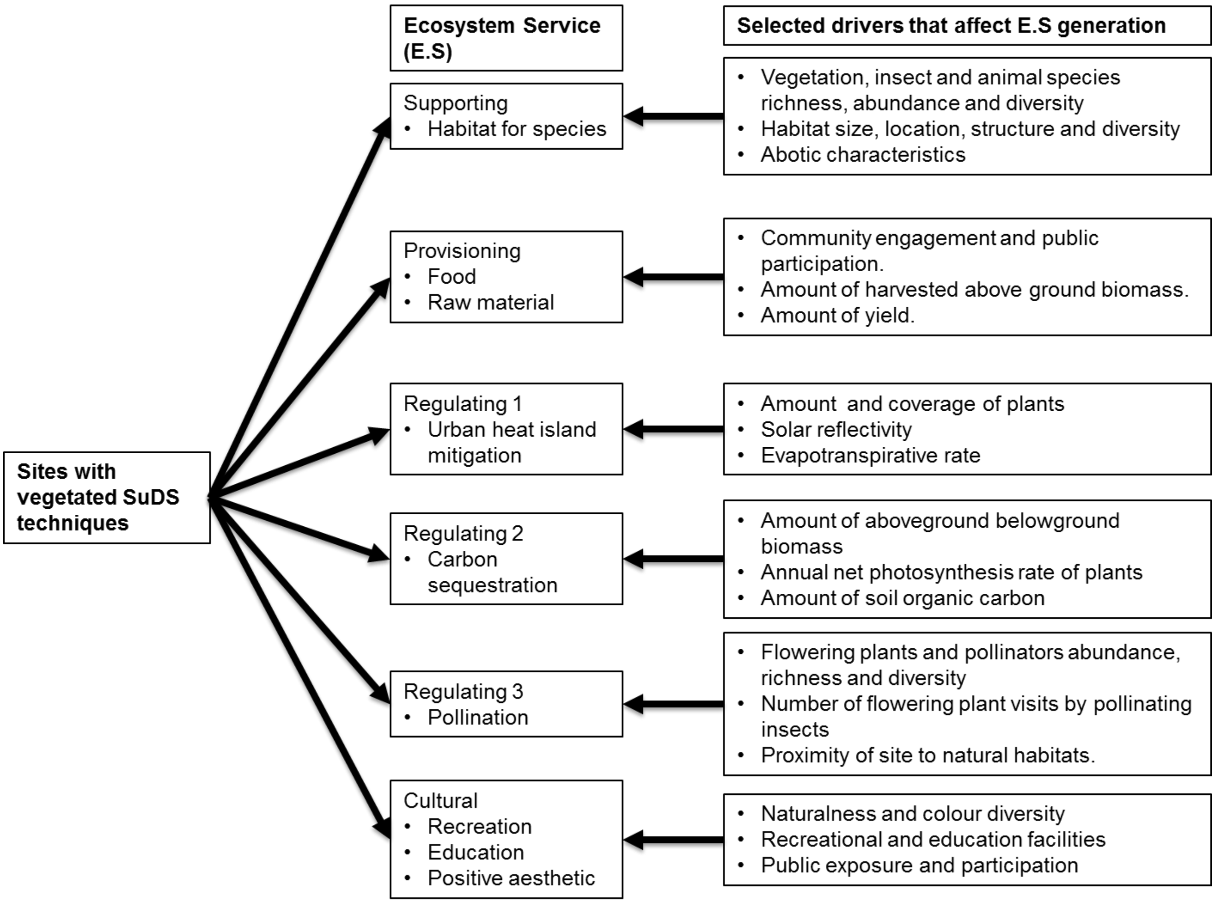

Figure 3.6 – Selected drivers that can affect the ecosystem services generation capability of sites with vegetated SuDS techniques

The second part of the SuDS Communication and Planning Framework in Figure 3.6 shows the selected drivers that can affect the ecosystem services generation by sites with vegetated SuDS techniques. The chosen ecosystem services drivers are justified by the critical analysis performed in section 3.3.5. Figure 3.7 contains the third part of the SuDS Communication and Planning Framework.

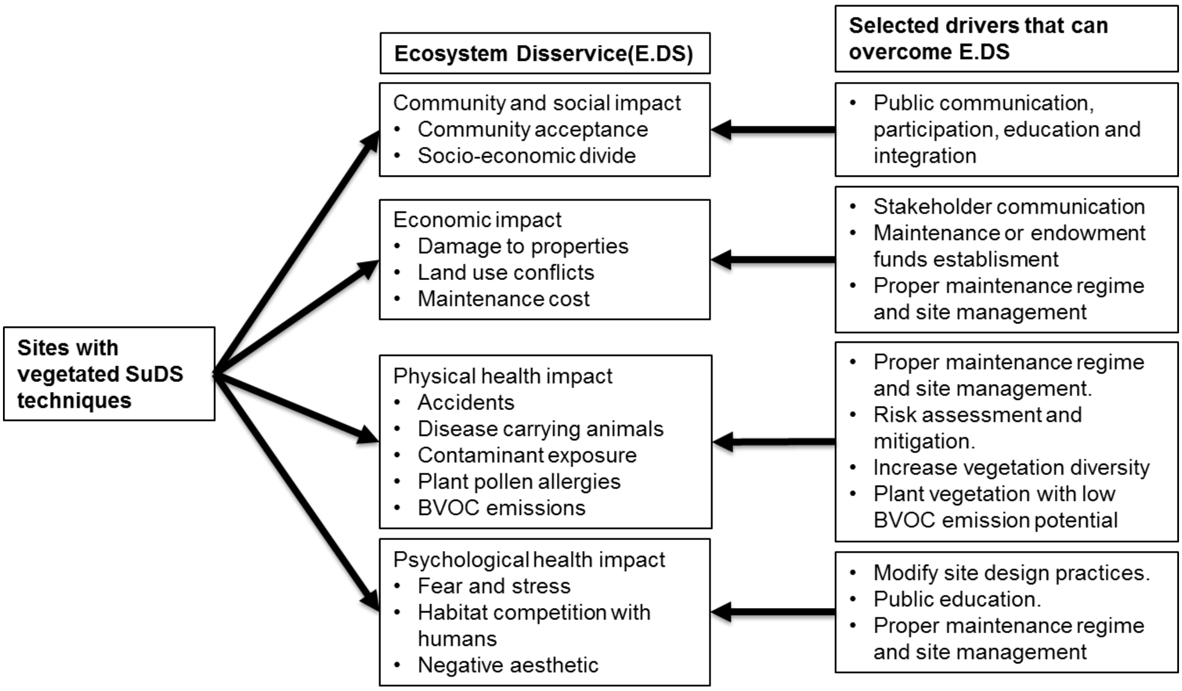

Figure 3.7– Selected drivers that can overcome the ecosystem disservice sites with vegetated SuDS techniques can produce

The third part of the SuDS Communication and Planning Framework in Figure 3.7 shows the selected drivers that can overcome the ecosystem disservices sites that vegetated SuDS techniques can produce. The choice of these disservices is justified by the critical analysis performed in section 3.3.7.

There are several novelties with regards to the research so far. First, the formulation of the SuDS Communication and Planning Framework, which categories the ecosystem services and disservices sites with vegetated SuDS techniques can generate that directly enhances the amenity and biodiversity of the sites. Second, for the purpose of the framework creation, a new ecosystem disservice category was invented, contributing to future ecosystem disservices research analysis. Third, ecosystem services drivers that can affect the services generation capacity of vegetated SuDS sites were formulated. Fourth, ecosystem disservices drivers that can overcome the disservices vegetated SuDS sites can produce were also formulated. Finally, the SuDS Communication and Planning Framework generated through this research (see Figure 3.5, 3.6 and 3.7) is one of the tools being incorporated in the UK NEA follow-on (UK NEA, 2014). The UK NEA follow-on project is a national Ecosystem Approach project that aims to bring together different scientific disciplines and generate specific tools for implementing the Ecosystem Approach (UK NEA, 2014).

After the creation of the SuDS Communication and Planning Framework, Chapter 4 will contain details of the methods used to validate the framework on site. Chapter 5 will contain details of the analysis result of the framework validation.

4. SuDS Communication and Planning Framework validation methods development and verification

Chapter 3 contained the critical literature analysis of the Ecosystem Approach, ecosystem services and disservices. The final product of the critical literature analysis was the creation of the SuDS Communication and Planning Framework, satisfying the “methods to develop the research solution” and “results from research solution development” components of the PhD research framework (Figure 1.1).

In this chapter, the two methods are presented that were used to examine elements of urban green infrastructures as a proxy for vegetation SuDS systems in order to validate the SuDS Communication and Planning Framework are presented. Therefore, this will form the “research solution validation” component of the PhD research framework (Figure 1.1). The two validation methods are:

- Examination of the vegetation structure cover-abundance of elements of vegetated SuDS sites and using this biodiversity variable as the proxy for appraising the habitat for species, urban heat island mitigation and carbon sequestration ecosystem services.
- Appraisal of cultural ecosystem services and disservices variables and using them as the proxies for analysing the recreation and education ecosystem services, and to identify possible ecosystem disservices on-site.

Overall, the aim of this chapter is to explain the creation of the two methods used to validate the SuDS Communication and Planning Framework detailed in Chapter 3 by evaluating the potential ecosystem services and disservices that can be produced by vegetated SuDS sites, using elements of urban green infrastructures as a proxy.

4.1. Site selection

Selecting the appropriate sites for ecosystem services and disservices examination and evaluation is an important process for the validation of the SuDS Communication and Planning Framework. This section details, firstly, the justification for selecting elements of urban green infrastructure as proxies for vegetated SuDS systems analysis. Secondly, this section provides the list of sites selected for ecosystem services and disservices examination and evaluation, with the overall aim of validating the SuDS Communication and Planning Framework.

4.1.1. Elements of Urban green infrastructure as proxies for vegetated SuDS systems

The first step towards validating the SuDS Communication and Planning Framework created in Chapter 3 is to determine the sites for ecosystem services and disservices examination and evaluation and to provide a justification for the selection of those sites.

Sites with vegetated SuDS techniques installed are assumed to be approximately comparable with elements of urban green infrastructure (or green spaces), in terms of the biodiversity and amenity related ecosystem services and disservices they promote (Hoffmann, 2005; Jackson & Boutle, 2008; Viol *et al.*, 2009; Kazemi *et al.*, 2011; Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012; Demuzere *et al.*, 2014; Loder, 2014; Bell, 2015; Church, 2015; Hansen et al, 2015; Matthews *et al.*, 2015; Norton *et al.*, 2015; Van Mechelen *et al.*, 2015).

In terms of biodiversity, not all vegetated SuDS techniques are comparable with their equivalent urban green infrastructure. Grassed swales and filter strips can be seen as equivalent to lawn grassed green spaces (Moore, 2011). However, with improved designs incorporating more complex vegetation types (e.g. woody vegetation) and aquatic features, they can be made to be more biologically diverse (Beard & Green 1994 cited in Moore, 2011). Incorporating woody vegetation and flowering plants can also transform grassed swales and filter strips into aesthetically pleasing green infrastructure, providing local people with easy access to nature and a touch of wilderness, which encourages public engagement and acceptance of these types of vegetated SuDS systems, similar to other more biologically diverse vegetated SuDS and urban green infrastructures (Wolf, 2004; 2008; 2010; 2015; Krasny *et al.*, 2014; Loder, 2014; Church, 2015). Yet, a balance must be struck between enhancing the biodiversity value of grassed swales and filter strips and maintaining their hydraulic and water purification functions. This is because grassed swales and filter strips are designed to convey stormwater runoff from one SuDS system to another, whilst slowing down the flow rate and purifying the stormwater runoff (Woods-Ballard *et al.*, 2007). Therefore, grassed swales and filter strips are not anticipated to have a high biodiversity value (Moore, 2011). Nonetheless, improvements can be made to grassed swales and filter strip designs, especially in retrofit situations, to increase their biodiversity and aesthetic values. Lessons can therefore be learned by examining and evaluating existing urban green spaces, where their biodiversity and aesthetic qualities were enhanced by altering the management of green spaces and encouraging public participation (Buri *et al.*, 2013; Krasny *et al.*, 2014; Wolf, 2015), in order to improve grass swales and filter strip designs.

Stormwater wetlands were found to be less biodiverse compared to natural wetlands because of the polluted stormwater runoff they are designed to treat (Scholes *et al.*, 1998; Hunt & Lord, 2006; Lee & Scholz, 2007; Rooney *et al.*, 2015). Yet, in examining and evaluating the ecosystem services of urban wetlands and other green spaces, a biodiversity benchmark can be created for future stormwater wetland retrofits to achieve (van Roon, 2012; Rooney *et al.*, 2015), whilst not compromising on the hydraulic and water purification functions of the stormwater wetlands. Also, in examining and evaluating the ecosystem disservices of urban wetlands and other green spaces (Petherick, 2001; Allen *et al.*, 2012; Byrne, 2012; Safransky, 2014; Wolch *et al.*, 2014; Maruthaveeran & Konijnendijk van den Bosch, 2014), factors leading to the disservices generation are identified so that future stormwater wetland retrofits can aim to avoid the disservices currently being generated by existing urban green infrastructures. Lessons on cultural ecosystem services can also be learned through the examination and evaluation of urban wetlands and other green spaces, such as urban parks and gardens, to allow future stormwater wetland retrofits to contribute more to public health and well-being, and social integration (Krasny *et al.*, 2014; Church, 2015; Wolf, 2015).

Green roofs were found to support less abundant pollinator numbers than their ground-based equivalents (Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012). Yet, they support comparable pollinators and vegetation species diversity compared with their ground-based equivalents (Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012). Overall, green roofs provide biodiversity values to urban environments by supporting a variety of plants and animals species types that are comparable to ground-based systems (Jones, 2002; Kim, 2004; Getter & Rowe, 2006; Grant, 2006; Kadas, 2006; Oberndorfer *et al.*, 2007; Richardson & Jones, 2009; Dvorak & Volder, 2010; Coffman & Waite, 2011; MacIvor & Lundholm, 2011; Pearce & Walters, 2012; Lin *et al.*, 2015; Van Mechelen *et al.*, 2015). Therefore, examining and evaluating ground-based green infrastructure can inform the design of green roofs to maximise their ecosystem service generations, whilst minimising the factors leading to ecosystem disservice generation.

Aesthetically, extensive green roofs can be seen as a form of urban nature (Loder, 2014), and they can offer other cultural ecosystem services if designed appropriately (Kim, 2004; Song *et al.*, 2013; Wolf, 2015). Therefore, green roofs can offer cultural ecosystem services comparable to ground-based vegetated SuDS systems and urban green infrastructure. Consequently, the cultural ecosystem services examination and evaluation of urban green spaces can inform future green roof retrofits (Krasny *et al.*, 2014; Church, 2015; Wolf, 2015).

Stormwater management ponds, such as retention and detention ponds, are designed to retain or detain and purify polluted stormwater runoff (Woods-Ballard *et al.*, 2007). Yet, invertebrate species were observed using these ponds as habitats (Jackson & Boutle, 2008; Viol *et al.*, 2009; Moore and Hunt, 2012; Briers, 2014). In some research, stormwater management ponds, such as motorway stormwater retention ponds in Australia, were found to support "aquatic macroinvertebrate communities at least as rich and diverse at the family level as surrounding ponds and exhibited similar variability in family community composition and structure" (Viol *et al.*, 2009, p.3163). Certainly, due to water quality and hydraulic issues, stormwater management ponds will not be able to sustain equivalent level of biodiversity compared with natural ponds. However, improving the vegetation structure diversity of the pond surroundings and providing recreational facilities at areas adjacent to the ponds can improve the biodiversity and amenity values of these stormwater management ponds (Moore and Hunt, 2012; Wolf, 2015). Therefore, examining and evaluating other elements of urban green infrastructure can inform the design of stormwater management ponds to maximise their biodiversity and amenity related ecosystem services generation, whilst minimising the factors leading to ecosystem disservices generation, as recommended for the vegetated SuDS systems already mentioned.

Biodiversity in bioretention basins in Melbourne, Australia, was found to be more diverse than adjacent lawn-grass based green spaces (Kazemi *et al.*, 2009; 2011). Major factors affecting the biodiversity of the bioretention basins include vegetation structure diversity. Consequently, examining other urban green infrastructures and evaluating their vegetation structure diversity can inform the design of bioretention devices to maximise their biodiversity related ecosystem services generation, whilst minimising the factors leading to ecosystem disservices generation. Amenity related ecosystem services can also be improved (Krasny *et al.*, 2014; Church, 2015; Wolf, 2015) and disservices can be mitigated (Petherick, 2001; Allen *et al.*, 2012; Byrne, 2012; Safransky, 2014; Wolch *et al.*, 2014; Maruthaveeran & Konijnendijk van den Bosch, 2014) by evaluating the approaches adopted in other urban green infrastructures.

In America, elements of green infrastructure are credited for their stormwater management qualities; therefore, they are now recognised as being an important aspect of the Best Management Practises and Low Impact Development stormwater management approaches (US Environmental Protection Agency., 2007; Odefey *et al.*, 2012; Struck *et al.*, 2010 cited in Fletcher *et al.*, 2014; Wolf, 2015). Currently in the UK, efforts are being made to integrate vegetated SuDS techniques into urban green infrastructure, in order to contribute to reversing habitat fragmentation caused by increased urbanisation and climate change (Ashton *et al.*, 2010; Wise *et al.*, 2010; Natural England, 2011; Ellis, 2013; Graham *et al.*, 2013).

With the above reasons in mind, sites selected for the validation of the SuDS Communication and Planning Framework should include elements of urban green infrastructure. Furthermore, since the validation of the framework involves analysis of the ecosystem services and disservices derived from the biodiversity and amenity objective of the SuDS approach, examining and evaluating elements of urban green infrastructure in this research will inform planning and design of future vegetated

SuDS retrofits, so that a complete urban green network can be created by integrating vegetated SuDS with green infrastructure (Ellis, 2013; Graham *et al.*, 2013; Wolf, 2015).

4.1.2. Selection of urban green infrastructure sites for ecosystem services and disservices examination and evaluation

Greater Manchester (situated in the North West England) is one the most urbanised areas within England. Situated in the North West, Greater Manchester has a population of 2,682,500, according to the 2011 census (Office of National Statistics, 2012). The reason for choosing Greater Manchester is because lessons learned from the evaluation of this urbanised and post-industrial city region can be incorporated into similarly urbanised and post-industrial cities around the world.

There has been a previous University of Salford civil engineering undergraduate research, focusing on identifying and assessing potential SuDS sites across Greater Manchester. Therefore, sites for this research were randomly chosen within the pool of 146 sites (102 sites from the undergraduate project and 44 sites provided by Red Rose Forest, which is a community forest in Greater Manchester with expert knowledge on the regions' SuDS suitability). Sites that cannot be accessed were eliminated. That left 60 sites which were potentially suitable for this research. Proximity of the site to the University of Salford was considered, ruling out sites too far away from the University. After taking account of these factors, 49 sites remained, which were used for this research. Table 4.1 contains the list of 49 sites, along with their geographical locations and infrastructure types, chosen for the ecosystem services and disservices examination and evaluation.

Table 4.1 – Sites for ecosystem services and disservices examination and evaluation

No.	Site name	Latitude	Longitude
1	Acorn Close allotments green roof	53.440248	-2.203900
2	Adelphi House Car Park	53.484281	-2.265072
3	Alexandra Park pond	53.449894	-2.250524
4	Blackfish pond one	53.538521	-2.24886
5	Blackfish pond two	53.538633	-2.246254
6	Blackley New Road pond one	53.524924	-2.239487
7	Blackley New Road pond two	53.524445	-2.230899
8	Brownfield site beside Asda Hulme petrol station	53.463506	-2.247587
9	Brownfield site beside houses behind Salford University	53.492007	-2.272459
10	Canal Road pond	53.401033	-2.344878
11	Castle Irwell	53.508000	-2.268610
12	Chorlton Water Park pond	53.421494	-2.266823
13	Farmer Norton Car Park	53.485379	-2.263877
14	Footpath beside David Lewis Sports Ground	53.490975	-2.272310
15	Green space behind old Salford Royal Hospital	53.484605	-2.264291
16	Green space behind Salford Cathedral	53.484394	-2.262291
17	Green space opposite David Lewis Sports Ground	53.492886	-2.273199
18	Heaton Park boating pond	53.531135	-2.255221
19	Heaton Park Dell Garden pond	53.535917	-2.257401

Continued…

No.	Site name	Latitude	Longitude
20	Heaton Park Western Pleasure Ground pond	53.535423	-2.259795
21	Hullard Park pond	53.461559	-2.268532
22	Littleton Rd and Reading Street brownfield site	53.499451	-2.279085
23	Nan Nook Woods	53.406626	-2.290173
24	Nutsford Vale	53.452700	-2.183460
25	Old Trafford INCOM site	53.466232	-2.296087
26	Peel Park cycle path	53.490052	-2.270995
27	Peel park grass pit	53.488677	-2.270075
28	Peel park area one	53.487437	-2.272174
29	Pendleton site one	53.484652	-2.281498
30	Pendleton site two	53.480774	-2.283703
31	Pendleton site three	53.485707	-2.286555
32	Platt Field pond	53.445348	-2.225610
33	Primrose Primary School pond	53.474146	-2.280356
34	Quays Reach business park pond	53.479255	-2.296268
35	Range Road public garden	53.453379	-2.253287
36	Salford University garden	53.488282	-2.273848
37	Salford University Woodland	53.490107	-2.273583
38	Scott Avenue allotments green roof	53.448256	-2.276964
39	Stamford Brook retention basin one	53.406740	-2.358192

Continued…

No.	Site name	Latitude	Longitude
40	Stamford Brook retention basin two	53.406736	-2.358884
41	Stamford Brook retention basin three	53.407735	-2.361775
42	Stamford Brook retention basin four	53.408202	-2.361382
43	Stevenson Square green roof	53.482698	-2.234142
44	The Meadow	53.485255	-2.266462
45	Three Sisters	53.493056	-2.338897
46	Trafford City Council office bioretention swale	53.458963	-2.287783
47	Untrimmed vegetation area inside Hulme Park	53.469484	-2.252390
48	Whitworth Art Gallery green roof	53.460131	-2.229322
49	Woodland walkway within Alexandra Park	53.451931	-2.251945

The following sections of this chapter contain details of the methods used to analyse and evaluate the ecosystem services and disservices that can be generated by the sites listed in Table 4.1. Consequently, the results from the analysis and evaluation can be used to validate the SuDS Communication and Planning Framework created in Chapter 3.

4.2. Vegetation structure coverage abundance survey

Referring back to section 4.1, the biodiversity and amenity related ecosystem services and disservices that result from elements of urban green infrastructure can be used to inform future vegetated SuDS retrofitting. Therefore, common variables between vegetated SuDS sites and elements of urban green infrastructure should be identified and examined. These common variables need to be identified so that future vegetated SuDS retrofitting can learn from the successes and failings of existing urban green infrastructure. One of the common variables is vegetation structure diversity. Therefore, the first method created to validate the SuDS Communication and Planning Framework involves the examination and evaluation of the vegetation structure cover-abundance of sites listed in Table 4.1. Section 4.2 illustrates the logic behind the first method.

4.2.1. Method justification

Vegetation structure diversity is directly linked to the site's biodiversity. Kazemi *et al.* (2011) conducted biodiversity analysis of a number of bioretention swales and urban green spaces in Melbourne, Australia. They discovered that the bioretention swales added to urban habitat heterogeneity because they support diverse vegetation structure. This is one major factor that positively influences habitat resources for invertebrates (Kazemi *et al.*, 2011). The research conducted by Kazemi *et al.* (2011) implies that vegetation structure diversity in vegetated SuDS systems has a key role to play in offering more resources and opportunities to different organisms in SuDS systems, which is compatible with the ecological niche theory (Cain *et al.*, 2011). Habitat structure diversity, as represented by vegetation structure diversity (both vertical and horizontal), is, therefore, positively correlated to biodiversity, especially in urban areas. This is proven through findings from past studies of green infrastructure using vegetation structure as a proxy for biodiversity (Hercock, 1997; Hermy & Cornelis, 2000; Savard *et al.*, 2000; Fernández-Juricic & Jokimaki, 2001; Young & Jarvis, 2001; Honnay *et al.*, 2003; Livingston *et al.*, 2003; Cornelis & Hermy, 2004; Tzoulas & James, 2009; Iswoyo *et al.*, 2013; Beumer & Martens, 2015; Voigt & Wurster, 2015).

Vegetated SuDS systems are being retrofitted in urban areas and these areas are dominated by impermeable surfaces and have constant human activity. More importantly, humans interact constantly with wildlife in urban areas. Therefore, an analysis of vegetation structural diversity should include methods to assess built areas in relation to green spaces to reflect on human's influence to the urban ecosystem (Tzoulas & James, 2009; Douglas & James, 2015).

As discussed in Chapter 2, habitat fragmentation due to urbanisation can be reversed using techniques from ecological restoration, and vegetation can be used to establish habitat corridors and buffer zones to connect and protect fragmented habitats. Vegetation structural diversity analysis is part of the pattern-oriented approach in studying landscape modification (Fischer & Lindenmayer, 2007). This approach utilises the theory of ecological niches, disturbance and ecological succession, which are central to ecological restoration (Collinge, 1996).

Diverse vegetation structure (both vertical and horizontal) allows a variety of microhabitats to exist, which in turn satisfy many ecological niche requirements because these microhabitats can provide a different range of conditions that allow an organism to grow and reproduce (Cain *et al.*, 2011). In other words, both vertically and horizontally diverse vegetation structures can provide niches with multiple dimensions for different organisms (Cain *et al.*, 2011).

Vegetation structural diversity (both vertical and horizontal) is one of the best predictors of animal diversity occurring within gardens, which is a common urban green infrastructure type (Gaston *et al.*, 2004 cited in Tzoulas, 2010). Vegetation structural diversity may be measured in terms of complexity and by features such as the occurrence, number, height and clumping of trees (Douglas & James, 2015). Vegetation structural diversity of a site also signifies different stages of ecological succession (Binelli *et al.*, 2001).

Urban green spaces are highly managed and constantly being disturbed, therefore, vegetation species from different succession stages can simultaneously occupy a site (UK National Ecosystem Assessment, 2011a; Wu, 2014; Douglas & James, 2015). In terrestrial succession, one area of a mature woodland habitat can be disturbed by site management clearing the area for a car park (site A), and another separate area of the woodland can have their vegetation stripped so that the soil is left exposed (site B). Both disturbance events (site A and B) triggered different starting points of a secondary succession. For site A, if it is abandoned after a period of time, pioneering plants (mosses and lichens) will grow and start to colonise the car park.   Pioneering plants will eventually improve the soil of the car park to an extent that grasses and flowering plants can grow and dominate. Of course, grasses and flowering plants will improve the soil even more to allow perennial plants to grow and dominate, and then woody plants will invade. Eventually, site A will, theoretically, return to its pre-disturbed woodland form.

Focusing on site B, if it is left abandoned for a period of time, annual weeds will start to invade and colonise the area. Annual weeds will improve the soil which will allow biennials and perennials plants to grow and dominate. Eventually, perennial plants will colonise, which will improve the soil to allow woody plants to invade. Comparable to site A, site B will eventually return to its pre-disturbed woodland form.

Consequently, if the entire mature woodland habitat was subjected to a habitat survey at a randomly selected period of time, the surveyor will be able to observe the car park area (site A) in a particular successional stage, occupied by the associated vegetation type. The surveyor will also be able to observe the exposed soil area (site B) in a separate successional stage from the car park (site A), occupied by the associated vegetation type. Finally, the undisturbed mature woodland will be occupied by vegetation associated with the climatic stage of succession, which is different from the vegetation occupying site A and B, at that particular time when the survey is conducted. Overall, due to site management and unintentional disturbances, urban areas constantly contain patches of land in various successional stages adjacent to each other. Therefore, a surveyor can observe different stages of succession, represented by associated vegetation types, when conducting a site survey in an urban area, at a pre-determined time.

A surveyor can also reference the different vegetation types found on-site when surveying habitats containing aquatic bodies, such as a wetland. This is because a wetland is a transitional phase between fully aquatic and completely terrestrial ecosystems. Therefore, wetlands are ideal habitats to observe several hydrosere (aquatic succession) stages at the same time. The stages of a hydrosere in the UK are: open water, submerged plants, swamp, marsh, alder or willow carr, and climax woodland (Offwell Woodland & Wildlife Trust, 1998). Both terrestrial and aquatic succession can be altered by human activities to arrive at alternative stable states (Cain *et al.*, 2011). Referring back to site A (abandoned car park) and site B (exposed soil) in the mature woodland habitat, both sites have been manipulated by human activities. These manipulations will cause the two sites to arrive at climatic succession states which differ from the original, undisturbed, mature woodland due to the alternative stable states theory.

Overall, because vegetation associated with different successional stages have different physical attributes (e.g. height and size), they can be distinguished by observing these attributes. Therefore, vegetation structural diversity can be used to distinguish different stages of succession.

Whilst biodiversity analysis can involve examination of many different variables (Jackson & Boutle, 2008; Viol *et al.*, 2009; Kazemi *et al.*, 2011; Moore & Hunt, 2012; Briers, 2014; Rooney *et al.*, 2015), coarse scale assessments can be made to provide information on biodiversity and subsequent ecosystem services of an area (Iswoyo & Bryant, 2013; Scholz & Uzomah, 2013; Peh, *et al.*, 2013; Uzomah *et al.*, 2014; Voigt & Wurster, 2015). A method developed by Tzoulas & James (2009) aimed to provide a way to analyse the biodiversity potential and subsequent ecosystem services of urban green spaces that can be used by non-specialists, is quick to carry out and is ecologically justifiable (Voigt & Wurster, 2015). Therefore, the method developed by Tzoulas & James (2009) was used, with amendments, for site analysis in order to verify the ecosystem services of the sites listed in Table 4.1. Figure 4.1 contains an illustration of the original Tzoulas-James method data collection sheet.

1. Vegetation layers	**2. Height ranges**	**3. Vegetation types**	**4. Percentage of cover (%) observed on-site**	**5. Domin value corresponding to column 3.**
1. High trees	More than or equals to 10m.	Conifer, broadleaf, mixed		
2. Low trees	5 to 9.9m.	Conifer, broadleaf, mixed		
3. Bushes	1 to 4.9m.	Shrub, scrub, hedgerows		
4. High grasses and forbs	20cm to 90cm.	Low bush, grasses, herbs		
5. Low grasses and forbs	5cm to 19cm.	Cropped or mown grassland, road or rail verges		
6. Ground flora	Less than or equal to 4cm.	Bare ground, bryophytes, fungi or lichens, algae		
7. Aquatic	Not defined.			
8. Built	Not defined.			

6. Range of cover (%)	**7. Domin values**
91 to 100	10
76 to 90	9
51 to 75	8
34 to 50	7
26 to 33	6
11 to 25	5
4 to 10	4
<4 (with many individual species)	3
<4 (with several individual species)	2
<4 (with few individuals species)	1

8. Habitat types	**9. Additional explanations**
Built surface	Includes roads.
Cemeteries	
Churchyards	
Civic and market squares	
Commercial or industrial	
Country park	Includes golf course and local nature reserves.
Incidental green space	Includes road side verges, housing green space, pedestrian streets, and informal recreational space.
Residential area with gardens	
Residential area with no gardens	
Urban farms	Includes community gardens and allotments.
Urban park	Includes village greens and formal gardens.
Waste land	

Figure 4.1– The Tzoulas-James method data collection sheet (adapted from Tzoulas & James, 2009).

Note: the Domin Scale used in the Tzoulas-James method (Dahl & Hadac, 1941 cited in Poore, 1955; Currall, 1987; Sutherland, 2006; Tzoulas & James, 2009). A *vascular plant genera checklist was also developed for use in this method, and it can be found in Tzoulas & James (2009).*

Figure 4.1 details the data the surveyor would collect on-site. The overall Tzoulas-James survey method consists of five parts (Tzoulas & James, 2009):

1. Estimate the percentage cover of eight vegetation structural layers (see fourth column in Figure 4.1) on-site using sampling points of 65m radius. The first, second and third columns in Figure 4.1 contain information that was designed to aid the surveyor to distinguish between each vegetation layers.
2. Assign the relevant Domin value from the Domin scale of cover (see the sixth column in Figure 4.1) in accordance with the estimated percentage cover of each vegetation layer. The Domin scale of cover (see the fifth column in Figure 4.1) also acted as a guide to help the surveyor to determine the percentage cover of each vegetation layers.
3. Identify the habitat type (see the seventh column in Figure 4.1) the site being surveyed belongs to.
4. Identify the dominant tree and bush species, as well as the field and low herb layer species. The vascular plant genera checklist can be found in Tzoulas & James (2009).
5. Note down other species observed on site and other relevant features of the site.

Familiarisation training for using the Tzoulas-James survey method was provided by Dr Tzoulas, one of the authors. The training was performed in Hulme Park (53.467409, -2.252189) and Spyder Park (53.468610, -2.247096) on 05/04/2012, from 12:30 to 14:30.

A trial was also conducted to determine the size of the sample area to be used for examining the sites listed in Table 4.1. Circular sample areas (25m, 50m, and 65m radius) detailed in Tzoulas & James (2009) were used during the trial. The 50m and 65m radius sampling areas were found to be too big to visually determine vegetation structural percentage cover accurately on-site. A 25m radius sampling area enables higher confidence in the visual determination of vegetation percentage cover.

However, it was found that the circular sample areas made visualisation of the vegetation percentage cover difficult as it was problematic to determine the circular boundary of the sample areas visually.

A 50m by 50m square (2500m^2) sampling plot (commonly used in UK vegetation surveys) was then trialled as the minimum sampling area depending on the size of the site (Forestry Commission, 2001; Humphrey *et al.*, 2003). It was found that the setting up of the 50m by 50m square was much easier and it was also more straight-forward when visualising the boundaries of the sample area, by using the corners of the square as marking points for the eyes. Therefore the 50m by 50m sampling area was adopted as the standard sample area. For sites that are smaller than 50m by 50m square, it was sampled in its entirety.

The second changes made to the original Tzoulas-James method was the replacement of the Domin scale with the Braun-Blanquet scale. The Domin coverage abundance scale used in the original Tzoulas-James method was not incorporated into the validation of the SuDS Communication and Planning Framework. The Braun-Blanquet scale (Poore, 1955; Moore, 1962; Podani, 2006; Sutherland, 2006) was used instead (see Figure 4.2) to guide the surveyor in estimating the observed percentage cover of each vegetation layer present on-site.

Domin values	**Range of cover (%)**
10	91 to 100
9	76 to 90
8	51 to 75
7	34 to 50
6	26 to 33
5	11 to 25
4	4 to 10
3	<4 (with many individual species)
2	<4 (with several individual species)
1	<4 (with few individual species)

Braun-Blanquet values	**Range of cover (%)**
6	76-100
5	51-75
4	26-50
3	6-25
2	1-5
1	<1
0	0

Figure 4.2 – Domin scale changed to Braun-Blanquet scale

The Braun-Blanquet scale (see Figure 4.2) is a set of percentage classes commonly used in phytosociological surveys (ecological studies that examine the structure and distribution of plant species in a given area). The Domin scale employed in the Tzoulas-James method (see Figure 4.1) was actually developed based on the Braun-Blanquet scale (Poore, 1955). There is another scale, the DAFOR scale, which is also commonly used in phytosociological surveys. DAFOR stands for Dominant, Abundant, Frequent, Occasional and Rare. It is a semi-qualitative sampling method used for plant species abundance/dominance and coverage estimates (Sutherland, 2006). The main disadvantages for using this method are, firstly, the categories are ill-defined and therefore subject to individual interpretations and even different interpretations from the same surveyor at different times (Sutherland, 2006). Secondly, it cannot detect temporal or spatial vegetation differences (Sutherland, 2006). Thirdly, it is subjected to large bias because vegetation layers that can be more obviously recognised and visually distinguished (e.g. upper tree layer) would score higher than plants not so obviously distinguishable (Sutherland, 2006), hence it does not highlight rare habitat types which can contribute greatly to many different ecosystem services. However, the DAFOR scale is employed to analyse dog faeces and litter on-site coverage, which will be explained in later sections of this chapter.

Even though both the Braun-Blanquet and the Domin scales are well-established, standard methods for measuring the cover-abundance of vegetation species in ecology (Sutherland, 2006), the Braun-Blanquet scale was chosen instead of the Domin scale for the validation of the SuDS Communication and Planning Framework. This is mainly because the Braun-Blanquet scale does not require vegetation species data to be inserted, therefore, no vegetation species identification need to be performed. The aim of this validation is to appraise the habitat for species vegetated SuDS can generate, by using vegetation structural diversity as a proxy to habitat diversity. The consideration of plant species is also problematic when a non-specialist, with no botanical training, wants to use the survey method to appraise the ecosystem services a site can generate. The way the survey method is set up in this research does not require any vegetation species data to be collected. Therefore, many more people can use the survey method for ecosystem services analysis. Other reasons for using the Braun-Blanquet scale instead are:

- The Braun-Blanquet scale is quick and simple to use, and does not require extra training for a non-specialist.
- It gives a good illustration of habitat structural diversity based on percentage of vegetation structural coverage.
- The scale is biased towards rarity. This is good because it can illustrate the importance of well-defined habitat types that do not dominate a particular site but provide habitats for various species and other ecosystem services to humans. For example, a site that is dominated by grass can have several mature trees (based on height) scattered around.
- The Braun-Blanquet scale is suitable for ordinal data analysis (Podani, 2006), which is similar to the ecosystem services results presented in the UK NEA (UK National Ecosystem Assessment, 2011b), hence ensuring compatibility with existing ecosystem services studies.

There are criticisms towards the use of Braun-Blanquet scale in the analysis of vegetation species coverage and abundance (Poore, 1955, Podani, 2006), but the aim of this research is not to analyse any specific vegetation species in a phytosociological way and the Braun-Blanquet scale is not employed for use in phytosociological studies. Therefore all the criticisms are irrelevant for the way the Braun-Blanquet scale is employed in this research, which is to analyse vegetation structure in the broadest sense (height and percentage cover) in order to give an appreciation of the biodiversity driven ecosystem services a site can generate. With only seven coverage classes, the Braun-Blanquet scale is better in mitigating the issue of when the initial cover estimate is at the borderline between two cover classes (Hurford, & Schneider, 2007). In this instance, the observer has to decide in which cover class the vegetation being analysed falls before allocating the cover class to the species (Hurford, & Schneider, 2007). This situation occurs more often for the Domin scale because it has more cover classes. With fewer cover classes, the Braun-Blanquet scale is better at dealing with this situation.

The criticism that cover-abundance analysis is too subjective is relevant for this research (Poore, 1955; Podani, 2006). Subjectivity is a shortcoming of all the methods employed for this research, but a balance must be struck between accuracy, efficiency and speed of survey (Scholz & Uzomah, 2013). When ecosystem services analysis is required to be performed before development decisions are made, rapid, accurate and cost effective methods are required to enable good planning decisions to be made (Scholz & Uzomah, 2013). Utilising cover-abundance analysis is a trade-off between accuracy and cost-effectiveness and is deemed to be acceptable in terms of enabling development planning decisions to be made. Figure 4.3 illustrates the first amendments to the Tzoulas-James method, by replacing the Domin scale with the Braun-Blanquet scale.

1. Vegetation layers	2. Height ranges	3. Vegetation types	4. Percentage of cover (%) observed on-site	5. Braun-Blanquet value corresponding to column 4.
1. High trees	More than or equals to 10m.	Conifer, broadleaf, mixed		
2. Low trees	5 to 9.9m.	Conifer, broadleaf, mixed		
3. Bushes	1 to 4.9m.	Shrub, scrub, hedgerows		
4. High grasses and forbs	20cm to 90cm.	Low bush, grasses, herbs		
5. Low grasses and forbs	5cm to 19cm.	Cropped or mown grassland, road or rail verges		
6. Ground flora	Less than or equal to 4cm.	Bare ground, bryophytes, fungi or lichens, algae		
7. Aquatic	Not defined.			
8. Built	Not defined.			

6. Range of cover (%)	7. Braun-Blanquet values
0	0
<1	1
1 to 5	2
6 to 25	3
26 to 50	4
51 to 75	5
76 to 100	6

8. Habitat types	9. Additional explanations
Built surface	Includes roads.
Cemeteries	
Churchyards	
Civic and market squares	
Commercial or industrial	
Country park	Includes golf course and local nature reserves.
Incidental green space	Includes road side verges, housing green space, pedestrian streets, and informal recreational space.
Residential area with gardens	
Residential area with no gardens	
Urban farms	Includes community gardens and allotments.
Urban park	Include village greens and formal gardens.
Waste land	

Figure 4.3 – First amendments to the Tzoulas-James method on-site data collection sheet. The Braun-Blanquet scale (see columns 5, 6 and 7) replaced the Domin scale.

After changes were made to the original Tzoulas-James method (see Figure 4.3), two separate pilot trials were performed to analyse whether the entire Tzoulas-James method (see Figure 4.3) was appropriate for the examination of the sites listed in Table 4.1. Amendments were made to the Tzoulas-James method based on feedback from the two trials in order to adapt it to the current research. The first trial involved three PhD researchers (the author and two other researchers) using the method on five sites, and the second trial involved ten ecology undergraduates using the method on one site. The following sections will explain each of the trials and findings from the trials.

4.2.2. First Pilot of the amended Tzoulas-James method

Three PhD researchers went out onto five sites (chosen from Table 4.1) on 03/03/2014 to collect pilot data using the amended Tzoulas-James method. The sites are (site name is followed by Latitude and Longitude):

- Castle Irwell (53.508000, -2.268610)
- Pendleton site one (53.484652, -2.281498)
- Pendleton site two (53.480774, -2.283703)
- Pendleton site three (53.485707, -2.286555)
- Three Sisters (53.493056, -2.338897)

The three PhD researchers were chosen because they specialised in three different disciplines: engineering (the author), ecology and geography. The aim of the pilot was to determine whether the amended Tzoulas-James method can be used by researcher irrespective of their botanical knowledge. This is important because in the future, non-specialists involved in SuDS development can use this method to appraise the biodiversity related ecosystem services potential of sites being considered for SuDS retrofitting. Therefore, the hypothesis statements are:

- H1: There is a significant difference in observed vegetation layers coverage between a geographer, an ecologist and an engineer.
- H0: There is no significant difference in observed vegetation layers coverage between a geographer, an ecologist and an engineer.

In order to gather the data for the trial, sample areas were set up for each site. On large sites 50m by 50m sampling areas were set up. For sites smaller than the standard sampling area, they were surveyed in their entirety. As the purpose of the trial was to determine if there was a significant difference in observed vegetation layers coverage between the three different surveyors, no sample area distribution strategies were employed for the large sites.

Tree heights (first and second rows in Figure 4.3) were checked using the Smart Measure function within the Smart Tools Android App (Android Boy, 2010). The mobile phone used was the dual-core Samsung Galaxy Ace 3. It ran the Android version 4.2.2 operating system, and its 5-megapixel camera was used to measure the tree heights. Figure 4.4 and 4.5 illustrate the process carried out to check the tree heights using the mobile phone. The concept is similar to a hypsometer, as they both use trigonometry to compute the height of a tree. Tree height measurements using the image processing capacity of a mobile phone were proved to be viable, with 5% relative measurement error (Dianyuan & Chengduan, 2011).

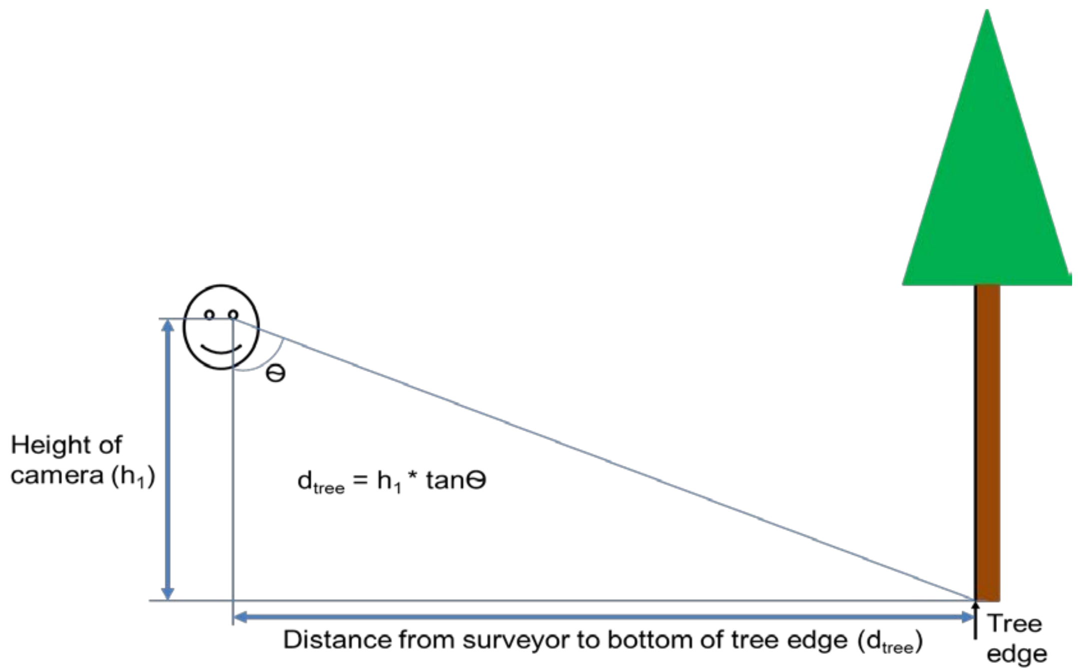

Figure 4.4 – Distance from surveyor to bottom of the tree being checked.

Note: Measurement was made after phone was calibrated. Please note that the ground was assumed to be level in all cases and the diameter of the tree trunk was not measured.

Figure 4.4 illustrates the steps taken to obtain the distance from the surveyor to the bottom of the tree edge, d_{tree}. This distance was measured after the phone was calibrated. The height of the surveyor was kept constant by having one person (height of the engineer = 1.75m) to take the height reading every time. The height of the phone camera was assumed to be the height of the surveyor minus 0.3m.

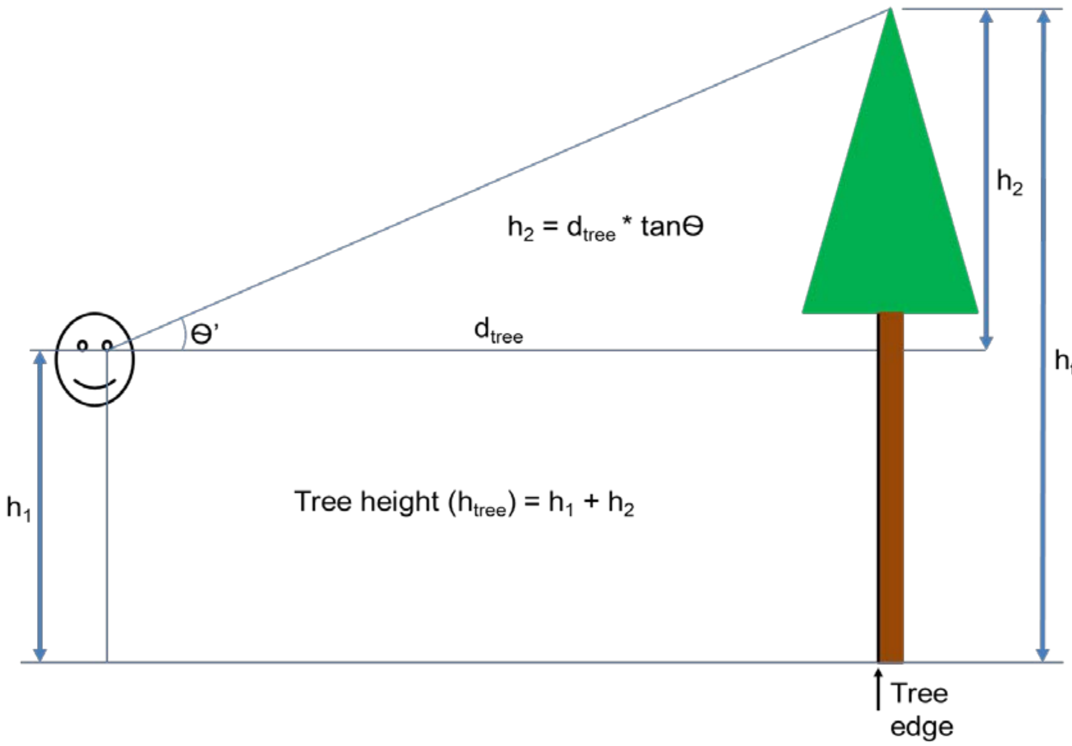

Figure 4.5 – Tree height

Figure 4.5 illustrates the process of obtaining the tree height, h_{tree}, after d_{tree} was obtained. After the tree heights were checked, the height ranges of the vegetation layers listed in Figure 4.3 and the vegetation types (see Figure 4.3) were also used to distinguish between for each vegetation layers on-site.

The percentage cover of the eight vegetation layers listed in Figure 4.3 was estimated using the Braun-Blanquet scale. Dominant vegetation species were not identified during the trial. The percentage coverage of each layer was then converted into the relevant Braun-Blanquet values.

The raw data collected during the survey are presented in Table B1 and B2 in Appendix B. Fisher's exact tests were employed for each vegetation layers to identify any significant differences between surveyors with regards to the percentage cover they observed on-site. The observed percentage covers were converted to their relevant Braun-Blanquet values. Therefore, the Braun-Blanquet values were used in the Fisher's exact tests instead. The statistical analysis results are presented in Table B3 to B16 in Appendix B. Summary of the statistical results are presented in Table 4.2.

Table 4.2 – Summary of the statistical results for the first pilot of the amended Tzoulas-James method.

Note: P-value stands for the probability (P) of the likelihood that when observing two or more different events, any detectable difference between them is purely coincidental. P is from 0 to 1 (between 0% to 100% probabilities). If the P-value is close to 0, then the detectable difference is unlikely to be purely coincidental (there is a logical reason for the observable difference from occurring). If the P-value is close to 1, then the detectable difference between the events is likely to be purely coincidental, caused by some random variations (Hinton, 2014).

Vegetation layers	**Fisher's exact test results**	**P-value**	**P-value more or less than 0.05**	**Significant difference (Y/N)**
1. High trees	4.664	0.628	Larger	N
2. Low trees	3.197	0.889	Larger	N
3. Bushes	6.514	0.641	Larger	N
4. High grasses and forbs	9.183	0.544	Larger	N
5. Low grasses and forbs	4.797	0.991	Larger	N
6. Ground flora	6.759	0.858	Larger	N
7. Aquatic	4.385	1.000	Larger	N

Table 4.2 illustrates the results of statistical analysis of the vegetation layers percentage covers observed on-site by the three PhD researchers. The significant p-value (calculated probability) was set at 0.05 (less than 1 in 20 chance of being wrong or 95% confidence level). Since the p-value is a measure of how much evidence there is against the null hypothesis (no change or no difference), if the significant p-value was calculated to be lower than 0.05, this means that there is evidence to reject the null hypothesis (Hinton, 2014). No significant differences were found for each of the vegetation layers analysed. Therefore, the amended Tzoulas-

James method can be used by researchers with or without specialist botanical training.

4.2.3. Second pilot of the Tzoulas-James method

As part of the University of Salford second year ecology class exercise to familiarise students with the concept of ecosystem services, ten ecology undergraduates (supervised by their tutor) went out to The Meadow (53.485255, -2.266462) on 14/03/2014 to collect trial data using the Tzoulas-James method. They surveyed the site in its entirety and the data gathered formed the second pilot of the Tzoulas-James method. The raw data collected during the survey are presented in Table B17 and B18 in Appendix B. Table 4.3 contains results from frequency analysis of the data from Table B18. The aim of the analysis is to determine whether the vegetation layers detailed in Figure 4.3 can be easily distinguished on-site, given the properties of the vegetation layers.

Table 4.3 – Frequency analysis of data from Table B18[1].

Row	Vegetation layers	Height range (m)	Expected vegetation types	Braun-Blanquet value	Range of % cover	No. of students who obtained the B.B value	Total no. of students	Students who obtained the B.B value (%)
1	High trees	>9	Conifer, broadleaf, mixed	3	6 to 25	10	10	100
2	Low trees	4.1 to 9	Conifer, broadleaf, mixed	2	1 to 5	8	10	80
				3	6 to 25	2	10	20
3	Bushes	0.51 to 4	Shrub, scrub, hedgerows	1	<1	2	10	20
				2	1 to 5	7	10	70
				3	6 to 25	1	10	10
4	High grasses and forbs	0.2 to 0.5	Low bush, long grasses, herbs	2	1 to 5	3	10	30
				3	6 to 25	6	10	60
				4	26 to 50	1	10	10
5	Low grasses and forbs	0.05 to 0.19	Cropped/mowed grassland	5	51 to 75	6	10	60
				6	76 to 100	4	10	40
6	Ground flora	<0.05	Bare ground, bryophytes, fungi or lichen, algae	2	1 to 5	9	10	90
				3	6 to 25	1	10	10
7	Aquatic	Not defined	Not defined	1	<1	9	10	90
				2	1 to 5	1	10	10
8	Built	Not defined	Not defined	1	< 1	9	10	90
				2	1 to 5	1	10	10

[1] Note: during survey, vegetation heights were not measured on-site. Instead, the height ranges were used as a guide to distinguishing each vegetation layer

The data contained in Table 4.3 allows evaluation to be made concerning whether each vegetation layers can be easily distinguished on-site, given the properties of the vegetation layers. This is based on the number of students reaching an agreement on the vegetation layers percentage cover observed on-site. A minimum of 7 out of 10 students (70%) must agree with each other's percentage cover observation to allow the vegetation layers properties to be used for the main survey. Table 4.4 contains evaluations and conclusions drawn from Table 4.3.

Table 4.4 – Evaluations and conclusions drawn from Table 4.3

Row	Evaluation	Conclusion	Changes to vegetation layers (Y/N)
1	100% of the students agreed with each other's observation.	High Trees vegetation layer properties can be used to distinguish this vegetation layer from the others.	N
2	80% of the students agreed with each other's observation. 20% did not agree.	Low Trees vegetation layer properties can be used to distinguish this vegetation layer from the others.	N
3	70% of the students agree with each other's observation. 30% did not agree.	Bushes vegetation layer properties can be used to distinguish this vegetation layer from the others	N
4	60% of the students agree with each other's observation. 40% did not agree.	High Grasses and Forbs vegetation layer properties cannot be used to distinguish this vegetation layers from the others.	Y
5	60% of the students agree with each other's observation. 40% did not agree.	Low Grasses and Forbs vegetation layer properties cannot be used to distinguish this vegetation layers from the others.	Y
6	90% of the students agree with each other's observation. 10% did not agree.	Ground Flora vegetation layer properties can be used to distinguish this vegetation layer from the others.	N
7	90% of the students agree with each other's observation. 10% did not agree.	Aquatic vegetation layer properties can be used to distinguish this vegetation layer from the others.	N
8	90% of the students agree with each other's observation. 10% did not agree.	Built vegetation layer properties can be used to distinguish this vegetation layer from the others.	N

The third row in Table 4.4 contains evaluation that implies 30% of the students (3 out of 10) who took part in the survey might have confused bushes with other vegetation layers (since they did not agree with the observation made by the 70% majority). The three students have either over-estimated (10%) or under-estimated (20%) the percentage of bushes that occupy the site. Nonetheless, 70% of the students who took part in the survey agree with each other's observation. Therefore, the conclusion can be drawn that the properties of the bushes vegetation layer provided is sufficient to enable a surveyor to properly estimate the percentage cover of this vegetation layer whilst conducting the vegetation structure cover-abundance survey.

The fourth row in Table 4.4 contains an evaluation that implies 40% of the students (4 out of 10) who took part in the survey might have confused high grasses and forbs with other vegetation layers (since they did not agree with the observation made by the 60% majority). The four students either over-estimated (10%) or under-estimated (30%) the percentage of high grasses and forbs that occupy the site. This situation is the same when the students were asked to determine the percentage cover of the low grasses and forbs vegetation layer on-site. A total of 40% of the students (4 out of 10) did not agree with the observation made by the majority (60%). The 60% agreement reached for observation of the two vegetation layers is lower than the minimum percentage agreement (70%). Therefore, the conclusion can be drawn that the properties of both the high grasses and forbs vegetation layer and the low grasses and forbs vegetation layer provided are not sufficient to enable a surveyor to properly estimate the percentage cover of this vegetation layer whilst conducting the vegetation structure cover-abundance survey. Consequently, additional information has to be provided to surveyors to enable them to distinguish this vegetation layer from the others.

4.2.4. Amendments made after the two pilots

After using the amended Tzoulas-James method for the two pilot studies, it was realised that the height ranges and the sample area size illustrated on Figure 4.3 had to be altered. Originally, the Tzoulas-James method was designed based on results gained from a local nature reserve (Risley Moss Local Nature Reserve) and the surrounding woodlands in Birchwood, Warrington (Tzoulas & James, 2009). The areas used to design the method contained mature trees, many of which were over ten metres high. However, majority of the sites chosen for this research are not comparable with the areas on whch the design of the Tzoulas-James method was based. Pilot trials of the Tzoulas-James method indicated that the height ranges needed to be altered to reflect the nature of the chosen sites for this research. Figure 4.6 contains illustrations of changes made to the Tzoulas-James method.

Original Vegetation layers	Original height ranges (m)	Expected vegetation types
1. High trees	≥10.	Conifer, broadleaf, mixed
2. Low trees	5 - 9.9.	Conifer, broadleaf, mixed
3. Bushes	1 - 4.9.	Shrub, scrub, hedgerows
4. High grasses and forbs	0.2 - 0.9.	Low bush, grasses, herbs
5. Low grasses and forbs	0.05 – 0.19.	Cropped or mowed grassland, road or rail verges
6. Ground flora	≤0.04.	Bare ground, bryophytes, fungi or lichens, algae
7. Aquatic	Not defined.	Not defined.
8. Built	Not defined.	Not defined.

New Vegetation layers	New height ranges (m)	Expected vegetation types
1. Upper canopy	>9.	Needleleaf, broadleaf, mixed.
2. Lower canopy	4.1 - 9.	Needleleaf, broadleaf, mixed.
3. Bush (woody)	0.51 - 4.	Same as before.
4. Low bush and long grass (non-woody)	0.2 - 0.5.	Different types of grass and forbs.
5. Cropped or mowed grass	0.05 – 0.19	Same as before.
6. Ground flora	<0.05	Same as before.
7. Open water	Not defined.	Possible submerged plants in shallow areas.
8. Emergent hydrophytes	Not defined.	Plants with base either temporarily or permanently submerged in water.
9. Floating hydrophytes	Not defined.	Plants with stomata that floats on water (exc. algae)
10. Built	Not defined.	Man made impermeable grounds (inc. permeable pavements) with minimal to no vegetation.

Figure 4.6 – Alterations (vegetation layers, height ranges and expected vegetation types) made to the Tzoulas-James method

Figure 4.6 contains illustration to the changes made to the vegetation layers category (first column in Figure 4.3), the height ranges (second column in Figure 4.3) and the expected vegetation types (third column in Figure 4.3) of the Tzoulas-James method for this research.

The first two vegetation layers detailed in Figure 4.6 (High trees, low trees, bushes, and high grasses and forbs) were renamed upper canopy, lower canopy, bush (woody), and low bush and long grass (non-woody). Their height ranges were amended based on pilot trials. The reason for reclassifying vegetation layer three (bushes) to bush (woody), and vegetation layer four (high grasses and forbs) to low bush and long grass (non-woody) was to distinguish them from non-woody plants that were observed to be of similar height.

The expected vegetation types for the fourth vegetation layer (high grasses and forbs; Figure 4.6) was redefined from “low bush, grasses, herbs” to “different types of grass and forbs”. The reason for the redefinition was to make the vegetation layer simpler to distinguish on-site.

The fifth vegetation layer in Figure 4.6 (low grasses and forbs) was reclassified to be cropped or mown grass, in order to reflect the degree of management performed on urban green infrastructures (Department of Transport and Local Government Regions, 2002; Natural England, 2009).

The seventh vegetation layer in Figure 4.6 (aquatic) was expanded to three layers: open water (vegetation layer seven; Figure 4.6), emergent hydrophytes (vegetation layer eight; Figure 4.6), and floating hydrophytes (vegetation layer nine; Figure 4.6). The reason for this expansion is to reflect that ponds contain mesohabitats which is a concept first used in biodiversity assessment of rivers, such as the UK River Habitat Survey (Raven *et al.*, 1998). The aquatic bodies encountered during the research were ponds. In this research the mesohabitats, therefore, are areas of habitat within a pond that form ecological niches for invertebrates and vertebrates (PondNet, 2013).   Ponds will also undergo aquatic succession (Offwell Woodland & Wildlife Trust, 1998). By expanding the list of vegetation types to include aquatic vegetation, more sites, therefore, can be surveyed, the succession phases in between complete aquatic to complete terrestrial can be observed, and credit can be awarded to sites possessing permanent aquatic vegetation (submerged vegetation was assumed to lay beneath open water) because they support organisms that cannot be supported in a completely terrestrial environment.

Otherwise, all the other vegetation layers were kept the same as the original. Note that vegetation layer ten is not actual “vegetation”. The reason for including it, as explained in Tzoulas & James (2009), is because built layer can support limited biodiversity and it reflects upon the early stages of succession.

Figure 4.7 illustrates the layout of the amended Tzoulas-James method data collection sheet used to collect data for validating the habitat for species potential of the chosen sites for this research.

1. Vegetation layers	**2. Height ranges (m)**	**3. Expected Vegetation types**	**4. Percentage of cover (%) observed on-site**	**5. Braun-Blanquet value corresponding to column 4.**
1. Upper canopy	>9	Needleleaf, broadleaf, mixed		
2. Lower canopy	4.1 to 9	Needleleaf, broadleaf, mixed		
3. Bush (woody)	0.51 to 4	Shrub, scrub, hedgerows		
4. Low bush and long grass (non-woody)	0.2 to 0.5	Different types of grass and forbs		
5. Cropped or mowed grass	0.05 to 0.19	Different types of cropped or mowed grass and forbs		
6. Ground flora	<0.05	Bare ground, bryophytes, fungi or lichens, algae		
7. Open water	Not defined.	Possible submerged plants in shallow areas		
8. Emergent hydrophytes	Not defined.	Plants with base either temporarily or permanently submerged in water		
9. Floating hydrophytes	Not defined.	Plants with stomata that floats on water (exc. algae)		
10. Built	Not defined.	Man made impermeable grounds (inc. permeable pavements) with minimal to no vegetation		

6. Range of cover (%)	**7. Braun-Blanquet values**
0	0
<1	1
1 to 5	2
6 to 25	3
26 to 50	4
51 to 75	5
76 to 100	6

8. Habitat types	**9. Additional explanations**
Built surface	Includes roads.
Cemeteries	
Churchyards	
Civic and market squares	
Commercial or industrial	
Country park	Includes golf course and local nature reserves.
Incidental green space	Includes road side verges, housing green space, pedestrian streets, and informal recreational space.
Residential area with gardens	
Residential area with no gardens	
Urban farms	Includes community gardens and allotments.
Urban park	Include village greens and formal gardens.
Waste land	

Figure 4.7 – Second amended Tzoulas-James method and the Braun-Blanquet scale (Sutherland, 2006, p.191)

4.2.5. Survey procedures

Before going out on-site, a desk study was performed for all 49 sites in order to gather as much information about the site as possible. Basic site information (area of site, site perimeter, site location) was obtained through Ordnance Survey maps and Google Earth satellite images. Satellite images from Google Earth were also used to gain an initial appreciation of the broad vegetation types that can be expected to be found on-site. The satellite images also provided a realistic 2D image of the sites, which helped to ensure on-site estimates of percentage cover for each vegetation layers were reasonably accurate. In terms of field work, the survey of the 49 sites began in August of 2013 (two sites, four days in total), but the main survey period was between April and August 2014 (40 sites, 80 days in total). Sites that were not surveyed within the main period were surveyed in March 2015 (seven sites, ten days in total). Therefore, the total number of days spent on field work is 94 days.

With regards to the sampling plots, 50m by 50m square (2500m^2) were used as the minimum sampling plot depending on the size of the site. Sites smaller than 2500m^2 were surveyed in their entirety (100% coverage) while for larger sites, Ordnance Survey maps and Google Earth satellite images were used as tools to randomly place 50m by 50m square sampling plots before surveys were carried out on-site. A degree of structure was also introduced when deciding where to place the sample plots to ensure that key features in the sites were not missed. When on-site, the coordinates were verified and adjusted using a Garmin Etrex handheld GPS. Also when on-site, the four corners and the mid-point of the sample plots were marked out using distinctive bamboo canes. The purpose was to enable easier visual identification of the vegetation layers within the sample plots, with the canes acting as visual boundaries for each plot. With regards to visually identifying the vegetation layers on-site, Figure 4.8 illustrates the vegetation layers from Figure 4.7, as seen on site.

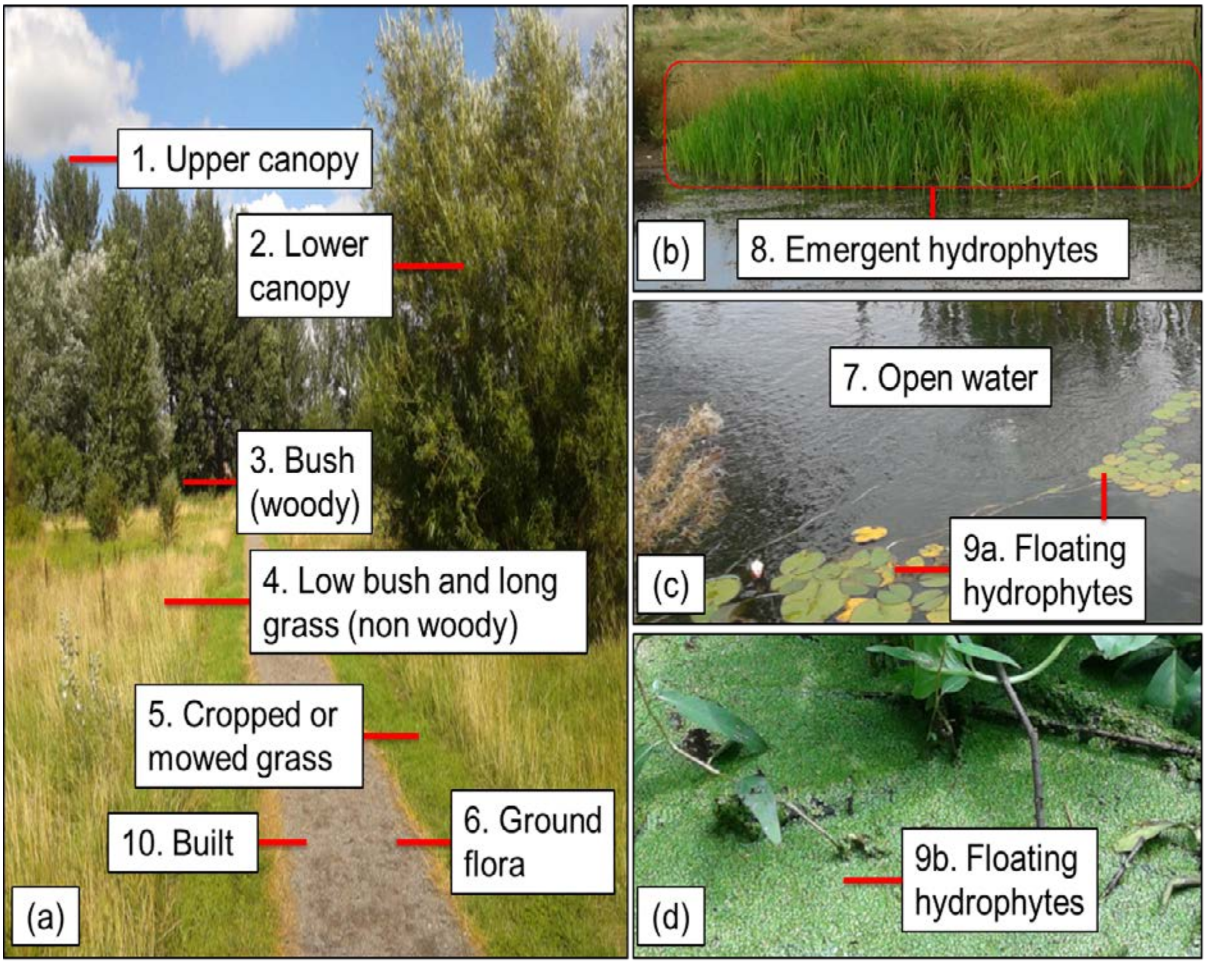

Figure 4.8 – Vegetation layers, as seen on site. (a) Terrestrial elements: (1) upper canopy, (2) lower canopy, (3) bush (woody), (4) low bush and long grass (non woody), (5) cropped or mowed grass, (6) ground flora, (10) built. (b), (c) and (d) Aquatic elements: (7) open water, (8) emergent hydrophytes, (9a) floating hydrophytes (water lilies), (9b) floating hydrophytes (duck weeds)

The upper canopy layer (see Figure 4.8a) was distinguished from the lower canopy layer (see Figure 4.8a) using the Smart Measure function within the Smart Tools Android App (Android Boy, 2010) mobile phone application (as detailed in section 4.2.2) to measure the relative height of each layer. Afterwards, a judgment of the percentage occupied by each vegetation layer within the sample area was made and data were recorded from the centre point (if view is uninterrupted) or during a walk round the sample area (Tzoulas & James, 2009). The sum total percentage cover of all the vegetation layers can be above 100% because they will be assigned a Braun-Blanquet value afterwards, so the percentage cover is merely a guide to matching the appropriate Braun-Blanquet value. Chapter 5 contains a case study to illustrate the entire survey process.

4.2.6. Vegetation structure cover-abundance analysis method

After the data collection, vegetation structure cover-abundance data were weighted, and habitat for species, urban heat island mitigation and carbon sequestration ecosystem services scores were computed using these weighted data. In sections 4.2.7 to 4.2.9 an explanation is set out of these procedures for ecosystem services scores generation and reasons for applying the weightings.

4.2.7. Scoring procedure for habitat for species

Figure 4.9 contains the scoring procedure for estimating the potential of a site to generate habitat for species ecosystem service, using the vegetation structural diversity data collected on-site. This scoring procedure is based on the theory of succession and ecological niche, as discussed in section 4.2.1.

Step 1: Every vegetation layer → Present (+1) or Absent (0), irrespective of the Braun-Blanquet value.

Step 2: Vegetation layers 1 to 9	**Step 3**: Vegetation layer 10 (Built)	Braun-Blanquet Value	% Cover
0	0	0	0
+1	+3	1	<1
+2	+2	2	1-5
+3	+1	3	6-25
+4	-1	4	26-50
+5	-2	5	51-75
+6	-3	6	76-100

Step 4: Habitat for species score = Step 1 + Step 2 + Step 3

Figure 4.9 – Scoring procedure for habitat for species using the vegetation structural diversity data.

Note: that step 3 does not apply if there is only vegetation layer 10 (Built) present on-site, or if this layer has a Braun-Blanquet value that is more than or equals to the *accumulated score from steps 1 and 2. The calculation procedure will be demonstrated through the Castle Irwell case study in Chapter 5.*

The first step of the scoring procedure as illustrated in Figure 4.9 implies that every vegetation layer, as illustrated in Figure 4.7, has a potential to be colonised by organisms. Therefore, one point was awarded for every vegetation layer observed on-site.

The second step of the scoring procedure as illustrated in Figure 4.9 makes the assumption that the contribution to biodiversity for vegetation layers one to nine is the same. For instance, the biodiversity value for 100% upper canopy layer coverage (as observed on-site) is assumed to be the same as the biodiversity value (again, as observed on-site) for 100% lower canopy coverage, and so on. Put another way, the scoring procedure, as illustrated in Figure 4.9, makes no distinction between which vegetation species occupies the site.

The third step of the scoring procedure as illustrated in Figure 4.9 makes the assumption that the biodiversity potential for built surfaces (e.g. roads and buildings) cannot be compared with the biodiversity potential for vegetated surfaces or aquatic bodies (Tzoulas & James, 2009). This is because a large amount of built cover is deemed to hold back succession (Godefroid and Koedam, 2007), since built surfaces tend to be impermeable. Impermeable surfaces do not allow water to infiltrate and do not allow plants to take root and colonise the surface. Therefore, no succession can take place. A decision, therefore, was taken to assign a negative score for when the Built cover is more than 25% of the site. This means that for a site to have built surface that is more than 25% of the entire site, the habitat for species value of the site will fall.

However, impermeable materials can also provide habitats for species, as long as it has time to accumulate moisture, is exposed to sunlight, and has time for substrates to accumulate. Normal pavements, in particular the gaps between paving stones, offer opportunities for organisms to colonise, forming an alternative habitat type. Permeable pavements use this phenomenon to promote water purification via microbiological action within the gaps between paving stones to clean surface runoff

(Scholz & Grabowiecki, 2007). This is also demonstrated through microhabitat observations on walls (Lisci *et al.*, 2003 cited in Douglas & James, 2015), where harsh conditions can still allow certain organisms to thrive. A small amount of built cover amongst other vegetation, therefore, can act as areas for species involved in primary succession to colonise. Consequently, a positive score was given to the built layer that was observed to be 25% or less on-site. Similarly, the scoring procedure was constructed so that no negative scores can occur (Tzoulas & James, 2009). This is because minimal vegetation amongst impermeable materials (e.g. 99.9% built, 0.1% vegetation) can still support habitats or the conditions for habitat to survive.

The fourth step of the scoring procedure as illustrated in Figure 4.9 is the total combination of the steps 1 to 3. This step would result in a score that reflect upon the habitat for species ecosystem service potential of the site.

4.2.8. Scoring procedure for urban heat island mitigation

Figure 4.10 contains the scoring procedure for estimating the urban heat island mitigation (UHIM) ecosystem service potential of a site, using the vegetation structure cover-abundance data collected on-site. Overall, the scoring procedure is biased towards vegetation coverage and the presence of open water because, as discussed in Chapter 3, the urban heat island effects are influenced by factors including evapotranspiration and evaporation rates, the amount of shades provided by vegetation, and solar reflectivity (or albedo). These factors are best served by the presence of vegetation and water bodies.

Step 1: Every vegetation layer → Present (+1) or Absent (0), irrespective of the Braun-Blanquet value.

Step 2: Vegetation layers 1, 2 & 7	**Step 3**: Vegetation layers 3 to 6, 8 & 9	**Step 4**: Vegetation layer 10 (built)	Braun-Blanquet Value	% Cover
0	0	0	0	0
+2	+1	-1	1	<1
+3	+2	-2	2	1-5
+4	+3	-3	3	6-25
+5	+4	-4	4	26-50
+6	+5	-5	5	51-75
+7	+6	+6	6	76-100

$$\textbf{Step 5}: \textbf{UHIM score} = \textbf{Step 1} + \textbf{Step 2} + \textbf{Step 3} + \textbf{Step 4}$$

Figure 4.10 – Scoring procedure for urban heat island mitigation (UHIM) using the vegetation structural diversity data.

Note: The calculation procedure will be demonstrated through the Castle Irwell case study in Chapter 5.

The first step of the scoring procedure illustrated in Figure 4.10 again implies that every vegetation layer, as illustrated in Figure 4.7, has a potential to be colonised by vegetation species. As explained in Table 3.3, all vegetation can evapotranspire, increase albedo and hold onto moisture. Water bodies also lower the surrounding air temperature due to evaporation and increase albedo due to reflection of solar radiation, although this varies depending on the angle of the sun. The daily average albedo of water is 10% (Ahrens et al., 2012). Therefore, one point was awarded for all vegetation layers observed on-site.

The second step of the scoring procedure, as illustrated in Figure 4.10, makes the assumption that trees and water bodies contribute the most to evapotranspiration of a site. That is why they can score the highest amongst all the eight layers. Trees can provide shading and retain a large amount of moisture compared with other plant species (Hall *et al.*, 2012). The presence of water on-site enhances the evaporation rate of the site. They combine to cool the surrounding air and surface temperatures and, therefore, contribute to mitigating the urban heat island effect.

The third step of the scoring procedure as illustrated in Figure 4.10 makes the assumption that plant species associated with vegetation layers 3 to 6, 8 and 9 (bush (woody), low bush and long grass (non-woody), cropped or mowed grass, ground flora, emergent hydrophytes, floating hydrophytes) contribute less to the site's evapotranspiration compared with trees and water bodies (Everson *et al.*, 2011; Hall *et al.*, 2012; Nosetto *et al.*, 2012; Heim & Lundholm, 2014) and also do not provide as much shading compared with fully grown trees due to their heights. Overall, plants associated with vegetation layers 3 to 6, 8 and 9 contribute to reducing the urban heat island effect, but they are not as effective as trees and water bodies.

The fourth step of the scoring procedure as illustrated in Figure 4.10 makes the assumption that materials associated with the built layer are dark coloured and impervious. Examples include tarmac road, carparks and slated roofs. These surfaces are not covered by vegetation, do not retain water, and absorb solar radiation (Arrau & Peña, 2011; Kleerekoper *et al.*, 2012). They are the main contributors to the urban heat island effects.

The fifth step of the scoring procedure as illustrated in Figure 4.10 is the total combination of the steps 1 to 4. This step would result in a score that reflect upon the urban heat island mitigation ecosystem service potential of the site.

4.2.9. Scoring procedure for biological carbon sequestration

Figure 4.11 contains the scoring procedure for estimating the biological carbon sequestration ecosystem service potential of the site, using the vegetation structure cover-abundance data collected on-site. Overall, the scoring procedure only takes account of live above-ground biomass and can only provide an approximate indication of potential carbon sequestration the site can provide. This is because the scoring procedure does not take account of other carbon pools, including living below-ground biomass, dead organic matter in wood, dead organic matter in litter, soil organic matter, wood products and landfills (Watson *et al.*, 2000).

Step 1: Every vegetation layer → Present (+1) or Absent (0), irrespective of the Braun-Blanquet value.

Step 2: Vegetation layers 1 to 4 & 7 to 9	**Step 3**: Vegetation layers 5, 6 & 10	Braun-Blanquet Value	% Cover
0	0	0	0
+1	-1	1	<1
+2	-2	2	1-5
+3	-3	3	6-25
+4	-4	4	26-50
+5	-5	5	51-75
+6	-6	6	76-100

$$\textbf{Step 4}: \textbf{Carbon sequestration score} = \textbf{Step 1} + \textbf{Step 2} + \textbf{Step 3}$$

Figure 4.11 – Scoring procedure for carbon sequestration using the vegetation structural diversity data

The first step of the scoring procedure illustrated in Figure 4.11 again implies that every vegetation layer, as illustrated in Figure 4.7, has a potential to be colonised by vegetation species, therefore, can potentially sequester carbon via photosynthesis. Consequently, one point was awarded for every vegetation layer observed on-site.

The second step of the scoring procedure as illustrated in Figure 4.11 makes the assumption that vegetation layers 1 to 4, 7 and 9 contribute to carbon sequestration via photosynthesis, accumulation of organic carbon or sediment organic carbon accumulation in waterbodies.

The third step of the scoring procedure as illustrated in Figure 4.11 assumes that vegetation layer 5 (cropped or mown grass) consists entirely of heavily maintained turf grass. Turf grass can sequester carbon (Milesi *et al.*, 2005) but due to the management requirements (e.g. heavy water use for irrigation, use of fertilisers and pesticides, constant mowing), the carbon sequestration capacity of turf grass-based green spaces cannot mitigate against green-house gas emission in urban areas (Milesi *et al.*, 2005; Townsend-Small & Czimczik, 2010). Therefore, vegetation layer

5 (cropped or mown grass) was given a negative score for carbon sequestration (see Figure 4.11).

The third step of the scoring procedure also assumes that vegetation layer 6 (ground flora) are found on surfaces with harsh conditions (roofs) which are suitable for primary succession species such as lichens to grow (Heim & Lundholm, 2014; Lisci *et al.*, 2003 cited in Douglas & James, 2015), but do not contribute to carbon sequestration of the site being examined. Similarly, the vegetation layer ten (built) does not contribute to the carbon sequestration of the site because no vegetation currently occupies it.

The fourth step of the scoring procedure as illustrated in Figure 4.11 is the total combination of the steps 1 to 3. This step would result in a score that reflect the biological carbon sequestration ecosystem service potential of the site.

4.3. Ecosystem services and disservices appraisal survey

Sections 4.2 contains details of the vegetation structure cover-abundance survey method for evaluating the ecosystem services produced by elements of urban green infrastructure, hence validating the SuDS Communication and Planning Framework established in Chapter 3. That method utilised common variables (vegetation types, layers, structure cover-abundance) to analyse ecosystem services of vegetated SuDS sites.

The purpose of this section is to establish a method to examine and evaluate cultural ecosystem services and ecosystem disservices of vegetated SuDS sites, thus validating the cultural ecosystem services and ecosystem disservices aspects of the SuDS Communication and Planning Framework established in Chapter 3.

This method again uses elements of urban green infrastructures as proxies for vegetated SuDS sites and mainly focused on cultural ecosystem services and ecosystem disservices, and therefore the data collected are qualitative rather than quantitative.

4.3.1. The first trial at gathering ecosystem services and disservices data with PhD researchers

Section 4.2.2 detailed the first pilot of the amended Tzoulas-James method. At the same time as that pilot study, the first trial of gathering data on ecosystem services and disservices data was conducted. The trial was conducted in early March 2014 with the aim of appraising the ecosystem services and disservices using on-site visual observation alone.

Scholz and Uzomah (2013) conducted ecosystem services appraisals in Greater Manchester, guided by ecosystem services categorisation and rankings, which are based on existing site characteristics and also the characteristics of surrounding areas. Moore and Hunt (2012) evaluated cultural ecosystem services of stormwater wetlands and ponds in America using a qualitative rubic, featuring variables considered representative to the recreation and education ecosystem services.

Therefore, the first aim of the pilot was to investigate the level at which explanations should be provided to researchers to enable them to conduct ecosystem services and disservices appraisals on-site. The question examined during the pilot was whether a descriptive site characteristic based categorisation of the actual services and disservices is sufficient, or whether employing proxy variables of the services and disservices is more applicable for on-site visual appraisal.

The second aim of the the pilot was to determine if there are significant differences in ecosystem services and disservices appraisals between researchers from different backgrounds. Identical to the first pilot of the amended Tzoulas-James method (see section 4.2.2), three PhD researchers specialising in three different subjects (geography, ecology and engineering) were chosen for this trial. The ecosystem services and disservices data collection sheet trialled is detailed in Figure 4.12.

	Site: Date:				
1. Ecosystem services and disservices	**2. Existence (Y/N)**	**3. Confidence level**	**4. Ranking (see Figure 4.13)**	**5. Confidence level**	**6. Comments**
Habitat for species					
Pollination					
Recreation					
Education					
Disease carrying animals					
Biogenic Volatile Organic Compound emissions					
Fear and stress					
Negative aesthetic					
7. Other ecosystem services and disservices:			**8. Comments:**		

Figure 4.12– Ecosystem services and disservices data collection sheet template

Figure 4.12 illustrates the ecosystem services and disservices data collection sheet template. Firstly, the three surveyors determined visually whether the ecosystem services or disservices (as listed in the first and second columns of Figure 4.12) existed on-site or not. The ecosystem services and disservices ranking definitions detailed in Figure 4.13 was provided the three researchers to aid their decisions.

Ecosystem services and disservices	Ranking no.	Definition
Habitat for Species	1	No vegetation.
	2	Dominated by one or two vegetation types.
	3	Contain several different vegetation types and structural layers.
	4	Contain many different vegetation types and structural layers. Presence of wild animals and birds.
Pollination	1	Site does not host any flowers.
	2	Site hosts few flowers.
	3	Site hosts many flowers.
	4	Site dominated by flowers.
Recreation	1	Site has the following attributes: (1) open to public access, access is not restricted, (2) recreational infrastructure is present and well-maintained, (3) frequent public transport links, (4) car park on-site.
	2	Site has the following attributes: (1) public access by permission only, (2) physically accessible but not highly visible, (3) recreational infrastructure is present but not well-maintained, (4) infrequent public transport links, (5) road parking is allowed.
	3	Site has the following attributes: (1) prohibited public access, (2) access is physically restricted by fence, steep embankment or other barrier, (3) recreational infrastructure is not present or so poorly maintained as to present safety hazard, (4) no public transport links, (5) no parking nearby is allowed.
Education	1	Education infrastructure is present and well-maintained.
	2	Education infrastructure is present but poorly maintained.
	3	Education infrastructure is not present.
Disease carrying animals	1	No open water bodies and no vegetation, no dog faeces observed.
	2	Site contains only vegetation which is cropped or mowed regularly, no open water bodies, few dog faeces present.
	3	Site contains vegetation which is lightly trimmed, contains small water puddles, some dog faeces present.
	4	Site dominated by overgrown and diverse vegetation, contains large open water bodies, plenty of dog faeces present.
Biogenic Volatile Organic Compound emissions	4	Site dominated by trees.
	3	Site hosts a couple of trees.
	2	Site do not hosts trees.
	1	No vegetation on site.
Fear and stress	1	Plenty of street lights on site, vegetation well-trimmed and tidied, no open water bodies observed.
	2	Small amount of street lights on site, vegetation well-trimmed and tidy, no open water bodies observed.
	3	No street lights on site, vegetation trimmed and tidied, small open water bodies observed.
	4	No street lights on site, vegetation not-trimmed untidy, large and unfenced open water bodies observed.
Negative aesthetic	1	Plenty of bins on site, plenty of bins for dog excrements, no litters and dog excrements observed.
	2	One or two bins for dog excrements, litters and dog excrements observed.
	3	No bins for dog excrements, plenty of litters and dog excrements observed.
	4	Plenty of litters and dog excrements observed.

Figure 4.13 - Ecosystem services and disservices ranking definitions sheet

According to Figure 4.13, if a site falls between rankings for vegetation, the surveyor has to make a choice based on his or her experience. After determining the existence of the ecosystem services and disservices, the second task the researchers performed was to rate how confident they individually felt of their decision to determine the existence (or not) of the ecosystem services via on-site observation (see third column in Figure 4.12). Table 4.5 illustrates the definitions of the confidence level.

Table 4.5 – Ecosystem services and disservice appraisal confidence level

Confidence level	**Code**	**Definition**
High	2	High confidence in the data collected being representative of the site. The data collector may have been trained or have expert knowledge of the ecosystem service or disservice he or she is examining.
Medium	1	Some confidence in the data collected being representative of the site. The data collector may not have been trained but have some knowledge of the ecosystem service or disservice he or she is examining.
Low	0	Low confidence in the data collected being representative of the site. The data collector has not been trained and has little knowledge of the ecosystem service or disservice he or she is examining.

The confidence levels illustrated in Table 4.5 were designed to address the uncertainties of visually determining the extent of each of the ecosystem services and disservices listed in Table 4.9 on-site. Uncertainty arises based on the surveyor's experience and knowledge of the subject he or she is investigating (Schultze *et al.*, 2012 cited in Scholz, 2013a; 2013b).

Thirdly, the three researchers ranked the chosen ecosystem service and disservices in accordance with the ranking definitions in Figure 4.13. The researchers also rated how confident they individually felt with regards to their choice of ecosystem service and disservices ranking (see Table 4.5).

Fourthly, the researchers commented upon their individual site observations with regards to the ecosystem services and disservices listed in Figure 4.12.

Finally, the researchers noted any ecosystem services and disservices encountered on-site that were missing from Figure 4.12. The raw data collected during the trial is presented in Table C1 to C4 in Appendix C. After analysing the comments received from the researchers, it was clear that March was the wrong time of the year for examining this ecosystem service. The best time to do so is late spring to end of summer, when the flowers are blooming.

The second item discovered during the trial and after examining the raw data in Table C2 is that the data for the education ecosystem service cannot be relied upon. This is because on-site observation cannot determine the extent of educational activities taking place at that particular site, nor the number of education establishment nearby that can potentially use the site for educational purpose. An alternative to on-site observation therefore needed to be derived to examine this ecosystem service.

The third item discovered after examining the raw data in Table C3 and after considering the feedback from the three researchers was that the biogenic volatile organic compound emission ecosystem disservice cannot be observed on-site. Instead, this disservice can be estimated using the vegetation cover abundance data.

The fourth item discovered during the trial and after examining the raw data in Table C3 and 4 was that the ranking definition for disease carrying animals and negative aesthetic (see Figure 4.13) were unclear. The feedback from the researchers indicates that variables used to define the rankings for disease carrying animals (vegetation management, presence of water bodies, dog faeces) should be examined separately. The presence of bins and the coverage of litter and dog faeces for negative aesthetic should be separated, since there was not a clearly observable relationship between them. In fact, some sites do not have any bins present and also do not have litter. Whilst some sites have bins present yet also have litter scattered all over the site. Table 4.6 illustrates the summary statistical results for the first cultural system services and disservices survey pilot.

Table 4.6 – Summary of the statistical results for the PhD researchers' estimates on the existence of ecosystem services and disservices.

Note: CES = cultural ecosystem services, EDS = ecosystem disservices

Ecosystem services (CES) and disservices (EDS)	**Fisher's exact test results**	**P-value**	**P-value more or less than 0.05**	**Significant difference (Y/N)**
Existence of CES and EDS verses PhD researchers' subjects				
Habitat for Species	1.885	1.000	larger	N
Recreation	2.033	0.754	larger	N
Education	9.617	0.012	smaller	Y
Fear and Stress	1.885	1.000	larger	N
Confidence of the existence of CES and EDS verses PhD researchers' subjects				
Habitat for Species	2.909	0.310	larger	N
Recreation	6.543	0.038	smaller	Y
Education	6.332	0.024	smaller	Y
Fear and Stress	1.568	0.516	larger	N
CES and EDS ranking verses PhD researchers' subjects				
Habitat for Species	1.388	0.938	larger	N
Recreation	8.790	0.284	larger	N
Education	10.851	0.080	larger	N
Fear and Stress	9.331	0.486	larger	N
Confidence of CES and EDS ranking verses PhD researchers' subjects				
Habitat for Species	4.764	0.122	larger	N
Recreation	5.858	0.075	larger	N
Education	7.407	0.027	smaller	Y
Fear and Stress	1.214	1.000	larger	N

After initial trials of the survey method detailed in Figures 4.12 and 4.13, the entire method was abandoned. This is because the ecosystem services illustrated in Figure 4.12 and the definitions in Figure 4.13 were not clear. Too much guess work was employed to appraise the ecosystem services, resulting in highly subjective data. The ecosystem services illustrated in Figure 4.12 were also discovered to be too different from each other, and visual observation alone cannot appraise most of these services.

After the initial attempt at validating the framework on-site, it was realised that variables would have to be defined and then utilised in order to perform adequate tests to validate the SuDS Communication and Planning Framework.

4.3.2. Ecosystem services and disservices variables appraisals

After the ecosystem services and disservices data gathering trial, it was concluded that independent variables have to be used in order to appraise the cultural ecosystem services and disservices (dependent variables) on-site. Figures 4.14 and 4.15 illustrates the independent variables used to appraise the cultural ecosystem services and disservices on-site, and additional information that further clarifies the variable categories.

Independent variables	**Variables categories**	**Confidence (H, M, L)**
1. Legal Accessibility	a) Access prohibited. b) Access by permission only. c) Open to public access.	
2. Physical Accessibility	a) Physically restricted. b) Physically accessible but not highly visible. c) Access to site is not restricted.	
3. Recreational Infrastructure	a) Not present or so poorly maintained as to present safety hazard. b) Present but not well-maintained. c) Present and well-maintained.	
4. Proximity to Public Transport	a) No public transport links. b) Infrequent public transport links. c) Frequent public transport links.	
5. Ease of Parking	a) No parking nearby is allowed. b) Road parking is allowed. c) Car park on site.	
6. Education Infrastructure	a) Present. b) Present but poorly maintained. c) Present and well-maintained.	
7. Dog Faeces	D, A, F, O, R or N	
8. Street Lights	F, O, R or N	
9. Evidence of Vegetation Management	WM, PM or NM	
10. Bins	F, O, R or N	
11. Litter	D, A, F, O, R or N	
12. Flowers	D, A, F, O, R or N	

Figure 4.14 – Cultural ecosystem services and disservices independent variables appraisal template.

Note: H = high, M = medium, L = low, WM = well managed, PM = poorly managed, NM = not managed, D = dominant, A = abundant, F = frequent, O = occasional, R = rare, N = none

Independent variables	Additional information to variable categories
1. Legal Accessibility	No additional information.
2. Physical Accessibility	a) Access to site is physically restricted by fence, steep embankment or other barriers. b) The site is physically accessible but not highly visible. The site could be at an out-of-sight location, behind buildings or behind dense understory. c) Access to the site is not restricted by any physical means.
3. Recreational Infrastructure	Recreational infrastructures can include trails, wildlife viewing areas, benches, footpaths and so on. The idea is for the data collector to judge how well the infrastructures are maintained.
4. Proximity to Public Transport	No additional information.
5. Ease of Parking	No additional information.
6. Education Infrastructure	Education infrastructures include signs, activity stations and so on. The idea is for the data collector to judge how well the education infrastructures are maintained at the site. The three categories are defined as: a) Education infrastructures are present. An example would be a notice board with a map containing site information at the entrance of a site. This notice board is an education infrastructure. b) Education infrastructures are present but poorly maintained. This can be due to signs fading or blocked by dense vegetation, therefore the information on it cannot be read by visitors. c) Education infrastructures are present and well-maintained.
7. Dog Faeces	D = Dominant; A = Abundant; F = Frequent; O = Occasional; R = Rare; N = None
8. Street Lights	F = Frequent; O = Occasional; R = Rare; N = None
9. Evidence of Vegetation Management	WM = Well managed; PM = Poorly managed; NM = Not managed. Evidence of vegetation management includes mowed grass.
10. Bins	F = Frequent; O = Occasional; R = Rare; N = None
11. Litter	D = Dominant; A = Abundant; F = Frequent; O = Occasional; R = Rare; N = None
12. Flowers	D = Dominant; A = Abundant; F = Frequent; O = Occasional; R = Rare; N = None

Figure 4.15 - Cultural ecosystem services and disservices independent variables additional information.

Figure 4.14 contains variables that are associated with cultural ecosystem services and ecosystem disservices. Each of the variables in Figure 4.14 have separate categories, where the surveyor has to choose one for each sites. Additional information was illustrated in Figure 4.15 to clarify each of the variable categories.

The first three and the sixth variables (legal accessibility, physical accessibility, recreational infrastructures, and education infrastructures) in Figure 4.15 were adopted from Moore and Hunt (2012). They can indicate the site's potential in providing recreation and education ecosystem services. These variables were also found to be major factors that can influence the public's perception of the site (Nassuer, 2004; Moore & Hunt, 2012).

The fourth and fifth variables (Proximity to Public Transport and Ease of Parking) in Figure 4.15 were chosen for ecosystem service appraisal because transportation methods, the proximity of either public transport stations or car parks were found to influence people's choice of whether they use the green space and how often they use it (Hillsdon *et al.*, 2011).

The seventh variable (dog faeces) in Figure 4.15 provides an indication of the community acceptance of the site. This is because, firstly, dog owners in the UK are legally bound to clean up their dog's excrement under the Clean Neighbourhoods and Environment Act 2005 (Keep Britain Tidy, 2002; Clean Neighbourhoods and Environment Act, 2005). Therefore, if the site being examined is covered by dog faeces, this implies that the Act has not been enforced properly on that site. Dog faeces also contain a large amount of *Toxocara* eggs, as dogs act as a reservoir for toxocariasis (Keep Britain Tidy, 2002; Gavignet *et al.*, 2008; Smith *et al.*, 2009; Fahrion *et al.*, 2011). Therefore examining dog faeces coverage can provide an indication to the disease carrying animals' ecosystem disservice of the site.

The eighth and ninth variables (street lights and evidence for vegetation management) in Figure 4.15 were selected for ecosystem services and disservices appraisals because they provide indications towards the safety of the site. The eighth variable (street lights) indicates whether the site can be safely accessed at night (Bixler & Floyd, 1997 cited in Gómez-Baggethun & Barton, 2013). The ninth variable (evidence for vegetation management) is an indicator for public's perception of site safety. This is because of a general perception that overgrown green areas are not safe at night (Bixler & Floyd, 1997 in Gomez-Baggethun & Barton, 2013), and wild animals living within these areas can cause fear and distress to the public (Bixler & Floyd, 1997 in Gomez-Baggethun & Barton, 2013). The ninth variable is also an aesthetics indicator, as the management of vegetation can provide an indication of the "pleasantness" of the site (Lyytimaki *et al.*, 2008).

The tenth variable (bins) in Figure 4.15 provides an indicator for the habitat competition with humans, disease carrying animals and negative aesthetics ecosystem disservices. This is because bins can act as food source for wild animals, especially opportunistic foragers (Bellebaum *et al.*, 2000; Matsubara, 2003; Maciusik *et al.*, 2010; Sol *et al.*, 2013). The presence of bins not only result in the animals (often considered as pests) littering the site through their forage for food in them, the animal population density will also likely to increase because of easy access to food (Maciusik *et al.*, 2010; Sol *et al.*, 2013). These animals may carry disease which can cause harm to the local community.

The eleventh variable (litter) in Figure 4.15 provides an indicator for community acceptance and negative aesthetics ecosystem disservices. This is because it is an offence in the UK for anyone to leave litter, and site owners are also required by law to clean up their sites, under the Clean Neighbourhoods and Environment Act 2005 (Clean Neighbourhoods and Environment Act, 2005). Therefore, people may be discouraged to visit and enjoy the site if it is covered by unsightly litter; hence, the site would not be accepted by the local communities.

The twelfth variable (flowers) in Figure 4.15 provides an indicator to the positive aesthetics ecosystem service. This is because the presence of flowers enhances the site's attractiveness due to flower's ornamental values (Moore, 2011). This variable can also be an indicator to the pollination ecosystem service.

4.3.3. Trial of the cultural ecosystem services and disservices variables appraisal method

Together with participating in the second pilot of the Tzoulas-James method (see section 4.2.2); the ten second year University of Salford ecology undergraduates participated in a trial of the cultural ecosystem services and disservices variables appraisal method detailed in Figures 4.14 and 4.15 on 14/03/2014. They were supervised by their tutor during the whole process. The site of the trial is The Meadow, which is the same as the second pilot of the Tzoulas-James method. They again surveyed the site in its entirety, and the raw data collected during the trial can be found in Table C5 to Table C10, in Appendix C. The aim of the analysis is to determine whether the cultural ecosystem services and disservices variables categories detailed in Figures 4.14 and 4.15 can be easily distinguished on-site or not, based on the information given in Figures 4.14 and 4.15. Table 4.7 illustrates the frequency analysis of the data in Table C5 to C10. The data contained in Table 4.7 allow an evaluation to be made concerning whether each cultural ecosystem service and disservice independent variables and associated categories (see Figures 4.14 and 4.15) can be easily distinguished on-site, given the information describing them in Figures 4.15 and 4.16.

Table 4.7 – Frequency analysis of data in Table C5 to C10.

Note: CES = Cultural Ecosystem Services, EDS = Ecosystem Disservices. LA = Legal Accessibility, PA = Physical Accessibility, RI = Recreational Infrastructure, PPT = Proximity of Public Transport, EofP = Ease of Parking, EI = Education Infrastructure, DF = Dog Faeces, SL = Street Lights, EofVM = Evidence of Vegetation Management, B = Bins, L = Litter, FL = Flowers

1. CES & EDS variables	**2. No. of students responded**	**3. Percentage response**	**Confidence level based on students who responded**							
			4. High (no. of students)	**5. Percentage response**	**6. Medium (no. of students)**	**7. Percentage response**	**8. Low (no. of students)**	**9. Percentage response**	**10. Missing (no. of students)**	**11. Percentage response**
1. LA	10	100	10	100	0	0	0	0	0	0
2. PA	10	100	6	60	4	40	0	0	0	0
3. RI	10	100	8	80	2	20	0	0	0	0
4. PPT	7	70	1	14.3	4	57.1	0	0	2	28.6
5. EofP	9	90	6	66.7	2	22.2	0	0	1	11.1
6. EI	8	80	4	50	4	50	0	0	0	0
7. DF	10	100	3	30	2	20	0	0	5	50
8. SL	10	100	5	50	0	0	0	0	5	50
9. EofVM	8	80	2	25	2	25	0	0	6	75
10. B	10	100	3	30	1	10	0	0	6	60
11. L	10	100	2	20	3	30	0	0	5	50
12. FL	10	100	2	20	1	10	2	20	5	50

The percentage of responses (third column), the confidence level percentages (fifth, seventh and ninth columns), and the percentages of missing responses (eleventh column) in Table 4.7 were evaluated according to the following rules:

- Independent variables with percentage of responds more than or equal to 80%, coupled with more than or equal to 80% of the students have high confidence and no one has low confidence in their choices of variable categories, were allowed to pass the trial and be appraised on-site with minimal changes required.
- Otherwise, the variables, variables categories and the definitions shown in Figures 4.14 and 4.15 were either abandoned or amended before the actual site survey.

Table 4.8 contains evaluations and conclusions drawn from Table 4.7.

Table 4.8 – Evaluations and conclusions drawn from Table 4.7.

Note: IV = independent variables, LA = legal accessibility, PA = physical accessibility, RI = recreational infrastructure, PPT = Proximity of Public Transport, EofP = Ease of Parking, EI = Education Infrastructure, DF = Dog Faeces, SL = Street Lights, EofVM = Evidence of Vegetation Management, B = Bins, L = Litter, FL = Flowers

1. IV	**2. Evaluation**	**3. Conclusion**	**4. Changes required (Y/N)**
1. LA	100% of the students responded by choosing from the three variable categories. All the students responded have high confidence in their choice of categories.	Legal Accessibility can be appraised on-site under the existing categories and definition.	N
2. PA	100% of the students responded by choosing from the three variable categories. 60% have high and 40% have medium confidence in their choice.	Physical Accessibility can be appraised on-site under the existing categories and definition, but with some difficulties. Further clarifications are required.	Y
3. RI	100% of the students responded by choosing from the three variables categories. 80% have high and 20% have medium confidence in their choice.	Recreational Infrastructures can be appraised on-site under the existing categories and definition.	N
4. PPT	70% of the students responded by choosing from the three variable categories. Only 14.3% (1 in 7) have high confidence and 57.1% (4 in 7) have medium confidence in their choice. 28.6% (2 in 7) did not state their confidence.	Proximity of Public Transport cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y
5. EofP	90% of the students responded by choosing from the three variable categories. 66.7% (6 in 9) have high confidence and 22.2% (2 in 9) have medium confidence in their choice. 11.1% (1 in 9) did not state their confidence.	Ease of Parking can be appraised on-site under the existing categories and definition, but with some difficulties. Further clarifications are required.	Y

Continued…

6. EI	80% of the students responded by choosing from the three variable categories. 50% (4 in 8) have high confidence and 50% (4 in 8) have medium confidence in their choice.	Education Infrastructure can be appraised on-site under the existing categories and definition, but with great difficulties. Further clarifications are required.	Y
7. DF	100% of the students responded by choosing from the six variable categories. Only 30% (3 in 10) have high confidence and 20% (2 in 10) have medium confidence in their choice. 50% (5 in 10) did not state their confidence.	Dog Faeces cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y
8. SL	100% of the students responded by choosing from the four variable categories. 50% (5 in 10) have high confidence in their choice. 50% (5 in 10) did not state their confidence.	Street Lights can be appraised on-site under the existing categories and definition, but with great difficulties. Further clarifications are required.	Y
9. EofVM	80% of the students responded by choosing from the three variable categories. Only 25% (2 in 8) have high confidence and 25% (2 in 8) have medium confidence in their choice. 75% (6 in 8) did not state their confidence.	Evidence of Vegetation Management cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y
10. B	100% of the students responded by choosing from the four variable categories. Only 30% (3 in 10) have high confidence and 10% (1 in 10) have medium confidence in their choice. 60% (6 in 10) did not state their confidence.	Bins cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y
11. L	100% of the students responded by choosing from the six variable categories. Only 20% (2 in 10) have high confidence and 30% (3 in 10) have medium confidence in their choice. 50% (5 in 10) did not state their confidence.	Litters cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y
12. FL	100% of the students responded by choosing from the six variable categories. 20% (2 in 10) have high confidence, 10% (1 in 10) have medium confidence and 20% (2 in 10) have low confidence in their choice. 50% (5 in 10) did not state their confidence.	Flowers cannot be appraised on-site under the existing categories and definitions. Changes to the categories and definitions are required.	Y

As illustrated in the fourth column of Table 4.8, only legal accessibility and recreational infrastructures passed the trial with minimal amendments required (no changes are required). All the other variables have to be amended, with both changes to the categories and definitions enhancements made to them. Some variables were dropped all together because comments from the undergraduates indicated that these variables were too difficult to be appraised on-site.

4.3.4. Final cultural ecosystem services and disservices variables appraisal method

In accordance with the analysis of the trial data results in Table 4.8, proximity of public transport and ease of parking were dropped from the final version of the cultural ecosystem services and disservices variables appraisal method. Evidence of vegetation management was considered to be closely related to data collected for the vegetation structure cover-abundance. Therefore, this variable was also dropped from the final appraisal method. The following sections illustrate the variables that were used in the final cultural ecosystem services and disservices investigation and the changes made to them.

4.3.4.1. Legal accessibility

Desktop studies were carried out to establish the legal accessibility status for all of the 49 sites being surveyed for this research. Most legal accessibility issues were dealt with in accordance with the Countryside and Rights of Way Act 2000 (Natural England, 2015). Other sites that were situated on private land were investigated to see whether there is a permit scheme in operation to allow payment access. The ranking system for legal accessibility is presented in Figure 4.16.

4.3.4.2. Proximity of the closest education establishment to sites

Google Earth was used to analyse the proximity of education establishments. Buffers of 100m (easiest to get to by foot), 400m (moderately easy to get to by foot) and 1000m (difficult to get to by foot) were applied to the polygons that represent each of the SuDS sites (Fields in Trust / National Playing Fields Association, 2008; Moseley *et al.*, 2013). This approach is closely related to English Nature's finding that no person should live more than 300m from their nearest area of natural greenspace of at least two hectares in size (English Nature, 2003; Natural England, 2010;). However, due to the small size of the sites chosen for the research, the standard for outdoor recreational facilities for children published by Fields in Trust or National Playing Fields Association (2008) was adopted instead of the English Nature's standard. Fields in Trust (previously the National Playing Fields Association) is a UK charitable organization that aims to protect outdoor recreational spaces across the country (Fields in Trust / National Playing Fields Association, 2008). One of the main product available from Fields in Trust is the outdoor recreational space design standard. The standard allows designers and planners to provide sustainable outdoor sport and play areas, which will be used by the local community in a formal and informal manner, thereby, allowing local people to conduct and benefit from different kinds of recreational activities (Fields in Trust / National Playing Fields Association, 2008).

The closest education establishment to the site was recorded and distance that was recorded was the shortest straight line distance from the site to the establishment using the distance measuring tool offered by Google Earth. The education establishments included in the analysis are: (1) nurseries and pre-schools; (2) primary schools, high schools and colleges; (3) universities; (4) vocational education establishments, such as music colleges. The ranking system for proximity of educational establishments is presented in Figure 4.16.

4.3.4.3. Evidence of educational use

This variable reflects the public educational and engagement potential of the sites being examined. Desktop studies (internet searches and literature reviews) were conducted to investigate whether there are dedicated websites and whether there are any community organisations attached to the sites. Examples of community organisations include Friend of groups, community forests and other similar local resident run volunteering groups. When the sites being investigated are local council owned, council websites were consulted to examine whether there are community engagement activities (educational events, volunteering opportunities) currently on-going. Some of the sites being examined are existing SuDS sites. Therefore, publicly available information with regards to these sites was consulted and their contributions to SuDS design and construction best practises were included as evidence of educational use. The ranking system for evidence of educational use is illustrated in Figure 4.16.

4.3.4.4. Coverage of dog faeces and litter on-site, and the presence of bins

The categories for these two variables were reduced from six (D, A, F, O, R and N) to three: Frequent, Occasional, and Rare (F, O and R). A 50m by 50m standard quadrat used for the vegetation structure cover-abundance survey was again employed to survey dog faeces and litter coverage on-site. The reason for using this quadrat size was to achieve a balance between rapid survey, through maintaining quadrat consistency, and representative data collection on-site. The number of dog faeces and items of litter encountered on-site were not recorded. Alternatively, dog faeces and litter coverage were designated as Frequent, Occasional or Rare.

For a Frequent rating to be scored for dog faeces or litter coverage within a 50m by 50m sampling plot (or the entire site if no sampling plots were used), it has to comply with any one of the three criteria:

- If dog faeces or litter were found in more than four places in the sampling plot or the entire site (for a pond, if more than four items of litter were observed floating on the water)
- If dog faeces or litter were only present in one part of the sampling plot or present on the entire site, but were highly concentrated in one part (for example, concentration of litter beside bins or gathered by the sides of a pond), forming a hot-spot.
- Every step taken whilst walking within the sampling plot was in danger of encountering dog fouling or stepping onto litter.

For an Occasional rating to be scored for dog faeces or litter coverage within a 50m by 50m sampling plot (or the entire site if no sampling plots were used), it has to comply with either one of the two criteria:

- If dog faeces or litter were found in three or four places in the sampling plot or the entire site (for a pond, if three or four litter were observed to be floating on the water), with no hot-spots present.

- If dog faeces or litter were encountered for every 30 to 50 steps, assuming one step equals one metre, within the sampling plot or the entire site.

For a Rare rating to be scored for dog faeces or litter coverage within a 50m by 50m sampling plot or the entire site, dog faeces or litter were either not found or were found in only one or two places in the sampling plot, with no hot-spots present.

With the designated as Frequent, Occasional or Rare, the data collected for dog faeces and litter were, therefore, coarse and qualitative rather than detailed and quantitative.

The categories for bins have been reduced to simply stating if there are bins present on-site or not. Bin provision and litter coverage were combined to provide an indication of whether the provision of bins on-site encourages or discourages people to litter. The ranking system for the coverage of dog faeces and litter on-site, and the presence of bins is illustrated in Figure 4.16.

4.3.4.5. Amended cultural services and disservices appraisal method

Figure 4.16 illustrates the amended cultural ecosystem services and disservices variables appraisal method that was used for the research. Figure 4.17 illustrates the additional information to clarify the variables for site surveys. The confidence of the variable categories choice indicators was abandoned. This is because for a single surveyor, this variable offers little valuable information.

CES and EDS variables	Variables categories and ranking	Desktop or site survey
1. LA	Public Access prohibited = 0 Access by permission only = 1 Open to public access = 2	Desktop study (see section 4.3.4.1).
2. PA	Physically restricted and/or not visible to public = 0 Physically accessible but not highly visible to public, or site situated a distance above ground = 1 Access to site is not restricted and is completely visible to public = 2	Site survey (see Figure 4.17)
3. RI	Not present or so poorly maintained as to present safety hazard = 0 Present but not well-maintained = 1 Present and well-maintained = 2	Site survey (see Figure 4.17)
4. ES	Not present = 0 Present but poorly maintained signs which explain only one or two aspects of the site and/or not easily readable or visible = 1 Present and well-maintained signs which explain multiple aspects of the site = 2	Site survey (see Figure 4.17)
5. PEE	The closest educational establishment being further than 1000m = 0 The closest educational establishment being between 401m to 1000m = 1 The closest educational establishment being between 101m to 400m = 2 The closest educational establishment being less than or equals to 100m = 3	Desktop study (see section 4.3.4.2)
6. EEU	No evidence of educational use was found = 0 Evidence of past educational activities were found = 1 Evidence of on-going educational activities were found = 2	Desktop study (see section 4.3.4.3)
7. DF	Frequent = 0 Occasional = 1 Rare = 2	Site survey (see Figure 4.17)
8. B	Present = 1 Not present = 0	Site survey (see Figure 4.17)
9. L	Frequent = 0 Occasional = 1 Rare = 2	Site survey (see Figure 4.17)

Figure 4.16 – The amended cultural ecosystem services and disservices appraisal method.

Note: The first four variables were adapted from Moore (2011), with amendments. CES = Cultural ecosystem services, EDS = Ecosystem disservices, LA = Legal Accessibility, PA = Physical Accessibility, RI = Recreational Infrastructure, ES = Educational signs, PEE = Proximity of the closest education establishment to sites, EEU = Evidence of educational use, DF = Dog Faeces, B = Bins, L = Litter

Cultural Ecosystem Services and Disservices variables	Additional information to variable categories
2. Physical Accessibility	To achieve zero, access to site should be physically restricted by fence, steep embankment or other barriers such as dense vegetation. To achieve one, the site should be physically accessible (including being surrounded by easily surmountable low fence) but not highly visible. Also, the site could be at an out-of-sight location, behind buildings, behind dense understory or situated above ground level (i.e. green roofs). To achieve two, access to the site should unrestricted by any physical means.
3. Recreational Infrastructure	These infrastructures include sports grounds, trails, wildlife viewing areas, benches, footpaths and so on. When appraising recreational infrastructures, facilities adjacent to sites were also included. For example, football pitches, athletics grounds beside woodland walkway, and the allotment where a green roof situates are included. For a water body, no safety features (e.g. no fence around the water body) to prevent people from accidentally falling into the water constitute poorly maintained infrastructure. If the fence around the water body only partially surround it, or if the fence is broken, this constitute to not well-maintained.
4. Educational Signs	No additional information.
7. Dog Faeces	Frequent means dog faeces are perceived to be frequently encountered on-site, where great care has to be taken when walking around site to avoid stepping onto dog faeces. Occasional means dog faeces are perceived to be occasionally encountered on-site, where walking around the site is not of great concern. Rare means dog faeces are perceived to be rarely or not encountered on-site at all. Also see section 4.3.4.4 for further clarification.
8. Bins	No additional information.
9. Litter	Frequent means litter is perceived to be frequently encountered on-site, where different colours and man-made waste objects are frequently and clearly seen in amongst natural green vegetation. Occasional means litter is perceived to be occasionally encountered on-site, where different colours and man-made waste objects are occasionally seen in amongst natural green vegetation. Rare means litter is perceived to be rarely or not encountered on-site at all. Also see section 4.3.4.4 for further clarification.

Figure 4.17 – Additional information to clarify site survey variables.

Note: PA = Physical Accessibility, RI = Recreational Infrastructure, ES = Educational signs, DF = Dog Faeces, B = Bins, L = Litter

Chapter 5 contains a case study to illustrate how the two validation methods (the vegetation structure cover-abundance survey and the cultural ecosystem services and disservices appraisal) can be used to generate ecosystem services scores. The case study is at site 11 (Castle Irwell).

5. Case study – Castle Irwell

Chapter 4 contained details of the creation of the two methods (vegetation structure cover-abundance survey and cultural ecosystem services and disservices appraisals) that were used to examine elements of urban green infrastructure as a proxy for vegetation SuDS systems in order to validate the SuDS Communication and Planning Framework. Therefore, the chapter satisfied the "research solution validation" component of the PhD research framework (Figure 1.1).

This chapter presents a case study, which was assessed during June 2014, to illustrate how the two validation methods were used to gather data and produce ecosystem services and disservice scores for one site: Castle Irwell. This chapter will then be followed by Chapter 6, which will present the result for all the 49 sites (Table 4.1) selected for this research.

5.1. Castle Irwell

Castle Irwell was part of the site of the former Manchester Racecourse, and it is located immediately north of University of Salford's Castle Irwell Student Accommodation (Gardiner *et al.*, 1998; Irwell Valley Sustainable Communities Project, 2014), and is surrounded on three sides by the River Irwell. This site contains a number of different habitats. Figure 5.1 is an aerial photograph of the site.

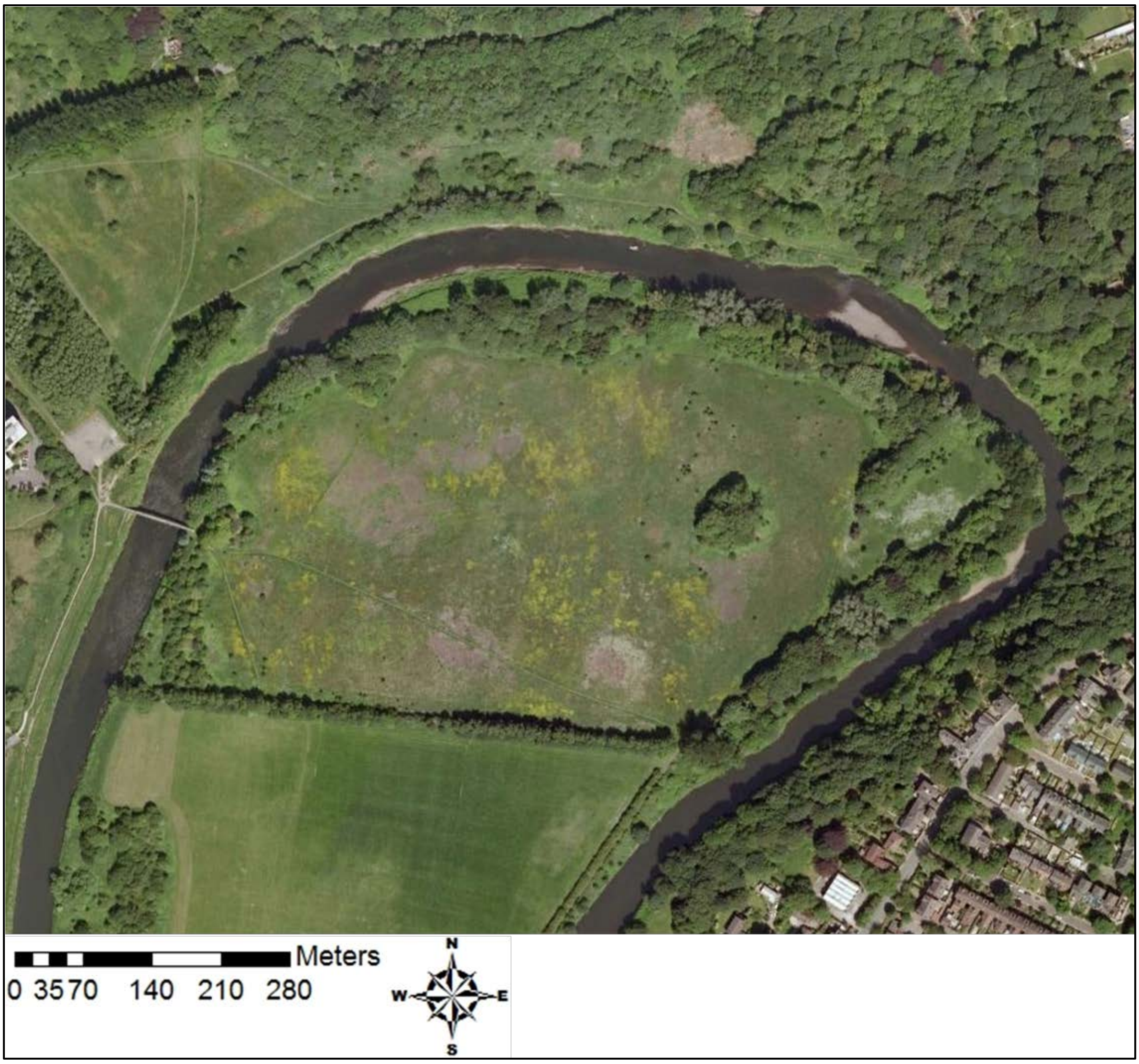

Figure 5.1 – Castle Irwell satellite image (Google, 2015)

Figure 5.1 conveys broad vegetation types (trees, grasses) that can be found on-site. According to the figure, grass dominated the site, and trees were found around the edge of the site and also dotted in one or two areas within the middle of the site. There was also a “tree island” located to the right of middle of the site. The image shown in Figure 5.1 was compared with vegetation structure cover-abundance data gathered on-site.

5.1.1. Vegetation structure cover-abundance examination

Figure 5.2 is a map which details the sampling plots employed for vegetation cover-abundance data collection in June 2014.

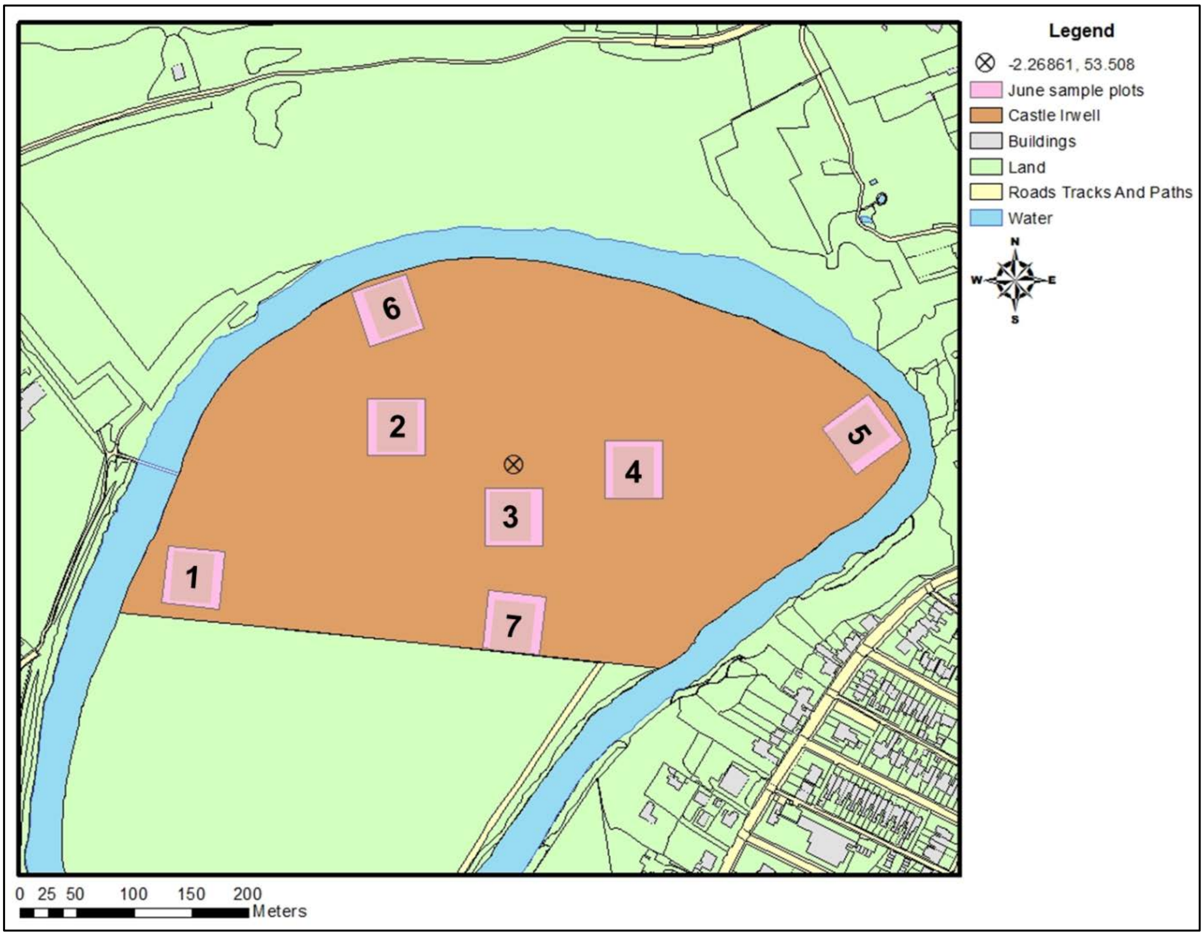

Figure 5.2 – Castle Irwell site and sample plots Vale (Crown Copyright/database right 2013. An Ordnance Survey/EDINA supplied service.)

Basic site information was obtained through analysis of the map shown in Figure 5.2. These are as follows:

- The area of the site is 171754m^2 and the perimeter is 1676.72m.
- Latitude of the mid-point is 53.50800 degree decimals and longitude of the mid-point is -2.26861 degree decimals.

Table 5.1 contains details of the survey date, area, perimeter, and mid-point coordinates (latitudes and longitudes) as recorded on-site for all the sample plots employed for data collection in June 2014. The coordinates were verified and adjusted using a Garmin Etrex handheld GPS. The standard 50m by 50m sample plot was employed on site, as explained in section 4.2.5.

Table 5.1 – Sample plots basic details

Sample plot	Survey date	Area (m^2)	Perimeter (m)	Site measured Longitude (degree decimals)	Site measured Latitude (degree decimals)
1	05/06/2014	2500	200	-2.273920	53.507780
2	05/06/2014	2500	200	-2.271700	53.508500
3	05/06/2014	2500	200	-2.270710	53.507750
4	05/06/2014	2500	200	-2.268287	53.508205
5	05/06/2014	2500	200	-2.266562	53.508329
6	05/06/2014	2500	200	-2.271063	53.509445
7	05/06/2014	2500	200	-2.270023	53.506769

The sample plots shown in Table 5.1 were marked out using bamboo canes on site (see Figure 5.3).

Figure 5.3 – Bamboo cane for marking out sample plots

The bamboo canes were used to mark the corners of the sample plots so that they act as a guide to distinguish visually the boundaries of each plot. Coloured plastic bags were tied at the top of the cane (Figure 5.3) to allow the crane to be seen from distance. The lengths and breadths of a sample plot were set out on site using the surveyor's strides calibrated using a tape measure beforehand to ensure every stride was consistently one metre in length. After a sample plot was set up on site, the percentage cover of all the vegetation layers was recorded, in accordance with the method illustrated in section 4.2.5.

The vegetation structure layers for each sample plot illustrated in Figure 5.2 are shown in Figure 5.4. The Braun-Blanquet values shown in Figure 5.4 were obtained from the conversion of the observed percentage cover of all the vegetation layers (in accordance with the method illustrated in Figure 4.7 and section 4.2.5) for the sample plots illustrated in Figure 5.2. The observed percentage cover data are illustrated in Table D1 in Appendix D.

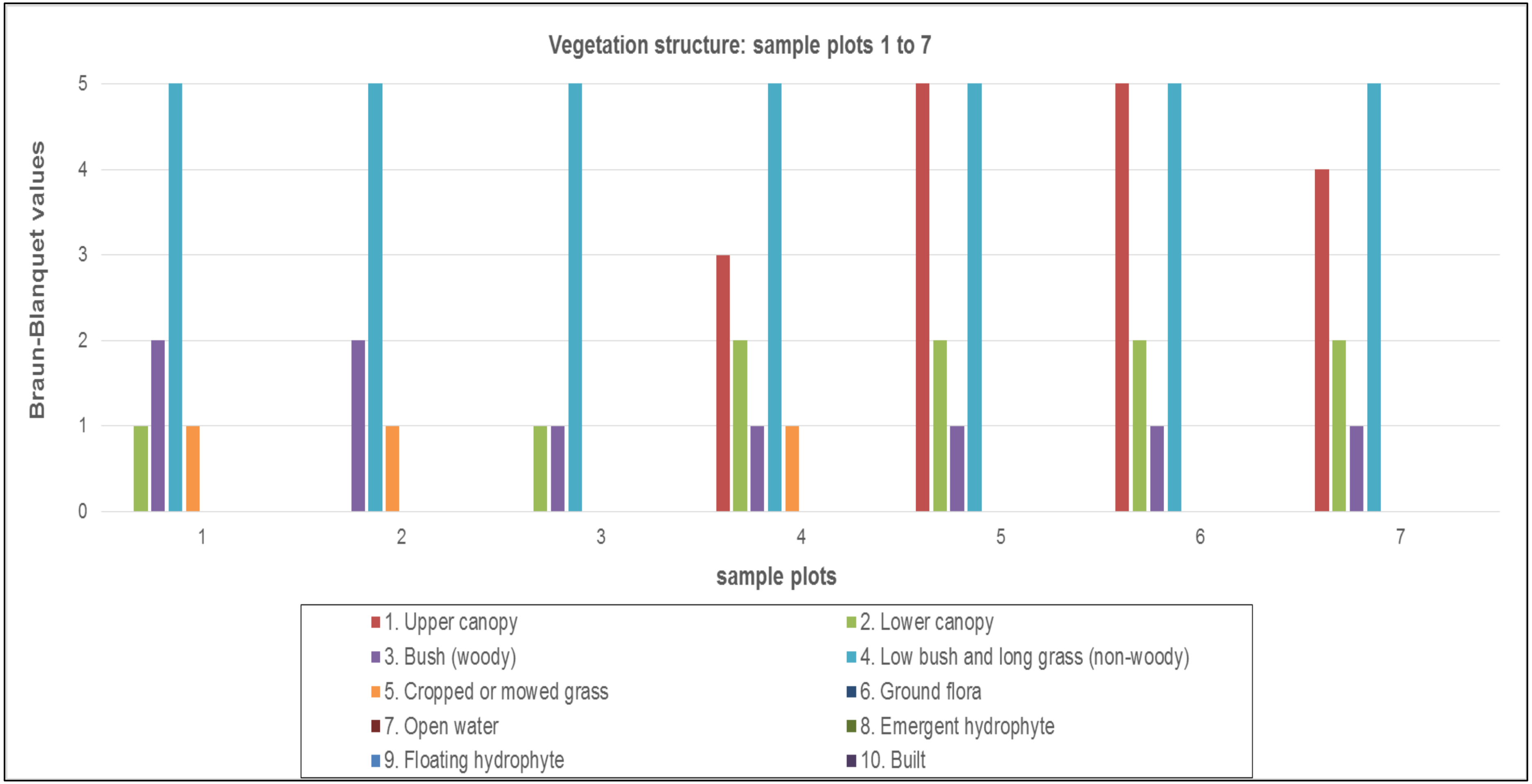

Figure 5.4 – Distribution of vegetation structure layers in Castle Irwell during June 2014

Overall, the vegetation structures in Castle Irwell were dominated by the fourth vegetation layer (low bush and long grass (non-woody)). This is illustrated by all seven sample plots having the Braun-Blanquet value 5 for this layer, as shown in Figure 5.4. This result is consistent with the observed dominance of grass in the aerial photograph (Figure 5.1). The dominance of the fourth vegetation layer also suggests that the site was equally likely to be covered by forbs as well as grass, in accordance with the vegetation types for this vegetation layer as shown in Figure 4.7.

However, the aerial photograph was not able to show the presence of vegetation layers other than grass and trees within the site. For instance, the third vegetation layer (bush (woody)) was also observed at all the sample plots (Braun-Blanquet value 2 for plots one and two; and Braun-Blanquet value 1 for plots three to seven, as shown in Figure 5.4). The data suggest a relatively low abundance of the third vegetation layer (due to the low Braun-Blanquet values) and therefore the low abundance of the associated vegetation types (shrubs, scrubs, hedgerows) on-site. The presence of the third vegetation layer cannot be seen from the aerial photograph shown in Figure 5.1.

Sample plots two and three were located in the grass and forbs dominated middle of the site, as shown in Figure 5.2. Aside from the third vegetation layer (bush (woody)) and the fourth vegetation layer (low bush and long grass (non-woody)), plots two and three also contained the second (lower canopy) and the fifth (cropped or mowed grass) vegetation layers. Plot two has a Braun-Blanquet value 1 for the fifth layer, but plot three were found to not have any cropped or mowed grass (Braun-Blanquet value equals zero). Similarly, plot three has a Braun-Blanquet value of one for the second vegetation layer, but plot two was found to contain no trees (Braun-Blanquet value equals zero for the first and second vegetation layers).

In order to understand the overall vegetation structures in Castle Irwell, the sample plots were split into two separate categories based on their relative positions (middle of site or edge of site). Using the data from Table D1, the mean observed vegetation layers percentage cover for the two relative position categories were calculated. The overall mean observed vegetation layer’s percentage cover was taken as the mean of the means for the two relative position categories. The aim of the analysis was to determine the overall coverage of the vegetation structure layers for Castle Irwell so that a habitat for species, urban heat island mitigation and carbon sequestration ecosystem services scores can be calculated. Table 5.2 illustrates the descriptive analysis of the observed vegetation layers percentage cover for all seven sample plots.

Table 5.2 – Descriptive statistics of the observed vegetation layers percentage cover shown in Table D1 and D2.

Note: UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophyte; FH = Floating hydrophyte; BT = Built

Row	**Vegetation layers**	**Height range (m)**	**Relative position**	**Total no. of plots**	**Mean observed % cover**	**Std. Deviation (+/-)**	**Overall mean observed % cover**	**Corresponding Braun-Blanquet value**
1	1. UC	>9	Middle of site	3	13.3	23.094	36	3
			Edge of site	4	58.8	39.238		
2	2. LC	4.1 to 9	Middle of site	3	7.0	11.269	10	2
			Edge of site	4	13.8	7.500		
3	3. BW	0.51 to 4	Middle of site	3	6.7	2.887	8	2
			Edge of site	4	8.8	7.500		
4	4. LBLG	0.2 to 0.5	Middle of site	3	93.3	2.887	92	5
			Edge of site	4	91.3	7.500		
5	5. CMG	0.05 to 0.19	Middle of site	3	2.0	2.646	1	1
			Edge of site	4	0.3	0.500		
6	6. GF	<0.05	Middle of site	3	0.0	0.000	0	0
			Edge of site	4	0.0	0.000		
7	7. OW	na	Middle of site	3	0.0	0.000	0	0
			Edge of site	4	0.0	0.000		
8	8. EH	na	Middle of site	3	0.0	0.000	0	0
			Edge of site	4	0.0	0.000		
9	9. FH	na	Middle of site	3	0.0	0.000	0	0
			Edge of site	4	0.0	0.000		
10	10. BT	na	Middle of site	3	0.0	0.000	0	0
			Edge of site	4	0.0	0.000		

With the overall mean observed vegetation layers percentage cover of the entire site calculated, the associated Braun-Blanquet values were assigned to each percentage cover (see Table 5.2). These Braun-Blanquet values were used to calculate the habitat for species, urban heat island mitigation (UHIM) and carbon sequestration ecosystem services scores, in accordance with the methods detailed in Figures 4.9 to 4.11. Tables 5.3 to 5.5 illustrate the habitat for species, urban heat island mitigation and carbon sequestration scores for Castle Irwell and the procedure for calculating them.

Table 5.3 – Habitat for species score for Castle Irwell.

Note: See Figure 4.9 for details of the scoring procedure

Vegetation layers	**Braun-Blanquet (B.B) values**
1. Upper canopy (UC)	3
2. Lower canopy (LC)	2
3. Bush (woody) (BW)	2
4. Low bush and long grass (non-woody) (LBLG)	5
5. Cropped or mowed grass (CMG)	1
6. Ground flora (GF)	0
7. Open water (OW)	0
8. Emergent hydrophyte (EH)	0
9. Floating hydrophyte (FH)	0
8. Built (BT)	0
Step 1 (+1 for every layer present, irrespective of B.B value)	+1+1+1+1+1 = +5
Step 2 (B.B value for UC = 3, therefore +3; B.B value for LC = 2, therefore +2; B.B value for BW = 2, therefore +2; B.B value for LBLG = 5, therefore +5; B.B value for CMG = 1, therefore +1; B.B values for GF, OW, EH and FH = 0, therefore 0)	+3+2+2+5+1+0 +0+0+0 = +13
Step 3 (B.B value for BT = 0, therefore 0)	0
Step 4 (Sum of steps 1 to 3)	+5+13+0 = 18

Table 5.4 – Urban heat island mitigation score for Castle Irwell.

Note: See Figure 4.10 for details of the scoring procedure

Vegetation layers	**Braun-Blanquet (B.B) values**
1. Upper canopy (UC)	3
2. Lower canopy (LC)	2
3. Bush (woody) (BW)	2
4. Low bush and long grass (non-woody) (LBLG)	5
5. Cropped or mowed grass (CMG)	1
6. Ground flora (GF)	0
7. Open water (OW)	0
8. Emergent hydrophyte (EH)	0
9. Floating hydrophyte (FH)	0
10. Built (BT)	0
Step 1 (+1 for every layer present, irrespective of B.B value)	+1+1+1+1+1 = +5
Step 2 (B.B value for UC = 3, therefore +4; B.B value for LC = 2, therefore +3; B.B value for OW = 0, therefore 0)	+4+3+0 = +7
Step 3 (B.B value for BW = 2, therefore +2; B.B value for LBLG = 5, therefore, +5; B.B value for CMG = 1, therefore +1; B.B value for GF = 0, therefore 0; B.B values for EH and FH = 0, therefore 0)	+2+5+1+0+0+0 = +8
Step 4 (B.B value for BT = 0, therefore 0)	0
Step 5 (Sum of steps 1 to 4)	+5+7+8+0 = 20

Table 5.5 – Carbon sequestration score for Castle Irwell.

Note: See Figure 4.11 for details of the scoring procedure

Vegetation layers	**Braun-Blanquet (B.B) values**
1. Upper canopy (UC)	3
2. Lower canopy (LC)	2
3. Bush (woody) (BW)	2
4. Low bush and long grass (non-woody) (LBLG)	5
5. Cropped or mowed grass (CMG)	1
6. Ground flora (GF)	0
7. Open water (AQ)	0
8. Emergent hydrophyte (EH)	0
9. Floating hydrophyte (FH)	0
10. Built (BT)	0
Step 1 (+1 for every layer present, irrespective of B.B value)	+1+1+1+1+1 = +5
Step 2 (B.B value for UC = 3, therefore +3; B.B value for LC = 2, therefore +2; B.B value for BW = 2, therefore +2; B.B value for LBLG = 5, therefore +5; B.B value for OW, EH, FH = 0, therefore 0)	+3+2+2+5+0+0+0 = +12
Step 3 (B.B value for CMG = 1, therefore -1; B.B value for GF = 0, therefore 0; B.B value for BT = 0, therefore 0)	-1-0-0 = -1
Step 4 (Sum of steps 1 to 3)	+5+12-1 = 16

5.1.2. Cultural ecosystem services and disservices variables appraisal results

Aside from vegetation structure coverage abundance analysis, Castle Irwell was also subject to the cultural ecosystem services and disservices variables appraisal. Table 5.10 contains details of the cultural ecosystem services and disservices variables appraisal for Castle Irwell, showing the profile of the variables, instead of the actual ecosystem services and disservices scores. The procedure described in section 4.3.4.5 was followed when conducting the appraisal.

Table 5.6 – On-site cultural ecosystem services and disservices variables appraisal results for Castle Irwell

Variables	**Chosen categories (see Figures 4.16 and 4.17 for definitions)**
1. Legal accessibility (LA)	2 – Open to public access
2. Physical accessibility (PA)	1 – Physically accessible but not highly visible
3. Recreational infrastructures (RI)	1 – Present but not well maintained
4. Educational signs (ES)	0 – Not present
5. Proximity of the closest education establishment to site (PEE)	2 – between 101m to 400m (278.15m, Brentnall Primary School)
6. Evidence of educational use (EEU)	2 - The Irwell Valley Sustainable Communities Project is an ongoing community project that is designed to support local residents to adapt to climate change and live more sustainably (Irwell Valley Sustainable Communities Project, 2014). The project's website also details of Castle Irwell's proposed transformation from a recreational grassland to a flood retention basin, as part of the River Irwell flood mitigation strategy (Irwell Valley Sustainable Communities Project, 2014). Gardiner *et al.* (1998) has written about the site in their fieldwork guide to Greater Manchester.
7. Dog Faeces (DF)	2 – Rare
8. Bins (B)	0 – Not present
9. Litters (L)	0 – Frequent

At the time of the appraisal, Castle Irwell was owned by Salford City Council and there was no restrictions to access, as shown in the first row of Table 5.6. Previously the site was part of the old Manchester Racecourse. But now it has become a place where people walk and enjoy the local nature (Gardiner *et al.*, 1998; Irwell Valley Sustainable Communities Project, 2014).

At the time of this appraisal the site was situated behind the Castle Irwell Student Village, University of Salford, and therefore the site is not visible to the general public, as shown in the second row of Table 5.6. Access from the student village was via a small gap between the trees at the south-east boundary of the site, and access to the site by the general public was provided by a footbridge crossing the River Irwell at the west of the site (see Figure 5.5).

Figure 5.5 – Footbridge at the western entrance of Castle Irwell

After crossing the footbridge, there is a dirt track (Figure 5.6) leading up to the actual site.

Figure 5.6 – Footpath leading from the bridge to the site

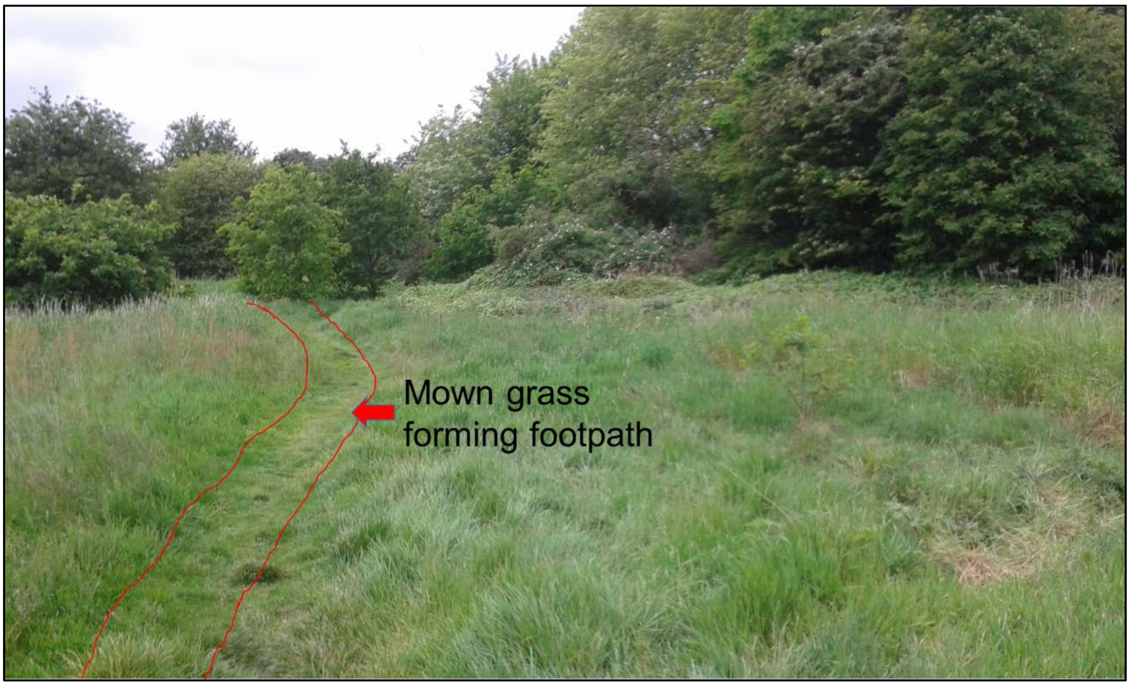

Figure 5.7 – Footpaths across the site, created by mowing grass to a shorter length

The rest of the site can be walked by following footpaths created by differential mowing (see Figure 5.7). There were sightings of at least one deer within the site. Giant hogweed (*Heracleum mantegazzianum*) was also encountered on site (see Figure 5.8).

Figure 5.8 – Example of giant hogweed (Heracleum mantegazzianum)

The giant hogweed has poisonous sap which is harmful to humans. The deer might also be perceived as being dangerous.

The vegetation at the site was mostly overgrown, which obscured the litter lying on the ground, beneath the vegetation. However, litter were found in more than four places within each sample plots and litter were also encountered for every few steps (less than 30) taken whilst walking within the sample plots. Therefore, at all seven sample plots, litter was rated as frequent (see the seventh row at Table 5.6). Dog faeces were rated as rare (see the fifth row at Table 5.6) because it was not encountered on-site. There were no litter bins on site.

At the edges of the site and surrounding the tree island were plants with thorns and large spikes, such as bramble bushes (*Rubus fruticosus*) (Figure 5.9). These plants can injure walkers.

Figure 5.9 – Examples of thorny and spiky plants

Overall, the combination of overgrown vegetation, wild deer, giant hogweed and thorny plants can contribute to accidents occurring for people using the site.

There were not many recreational infrastructure elements found on site, apart from three to four wooden benches (Figure 5.10).

Figure 5.10 – A wooden bench in Castle Irwell

The wooden bench shown in Figure 5.10 allows walkers to relax and enjoy the nature being provided on site.

Overall, this chapter managed to convey the survey process that was followed to collect the raw data for ecosystem services and disservices analysis. Chapter 6 will be used to present the final results of the 49 sites chosen for the research (Table 4.1).

6. Results

Chapter 5 contained a case study (Castle Irwell) which illustrated how the methods described in Chapter 4 were implemented to gather data for the validation of the SuDS Communication and Planning Framework.

The chapter presents the survey data analysis results of the 49 sites chosen for the validation of the SuDS Communication and Planning Framework (Table 4.1). The results are presented in accordance with the two validation methods (vegetation cover-abundance survey and cultural ecosystem services and disservices variables appraisals). Table E1 in Appendix E contains the preliminary site information for the 49 sites. Information contained in Table E1 consists of:

- Site ID
- Name of site
- Date the site was surveyed
- Area of site (m^2)
- Area group (0 = between $1m^2$ and $2499m^2$; 1 = between $2500m^2$ and $5499m^2$; 2 = between $5500m^2$ and $7999m^2$; 3 = larger than or equals to $8000m^2$) (Fields in Trust / National Playing Fields Association, 2008; Moseley *et al.*, 2013)
- Perimeter of site (m)
- Type of site (1 = aquatic; 2 = terrestrial)

The area groups were chosen in accordance with the standard sizes for outdoor recreational facilities for children, published by Fields in Trust or National Playing Fields Association (2008). These sizes were based on a minimum population of 1000 people. Table 6.1 illustrates the four different area groups and the definitions for each group.

Table 6.1 – The four area groups used in the result analysis and the definitions for each groups (Fields in Trust / National Playing Fields Association, 2008; Moseley et al., 2013)

Code	**Area group**	**Definition**
0	Between 1m^2 and 2499m^2	Too small to form any potential recreational space of children.
1	Between 2500m^2 and 5499m^2	Potential to form a designated outdoor recreational space for children.
2	Between 5500m^2 and 7999m^2	Potential to form an informal outdoor recreational space for children.
3	Larger than or equal to 8000m^2	Potential to form a total outdoor recreational space for children. Sites that are at least 10,000m^2 (one hectare) in size have the potential to become a local nature reserve, according to the Accessible Natural Greenspace Standard (ANGst) model (Natural England, 2010).

The 49 sites surveyed were also categorised into either aquatic or terrestrial. Aquatic represents sites with permanent water bodies and/or have aquatic vegetation present on-site. In terms of vegetated SuDS types, wetlands, ponds and rain gardens fall into this category. Terrestrial represents sites with no water bodies or any aquatic vegetation present on-site. In terms of vegetated SuDS types, swales, filter strips and green roofs fall into this category.

Referring back to Table E1 in Appendix E, vegetation structure cover-abundance and cultural ecosystem services and disservices variables appraisals were carried out in all 49 sites. The following sections will present the results for the two ecosystem services and disservices examinations (vegetation structure cover-abundance and cultural ecosystem services and disservices variable appraisals) for all the sites mentioned in Table E1.

6.1. Overall vegetation structure cover-abundance results

Overall, 49 sites were examined for their vegetation structure cover-abundance.Subsequently, habitat for species, urban heat island mitigation and carbon sequestration ecosystem services scores were calculated based on the cover-abundance raw data. The observed percentage cover of vegetation layers for all 49 sites are presented in Table E3 in Appendix E.

Six sites (11 - Castle Irwell, 24 - Nutsford Vale, 25 - Old Trafford INCOM site, 29 - Pendleton site one, 44 - The Meadow, and 45 - Three Sisters) were surveyed using the standard 50m by 50m sample plots. The data for site 11 are presented in Table D1 in Appendix D. The initial observed percentage cover of vegetation layers for sites 24, 25, 29, 44 and 45 are presented in Table E2 in Appendix E.

The mean observed percentage cover of vegetation layers for the six sites mentioned above are presented in Table E3. The other sites were surveyed in their entirety, and therefore the actual observed percentage cover of vegetation layers for these sites are presented in Table E3 instead. The observed percentage cover of vegetation layers in Table E3 were then converted to their relevant Braun-Blanquet values (see Table E4).

Figures 6.1 to 6.10 illustrate the distribution of all the vegetation layers for the 49 sites based on the size of the sites. The sites were separated into two area groups (one (less than or equal to 5500m^2) and two (greater than 5500m^2)) for the distribution analysis. The reason for this was because for sites less than 5500m^2, they are either too small to form recreational space or can only form limited, designated outdoor recreational spaces for children (Fields in Trust/National Playing Fields Association, 2008). Conversely, sites greater than 5500m^2 can potentially form either informal or total outdoor recreational spaces (Fields in Trust/National Playing Fields Association, 2008), or can become Local Nature Reserves (Natural England, 2010). The aim therefore was to examine whether large recreational spaces correspond to greater vegetation structure cover-abundance. Therefore, analysis was performed to determine the relationship between the size of the site and the distribution of vegetation layers observed on-site. The hypothesis statements are:

- H1: There is a significant difference in the distribution of vegetation layers present on-site based on the size of the site.

- H0: There is no significant difference in the distribution of vegetation layers present on-site based on the size of the site.

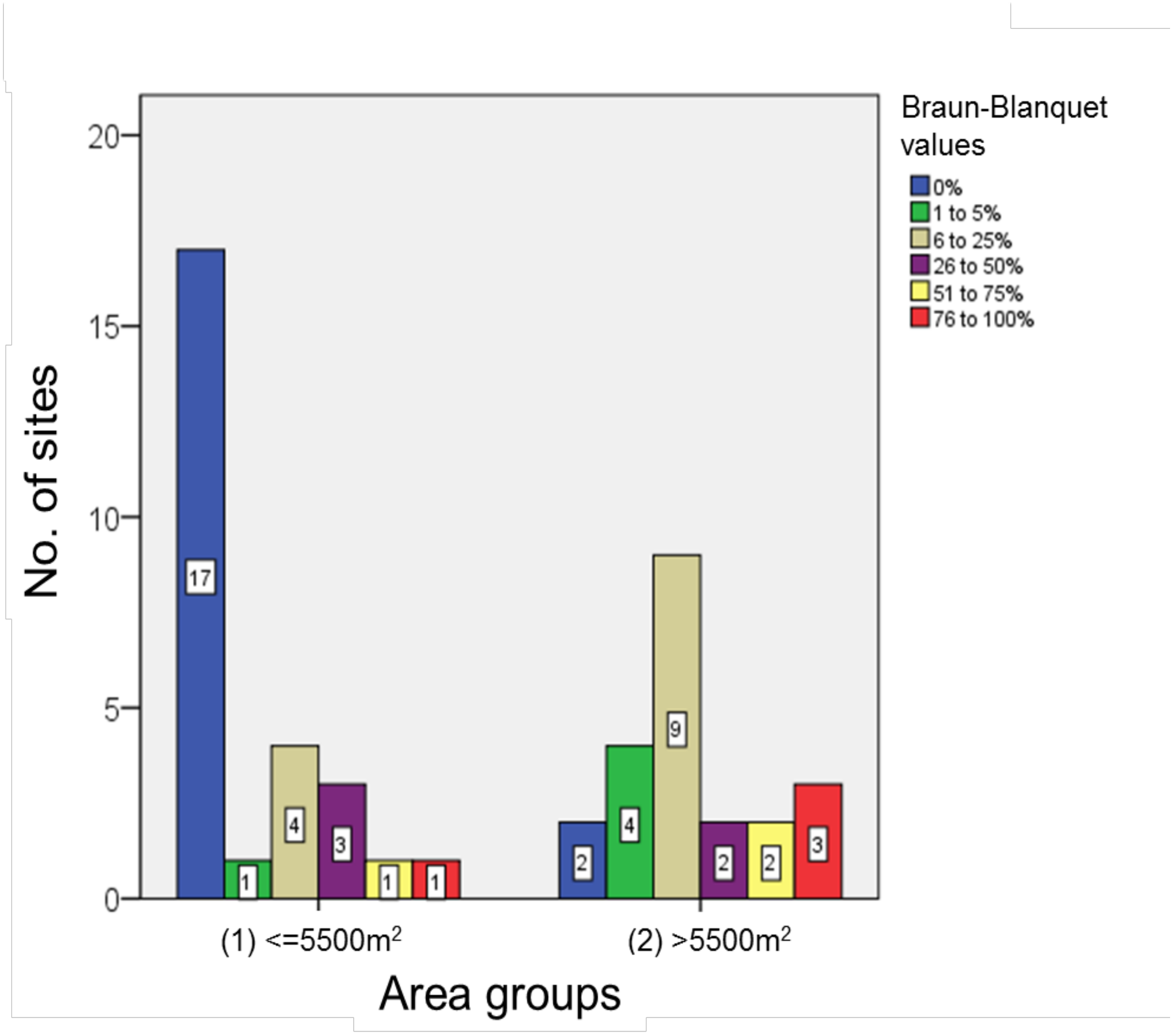

Figure 6.1 – Distribution of the upper canopy vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

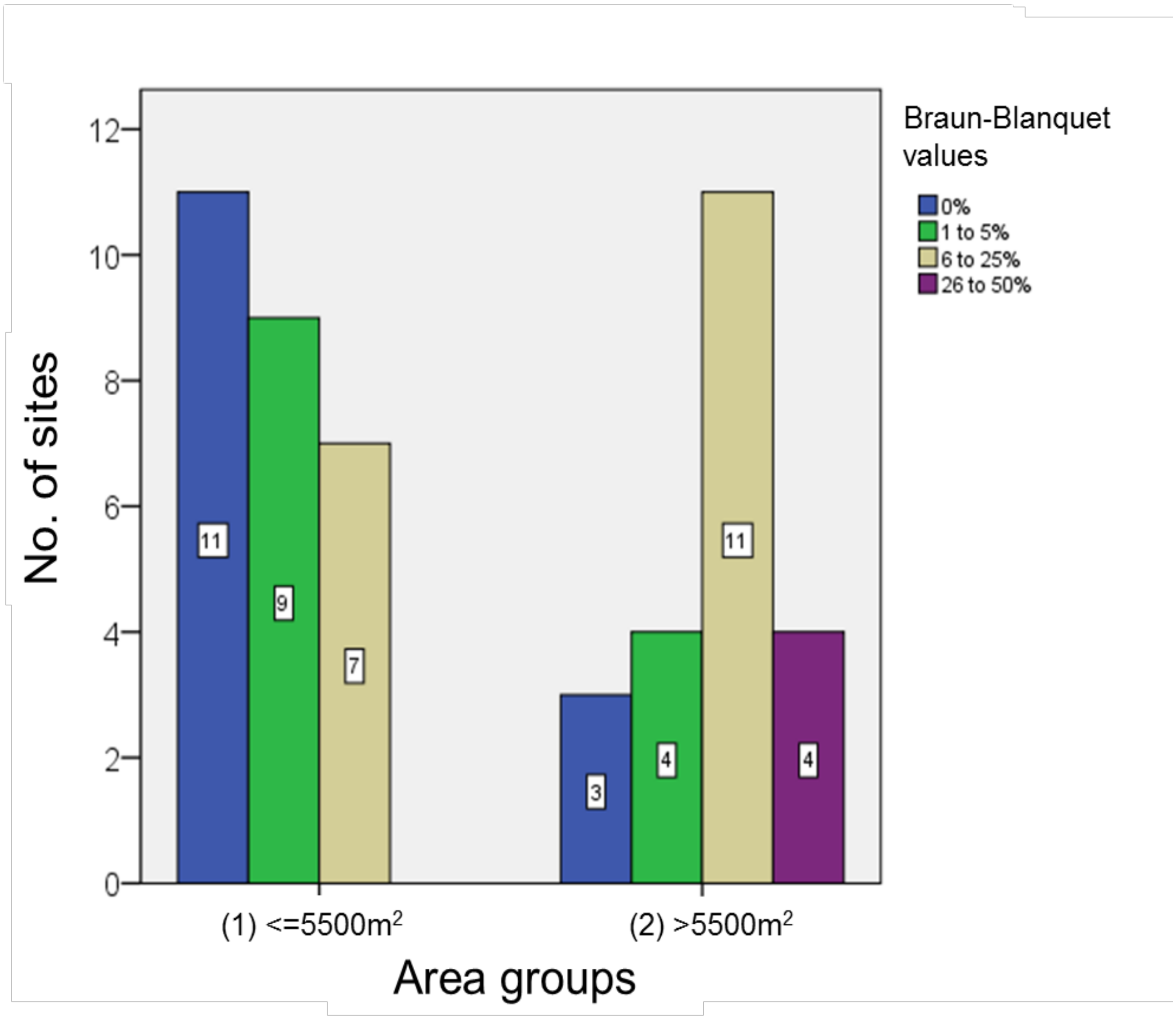

Figure 6.2 – Distribution of the lower canopy vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

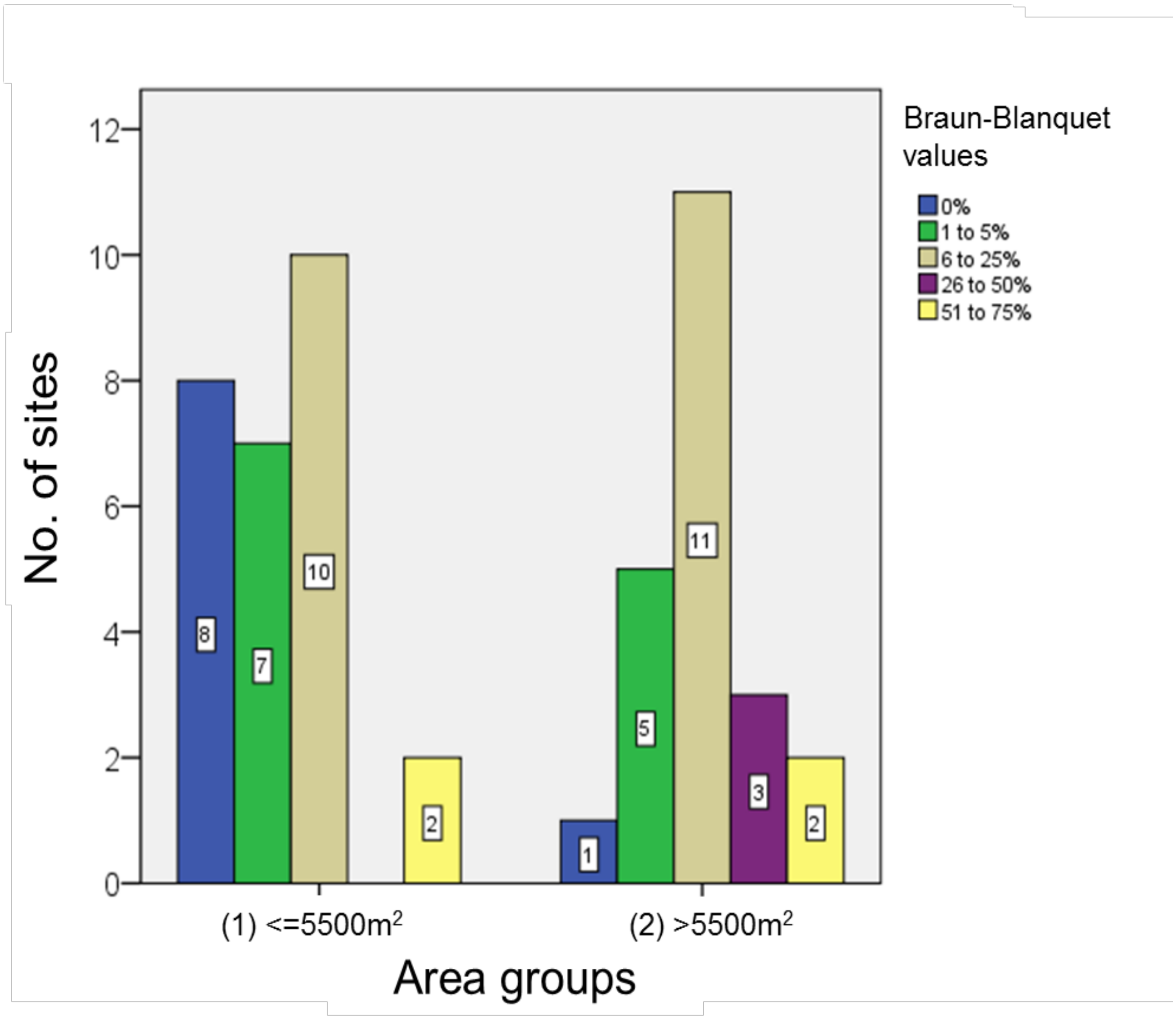

Figure 6.3 – Distribution of the bush (woody) vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

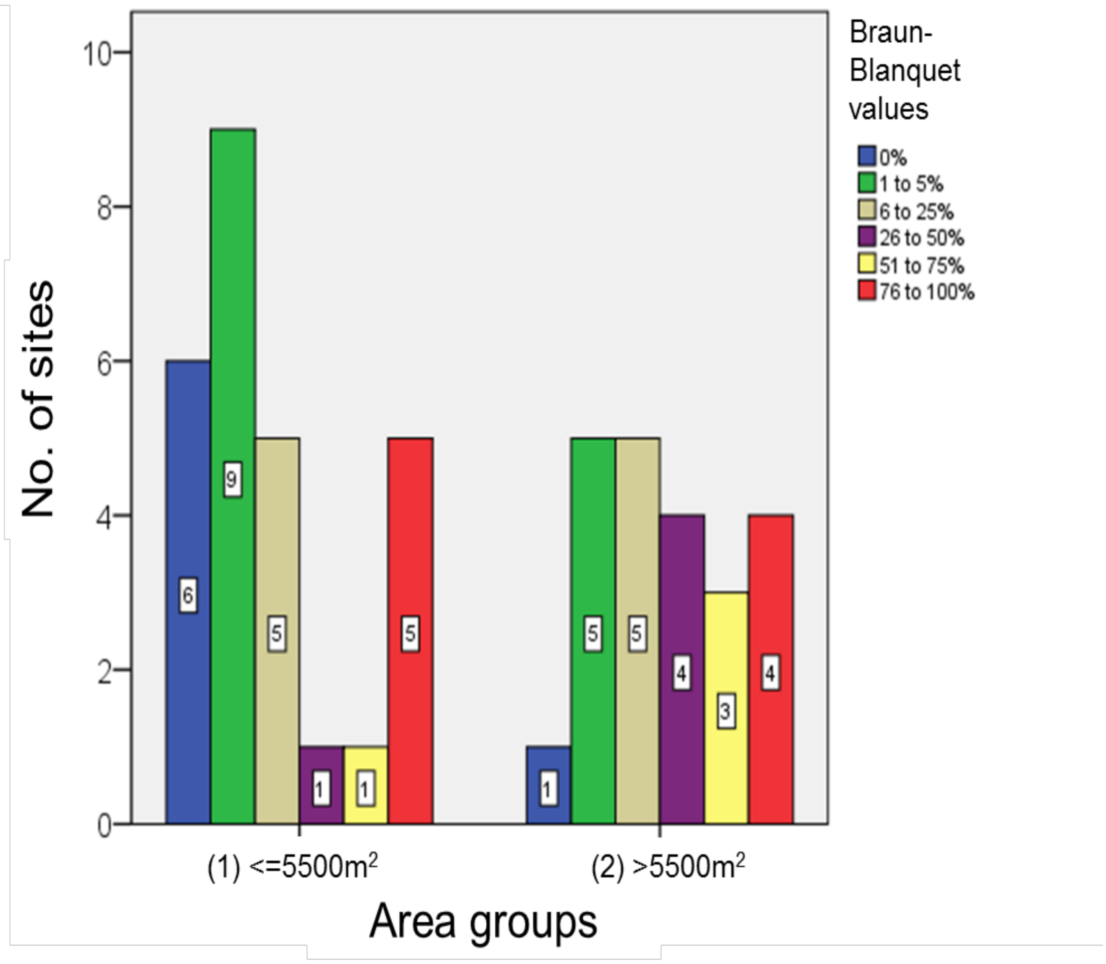

Figure 6.4 – Distribution of the low bush and long grass vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

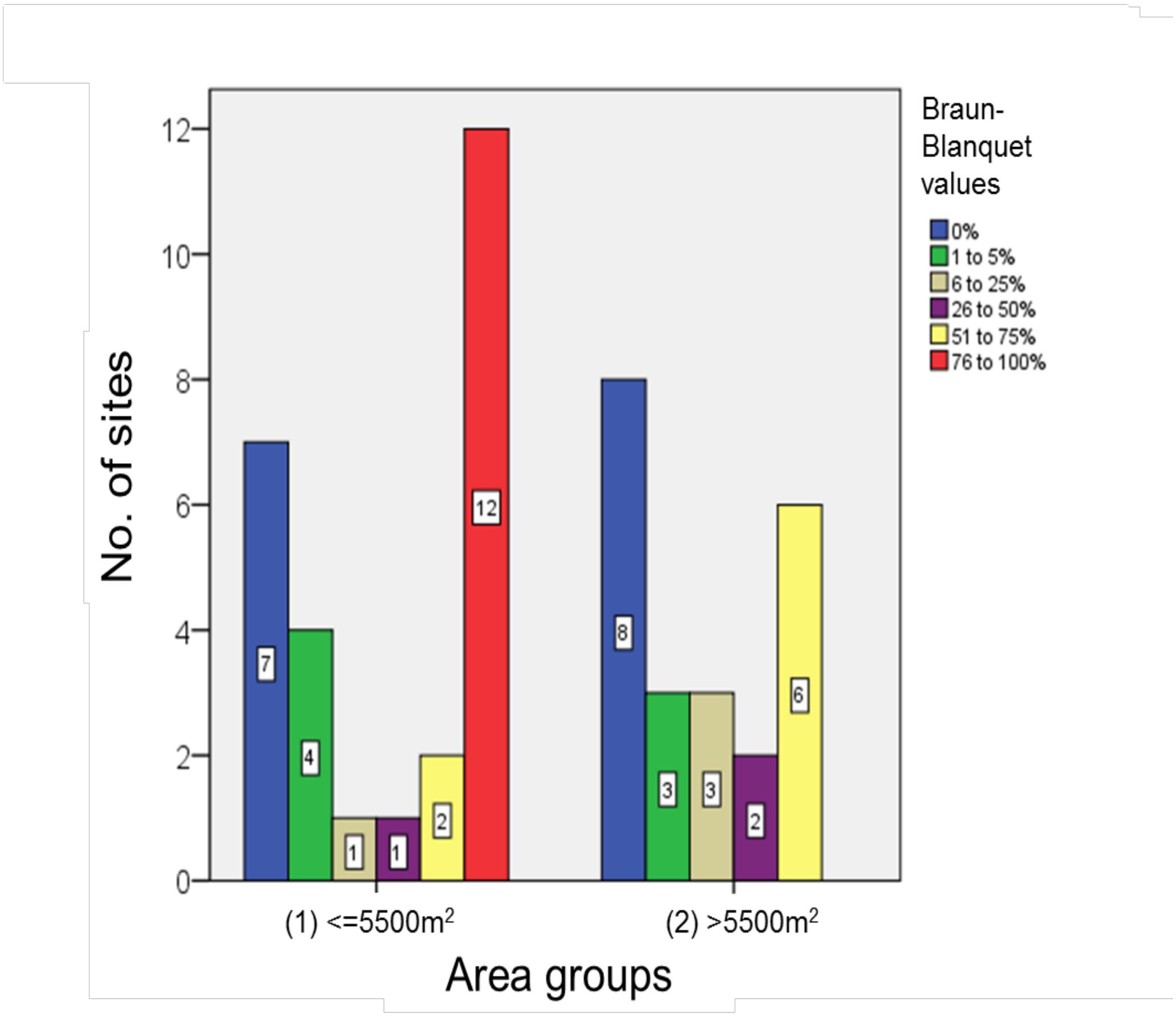

Figure 6.5 – Distribution of the cropped or mowed grass vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

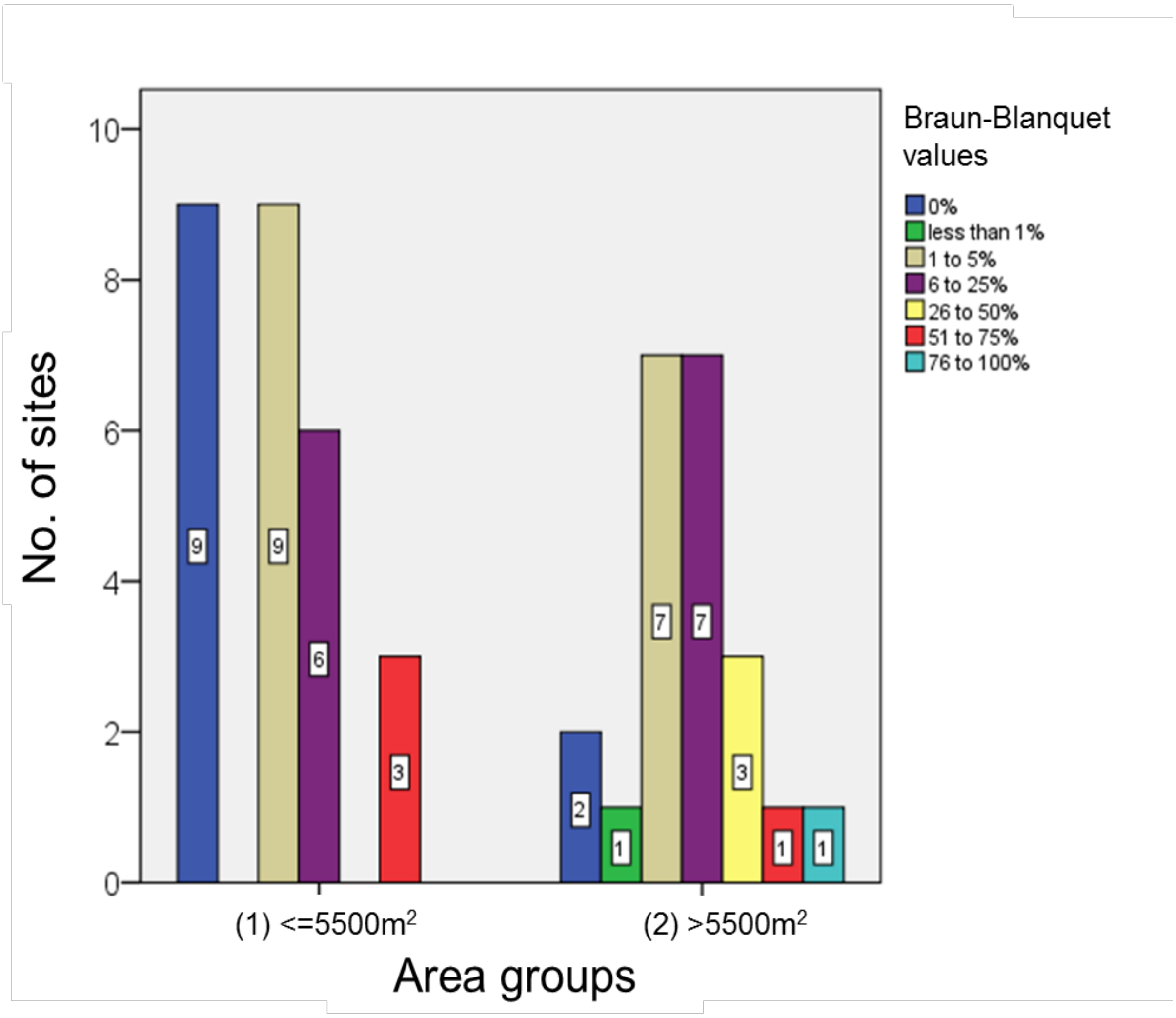

Figure 6.6 – Distribution of the ground flora vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

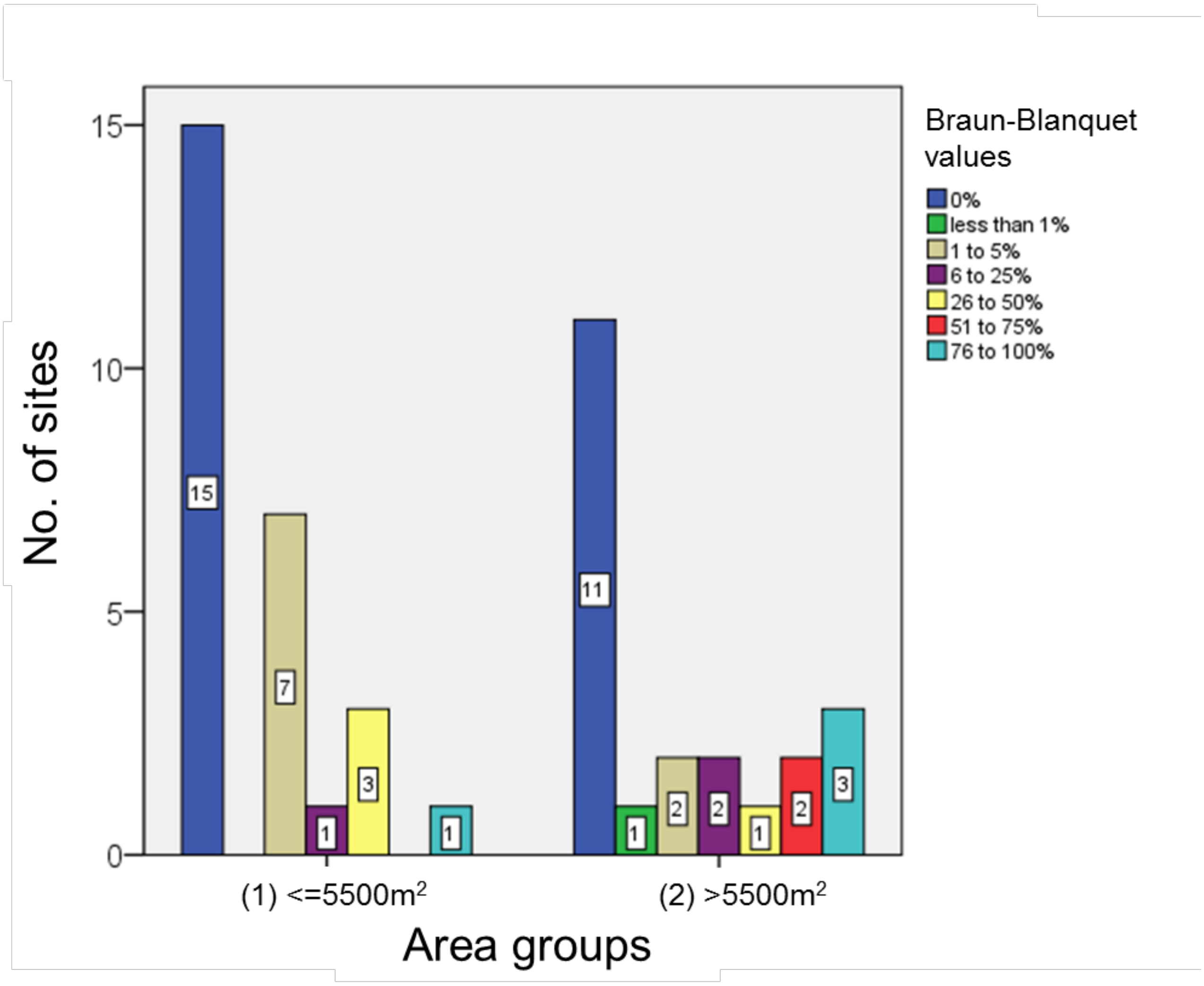

Figure 6.7 – Distribution of the open water vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

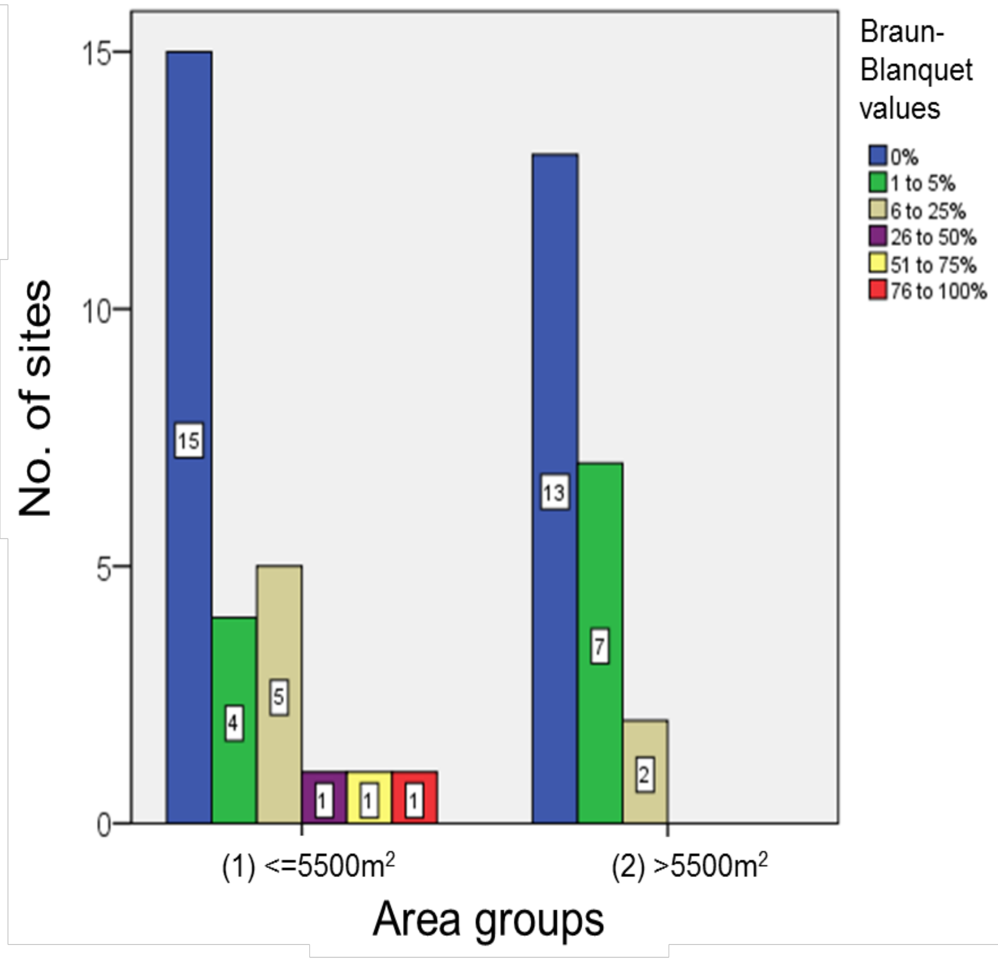

Figure 6.8 – Distribution of the emergent hydrophytes vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

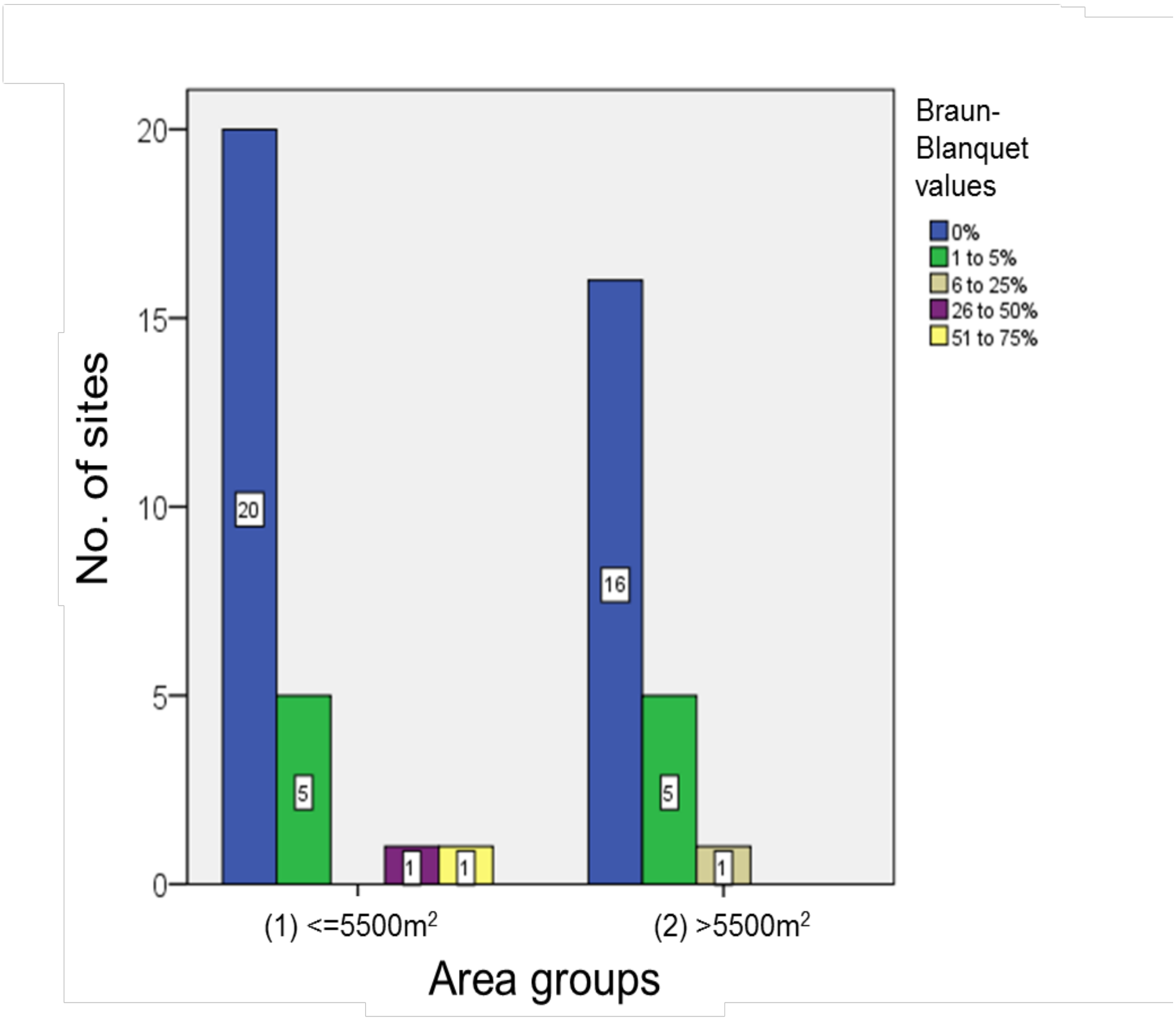

Figure 6.9 – Distribution of the floating hydrophytes vegetation layer based on the size of the site.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

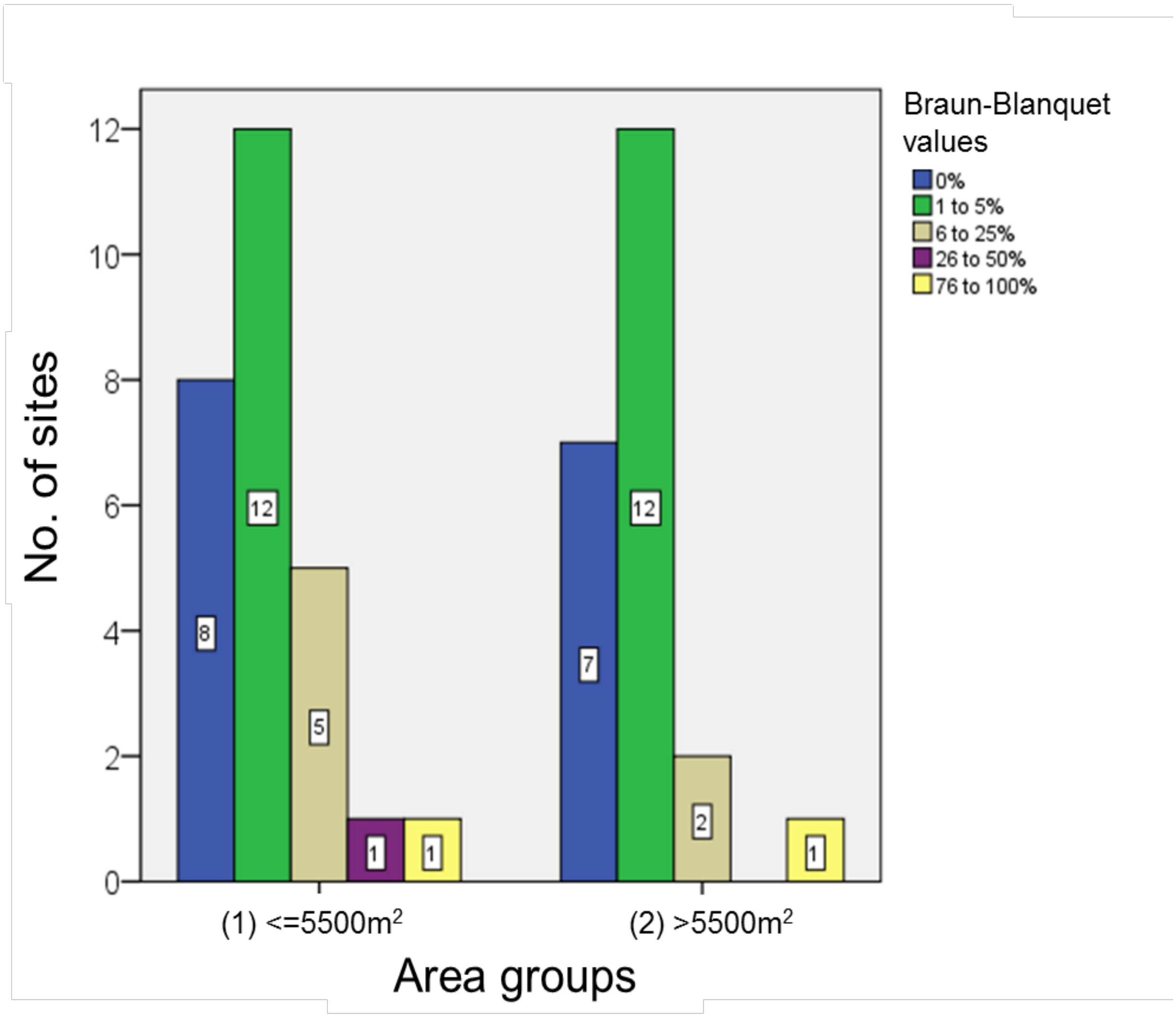

Figure 6.10 – Distribution of the built vegetation layers based on the size of the sites.

Note: Total number of sites less than or equals to 5500m^2 = 27. Total number of sites greater than 5500m^2 = 22.

Figures 6.1 to 6.10 illustrate the distribution of all the vegetation layers within the 49 sites examined. Summary of the statistical results are presented in Table 6.2.

Table 6.2 – Summary of the statistical results for the area groups (m^2) versus the distribution of vegetation layers present on-site.

Vegetation layers versus area groups	**Cells that have expected count less than 5**	**Fisher's Exact Test result**	**P-value**	**P-value more than or less than 0.05**	**Significant difference at the P=0.05 level (Y/N)**
Upper Canopy	8	17.325	0.001	Less than	Y
Lower Canopy	2	10.487	0.010	Less than	Y
Bush (woody)	6	8.116	0.064	More than	N
Low Bush and Long Grass	9	6.861	0.227	More than	N
Cropped or Mowed Grass	8	16.773	0.002	Less than	Y
Ground Flora	9	9.726	0.079	More than	N
Open Water	12	7.670	0.214	More than	N
Emergent Hydrophytes	9	4.520	0.495	More than	N
Floating Hydrophytes	7	2.832	0.918	More than	N
Built	6	2.041	0.870	More than	N

According to the information in Table 6.2, every vegetation layer has cells that have an expected count less than five. This is a violation of one of the assumptions of the standard Pearson Chi-Square test, making the test invalid (Hinton, 2014). Therefore, Fisher's Exact test (accurate for all sample sizes) within the Pearson Chi-Square suite of tests was employed to examine if the size of the sites affect the distribution and the coverage of the vegetation layers.

According to the Fisher's Exact Test p-values (Table 6.2), the size of the site has a significant effect on the distribution of the upper canopy, the lower canopy and the cropped or mowed grass vegetation layers. However, the Fisher's Exact Test results does not provide information with regards to how significant the size of the site is on the distribution of the upper canopy, the lower canopy and the cropped or mown grass vegetation layers. Therefore, it is necessary to refer back to the vegetation layers against the area groups plots (Figures 6.1 to 6.10) in order to examine the significance of the size of the site on the distribution of the vegetation layers.

The effect of site size on the upper canopy is illustrated when the distribution of the vegetation layer was plotted against area groups (see Figure 6.1). Of the 27 sites that are smaller than or equal to 5500m^2, 17 sites (63%) have no upper canopy coverage. Only 10 sites (37%) have an upper canopy coverage ranging from 1% to 100%. On the other hand, of the 22 sites larger than 5500m^2, only two sites (9%) have no upper canopy coverage, with 20 sites (91%) having an upper canopy coverage ranging from 1% to 100%. Evidently, the percentage of no upper canopy coverage for sites smaller than or equal to 5500m^2 (63%) is greater than for sites larger than 5500m^2 (9%). Conversely, the percentage of upper canopy coverage for sites smaller than or equal to 5500m^2 (37%) is less than for sites larger than 5500m^2 (91%). Therefore, upper canopy was observed more often and at greater abundance at large sites (greater than 5500m^2).

The effect of site size on lower canopy is illustrated when the distribution of the vegetation layer was plotted against area groups (see Figure 6.2). Of the 27 sites that are smaller than or equal to 5500m^2, 11 sites (41%) have no lower canopy coverage. The rest (16 sites; 59%) have lower canopy coverage ranging from 1% to 100%. On the other hand, of the 22 sites larger than 5500m^2, only three sites (14%) have no lower canopy coverage. The rest (19 sites; 86%) have lower canopy coverage ranging from 1% to 100%. Evidently, the percentage of no lower canopy coverage for sites smaller than or equal to 5500m^2 (41%) is greater than for sites larger than 5500m^2 (14%). Conversely, the percentage of lower canopy coverage for sites smaller than or equal to 5500m^2 (59%) is less than for sites larger than 5500m^2 (86%). Therefore, lower canopy was observed more often and at greater abundance at large sites (greater than 5500m^2).

The effect of site size on cropped or mowed grass is illustrated when the distribution of the vegetation layer was plotted against area groups (see Figure 6.5). Of the 27 sites that are smaller than or equal to 5500m^2, 20 sites (74%) have cropped or mowed grass coverage ranging from 1% to 100%, and only 7 sites (26%) do not have any cropped or mown grass coverage. In particular, 12 sites within the 20 sites (60%) have dominant cropped or mown grass coverage, ranging from 76% to 100%. On the other hand, of the 22 sites larger than 5500m^2, 14 sites (64%) have cropped or mown grass coverage ranging from 1% to 100%, and only 8 sites (36%) do not have any cropped or mown grass coverage. However, none of the sites within the 14 sites are dominated by cropped or mown grass (i.e. coverage ranging from 76% to 100%). Whilst acknowledging of the fact that the percentage of cropped or mown grass coverage for sites smaller than or equal to 5500m^2 (74%) is only marginally greater than for sites larger than 5500m^2 (64%); however, 60% out of the 74% are dominated by cropped or mown grass. Therefore, cropped or mown grass occurred more often and at greater abundance at small sites (smaller than or equal to 5500m^2).

6.2. Overall distribution of vegetation structure layers

Vegetation layers with a Braun-Blanquet value were counted up for each site in order to find out how many layers are present in each site. This also formed the first step for calculating the three ecosystem services scores, by count the vegetation layers present on-site for each site. Table 6.3 contains the results of a cross-tabulation of the number of vegetation layers present on-site, based on the area group to which each site belongs.

Table 6.3 – Cross-tabulation of area group verses the number of vegetation layers present on-site

Area group	No. of vegetation structure layers										Total no. of sites
	1	2	3	4	5	6	7	8	9	10	
$1m^2$ to $2499m^2$	3	2	1	1	3	3	0	3	1	0	17
$2500m^2$ to $5499m^2$	0	1	0	1	0	0	2	2	2	2	10
$5500m^2$ to $7999m^2$	0	0	0	0	0	1	0	0	0	2	3
≥ $8000m^2$	0	0	0	2	3	3	4	3	3	1	19
Total no. of sites	3	3	1	4	6	7	6	8	6	5	49

According to the data in Table 6.3, five sites were observed to contain the maximum number of vegetation layers (10). Two sites lie within the second area group (between $2500m^2$ and $5499m^2$), and they are site 7(Blackley New Road pond – $4633m^2$) and site 10 (Canal Road pond – $2779m^2$). If site 7 and 10 were analysed for their recreational potential based on their size alone, they would be able to form designated recreational outdoor spaces, according to the Fields in Trust standard (Fields in Trust/National Playing Fields Association, 2008).

Two sites lie within the third area group (between $5500m^2$ and $7999m^2$), and they are site 40 (Stamford Brook retention basin two – $7423m^2$) and site 6 (Blackley New Road pond one – $7594m^2$). In accordance with the Fields in Trust standard, site 6 and 40 would be able to form informal outdoor recreational spaces (Fields in Trust/National Playing Fields Association, 2008). Finally, one site, site 3 (Alexandra Park pond – $12,787m^2$), lies within the fourth area group (larger than or equal to $8000m^2$). This site, if assessed through area alone, has the potential to form total outdoor recreational spaces for children (Fields in Trust/National Playing Fields Association, 2008) and also satisfies the minimum area ($10,000m^2$) required to become a Local Nature Reserve, in accordance with the ANGST model (Natural England, 2010).

Referring back to Table 6.3, three sites were observed to contain the minimum number of vegetation layers (one) on-site. They are sites 1 - Acorn Close allotments green roof, 38 - Scott Avenue allotments green roof, 43 - Stevenson Square green roof. All three sites have areas less than 2500m^2. If they were analysed for their recreational potential based on their size alone, they would be too small to form any potential recreational spaces, according to the Fields in Trust standard (Fields in Trust/National Playing Fields Association, 2008).

Furthermore, six sites were illustrated in Table 6.3 to contain the median number of vegetation layers (five) on-site. They are site 11 - Castle Irwell, 16 - Green space behind Salford Cathedral, 31 - Pendleton site three, 35 - Range Road public garden, 37 - Salford University Woodland, and 49 - Woodland walkway within Alexandra Park. Out of the six sites, three have areas less than 2500m^2 (16 - Green space behind Salford Cathedral 2142m^2, 31 - Pendlton site 3 2160m^2, and 35 - Range Road public garden 2283m^2). In accordance with the Fields in Trust standard, they would be too small to form any potential recreational spaces (Fields in Trust/National Playing Fields Association, 2008). Finally, three sites have areas larger than or equal to 8000m^2 (11 - Castle Irwell 17,1754m^2, 37 - Salford University Woodland 10,555m^2 and 49 - Woodland walkway within Alexandra Park 21,157m^2). These sites have the potential to form total outdoor recreational spaces for children, and also satisfy the minimum area (10,000m^2) required to become a Local Nature Reserve, in accordance with the ANGST model (Natural England, 2010).

Analysis was performed to determine the effect of the size of the site compared with the number of vegetation layers observed on-site. The hypothesis statements are:

- H1: There is a significant difference in the number of vegetation layers present on-site based on the size of the site.
- H0: There is no significant difference in the number of vegetation layers present on-site based on the size of the site.

Before the analysis was performed, the vegetation structure layer counts were checked to see if they are normally distributed or not. Figures 6.11 and 6.12 illustrate the histograms of the vegetation structure layer counts. The sites were split into two different area groups ([1] less than or equal to 5500m^2; [2] greater than 5500m^2) for the distribution analysis.

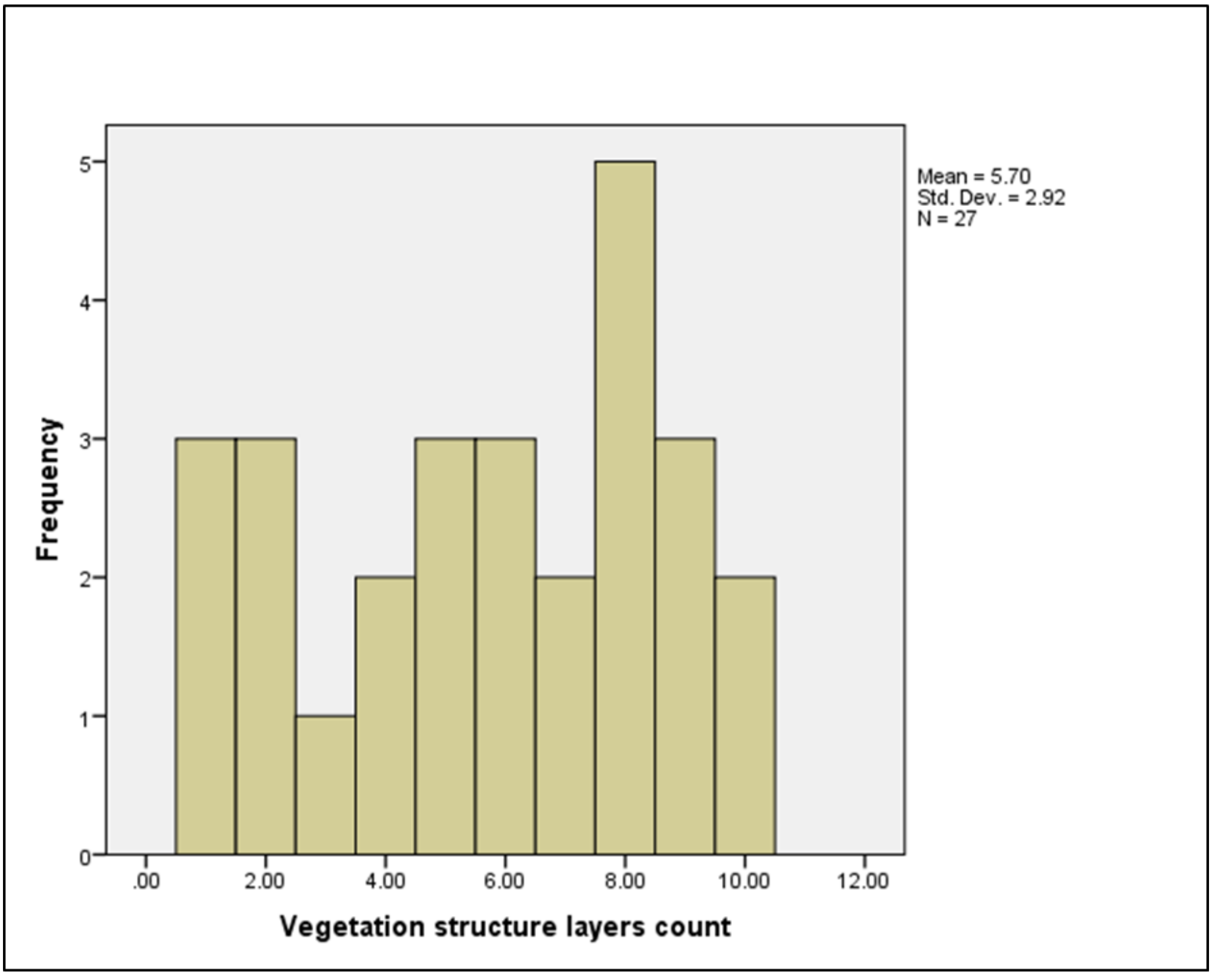

Figure 6.11 – A histogram of vegetation structure layer counts for sites that are smaller than or equals to 5500m^2.

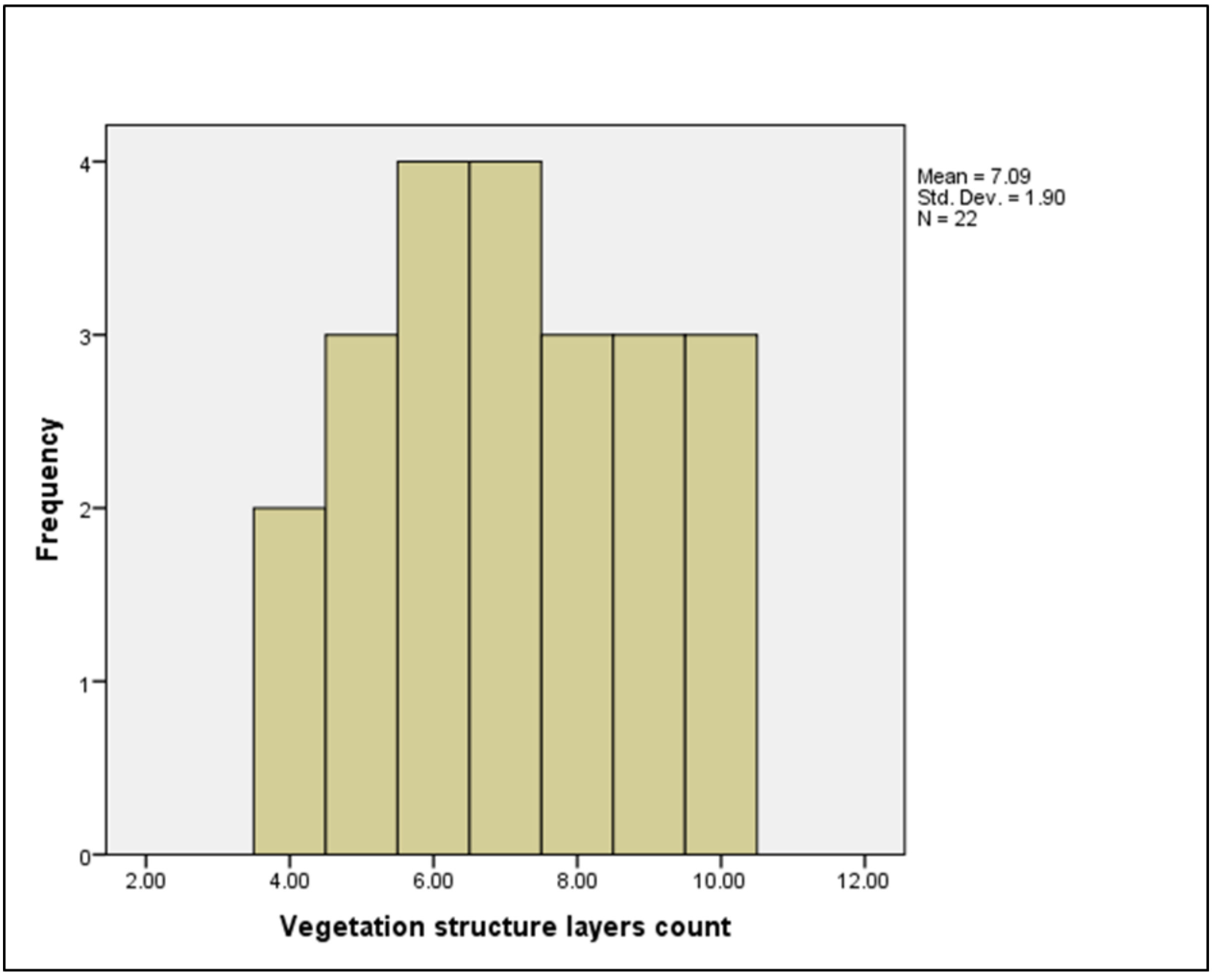

Figure 6.12 – A histogram of vegetation structure layer counts for sites that are larger than 5500m^2

According to the data presented in Figure 6.11, the distribution of the vegetation structure layer counts is negatively skewed, with a skewness value of -0.274. Whereas, the distribution of vegetation structure layer counts illustrated in Figure 6.12 is even, with skewness values of 0.041. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.4).

Table 6.4 – Kolmogorov-Smirnov normality test for vegetation structure layer counts compared with area groups

		Kolmogorov-Smirnov		
	Area groups	**Statistic**	**Degrees of freedom**	**P-value**
Number of vegetation layers	**Less than or equal to 5500m^2**	0.155	27	0.097
	Greater than 5500m^2	0.126	22	0.200

According to Table 6.4, the Kolmogorov-Smirnov normality test produced p-value of the two area groups that are greater than 0.05. This means that the number of vegetation layers can be classed as normally distributed for both area groups. Since the number of vegetation layers data is within an interval scale, and also referring back to the skewness values mentioned earlier, because they are no more than 3, parametric statistics can be used to analyse the data.

Independent Sample T-test was subsequently used to analyse the relationship between the number of vegetation structure layers observed on-site verses the size of site because the data is in an independent interval scale and the data is normally distributed (Table 6.4) and the skewness values were found to be less than three. The output of the Independent Sample T-Test is illustrated in Table 6.5.

Table 6.5 – Levene's Test for equality of variances and Independent Samples T-Test results for number of vegetation layers versus size of site

Independent Samples T-Test results (number of vegetation layers v size of site)			**Number of vegetation layers**	
			Equal variances assumed	**Equal variances not assumed**
Levene's Test for equality of variances	**F**		6.116	NA
	Sig.		0.017	NA
t-test for equality of means	**t**		-1.920	-2.003
	df		47.000	45.001
	Sig. (2-tailed)		0.061	0.051
	Mean difference		-1.387	-1.387
	Std. error difference		0.723	0.693
	95% confidence interval of the difference	**Lower**	-2.841	-2.782
		Upper	0.066	0.008

According to the data in Table 6.5, Levene's test shows that p-value (sig.) of 0.017 is smaller than 0.05. This implies that the group variances are not the same; therefore, the unequal variance reading is adopted. The mean difference in number of vegetation layers between the two area groups is 1.387. Test for equality of means produce p-values of 0.051 (equal variances not assumed). It is only slightly larger than 0.05, therefore, the means of the two groups are only slightly different. Consequently, there is a clear tendency to significance between the sizes of the site and the number of vegetation layers present.

6.3. Habitat for Species scores

After analysing the vegetation structure layers coverage and distribution for the 49 sites, ecosystem services scores were calculated in accordance with the methods illustrated in Chapter 4. The first scores were calculated for the habitat for species ecosystem service. Figure 6.13 illustrated the habitat for species scores distribution for all 49 sites.

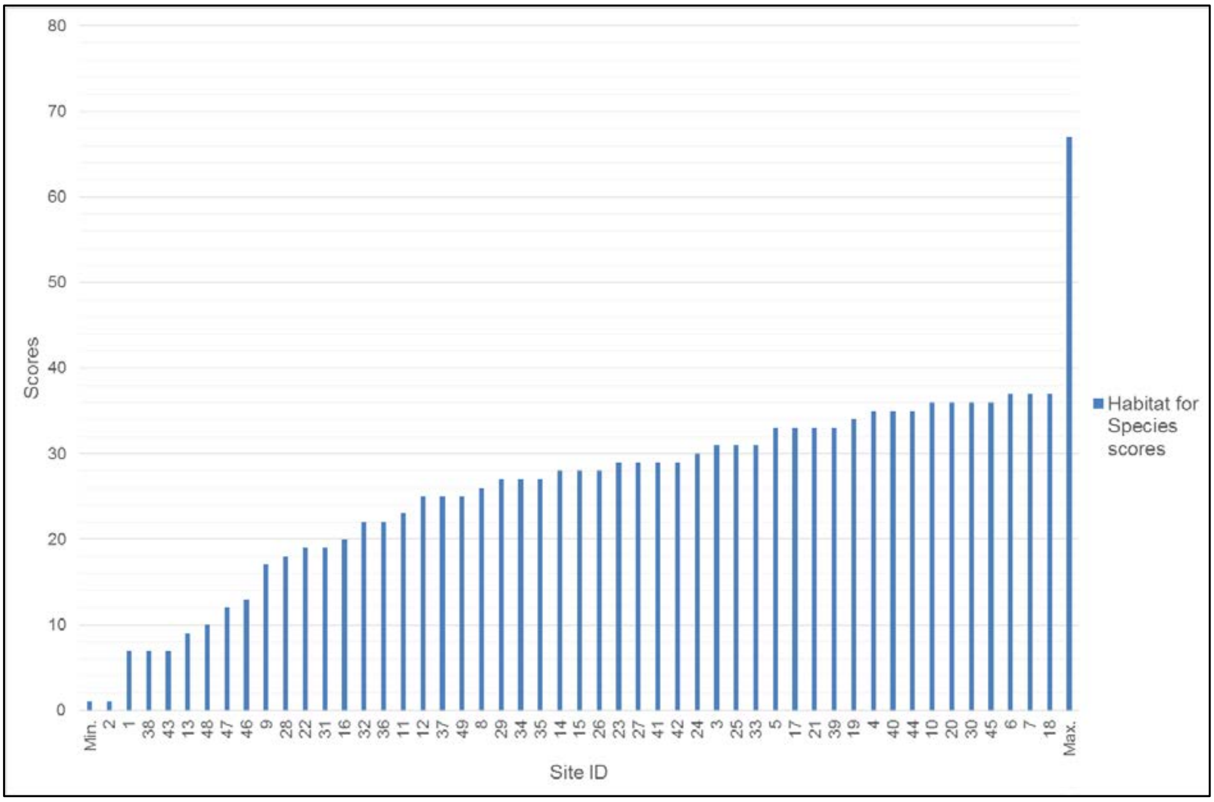

Figure 6.13 – Habitat for species scores for all 49 sites (including the theoretical minimum and max score possible).

According to the data in Figure 6.13, the theoretical maximum score is 67, which occurs when there is 0.1% built layer coverage on-site and 99.9% coverage of every other vegetation layers. However, this scenario cannot be achieved in reality due to upper canopy vegetation blocking sunlight from reaching the vegetation below, competition for nutrients and space to grow. Theoretical minimum score is 1, which occurs when a site is covered by 100% built layer and no other vegetation layers coverage. Incidentally, site two – Adelphi House Car Park – scored the minimum possible Habitat for Species score. Whereas, the maximum score out of the 45 sites examined is 37. It was achieved by site 18 – Heaton Park boating pond.

The scores illustrated in Figure 6.13 have been calculated by transforming the ordinal Braun-Blanquet scale (observed percentage covers were matched to their relevant Braun-Blanquet values) to weighted ratio scores (each Braun-Blanquet values was assigned a weighted value) as described in Chapter 4, Figure 4.9. The individual weights were finally combined using the formula stated in Chapter 4,

Figure 4.9, to produce the overall habitat for species score. The calculation process for each site was the same as the process illustrated in the Castle Irwell case study in Chapter 5.

6.3.1. Habitat for species scores verses size of site

Analysis was performed to find out if there is a relationship between the size of the sites and the habitat for species scores they can achieve. The 49 sites were split into two categories (1 = sites less than or equals to 5500m^2; 2 = sites more than 5500m^2). The hypothesis statements are:

- H1: There is a significant difference in the habitat for species scores based on the size of the site.
- H0: There is no significant difference in the habitat for species scores based on the size of the site.

Before the analysis was performed, the habitat for species scores were checked to see if they are normally distributed or not. Figure 6.14 and 6.15 illustrate the histogram of the habitat for species scores, split into the two different area groups.

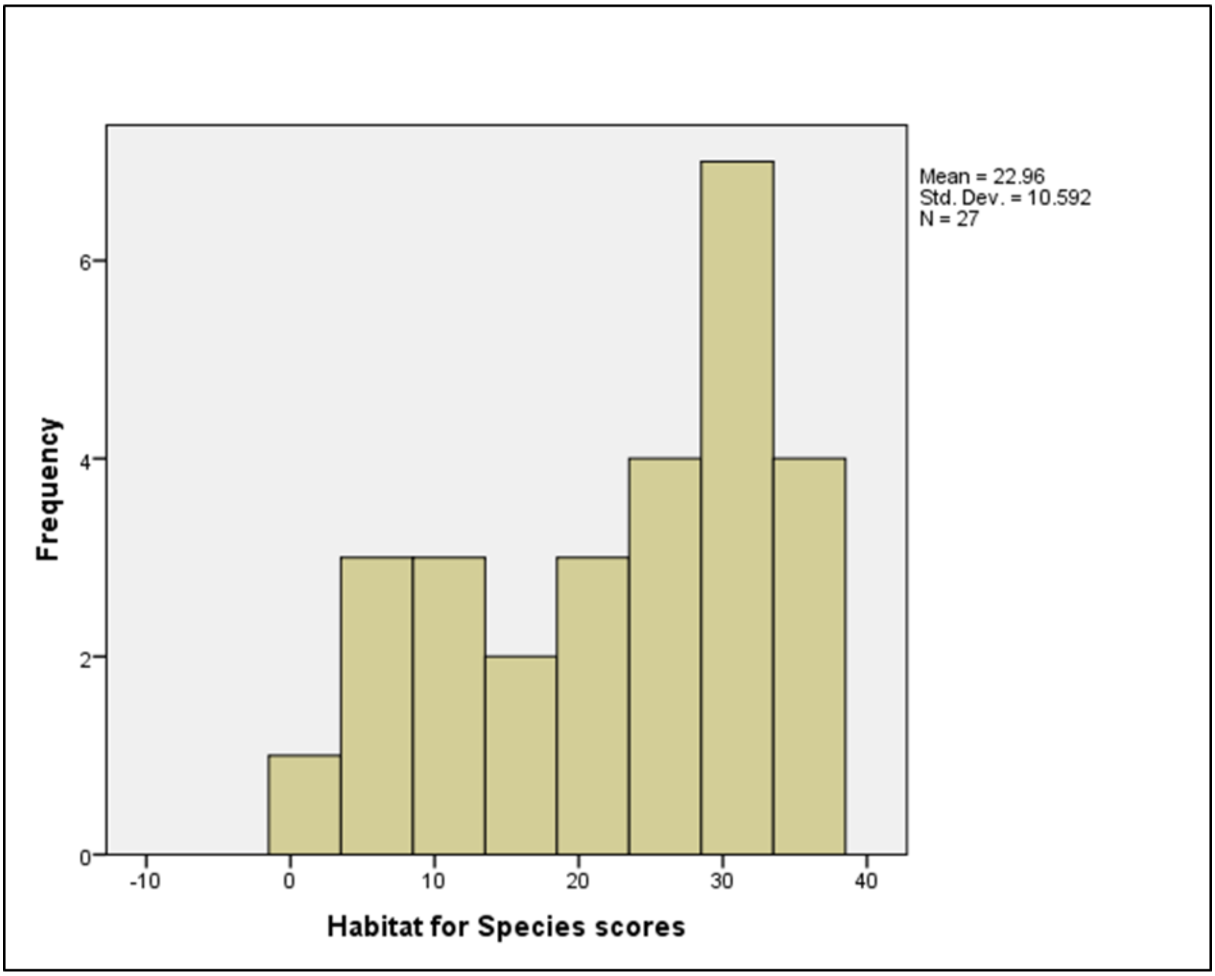

Figure 6.14 – A histogram of habitat for species scores for sites that are smaller than or equal to 5500m^2

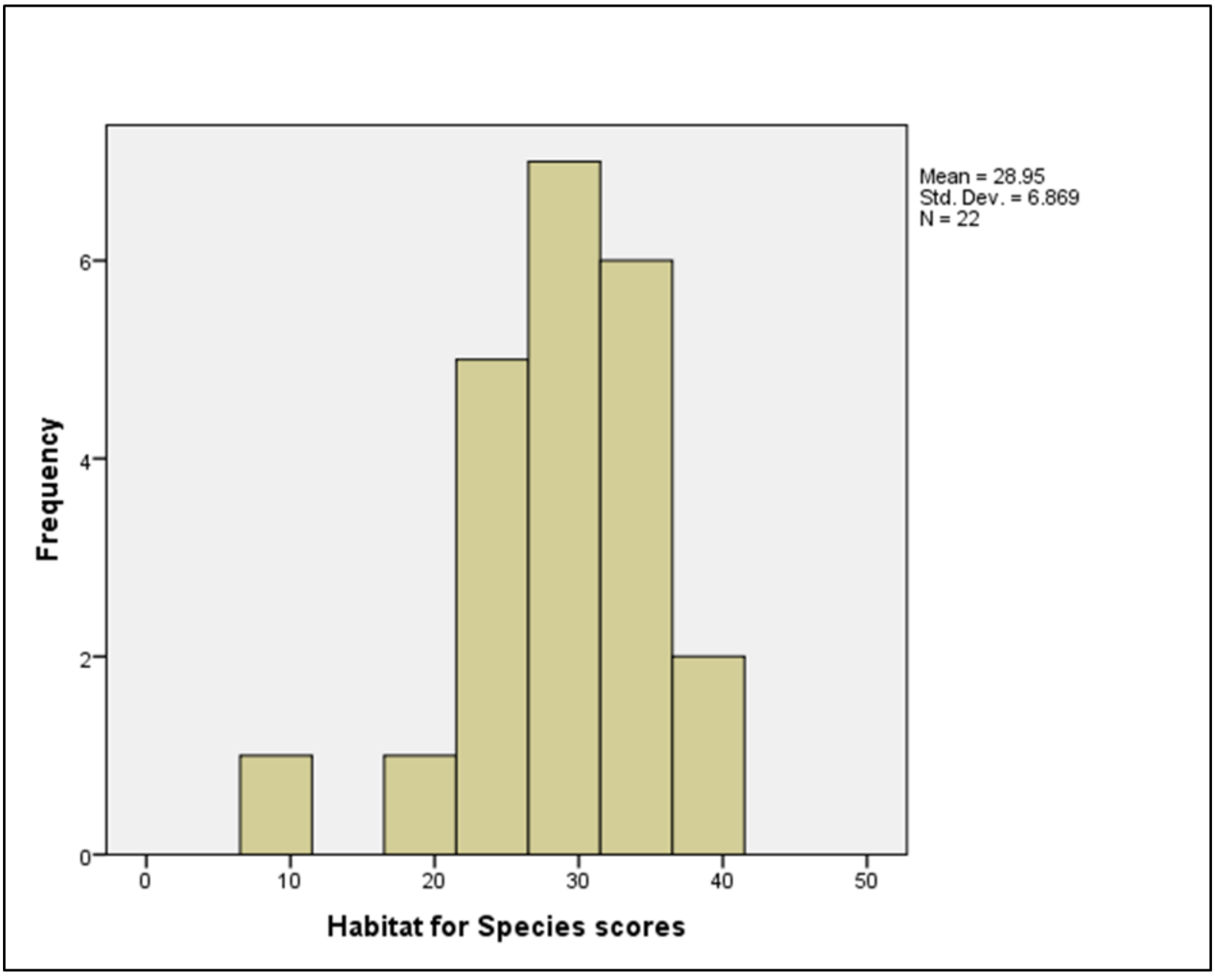

Figure 6.15 – A histogram of habitat for species scores for sites that are larger than 5500m^2.

According to the data in Figures 6.14 and 6.15, the distributions of the habitat for species scores are negatively skewed, with skewness value of -0.513 and -1.155 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.6).

Table 6.6 – Kolmogorov-Smirnov normality tests for habitat for species scores compared with size of site

		Kolmogorov-Smirnov		
	Area groups	**Statistic**	**Degrees of freedom**	**P-value**
Habitat for Species scores	**Less than or equal to 5500m^2**	0.167	27	0.052
	Greater than 5500m^2	0.129	22	0.200

According to the analysis in Table 6.6, the Kolmogorov-Smirnov normality test produced p-values of the two area groups that are greater than 0.05. This means that the habitat for species scores can be classed as normally distributed for both area groups. Referring back to the skewness values mentioned earlier, because of the negative skewness are no more than -3, parametric statistics can be used to analyse the data.

Independent Sample T-Test was subsequently used to analyse the relationship between habitat for species scores verses the size of site because they are robust enough to handle slight skewness of data. The output of the Independent Sample T-Test is illustrated in Table 6.7.

Table 6.7 – Levene's Test for equality of variances and Independent Samples T-Test results for habitat for species scores versus size of site

Independent Samples T-Test results (habitat for species scores v size of site)			Number of vegetation layers: Equal variances assumed	Number of vegetation layers: Equal variances not assumed
Levene's Test for equality of variances	**F**		7.802	NA
	Sig.		0.008	NA
t-test for equality of means	**t**		-2.288	-2.387
	df		47	44.943
	Sig. (2-tailed)		0.027	0.021
	Mean difference		-5.992	-5.992
	Std. error difference		2.619	2.510
	95% confidence interval of the difference	**Lower**	-11.260	-11.047
		Upper	-0.723	-0.936

According to the data in Table 6.7, Levene's test shows that p-value (sig.) of 0.008 is smaller than 0.05. This implies that the group variances are not the same; therefore, the unequal variance reading is adopted. The mean difference in habitat for species scores between the two area groups is 5.992. Test for equality of means produce p-values of 0.021 (equal variances not assumed). It is smaller than 0.05, therefore, the means of the two groups are not equal. Consequently, there is a significant difference between the habitat for species scores for sites that are smaller than or equals to 5500m^2 and sites that are larger than 5500m^2.

6.3.2. Habitat for species scores verses type of site

The 49 sites were split into either aquatic or terrestrial based on the types of vegetation present on site and presence or absence of open water. Aquatic represents sites with permanent water bodies and/or have aquatic vegetation present on-site. In terms of vegetated SuDS types, wetlands, ponds and rain gardens fall into this category. Terrestrial represents sites with no water bodies, nor any aquatic vegetation present on-site. In terms of vegetated SuDS types, swales, filter strips and green roofs fall into this category. Analysis was performed to test whether there is a relationship between the site being aquatic (having aquatic features) or terrestrial (do not have aquatic features) and the habitat for species scores the site obtained.

Before the analysis was performed, the habitat for species scores was checked to see if they are normally distributed or not. Figures 6.16 and 6.17 illustrate the histograms of the habitat for species scores, split into either aquatic or terrestrial sites.

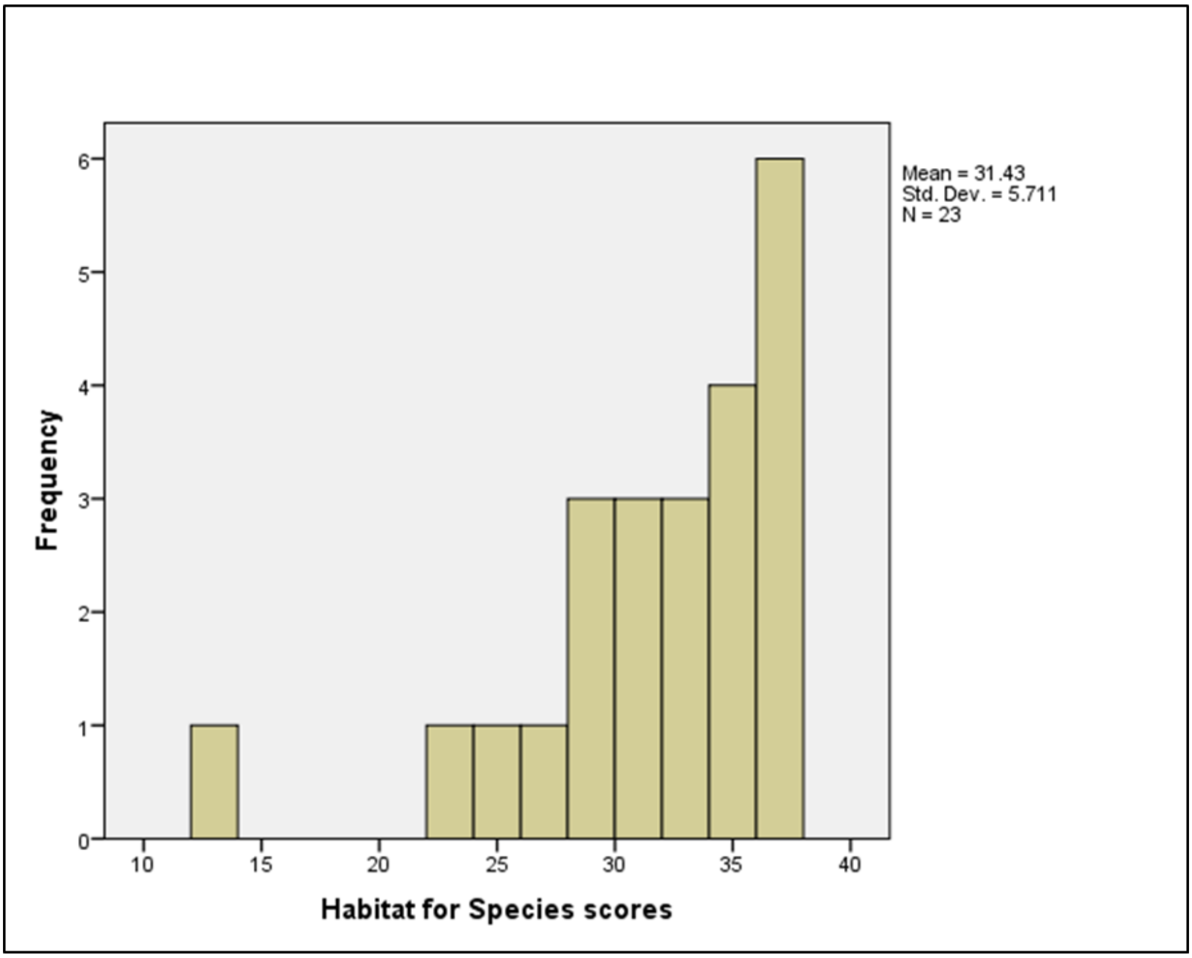

Figure 6.16 – A histogram of habitat for species scores for aquatic sites

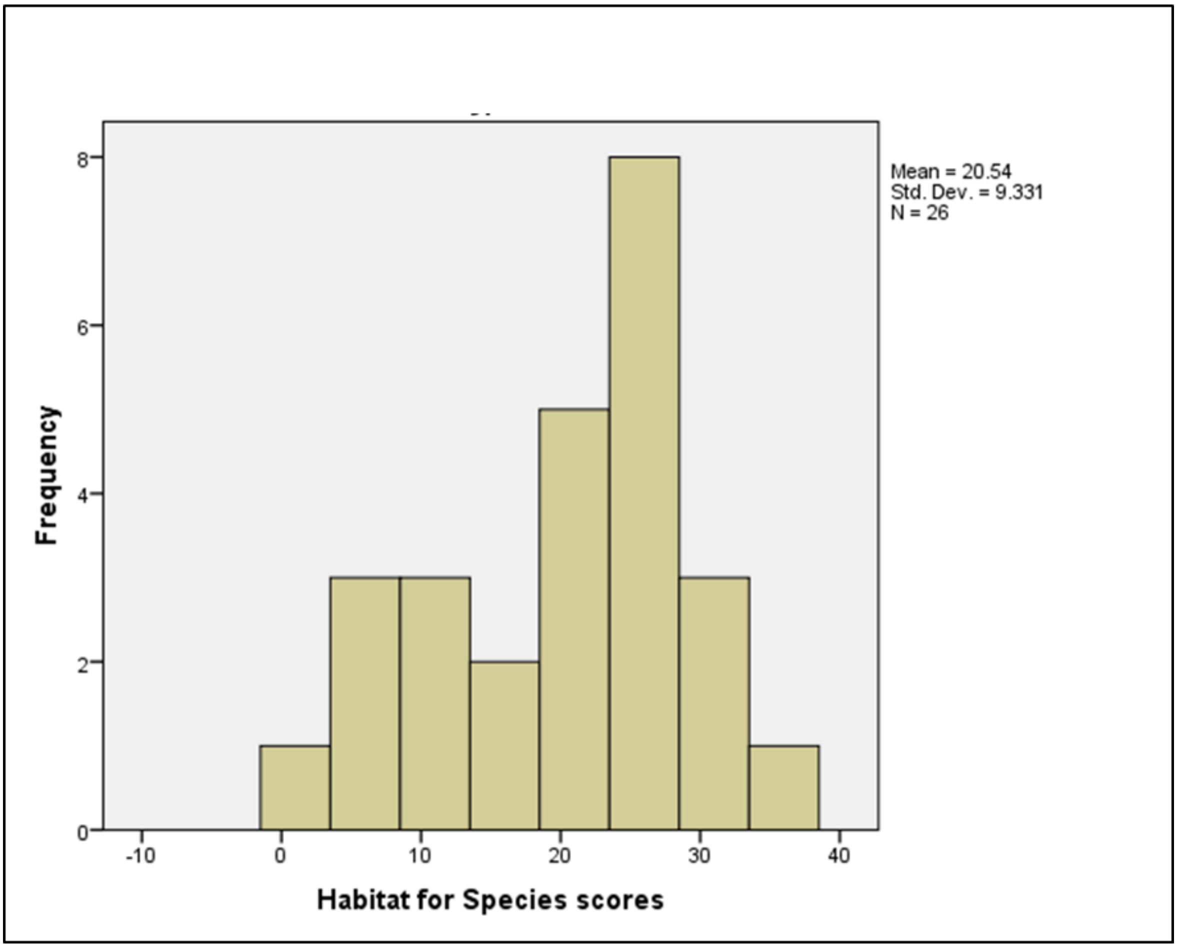

Figure 6.17 - A histogram of habitat for species scores for terrestrial sites

According to the data in Figures 6.16 and 6.17, the distributions of habitat for species scores are negatively skewed, with skewness value of -1.747 and -0.468 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.8).

Table 6.8 – Kolmogorov-Smirnov normality tests for habitat for species scores compared with type of site

		Kolmogorov-Smirnov		
Habitat for Species scores	**Type of site**	**Statistic**	**Degrees of freedom**	**P-value**
	Aquatic	0.173	23	0.072
	Terrestrial	0.145	26	0.167

According to Table 6.8, the Kolmogorov-Smirnov normality test produced p-values of the two area groups that are greater than 0.05. This mean that the habitat for species scores can be classed as normally distributed for both types of site. Referring back to the skewness values mentioned earlier, because of the negative skewness are no more than -3, parametric statistics can be used to analyse the data. Independent Sample T-Test was subsequently used to analyse the relationship between habitat for species scores verses the type of site because they are robust enough to handle slight skewness of data. The output of the Independent Sample T-Test is illustrated in Table 6.9.

Table 6.9 – Levene's Test for equality of variances and Independent Samples T-Test results for habitat for species scores versus type of site

<table>
<tr><th colspan="3" rowspan="2">Independent Samples T-Test results (habitat for species scores v type of site)</th><th colspan="2">Number of vegetation layers</th></tr>
<tr><th>Equal variances assumed</th><th>Equal variances not assumed</th></tr>
<tr><td rowspan="2">Levene's Test for equality of variances</td><td colspan="2">F</td><td>7.618</td><td>NA</td></tr>
<tr><td colspan="2">Sig.</td><td>0.008</td><td>NA</td></tr>
<tr><td rowspan="7">t-test for equality of means</td><td colspan="2">t</td><td>4.851</td><td>4.991</td></tr>
<tr><td colspan="2">df</td><td>47</td><td>42.084</td></tr>
<tr><td colspan="2">Sig. (2-tailed)</td><td>0.000</td><td>0.000</td></tr>
<tr><td colspan="2">Mean difference</td><td>10.896</td><td>10.896</td></tr>
<tr><td colspan="2">Std. error difference</td><td>2.246</td><td>2.183</td></tr>
<tr><td rowspan="2">95% confidence interval of the difference</td><td>Lower</td><td>6.377</td><td>6.491</td></tr>
<tr><td>Upper</td><td>15.415</td><td>15.302</td></tr>
</table>

According to the data in Table 6.9, Levene's test shows that p-value (sig.) of 0.008 is smaller than 0.05. This implies that the group variances are not the same; therefore, the unequal variance reading is adopted. The mean difference in habitat for species scores between the two types of site is 10.896. Test for equality of means produce p-values of 0.000 (equal variances not assumed). It is smaller than 0.05, therefore, the means of the two groups are not equal. Consequently, there is a significant difference between the habitat for species scores for aquatic sites and terrestrial sites.

Finally, a comparison was conducted to examine the relationships between the size of a site, type of site and the habitat for species scores. Figure 6.18 is the plot of the mean habitat for species scores against type of site, separated by the area of site.

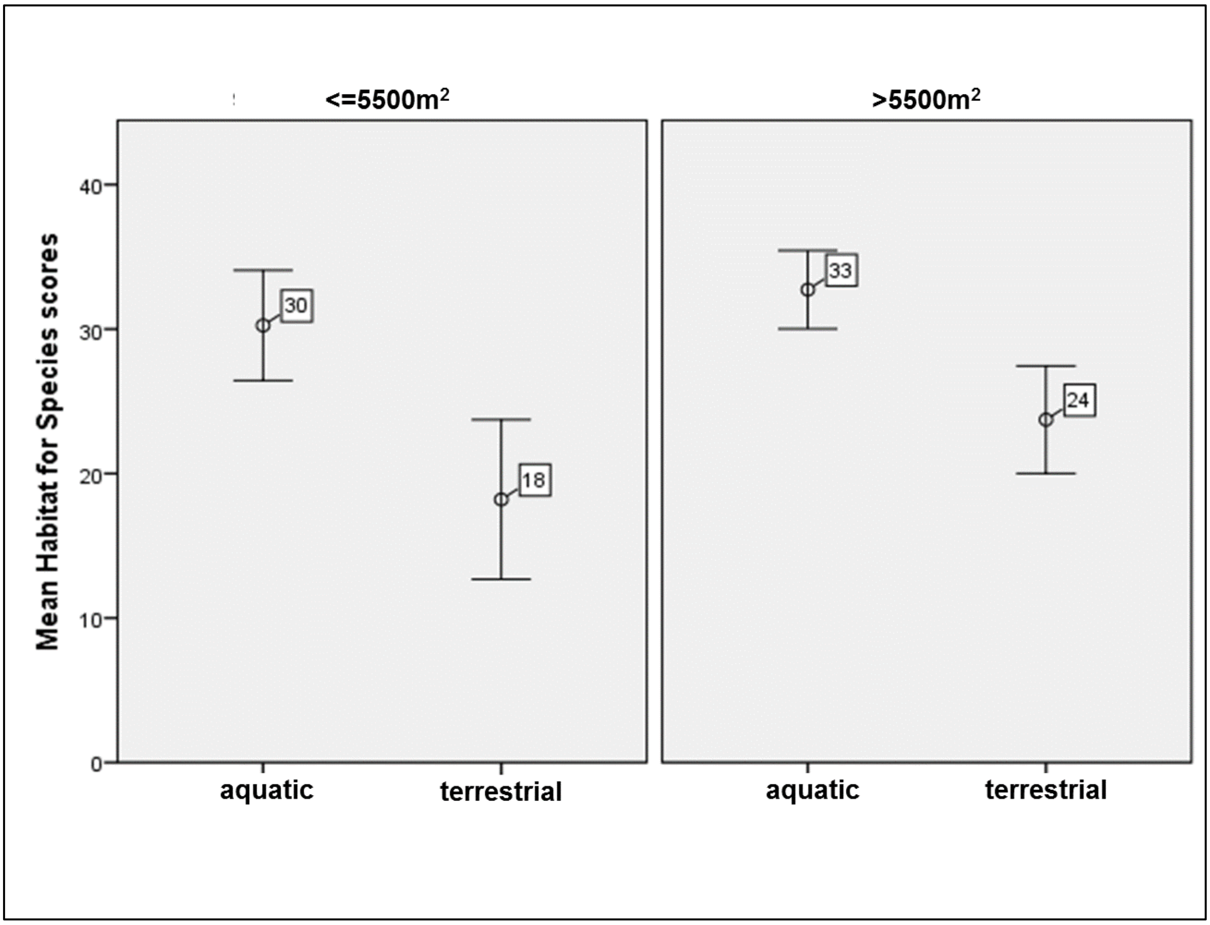

Figure 6.18 – A plot of mean habitat for species scores against type of site, for small and large sites. Error bars: +/- 2 standard errors.

According to Figure 6.18, large sites (greater than 5500m^2) with aquatic features generated higher habitat for species scores (mean = 33) compared with large sites with only terrestrial features (mean = 24). Additionally, small sites (less than or equals to 5500m^2) with aquatic features generated higher habitat for species scores (mean = 30) compared to small sites with only terrestrial features (mean = 18).

Consequently aquatic features are the key driver that influences habitat for species scores.

6.4. Urban heat island mitigation scores

In accordance with the method described in Chapter 4, the second scores were calculated for the urban heat island mitigation ecosystem service. Figure 6.19 contains the urban heat island mitigation scores distribution for all 49 sites.

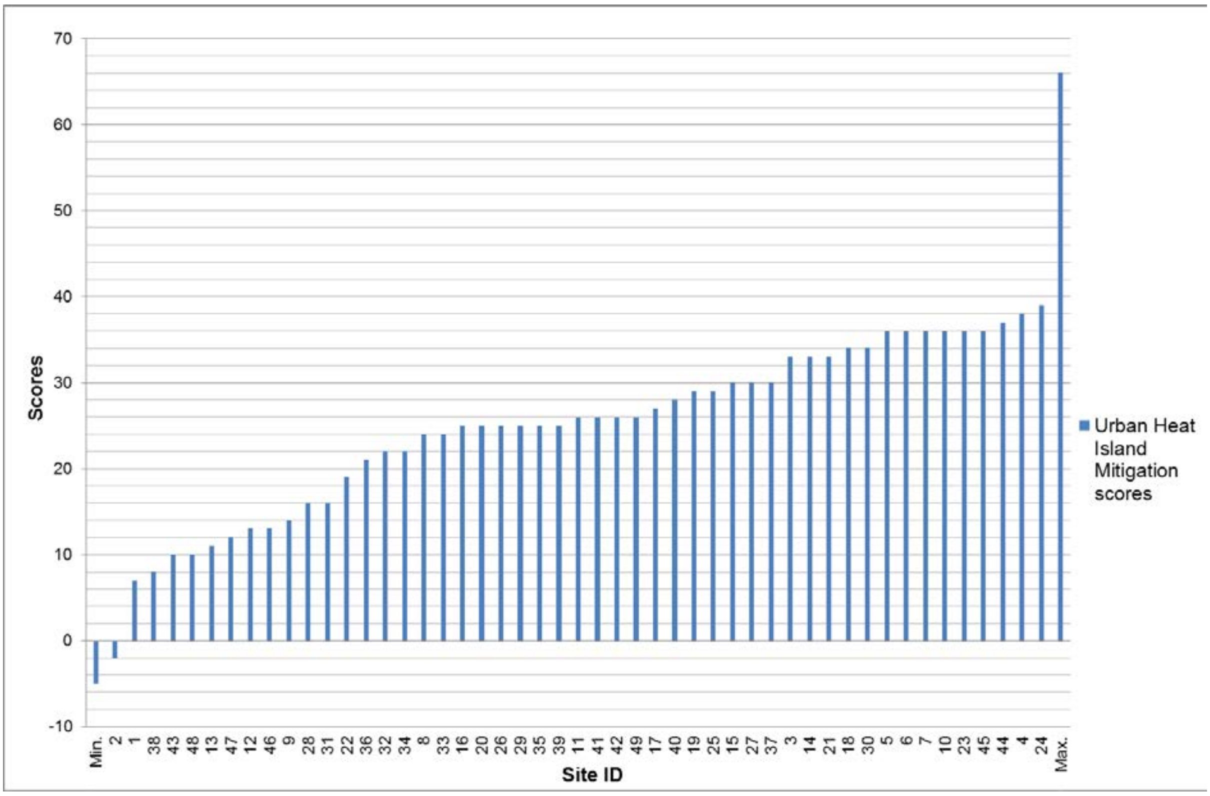

Figure 6.19 – Urban heat island mitigation scores for all 49 sites (including the theoretical minimum and maximum score possible).

According to the data in Figure 6.19, the theoretical maximum score is 66, which occurs when there is no built layer coverage on-site and every other layer has 76 to 100% coverage (Braun-Blanquet value 6). The theoretical minimum score is -5, which occurs when the site is covered by 100% built layer and no other vegetation layers are present. In this situation, the site contributes to the urban heat island effect instead of reducing it. Therefore, the site provides a disservice instead of a service; hence a negative score. Only site 2 - Adelphi House Car Park has a negative score. The maximum score in the 49 sites was 38 at site 4 - Blackfish pond one.

Analysis was performed to find out if there is a relationship between the size of the sites and the urban heat island mitigation scores they can achieve. The 49 sites were split into two categories (1 = sites less than or equals to 5500m^2; 2 = sites more than 5500m^2). The hypothesis statements are:

- H1: There is a significant difference in the Urban Heat Island Mitigation scores based on the size of the site.
- H0: There is no significant difference in the Urban Heat Island Mitigation scores based on the size of the site.

Before the analysis was performed, the urban heat island mitigation scores were checked to see if they are normally distributed or not. Figures 6.20 and 6.21 illustrate the histograms of the urban heat island mitigation scores, split into the two different area groups.

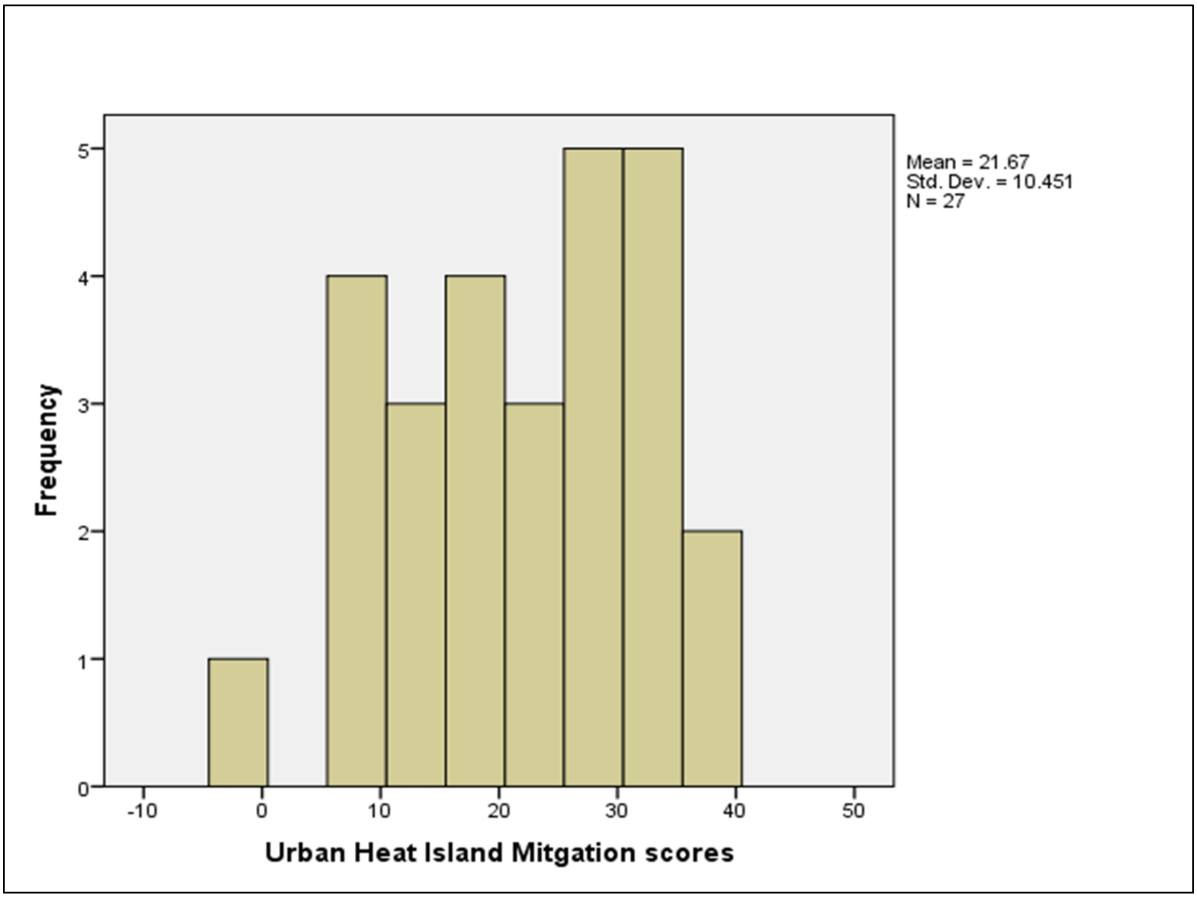

Figure 6.20 – A histogram of urban heat island mitigation scores for sites that are smaller than or equal to 5500m^2

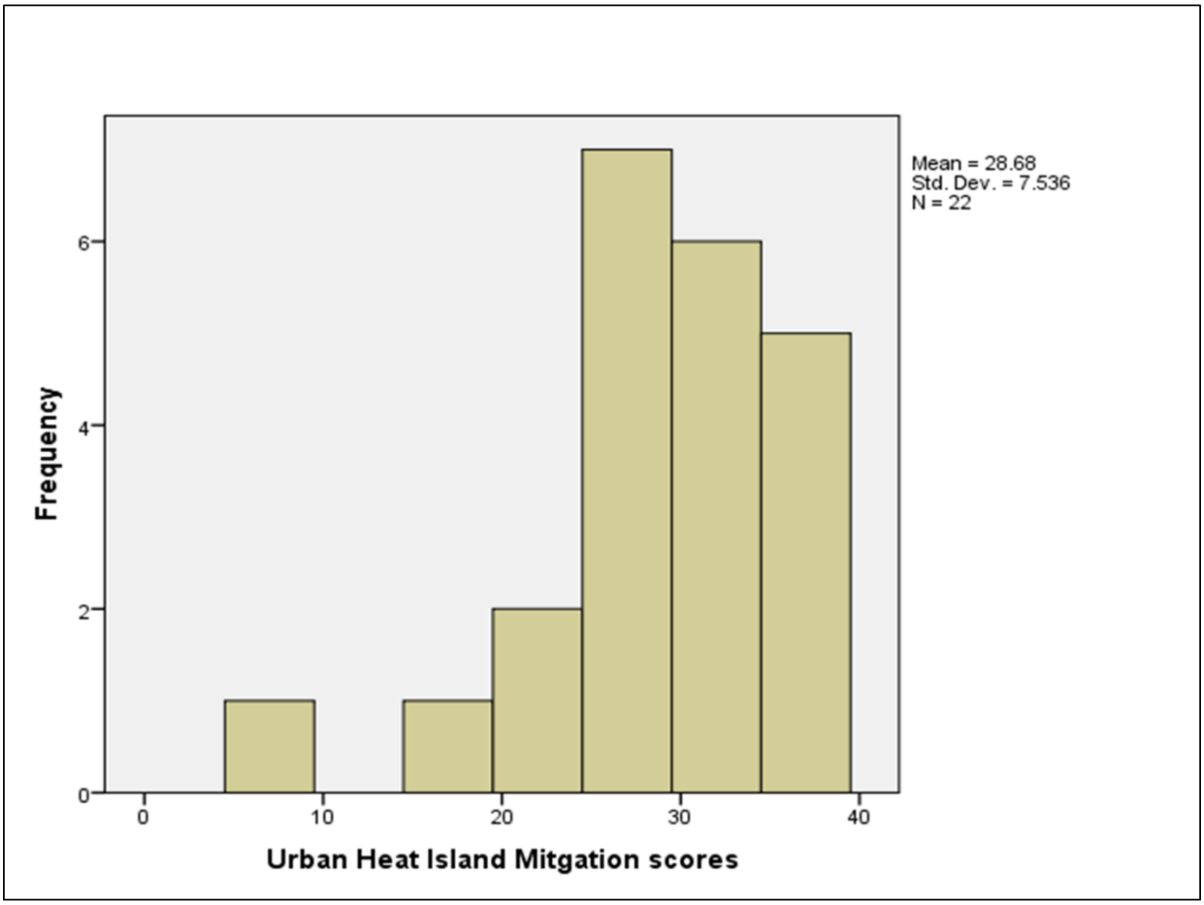

Figure 6.21 – A histogram of urban heat island mitigation scores for sites that are larger than 5500m^2.

According to the data in Figures 6.20 and 6.21, the distributions of urban heat island mitigation scores are negatively skewed, with skewness values of -0.460 and -1.306 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.10).

Table 6.10 – Kolmogorov-Smirnov normality test for urban heat island mitigation scores compared with size of site

		Kolmogorov-Smirnov		
	Area groups	**Statistic**	**Degrees of freedom**	**P-value**
Urban heat island mitigation scores	**Less than or equal to 5500m^2**	0.140	27	0.191
	Greater than 5500m^2	0.131	22	0.200

According to the data in Table 6.10, the Kolmogorov-Smirnov normality test produced p-values of the two area groups that are greater than 0.05. This means that the urban heat island mitigation scores can be classed as normally distributed for both area groups. Referring back to the skewness values mentioned earlier, because of the negative skewness are no more than -3, parametric statistics can be used to analyse the data.

Independent Sample T-Test was subsequently used to analyse the relationship between urban heat island mitigation scores versus the size of site because they are robust enough to handle slight skewness of data. The output of the Independent Sample T-Test is illustrated in Table 6.11.

Table 6.11 – Levene's Test for equality of variances and Independent Samples T-Test results for urban heat island mitigation scores versus the size of site

<table>
<tr><th colspan="3" rowspan="2">Independent Samples T-Test results (habitat for species scores v type of site)</th><th colspan="2">Number of vegetation layers</th></tr>
<tr><th>Equal variances assumed</th><th>Equal variances not assumed</th></tr>
<tr><td rowspan="2">Levene's Test for equality of variances</td><td colspan="2">F</td><td>4.81</td><td>NA</td></tr>
<tr><td colspan="2">Sig.</td><td>0.033</td><td>NA</td></tr>
<tr><td rowspan="7">t-test for equality of means</td><td colspan="2">t</td><td>-2.637</td><td>-2.725</td></tr>
<tr><td colspan="2">df</td><td>47</td><td>46.385</td></tr>
<tr><td colspan="2">Sig. (2-tailed)</td><td>0.011</td><td>0.009</td></tr>
<tr><td colspan="2">Mean difference</td><td>-7.015</td><td>-7.015</td></tr>
<tr><td colspan="2">Std. error difference</td><td>2.66</td><td>2.574</td></tr>
<tr><td rowspan="2">95% confidence interval of the difference</td><td>Lower</td><td>-12.367</td><td>-12.196</td></tr>
<tr><td>Upper</td><td>-1.663</td><td>-1.834</td></tr>
</table>

According to Table 6.11, Leven’s test shows that p-value (sig.) of 0.033 is smaller than 0.05. This implies that the group variances are not the same; therefore, the unequal variance reading is adopted. The mean difference in urban heat island mitigation scores between the two area groups is 2.725. Test for equality of means produce p-values of 0.009 (unequal variances assumed). It is smaller than 0.05, therefore, the means of the two groups are not equal. Consequently, there is a significant difference between the urban heat island mitigation scores for sites that are smaller than or equal to 5500m^2 and sites that are larger than 5500m^2. Referring back to Figures 6.20 and 6.21, the mean urban heat island mitigation score for sites larger than 5500m^2 is greater than the mean score for sites smaller than or equal to 5500m^2. This is consistent with the findings for the overall vegetation structure layer coverage and the overall distribution of vegetation structure layers – larger sites have more room to allow large and tall trees to grow and water bodies to form, and hence offer greater potential for mitigating the urban heat island effects.

Finally, a comparison was conducted to examine the relationships between the size of site, type of site and the urban heat island mitigation scores. Figure 6.22 is the plot of mean urban heat island mitigation scores against type of site, for large and small sites.

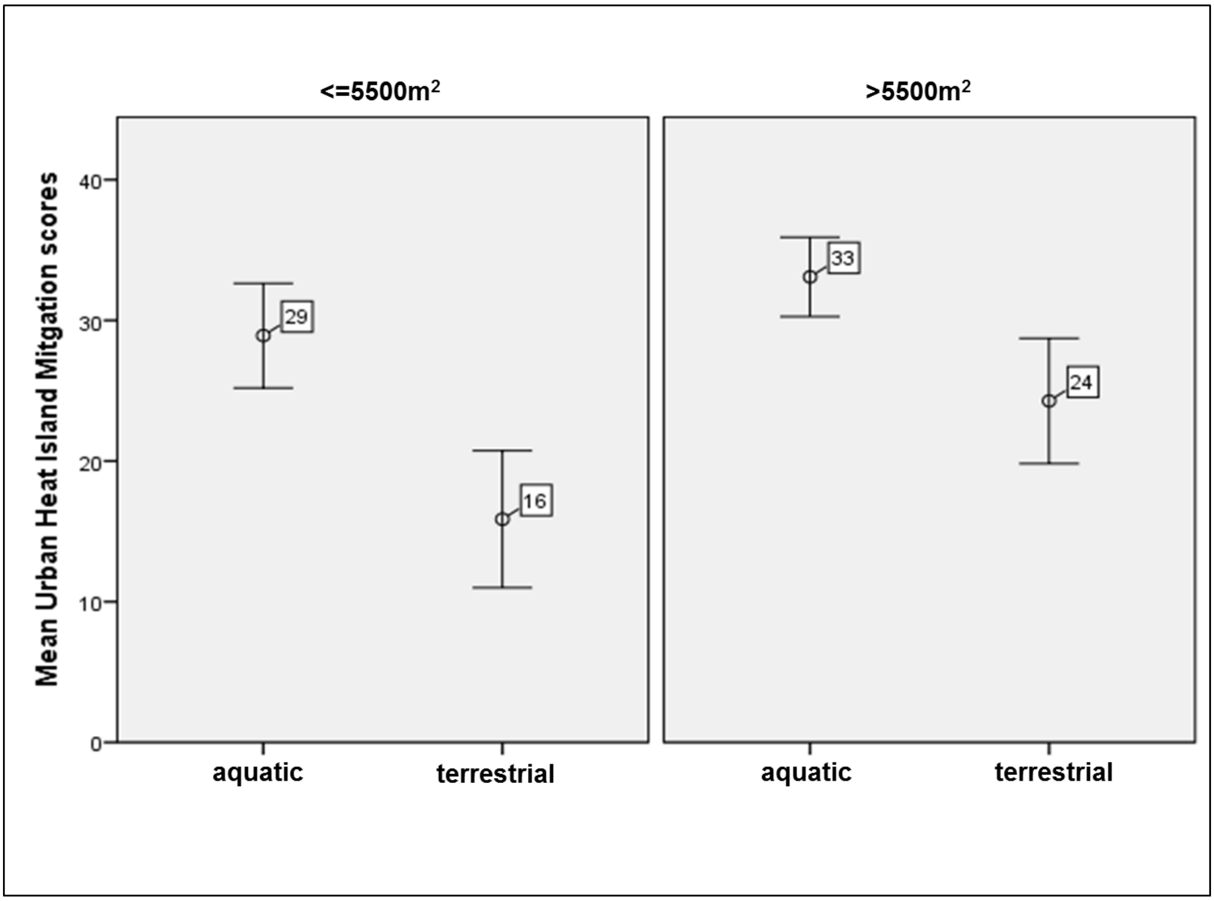

Figure 6.22 – A plot of mean urban heat island mitigation scores against type of site, for both large and small sites. Error bars: +/- 2 standard errors.

According to the data in Figure 6.22, large sites (greater than 5500m^2) with aquatic features generated higher urban heat island mitigation scores (mean = 33) compared with large sites with only terrestrial features (mean = 29). Additionally, small sites (less than or equals to 5500m^2) with aquatic features generated higher urban heat island mitigation scores (mean = 29) compared to small sites with only terrestrial features (mean = 16).

Consequently, of the 49 sites, it can be concluded that large sites with permanent aquatic features generate the greatest urban heat island mitigation ecosystem service. Therefore, a recommendation can be made that vegetated SuDS with permanent aquatic features and site area greater than 5500m^2 can generate the most urban heat island mitigation ecosystem service. Therefore, the most desirable vegetated SuDS system, in terms of achieving the most urban heat island mitigation ecosystem service, is stormwater wetlands. This is because this SuDS type has permanent ponding, areas for trees to grow, and tends to occupy large area.

6.5. Carbon sequestration scores

In accordance with the method described in Chapter 4, the third scores were calculated for the carbon sequestration ecosystem service. Figure 6.23 illustrates the carbon sequestration scores distribution for all 49 sites.

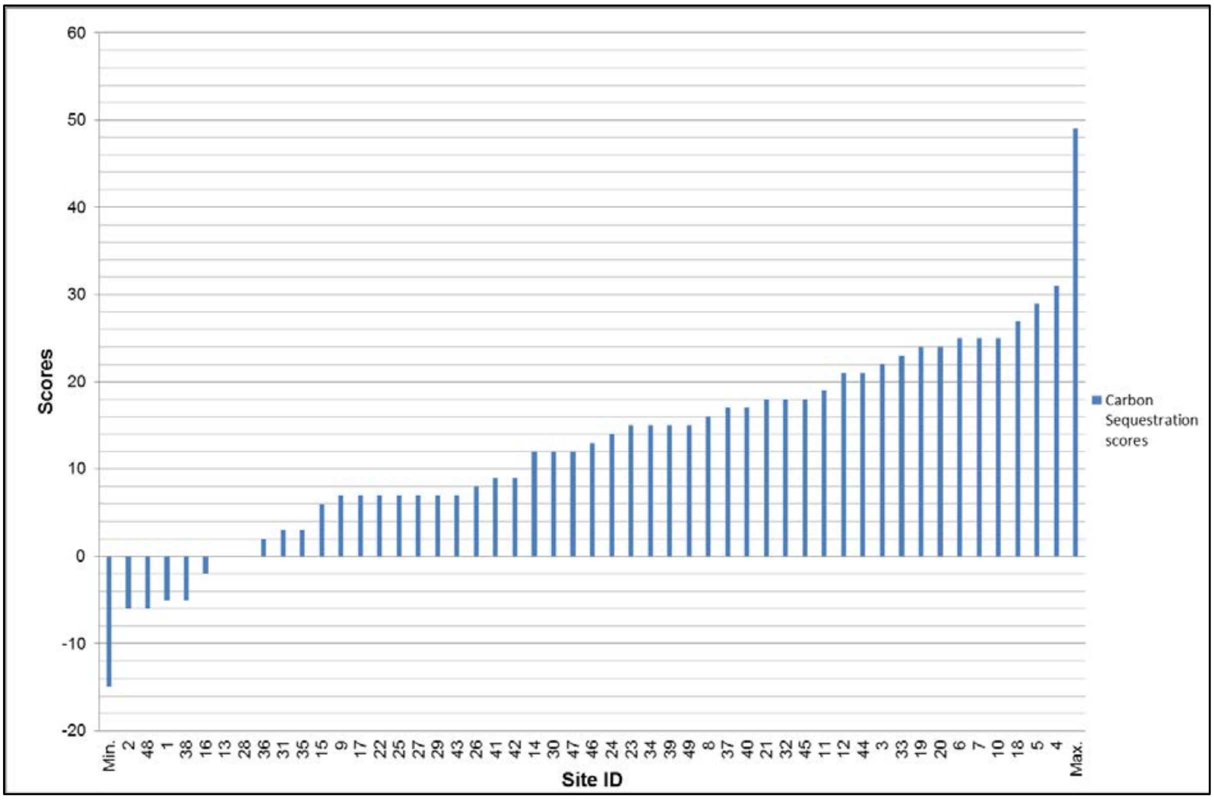

Figure 6.23 – Carbon sequestration scores for all 49 sites

According to the data in Figure 6.23, the theoretical maximum score is 49, which occurs when there is no cropped or mown grass, ground flora and built layers present on-site and every other layer has 76 to 100% coverage (Braun-Blanquet value 6). The theoretical minimum score is -15, which occurs when a site has 76 to 100% coverage of the cropped or mown grass, ground flora and built layers, and no other layers present. The reason for having positive as well as negative scores is to attempt to show sites that can be classed as carbon sinks (+ve) and sites that can be classed as carbon source (-ve), using the coverage of vegetation types currently on site.

The lowest scoring sites examined are sites 2 - Adelphi Car Park and 48 - Whitworth Art Gallery green roof. The highest scoring site is site 31 -Blackfish pond one.

Analysis was performed to find out if there is a relationship between the size of the sites and the carbon sequestration scores they can achieve. The 49 sites were split into two categories (1 = sites less than or equals to 5500m^2; 2 = sites more than

5500m^2). Independent Sample T-test was performed to test the following hypothesis:

- H1: There is a significant difference in the carbon sequestration scores based on the size of the site.
- H0: There is no significant difference in the carbon sequestration scores based on the size of the site.

The descriptive statistics and the Kolmogorov-Smirnov normality test results are illustrated in Table 6.12.

Table 6.12 – Descriptive statistics and the Kolmogorov-Smirnov normality test results

Test variable	**Area of site**	**N**	**Mean**	**Std. Deviation**	**Skewness**	**Kolmogorov-Smirnov normality test (P-value)**
Carbon Sequestration scores	smaller than or equal to 5500m^2	27	9.3	10.129	0.126	0.200
	larger than 5500m^2	22	16.23	7.795	0.024	0.200

According to the data in Table 6.12, the skewness values and the normality test results indicate that the carbon sequestration scores can be classed as normally distributed for both area groups, therefore independent sample t-test was carried out to examine the relationship between carbon sequestration scores versus the size of site. The output of the Independent Sample T-Test is illustrated in Table 6.13.

Table 6.13 – Levene's Test for equality of variances and Independent Samples T-Test results for carbon sequestration scores versus the size of site

Independent Samples T-Test results (habitat for species scores v type of site)			**Number of vegetation layers** Equal variances assumed	**Equal variances not assumed**
Levene's Test for equality of variances	**F**		2.556	NA
	Sig.		0.117	NA
t-test for equality of means	**t**		-2.634	-2.706
	df		47	46.872
	Sig. (2-tailed)		0.011	0.009
	Mean difference		-6.931	-6.931
	Std. error difference		2.631	2.562
	95% confidence interval of the difference	**Lower**	-12.224	-12.085
		Upper	-1.638	-1.777

According to the information in Table 6.13, Levene’s test shows that p-value (sig.) of 0.117 is larger than 0.05. This implies that the group variances are equal; therefore, the equal variance reading is adopted. The mean difference in carbon sequestration scores between the two area groups is 6.931. The test for equality of means produce p-values of 0.011 (equal variances assumed). It is smaller than 0.05, therefore, the means of the two groups are not equal. Consequently, there is a significant difference between the carbon sequestration scores for sites that are smaller than or equals to 5500m^2 and sites that are larger than 5500m^2. Referring back to Table 6.12, the mean carbon sequestration score for sites larger than 5500m^2 is greater than the mean score for sites smaller than or equal to 5500m^2. This is consistent with the findings for the overall vegetation structure layers coverage and the overall distribution of vegetation structure layers – larger sites have more room to allow large and tall trees to grow and water bodies to form, and hence offer greater potential to sequester carbon above ground.

Finally, a comparison was conducted to examine the relationships between the size of site, type of site and the carbon sequestration scores. Figure 6.24 illustrates the plot of mean carbon sequestration scores against type of site, for large and small sites.

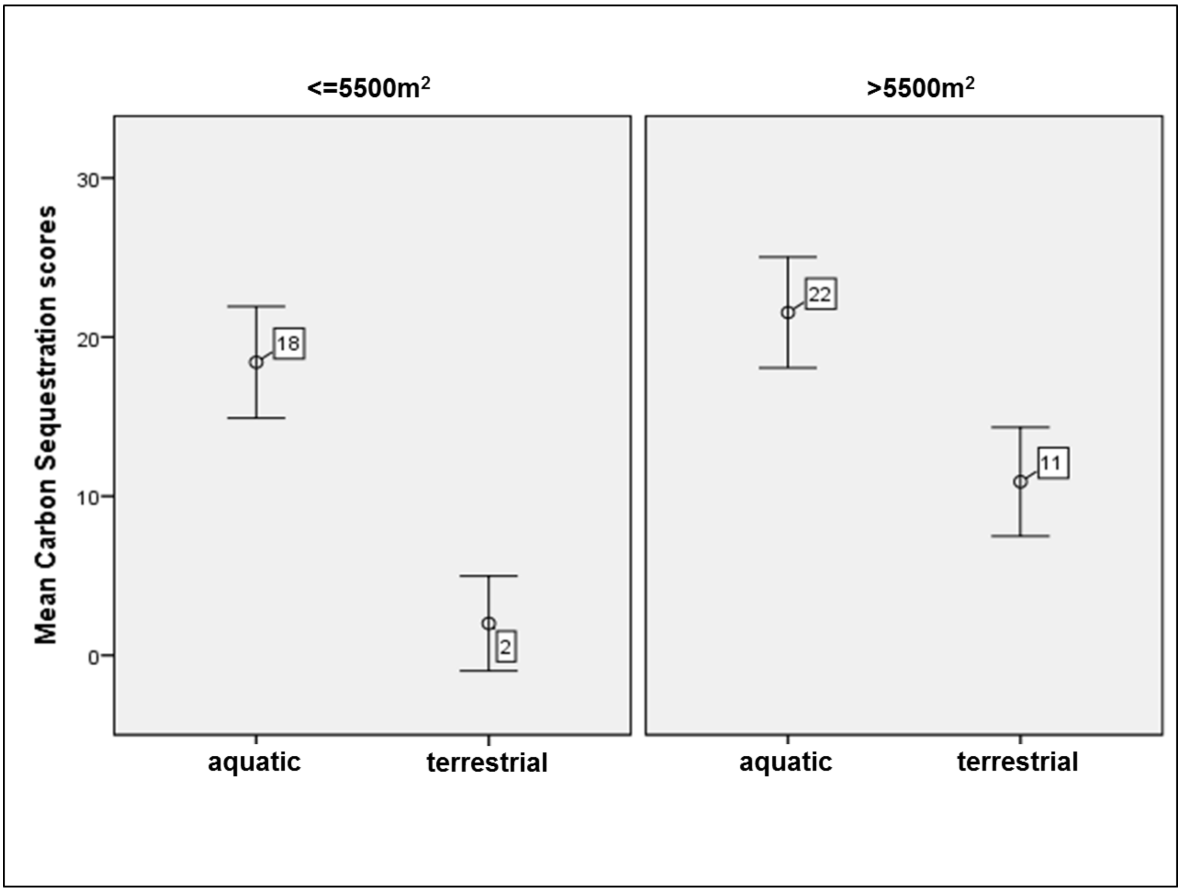

Figure 6.24 – A plot of mean carbon sequestration scores against type of site, for large and small sites.

Note: Error bars: +/- 2 standard errors.

According to the data in Figure 6.24, large sites (greater than 5500m^2) with aquatic features generated higher carbon sequestration scores (mean = 22) compared with large sites with only terrestrial features (mean = 11). Additionally, small sites (less than or equal to 5500m^2) with aquatic features generated higher habitat for species scores (mean = 18) compared to small sites with only terrestrial features (mean = 2).

Consequently, it can be concluded that large sites with permanent aquatic features generate greatest carbon sequestration ecosystem service. Therefore, a recommendation can be made that vegetated SuDS with permanent aquatic features and site area greater than 5500m^2 can generate the most carbon sequestration ecosystem service. Therefore, the most desirable vegetated SuDS system, in terms of achieving the most urban heat island mitigation ecosystem service, is stormwater wetlands. This is because this SuDS type has permanent ponding, areas for trees to grow, and tends to occupy large area.

6.6. Overall on-site cultural ecosystem services and disservices results

All 49 sites were examined for their cultural ecosystem services and disservices potentials by ranking each site based on the different cultural variables described in Chapter 4. The raw data are presented in Tables E5 to E10 in Appendix E. Table E5 contains the ranked data for all the cultural ecosystem services and disservices variables appraised (legal accessibility, physical accessibility, recreational infrastructures, educational signs, evidence for educational use, proximity of the nearest educational establishment, dog faeces, bins, and litter). Table E6 contains the ranked data for legal accessibility, evidence for the ranking and the evidence sources. Table E7 contains the ranked data for physical accessibility and reasons for the ranking. Table E8 contains the ranked data for recreational infrastructures and reasons for the ranking. Table E9 contains the ranked data for evidence for educational use, evidence for the ranking and the evidence sources. Table E10 contains the ranked data for proximity of the closest educational establishment and evidence for the ranking.

The following sections illustrate the distributions of the variable rankings across all 49 sites. The sites were split into the following groups based on their size:

- Between 1m^2 and 2499m^2
- Between 2500m^2 and 5499m^2
- Between 5500m^2 and 7999m^2
- Larger than or equal to 8000m^2

Legal accessibility, physical accessibility and recreational infrastructures were combined to form recreation scores for all 49 sites, as described in Chapter 4. Educational signs, evidence of educational use and proximity of educational establishments were also combined to form education scores for all 49 sites, as described in Chapter 4. The coverage of dog faeces and litter on site, and the presence of bins on site were used as ecosystem disservices variables to examine possible relationships between the variables and the habitat for species and recreation ecosystem services scores.

6.6.1. Legal Accessibility, Physical accessibility, Recreational infrastructures

Legal accessibility, physical accessibility and recreational infrastructures were cross-tabulated with the four different area groups in order to show the distribution of these variables and their ranks across all 49 sites (see Table 6.14).

Table 6.14 – Cross-tabulation of legal accessibility (LA), physical accessibility (PA) and recreational infrastructures (RI) with area group.

Note: LA1 = public access prohibited; LA2 = public access by permission only; LA3 = open to public access; PA1 = physically restricted and/or not visible to public; PA2 = physically accessible but not highly visible to public; PA3 = access to site is not restricted and is completely visible to public; RI1 = not present or so poorly maintained as to present safety hazard; RI2 = present but not well maintained or site situated a distance above ground; RI3 = present and well maintained

	Legal Accessibility (LA)				**Physical Accessibility (PA)**				**Recreational Infrastructures (RI)**			
Area group	**LA 1**	**LA 2**	**LA 3**	**Total no. of sites**	**P A1**	**P A2**	**P A3**	**Total no. of sites**	**RI 1**	**RI 2**	**RI 3**	**Total no. of sites**
$1m^2$ to $2499m^2$	6	0	11	17	2	1	14	17	6	1	10	17
$2500m^2$ to $5499m^2$	0	2	8	10	2	1	7	10	2	0	8	10
$5500m^2$ to $7999m^2$	0	1	2	3	0	0	3	3	0	0	3	3
≥ $8000m^2$	0	2	17	19	1	5	13	19	6	2	11	19
Total no. of sites	6	5	38	49	5	7	37	49	14	3	32	49

The data in Table 6.14 shows that majority of the sites surveyed were open to public access (38 out of 49, or 77.6%). Within these 38 sites, 17 of them (44.7%) are larger than or equal to $8000m^2$, which make these sites capable of forming total outdoor recreational spaces for children. 16 sites out of the 17 are larger than one hectare, which satisfy the minimum area (10,000 m^2) required to become a Local Nature Reserve, in accordance with the ANGST model (Natural England, 2010). Again within these 38 sites, 11 of them (28.9%) are smaller than 2500 m^2 also were surveyed to be open to public access. These sites are, however, too small to form any potential recreational spaces. Additionally, six of the 49 sites (12.2%) surveyed to be public access prohibited are smaller than 2500m^2, which make them too small to form any potential recreational spaces.

The data in Table 6.14 also show that majority of the sites (37 out of 49, or 75.5%) did not have any physical access issues. Within these 37 sites, 13 (35.1%) were larger than or equal to 8000m^2, which made these sites capable of forming total outdoor recreational spaces for children. 12 sites out of the 13 also satisfied the minimum area (10,000m^2) required to become a Local Nature Reserve, in accordance with the ANGST model (Natural England, 2010). Out of the 37 sites, 14 (37.8%) were smaller than 2500m^2. Even though they did not have any physical accessibility issues, they are too small to be considered as recreational spaces (Fields in Trust / National Playing Fields Association, 2008; Moseley *et al.*, 2013). Only five of the 49 sites (10.2%) were recorded to be physically restricted and/or not visible to the public. Two of these were less than 2500m^2, and only one is larger than or equal to 8000m^2.

The data in Table 6.14 shows that 32 of the 49 sites (65.3%) have well maintained recreational infrastructures. Within these 32 sites, 11 (34.4%) were larger than or equal to 8000m^2, which made these sites capable of forming total outdoor recreational spaces for children. 10 sites out of 11 also satisfied the minimum area (10,000m^2) required to become a Local Nature Reserve, in accordance with the ANGST model (Natural England, 2010). Of the 32 sites, 10 (31.3%) were smaller than 2500m^2. Even though they have well maintained recreational facilities, they are too small to be considered as recreational spaces (Fields in Trust / National Playing Fields Association, 2008; Moseley *et al.*, 2013).

6.6.2. Recreation

The legal accessibility, physical accessibility and recreational infrastructures data from Table E5 were summed up to form recreation ecosystem service scores for all 49 sites, similar to the method illustrated in Moore and Hunt (2013) and following descriptions provided in Chapter 4. Because of the summation of the ratings for legal accessibility, physical accessibility and recreational infrastructures, the recreation scores can be assumed to be within an interval scale (Sharma & Petosa, 2012). Cross-tabulation analysis was performed to illustrate the recreation scores across all 49 sites (see Table 6.15). The sites were again split into the four different area groups.

Table 6.15 – Cross-tabulation of recreation scores verses area groups

Area groups	Recreation scores					Total no. of sites
	2	3	4	5	6	
between 1m^2 and 2499m^2	2	1	7	0	7	17
between 2500m^2 and 5499m^2	0	3	1	0	6	10
between 5500m^2 and 7999m^2	0	0	0	1	2	3
larger than or equal to 8000m^2	0	2	4	6	7	19
Total no. of sites	2	6	12	7	22	49

Table 6.15 shows two sites (33 - Primrose Primary School pond and 38 - Scott Avenue allotment green roof) having a recreation score of two, and they both are less than 2500m^2. Site 33 is situated inside the school, and access to the pond is for the staff and students of the school only – public access prohibited. There is a tall fence and locked gate to prevent public access from outside of the school premise – physically restricting access. However, the recreational infrastructures (benches, viewing platform and footpaths) are well maintained. Site 38 is situated inside a council owned allotment. Access into the allotment is only for people who paid to rent out allotment plots for growing food, therefore the general public is prohibited from accessing the site. The allotment green roof requires a ladder for access, and the allotment itself has a tall fence surrounding it and a locked gate. Therefore, access is physically restricted.

At the other end of the scale, 22 sites achieved the maximum score of six. Seven of the 22 sites are larger than or equal to 8000m^2, and they are sites 14 - Footpath beside David Lewis Sports Ground, 18 - Heaton Park boating pond, 24 - Nutsford Vale, 32 - Platt Field pond, 44 - The Meadows, 45 - Three Sisters and 49 - Woodland walkway within Alexandra Park. These sites are all situated within either public parks or local nature reserves; hence there is no issue with legal accessibility or physical accessibility. They all have well maintained recreational facilities because of their land use purposes. Seven sites within the 21 sites that achieved the maximum score are smaller than 2500m^2. They are sites 12 - Chorlton Water park pond, 19 - Heaton Park Dell Garden pond, 21 - Hullard Park pond, 35 - Range Road public garden, 36 - Salford University garden, 43 - Stevenson Square green roof and 47 - Untrimmed vegetation area inside Hulme Park. Area wise, these sites appear to be too small to possess any recreational potential. However, sites 12, 19, 21 and 47 are situated within public parks, site 43 is a public garden, site 36 is situated in the middle of a university campus, and site 43 is in the middle of a public square in the Manchester city centre. Therefore, their maximum scores are justified based on the land use of their surrounding areas.

Even though land use made a difference in both the lowest and highest recreation scores achieved by the sites examined, analysing only legal accessibility, physical accessibility and recreational infrastructures is sufficient to generate a scoring system for determining the recreation ecosystem service of a site because the land use issue has already been directly taken account of within legal accessibility consideration. The recreational infrastructures analysis also took account of land use. Therefore, it is unnecessary to incorporate land use classifications within the recreation ecosystem scoring system.

Analysis was performed to find out if there is a relationship between the size of the sites and the recreation scores they can achieve. The 49 sites were split into two categories (1 = sites less than or equals to 5500m^2; 2 = sites more than 5500m^2). The hypothesis statements are:

- H1: there is a significant difference in the recreation scores based on the size of the site.
- H0: There is no significant difference in the recreation scores based on the size of the site.

Before the analysis was performed, the recreation scores were checked to see if they are normally distributed or not. Figures 6.25 and 6.26 illustrate the histograms of the recreation scores, split into two different area groups.

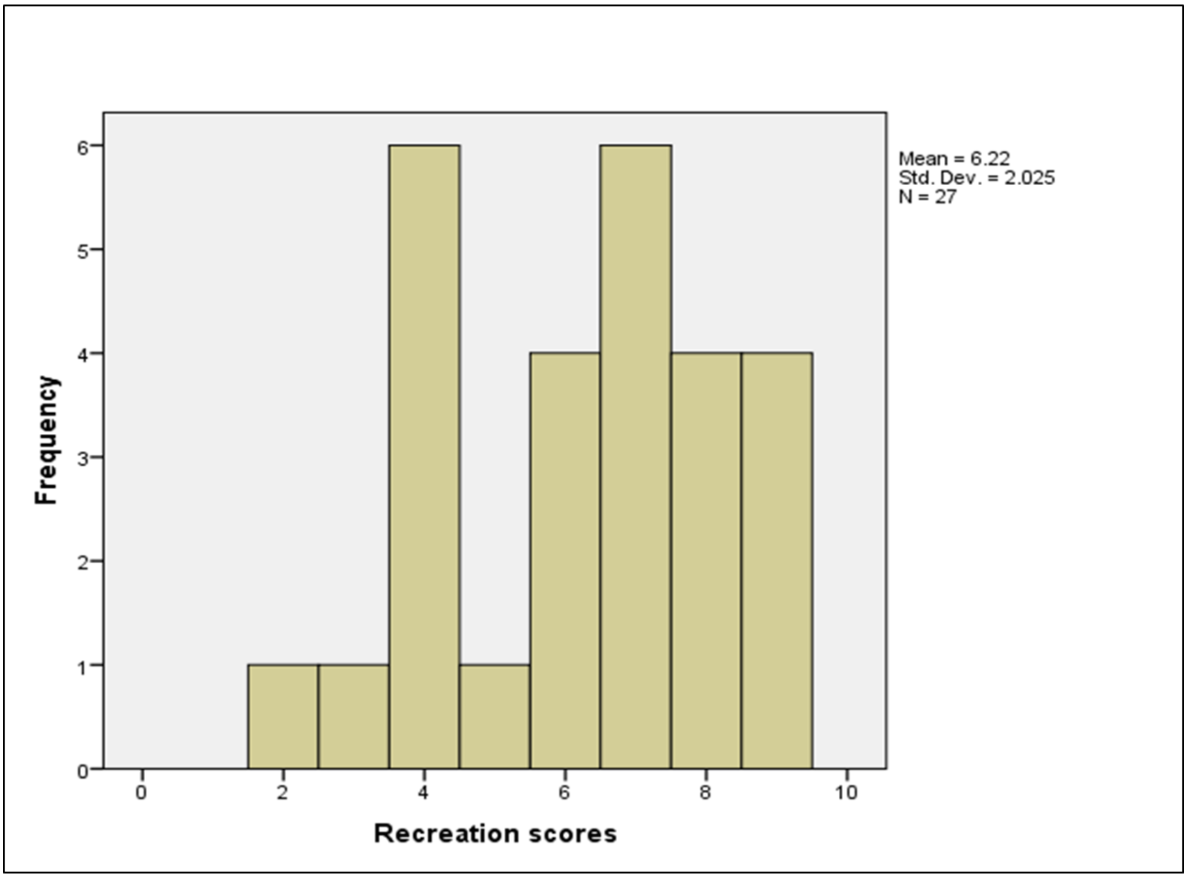

Figure 6.25 – A histogram of recreation scores for sites that are smaller than or equal to 5500m^2.

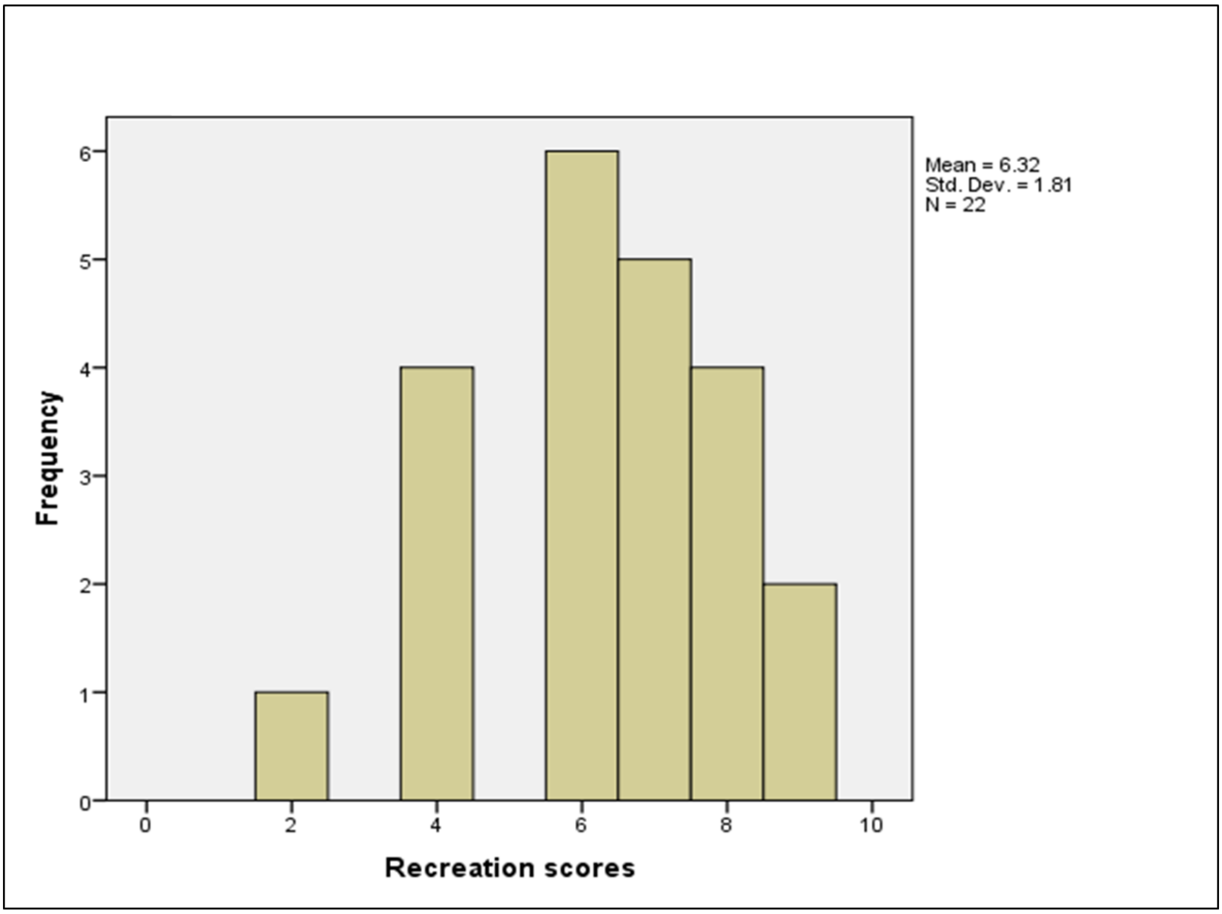

Figure 6.26 – A histogram of recreation scores for sites that are larger than 5500m^2

According to Figures 6.25 and 6.26, the distributions of recreation scores were negatively skewed, with skewness values of -0.327 and -0.631 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.16).

Table 6.16 – Kolmogorov-Smirnov normality test for recreation scores compared with size of site

		Kolmogorov-Smirnov		
	Area groups	**Statistic**	**Degrees of freedom**	**P-value**
Recreation scores	**Less than or equal to 5500m^2**	0.168	27	0.049
	Greater than 5500m^2	0.203	22	0.019

According to Table 6.16, the p-values calculated by the Kolmogorov-Smirnov normality test for the two area groups were smaller than 0.05 (even though the p-value for recreation scores within the less than or equals to 5500m^2 area group is only marginally smaller than 0.05). Therefore, parametric tests cannot be performed in this case because the recreation scores are not normally distributed (Table 6.16). This violated one of the key assumptions of a parametric test (normal distribution of data).

The variances are roughly homogenous after performing the Levene's test for non-parametric data (p-value = 0.991, which is larger than 0.05), therefore, the non-parametric Kruskal-Wallis analysis was chosen to examine whether there is a relationship between the size of site and recreation scores a site can obtain. Table 6.17 illustrates the mean ranks for the size of site and the Kruskal-Wallis results.

Table 6.17 – Mean ranks between the area groups and Kruskal-Wallis results

	Area groups	**N**	**Mean Rank**
Recreation scores	**Less than or equal to 5500m^2**	27	24.87
	Greater than 5500m^2	22	25.16
	Total	49	
	Chi-Square	0.005	
	df	1	
	Asymp. Sig.	0.943	

The Kruskal-Wallis test at Table 6.17 shows that p-value (asymp. sig.) of 0.943 is larger than 0.05. This implies that there is no significant difference between site sizes compared with the recreation score each site is awarded, out of the 49 sites surveyed.

The recreation scores were also cross-tabulated with the two different types of sites in order to show the distribution of the scores across all 49 sites (see Table 6.17).

Table 6.18 – Cross-tabulation of recreation scores versus type of sites

Type of site	Recreation scores					Total no. of sites
	2	**3**	**4**	**5**	**6**	
Aquatic	1	2	3	4	11	21
Terrestrial	1	4	9	3	11	28
Total no. of sites	2	6	12	7	22	49

According to Table 6.18, 22 out of 49 sites (44.9%) achieved the highest recreational score, which is six. The 22 sites are split evenly between sites with only terrestrial characteristics and sites with aquatic characteristics. The two sites that achieved the lowest scores (sites 33 – Primrose Primary School pond, and 38 – Scott Avenue allotment green roof) are also split evenly, with site 33 being aquatic dominated and site 38 being terrestrial dominated.

The recreation ecosystem service scores were examined to see if there is a significant difference between aquatic and terrestrial sites. Figures 6.27 and 6.28 illustrate the histograms of the recreation scores for aquatic and terrestrial sites.

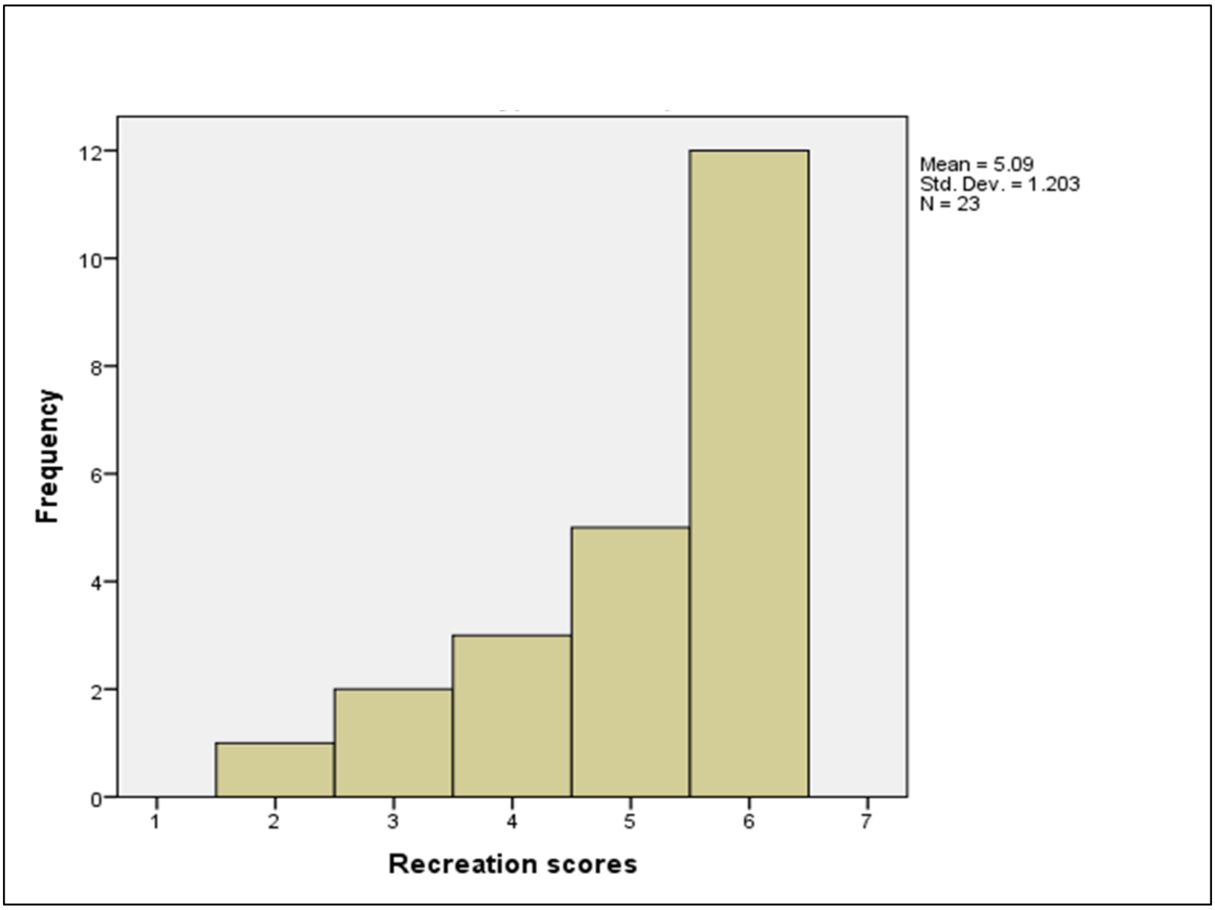

Figure 6.27 – A histogram of recreation scores for aquatic sites

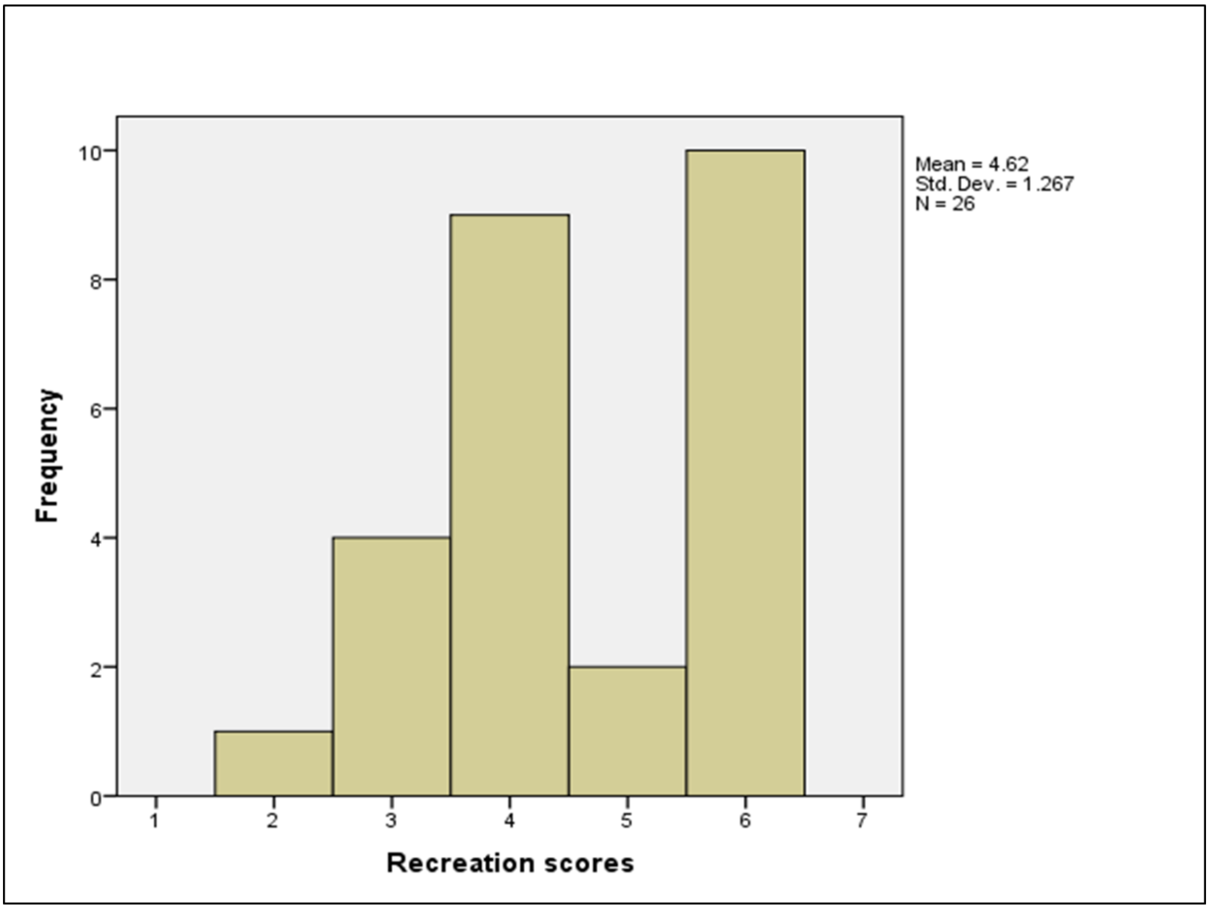

Figure 6.28 – A histogram of recreation scores for terrestrial sites

According to the data in Figures 6.27 and 6.28, the distribution of recreation scores are all negatively skewed, with skewness values of -1.211 and -0.217 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.19).

Table 6.19 – Kolmogorov-Smirnov normality test for recreation scores compared with type of site

		Kolmogorov-Smirnov		
Recreation scores	**Type of site**	**Statistic**	**Degrees of freedom**	**P-value**
	Aquatic	0.298	23	0.000
	Terrestrial	0.247	26	0.000

According to the data in Table 6.19, the p-values produced from the Kolmogorov-Smirnov normality test for aquatic and terrestrial sites were smaller than 0.05. Therefore, parametric tests cannot be performed in this case because the recreation scores are not normally distributed.

The variances are roughly homogenous after performing the Levene's test (p-value = 0.295, which is larger than 0.05), the non-parametric Kruskal-Wallis analysis was, therefore, performed to examine whether there is a relationship between the type of site and recreation scores a site can obtain. Table 6.20 illustrates the mean ranks for the type of site and the Kruskal-Wallis results.

Table 6.20 – Mean ranks between the type of site and Kruskal-Wallis results

	Type of site	**N**	**Mean Rank**
Recreation scores	**aquatic**	23	27.74
	terrestrial	26	22.58
	Total	49	
	Chi-Square	1.789	
	df	1	
	Asymp. Sig.	0. 181	

According to Table 6.20, the Kruskal-Wallis test shows that p-value (asymp. sig.) of 0.181 is larger than 0.05. This implies that there is no significant influence between the type of site compared with the recreation score each site gets, out of 49 sites surveyed.

Finally, based on the recreation scores illustrated in Table 6.18, the scores were ranked as either one (2 to 4) or two (5 to 7). Analysis was then performed to examine whether there is a relationship between the recreation scores and the habitat for species scores. The null hypothesis is that there is no significant influence between the the scores for these two ecosystem services.

Before the analysis was performed, the habitat for species scores were checked to see if they are normally distributed or not, when plotted against the ranked recreation scores. Figures 6.29 and 6.30 illustrate the histograms of the habitat for species scores, split into the two recreation scores ranks.

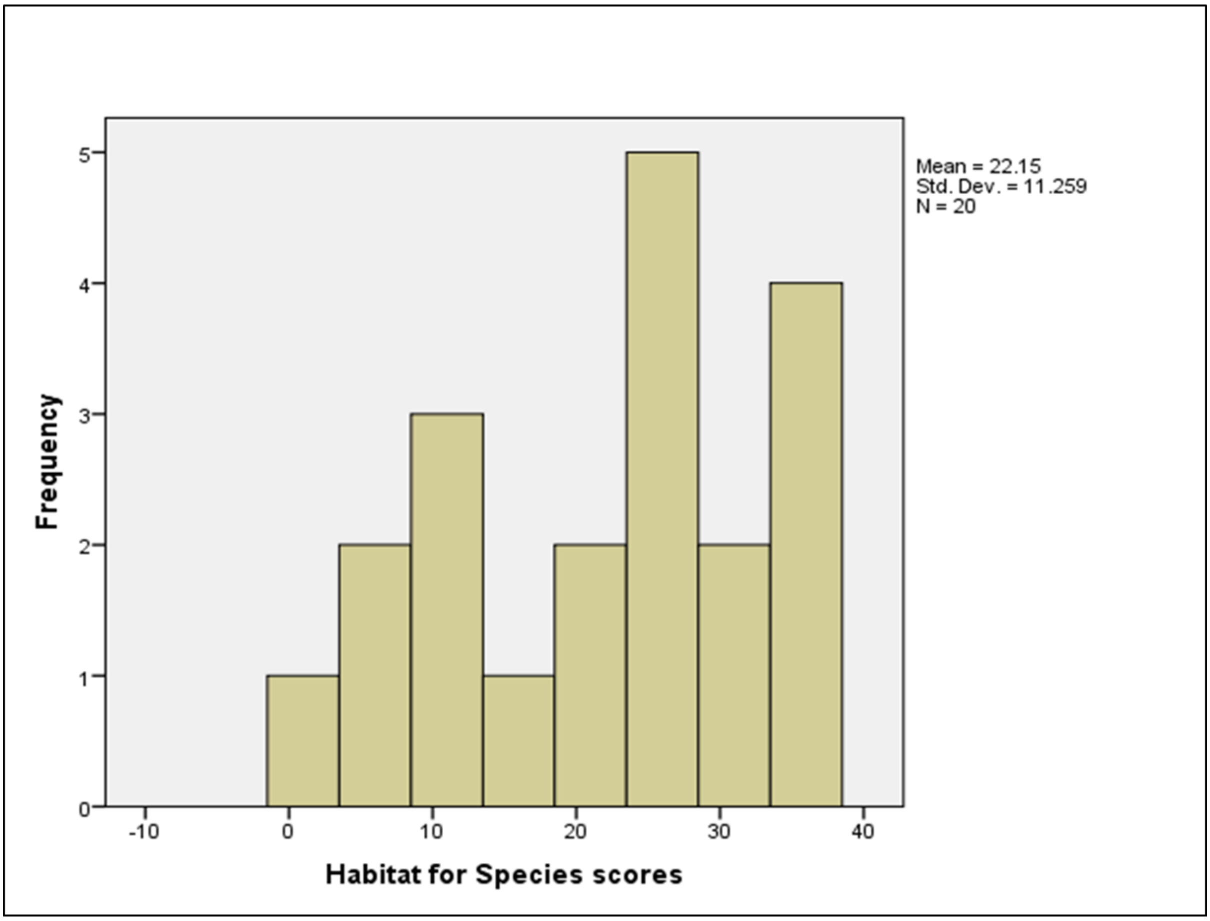

Figure 6.29 – A histogram of habitat for species scores for recreation scores from 2 to 4 (group one)

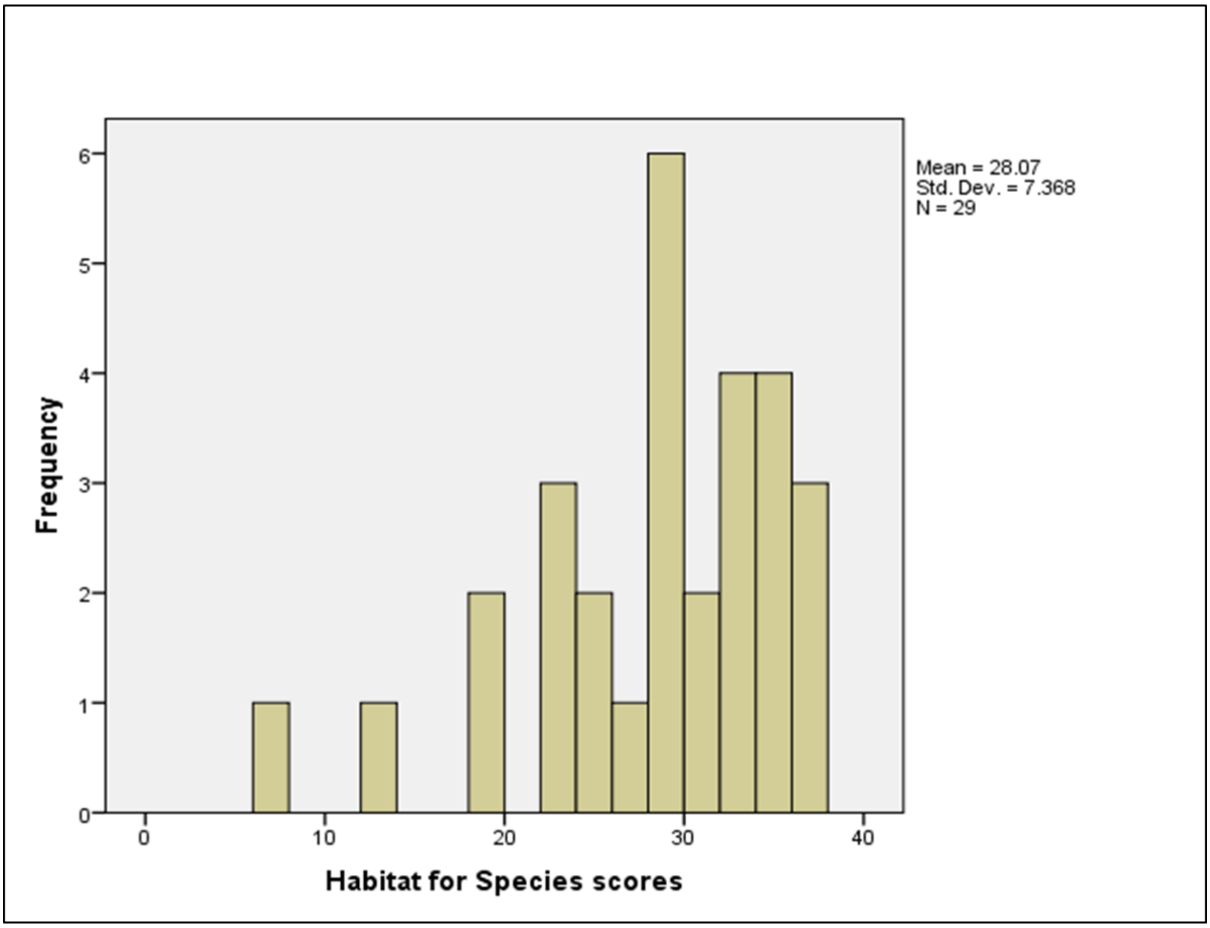

Figure 6.30 – A histogram of habitat for species scores for recreation scores from 5 to 7 (group two)

According to Figures 6.29 and 6.30, the distributions of recreation scores are negatively skewed, with skewness values of -0.340 and -1.176 respectively. A Kolmogorov-Smirnov normality test was also performed to examine the distribution of the data (see Table 6.21).

Table 6.21 – Kolmogorov-Smirnov normality tests for habitat for species scores compared with ranked recreation scores

Habitat for Species scores	**Ranked recreation scores**	**Kolmogorov-Smirnov**		
		Statistic	**Degrees of freedom**	**P-value**
	one	0.150	20	0.200
	two	0.151	29	0.087

According to Table 6.21, the Kolmogorov-Smirnov normality test produced p-values of the two ranked recreation scores that are greater than 0.05. This means that habitat for species scores can be classed as normality distributed. Referring back to the skewness values mentioned earlier, because of the negative skewness are no more than -3, parametric statistics can be used to analyse the data. Independent Sample T-test was subsequently used to analyse the relationship between habitat for species scores and recreation scores because they are robust enough to handle slight skewness of data. The output of the Independent Sample T-Test is illustrated in Table 6.22.

Table 6.22 – Levene's Test for equality of variances and Independent Samples T-Test results for habitat for species scores versus recreation scores

Independent Samples T-Test results (habitat for species scores v type of site)			**Number of vegetation layers**	
			Equal variances assumed	**Equal variances not assumed**
Levene's Test for equality of variances	**F**		7.836	NA
	Sig.		0.007	NA
t-test for equality of means	**t**		-2.227	-2.066
	df		47	30.098
	Sig. (2-tailed)		0.031	0.048
	Mean difference		-5.919	-5.919
	Std. error difference		2.657	2.865
	95% confidence interval of the difference	**Lower**	-11.265	-11.770
		Upper	-0.573	-0.068

According to the data in Table 6.22, Levene’s test shows that p-value (sig.) of 0.007 is smaller than 0.05. This implies that group variances are not the same; therefore, the unequal variance reading is adopted. The mean difference in habitat for species scores between the two ranked recreation scores is 5.919. The test for equality of means produced a p-value of 0.048 (equal variances not assumed). It is smaller than 0.05, therefore, the means of the two groups are not equal. Consequently, there is a significant difference between the habitat for species scores for recreation scores in rank one (2 to 4) or two (5 to 6).

Referring back to Figures 6.29 and 6.30, the mean habitat for species score for recreation scores between 2 to 4 (rank one; Figure 5.33) is 22.15, which is smaller than the mean habitat for species score for recreation scores between 5 to 6 (rank two; Figure 5.34), which is 28.07. This means that sites that achieved higher recreation scores tend to also achieve higher habitat for species scores, or vice versa.

6.6.3. Educational signs, evidence of educational use, proximity of educational establishments

The educational signs, evidence of educational use and proximity of educational establishments' data from Table E5 were cross-tabulated with the four different area groups in order to show the distribution of these variables across all 49 sites (see Table 6.23).

Table 6.23 – Cross-tabulation of educational signs (ES), evidence of educational use (EEU) and proximity of educational establishments (PEE) with area group.

Note: ES1 = not present; ES2 = present but poorly maintained signs which explain only one or two aspects of the site and/or not easily readable or visible; ES3 = present and well maintained signs which explains multiple aspects of the site; EEU1 = no evidence; EEU2 = past educational activities; EEU3 = on-going educational activities; PEE1 = further than 1000m away from site; PEE2 = between 401m to 1000m from site; PEE3 = between 101m to 400m from site; PEE4 = less than 100m away from site

	Educational Signs (ES)				**Evidence of Educational Use (EEU)**				**Proximity of Educational Establishments (PEE)**				
Area group	**ES 1**	**ES 2**	**ES 3**	**Total no. of sites**	**EE U1**	**EE U2**	**EE U3**	**Total no. of sites**	**PE E1**	**PE E2**	**PE E3**	**PE E4**	**Total no. of sites**
$1m^2$ to $2499m^2$	11	1	5	17	9	2	6	17	0	2	14	1	17
$2500m^2$ to $5499m^2$	8	2	0	10	3	3	4	10	0	2	6	2	10
$5500m^2$ to $7999m^2$	2	1	0	3	1	1	1	3	0	1	1	1	3
≥ $8000m^2$	11	4	4	19	8	1	10	19	0	6	9	4	19
Total no. of sites	32	8	9	49	21	7	21	49	0	11	30	8	49

The data in Table 6.23 show that 32 out of 49 sites (65%) do not have any educational signs present on-site. Within these 32 sites, 11 sites are larger than or equals to $8000m^2$, two sites are between $5500m^2$ and $7999m^2$, eight sites are between $2500m^2$ and $5499m^2$, and finally, 11 of them are smaller than $2500m^2$.

There were 17 of the 49 sites (35%) which have educational signs on-site to show the public about the site, but there were only 9 of those 17 sites that have well maintained educational signs which explain multiple aspects of the site. Overall, having educational signs on-site to explain the site to the public does not appear to be the priority to the 49 sites examined.

Looking at evidence of educational use in Table 6.23, 21 of the 49 sites (43%) have never been used for any educational purposes. Whereas, 28 sites (57%) have either had educational activities in the past (7 sites; 14%) or have on-going educational activities (21 sites; 43%). Overall, more emphasis was put into using the 49 sites for educational activities. Of the 21 sites that have on-going educational activities, they are all run by community groups (most set up and run by volunteers), collaborating with local councils. Examples of the community groups involved in the management of these 21 sites are as follows, details of the site they help to manage are illustrated in Table E9 in Appendix E:

- Red Rose Forest
- Friends of Alexandra Park
- Irwell Valley Sustainable Communities Project
- Sale and Altrincham Conservation Volunteers
- Friends of Peel Park
- Friends of Heaton Hall
- Heaton Park Trust
- Horticultural Friends Society
- Wythenshawe Parkwatch Group
- Friends of Wythenshawe Hall
- Friends of Platt Fields
- Feeding Manchester
- New Leaf residents group
- Salford Rangers

- Nutsford Vale Park Project

With regards to proximity of educational establishments, the data in Table 6.23 indicates that all of the sites were within easy to moderate walking distance from educational establishments. Most of the sites (30 of 49, or 61%) were between 101m to 400m from the nearest educational establishment, which makes these sites to be moderately easy to get to by foot for the students studying there. However, out of these 30 sites, only 9 were larger than or equal to 8000m^2. Therefore, only 30% were suitable to being total outdoor recreational spaces for the students.

6.6.4. Education

The educational signs, evidence of educational use and proximity of educational establishments' data in Table E5 were combined to form education ecosystem service scores for all 49 sites, similar to the method illustrated in Moore and Hunt (2013) and following descriptions provided in Chapter 4. Cross-tabulation analysis was performed to illustrate the education scores across all 49 sites (see Table 6.24). The sites were again split into four different area groups.

Table 6.24 – Cross-tabulation of education scores verses area groups

	Education scores							
Area groups	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total no. of sites**
between 1m^2 and 2499m^2	0	7	3	3	2	1	1	17
between 2500m^2 and 5499m^2	0	4	3	1	0	2	0	10
between 5500m^2 and 7999m^2	1	0	1	0	0	1	0	3
larger than or equals to 8000m^2	3	4	4	1	2	3	2	19
Total no. of sites	4	15	11	5	4	7	3	49

The data in Table 6.24 shows four sites having an education score of one. Three of these sites are larger than or equals to 8000m^2, and they are site 4 (Blackfish pond one), site 5 (Blackfish pond two), and site 25 (Old Trafford INCOM site). These sites do not contain educational signs to inform the public of aspects of the sites. There is no evidence of educational use found for these sites. Finally, they are all between 401m to 1000m walking distances from their nearest educational establishments, which makes them moderatelytoo difficult to get to by foot.

On the other end of the scale, three sites achieved the highest education score. Two of them (sites 3 - Alexandra Park pond and 45 - Three Sisters) are larger than or equal to 8000m^2. These two sites possess signs that inform the public about multiple aspects of the site, in particular, the biodiversity one can expect to find within the sites. They are also within 100m from their nearest educational establishment, which are easiest to get to by foot. Finally, there is evidence of on-going educational activities for both sites. Site 3 (Alexandra Park pond) is described within the main website of Alexandra Park, which contains information (history, ecology, and an interactive map) of the site. There is a learning centre specifically to tailor lessons for the children who use Alexandra Park. The pond itself has a secure education zone. There is also a Friends of Alexandra Park (a local resident group) caring for the park. These programs are on-going. Site 45 (Three Sisters) is managed by the Salford Rangers. They regularly organise volunteer conservation sessions on-site and these sessions are on-going.

One site out of the three that achieved the highest education scores, site 33 (Primrose Primary School pond), has an area less than 2500m^2. This site, incidentally, also achieved the lowest recreation score (see Table 6.24). However, site 33 is situated within Primrose Primary School. It has an educational sign that explains multiple aspects of the pond, and in particular, the biodiversity the students can expect to observe and learn from the pond. The pond is also regularly used as an educational tool for the students of the school, even though the pond is not accessible to the general public.

The education scores were also cross-tabulated with the two different types of sites in order to show the distribution of the scores across all 49 sites (see Table 6.25).

Table 6.25 – Cross-tabulation of education scores verses type of sites

Type of site	Education scores 1	2	3	4	5	6	7	Total no. of sites
Aquatic	3	5	7	0	1	2	3	21
Terrestrial	1	10	4	5	3	5	0	28
Total no. of sites	4	15	11	5	4	7	3	49

According to the data in Table 6.25, four of the 49 sites (8%) achieved the lowest educational score, which is one. The four sites that achieved the lowest education score, three of them are aquatic sites (site 4 – Blackfish pond one, site 5 – Blackfish pond two, and site 6 – Blackley New Road pond one), and one of them is a terrestrial site (site 25 – Old Trafford INCOM site). The three sites that achieved the highest education score are all aquatic sites (site 3 – Alexandra Park pond, site 33 – Primrose Hill Primary School pond, and site 45 – Three Sisters).

The education ecosystem service scores were examined to see if there is a significant difference between aquatic and terrestrial sites. Figures 6.31 and 6.32 are histograms of the education scores for aquatic and terrestrial sites.

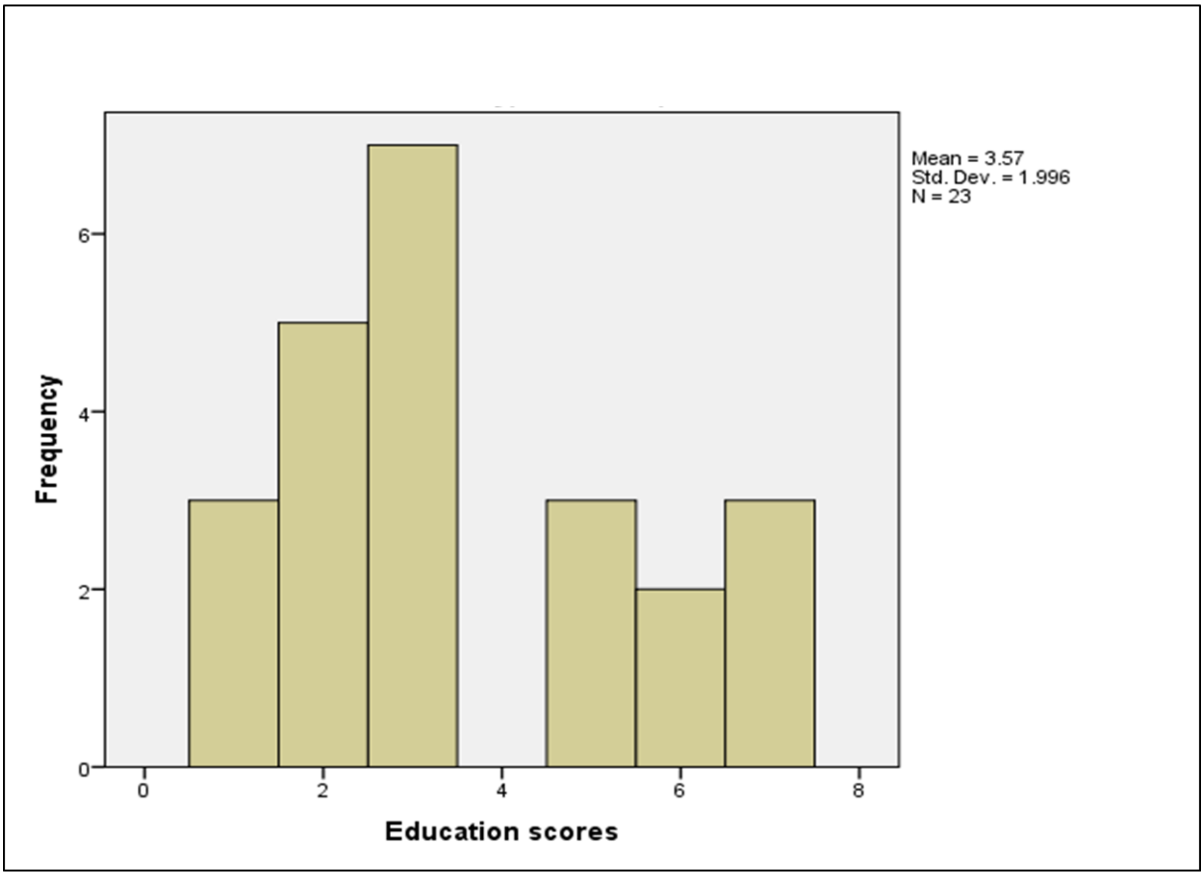

Figure 6.31 – A histogram of education scores for aquatic sites

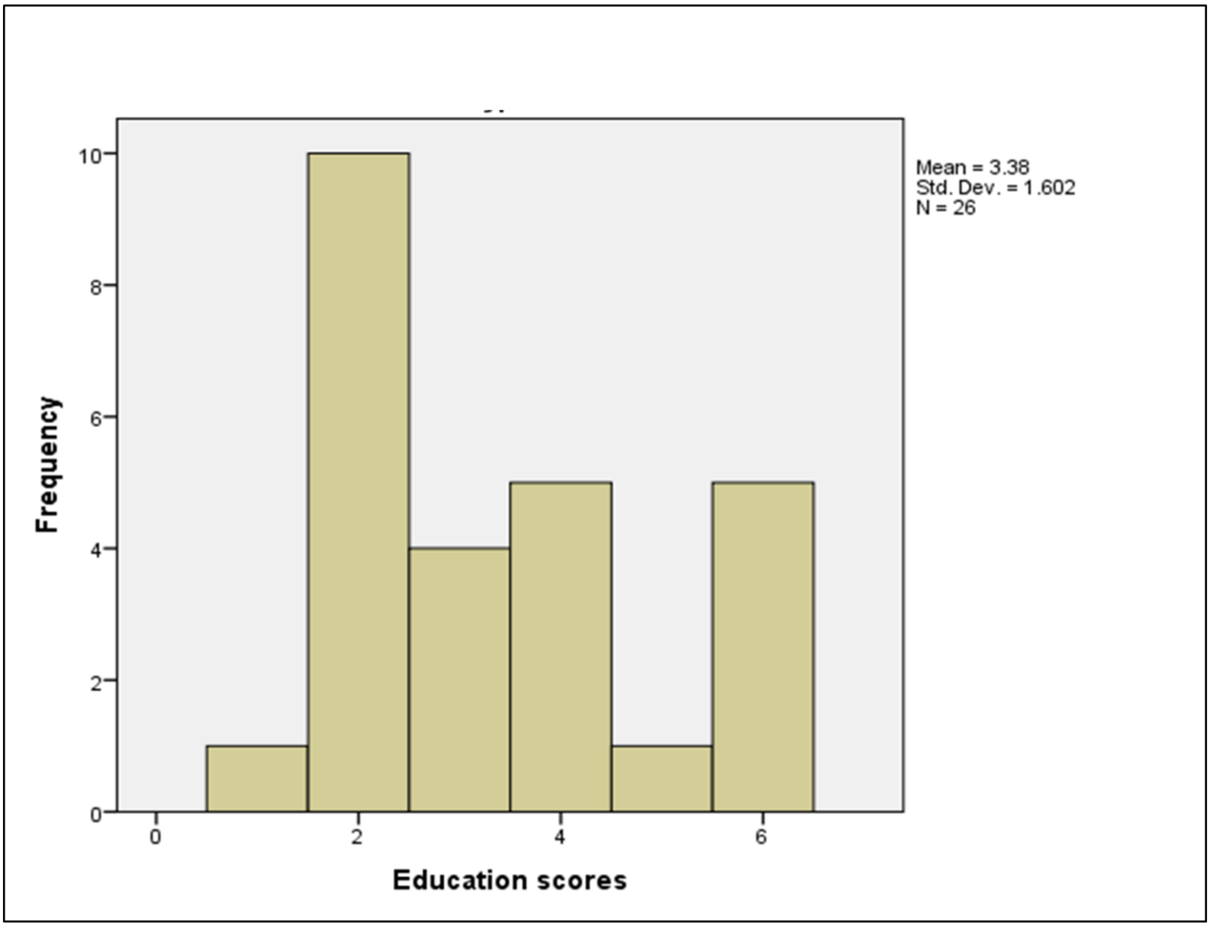

Figure 6.32 – A histogram of education scores for terrestrial sites

According to the data in Figures 6.31 and 6.32, the distributions of both education scores are positively skewed, with skewness values of 0.552 and 0.574 respectively. The p-values calculated by Kolmogorov-Smirnov normality test (0.000 for aquatic and 0.001 for terrestrial) were smaller than 0.05. Therefore, parametric tests cannot be performed in this case because the education scores are not normally distributed.

The variances are roughly homogenous after performing the Levene's test for non-parametric data (p-value = 0.750, which is larger than 0.05), the non-parametric Kruskal-Wallis analysis was, therefore, chosen to examine whether there is a relationship between the type of site and education scores a site can obtain. Table 6.26 contains the mean ranks for the type of site and the Kruskal-Wallis results.

Table 6.26 – Mean ranks between the type of site and Kruskal-Wallis results

	Type of site	N	Mean Rank
Education scores	**aquatic**	23	25.43
	terrestrial	26	24.62
	Total	49	
	Chi-Square	0.042	
	df	1	
	Asymp. Sig.	0.838	

According to the data in Table 6.26, the Kruskal-Wallis test shows that p-value (asymp. sig.) of 0.838 is larger than 0.05. This implies that there is no significant difference the between the type of sites compared with the education score each site gets, out of 49 sites surveyed.

Finally, based on the education scores illustrated in Table 6.25, the scores were ranked as either one (1 to 2), two (3 to 4), three (5 to 7). Analysis was then performed to examine whether there is a relationship between the education scores and the habitat for species scores. The null hypothesis is that there is no significant influence between the scores for these two ecosystem services.

Before the analysis was performed, the habitat for species scores were checked to see if they are normally distributed or not, when plotted against the ranked education scores. Figures 6.33 and 6.34 illustrate the histograms of the habitat for species scores, split into the three education scores ranks.

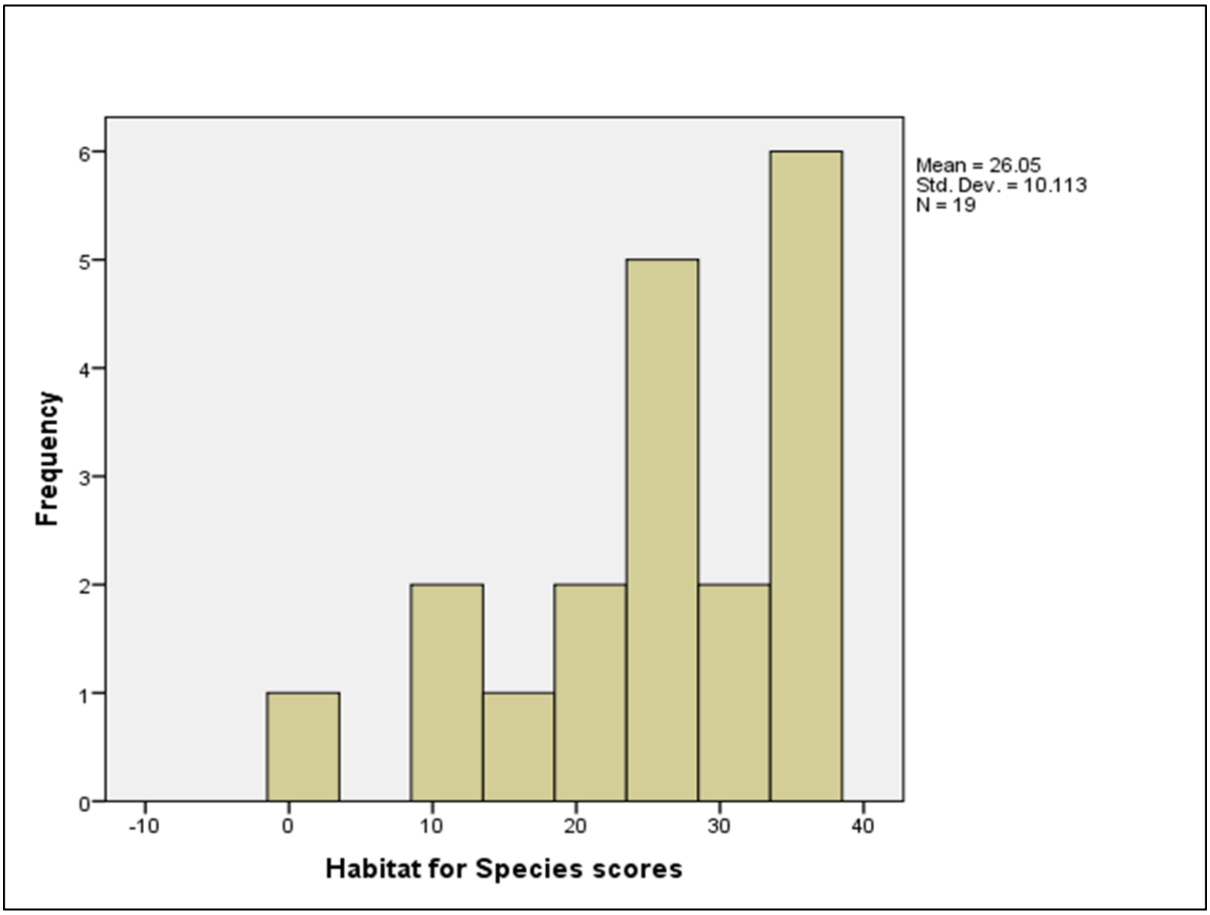

Figure 6.33 – A histogram of habitat for species scores for education scores from 1 to 2 (group one)

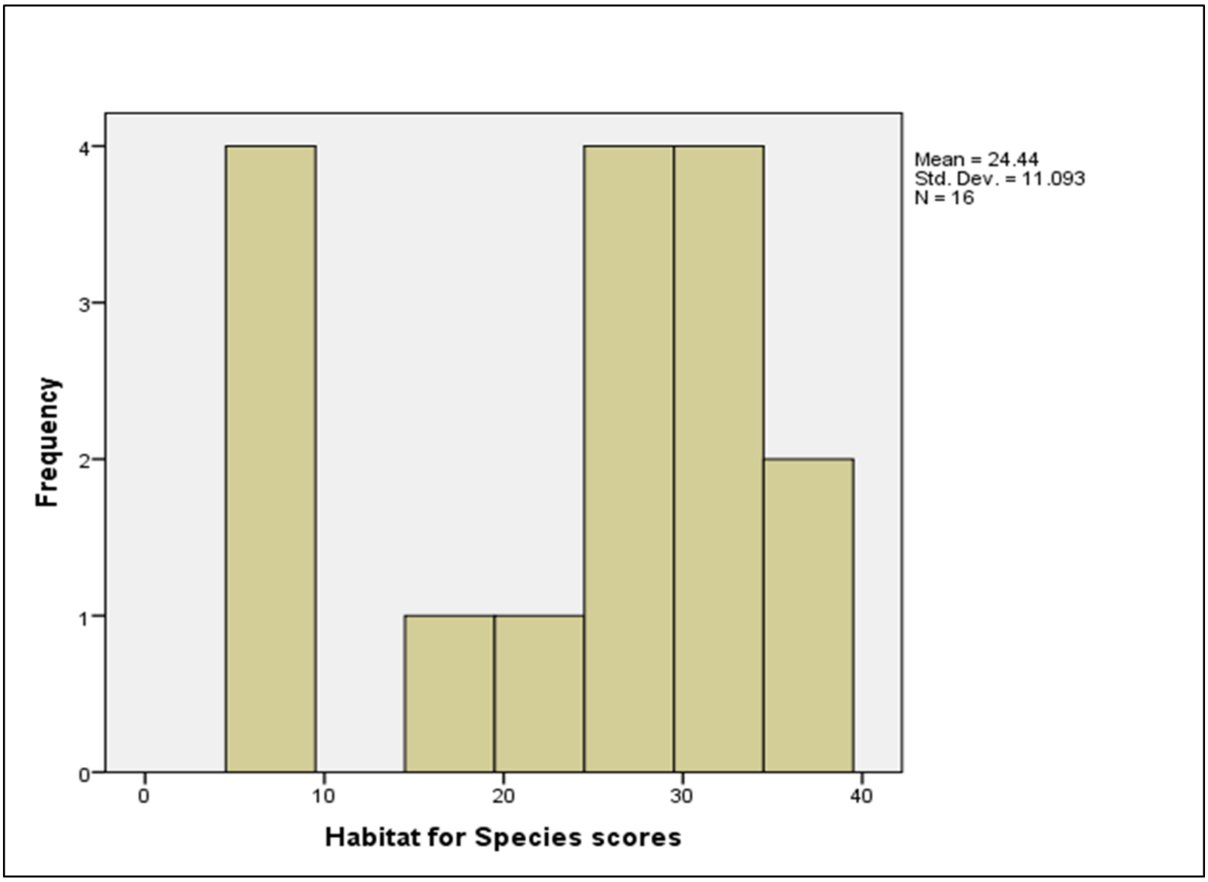

Figure 6.34 – A histogram of habitat for species scores for education scores from 3 to 4 (group two)

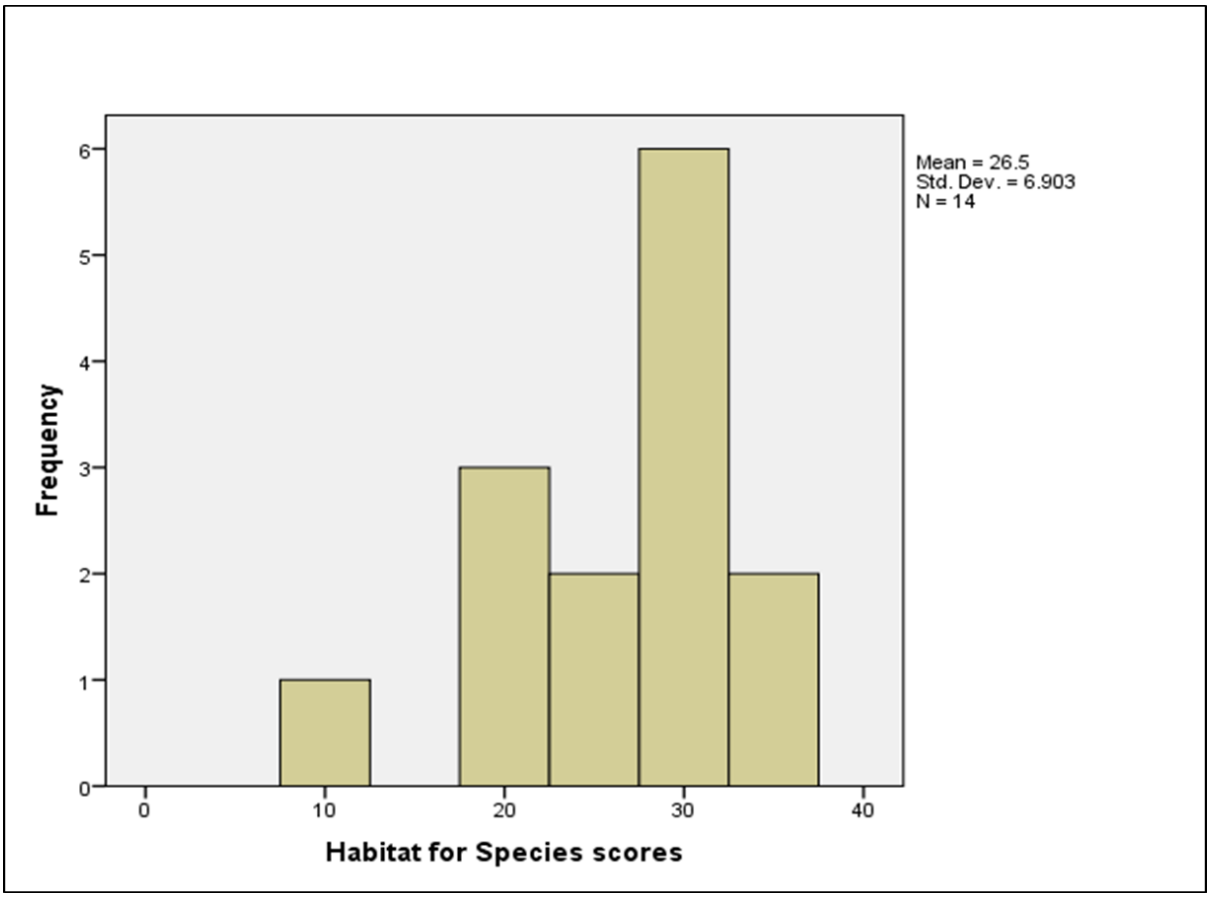

Figure 6.35 – A histogram of habitat for species scores for education scores from 5 to 7 (group three)

According to the data in Figures 6.33 and 6.35, the distributions of education scores are negatively skewed, with skewness values of -0.933, -0.737 and -0.972 respectively. The Kolmogorov-Smirnov normality test was performed to examine the distribution of the data (see Table 6.27).

Table 6.27 – Kolmogorov-Smirnov normality tests for habitat for species scores compared with ranked education scores

	Ranked education scores	Kolmogorov-Smirnov		
		Statistic	Degrees of freedom	P-value
Habitat for Species scores	**one**	0.143	19	0.200
	two	0.216	16	0.044
	three	0.157	14	0.200

According to Table 6.27, the Kolmogorov-Smirnov normality test produced p-values of the first and third ranks of education scores greater than 0.05, but the second rank education scores has a p-value smaller than 0.05. This means that habitat for species scores across the three ranks are not normally distributed. Non-parametric Kruskal-Wallis analysis was therefore performed to examine whether there is a relationship between habitat for species scores and education scores. Table 6.28 illustrates the mean ranks for the habitat for species scores and the Kruskal-Wallis results.

Table 6.28 – Mean ranks of habitat for species scores between the three ranked education scores groups and Kruskal-Wallis results

	Rank of education scores	**N**	**Mean Rank**
Habitat for species scores	**1**	19	25.95
	2	16	24.16
	3	14	24.68
	Total	49	
	Chi-Square	0.147	
	df	2	
	Asymp. Sig.	0.929	

According to Table 6.28, the Kruskal-Wallis test shows that p-value (asymp. sig.) of 0.929 is larger than 0.05. This implies that there is no significant influence between the habitat for species score and the education score each site gets, out of 49 sites surveyed. Figure 6.36 illustrates the plot of mean habitat for species against the three education scores ranks.

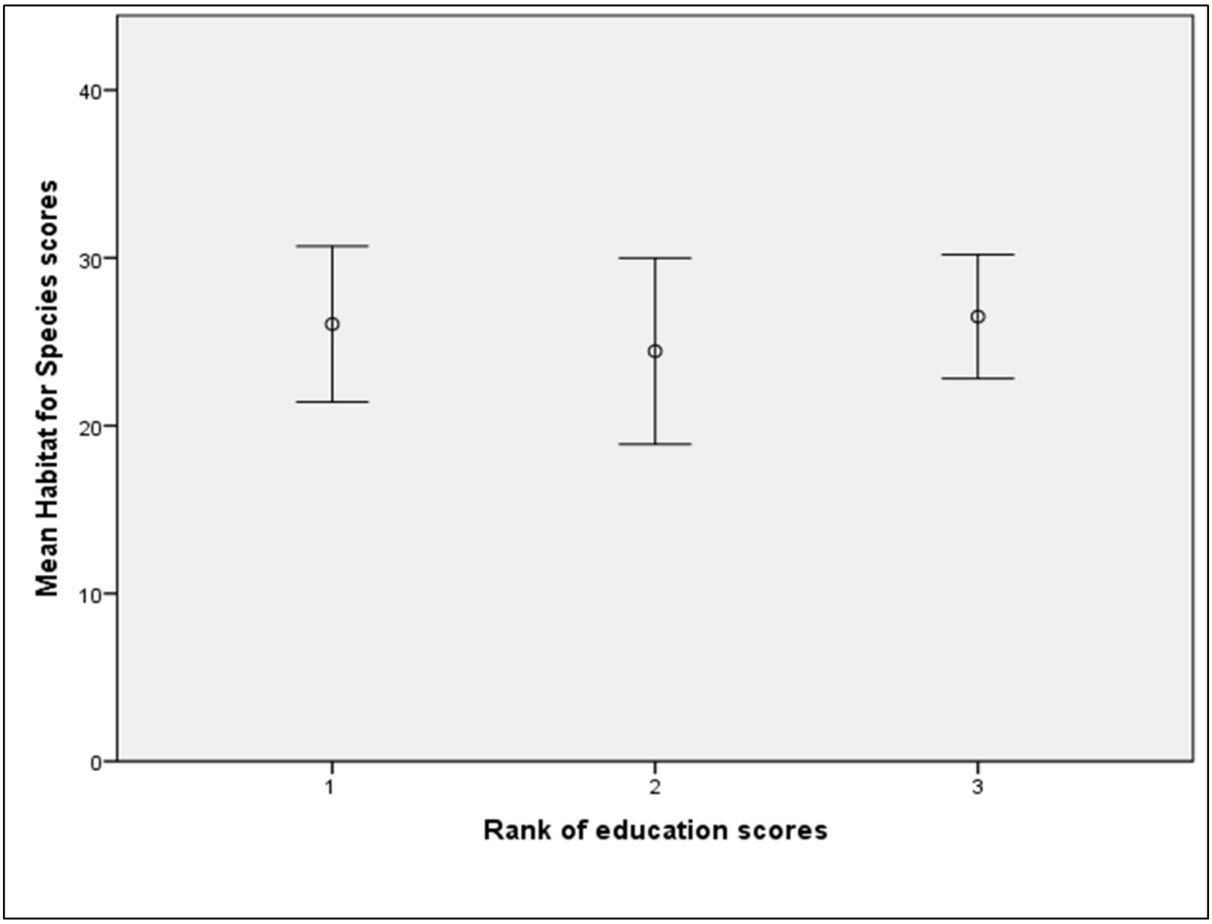

Figure 6.36 – A plot of mean habitat for species scores against the three ranks of education scores (one = education scores from one to two; two = education scores from three to four; three = education scores from five to seven).

Note: Error bars: +/- 2 standard errors.

According to the data in Figure 6.36, there is not much difference between the mean habitat for species scores across all three ranks of education scores. This confirms the statistics results in Table 6.28, and it also suggests that, statistically, just because one site scores high for habitat for species, doesn't mean it will also score high for education.

6.6.5. Dog faeces on-site, litter on-site, presence of bins

The data for coverage of dog faeces and litter on-site, and the presence of bins (Table E5), were cross-tabulated with the four different area groups in order to show the distribution of these variables across all 49 sites (Table 6.29).

Table 6.29 – Cross-tabulation of dog faeces coverage on-site (DF), litter coverage on-site (L) and presence of bins (B) with area group.

Note: DF1 = frequent; DF2 = occasional; DF3 = rare; L1 = frequent; L2 = occasional; L3 = rare; B1 = not present; B2 = present

	Dog Faeces (DF)				**Litter (L)**				**Bins (B)**		
Area group	**DF1**	**DF2**	**DF3**	**Total no. of sites**	**L1**	**L2**	**L3**	**Total no. of sites**	**B1**	**B2**	**Total no. of sites**
$1m^2$ to $2499m^2$	1	1	15	17	5	2	10	17	3	14	17
$2500m^2$ to $5499m^2$	0	1	9	10	2	2	6	10	2	8	10
$5500m^2$ to $7999m^2$	0	0	3	3	0	1	2	3	0	3	3
$\geq 8000m^2$	4	6	9	19	7	4	8	19	8	11	19
Total no. of sites	5	8	36	49	14	9	26	49	13	36	49

The data in Table 6.29 shows that 36 of the 49 sites (74%) were mostly free of dog faeces. Of these 36 sites, nine (25%) were larger than or equal to $8000m^2$, three (8%) were between $500m^2$ and $7999m^2$, nine (25%) were between $2500m^2$ and $5499m^2$, and 15 (42%) between $1m^2$ and $2499m^2$. Also illustrated in Table 6.29, dog faeces were frequently encountered on five out of 49 sites (10%). Four of these (80%) were larger than or equal to $8000m^2$, and only one (20%) were less than $2500m^2$.

The data in Table 6.29 shows that 26 of the 49 sites (53%) were mostly free of litter. Out of the 26 sites, eight (31%) were larger than or equal to $8000m^2$, two (8%) were between $5500m^2$ and $7999m^2$, six (23%) were between $2500m^2$ and $5499m^2$, and 10 (39%) were between $1m^2$ and $2499m^2$. Also illustrated in Table 6.29, litter were frequently encountered on 14 out of 49 sites (29%). Seven of these (50%) were larger than or equal to $8000m^2$, two (14%) were between $2500m^2$ and $5499m^2$, and five (36%) were between $1m^2$ and $2499m^2$.

The coverage of litter and dog faeces on-site can also be related to the presence of bins on-site, as they provide users with convenience, encouraging them to put litter and dog faeces into the bins, therefore, keeping the sites clean. In order to find out whether the presence of bins on-site has anything to do with the level of litter and dog faeces coverage on-site, a statistical analysis was performed for all 49 sites. Table 6.30 contains the cross-tabulation analysis of all 49 sites in accordance with the level of litter coverage on-site and the presence of bins.

Table 6.30 – Cross-tabulation of litter coverage on-site and presence of bins

	Litter			**Total no. of sites**
Bins	**Frequent**	**Occasional**	**Rare**	
Not present	9	2	2	13
present	5	7	24	36
Total no. of sites	14	9	26	49

In accordance with Table 6.30, 24 sites (49%) have bins present on site and were mostly free of litter. This suggests that there is a positive relationship between presence of bins and the level of litter coverage on-site. Table 6.31 contains the cross-tabulation analysis of all 49 sites in accordance with the level of dog faeces coverage on-site and the presence of bins.

Table 6.31 – Cross-tabulation of dog faeces coverage on-site and presence of bins

	Dog faeces			**Total no. of sites**
Bins	**Frequent**	**Occasional**	**Rare**	
Not present	5	2	6	13
present	0	6	30	36
Total no. of sites	5	8	36	49

In accordance with Table 6.31, 36 sites (74%) have bins present on-site and were mostly free of dog faeces. This suggests that there is a positive relationship between presence of bins and the level of dog faeces coverage on-site. The data in Table 6.32 illustrate the chi-square analysis of the level of litter and dog faeces coverage on-site and the presence of bins.

Table 6.32 – Chi-square analysis result of the level of dog faeces and litter coverage on-site verses the presence of bins

Comparisons	Pearson Chi-square result	P-value	P-value more than or less than 0.05	Significant difference (at P=0.05 level) (Y/N)
Level of litter coverage on-site verses the presence of bins	15.058	0.001	smaller	Y
Level of dog faeces coverage on-site verses the presence of bins	15.653	0.000	smaller	Y

In accordance with Table 6.32, there is a significant difference in terms of the level of litter and dog faeces coverage compared with the presence of bins on-site.

Section 6.6.1 and the associated sub-sections described the distributions of the cultural ecosystem services and disservices raw data for all 49 sites and produced recreation and education scores for all 49 sites. The next sections illustrate the effects of the ecosystem disservices variables being considered on the recreation ecosystem service scores.

6.6.6. The influence of dog faeces coverage on recreation scores

The recreation ecosystem service scores can be influenced by variables considered to influence the generation of ecosystem disservices. One of those variables being used for this analysis is the level of dog faeces coverage on-site. The hypothesis is that if the level of dog faeces on-site is high, then the recreation ecosystem service the site is able to provide is going to be low.

In order to test this hypothesis, the distributions of the recreation scores were examined to determine normality. Figures 6.37 to 6.38 illustrate the histograms of the recreation scores, split into different levels of dog faeces coverage on-site.

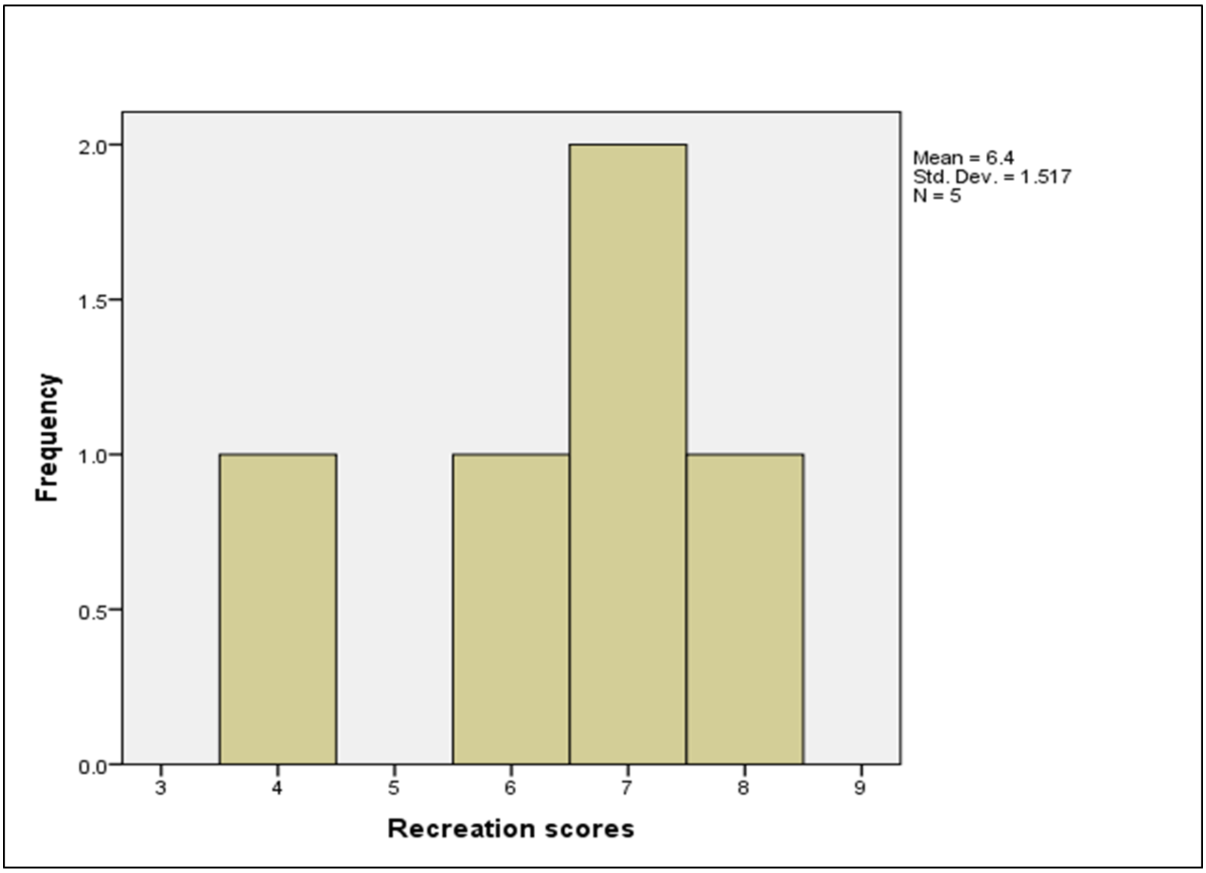

Figure 6.37 – A histogram of recreation scores for dog faeces frequently found on-site

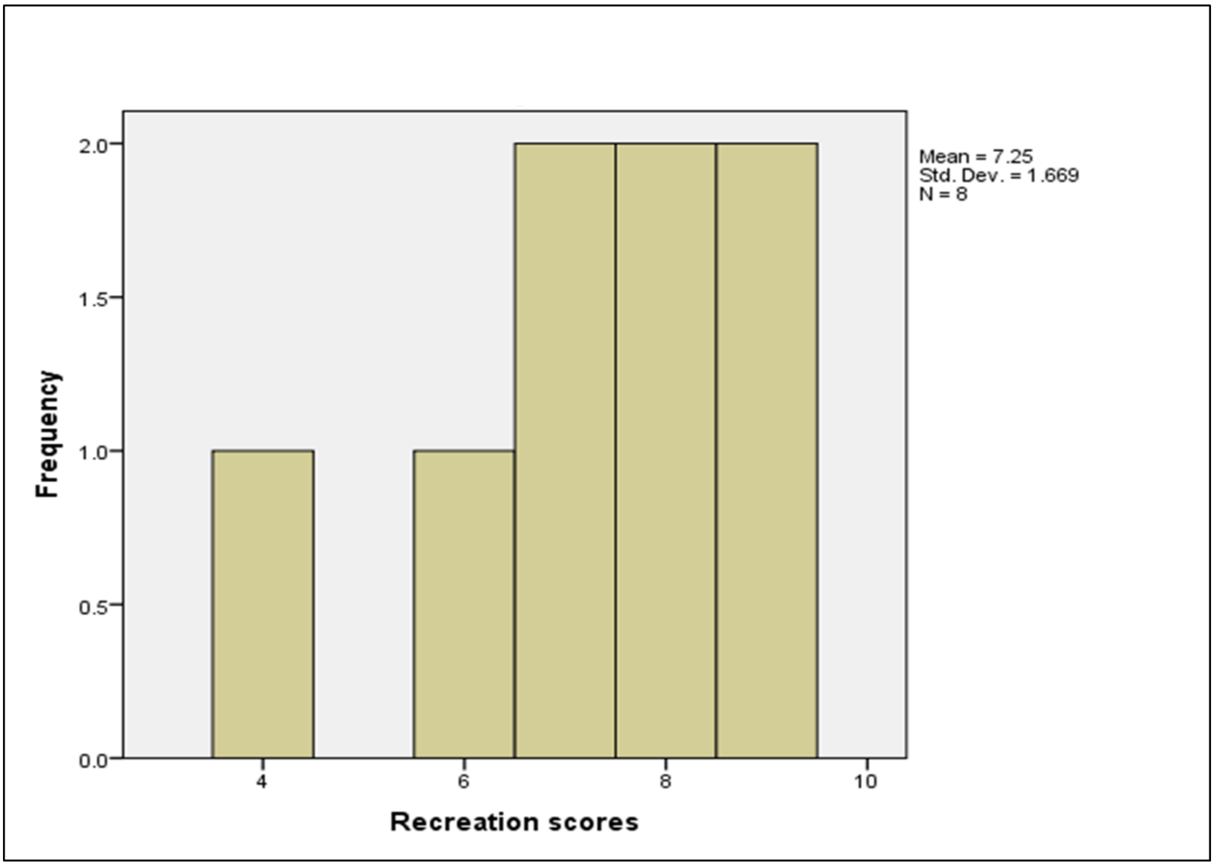

Figure 6.38 – A histogram of recreation scores for dog faeces occasionally found on-site.

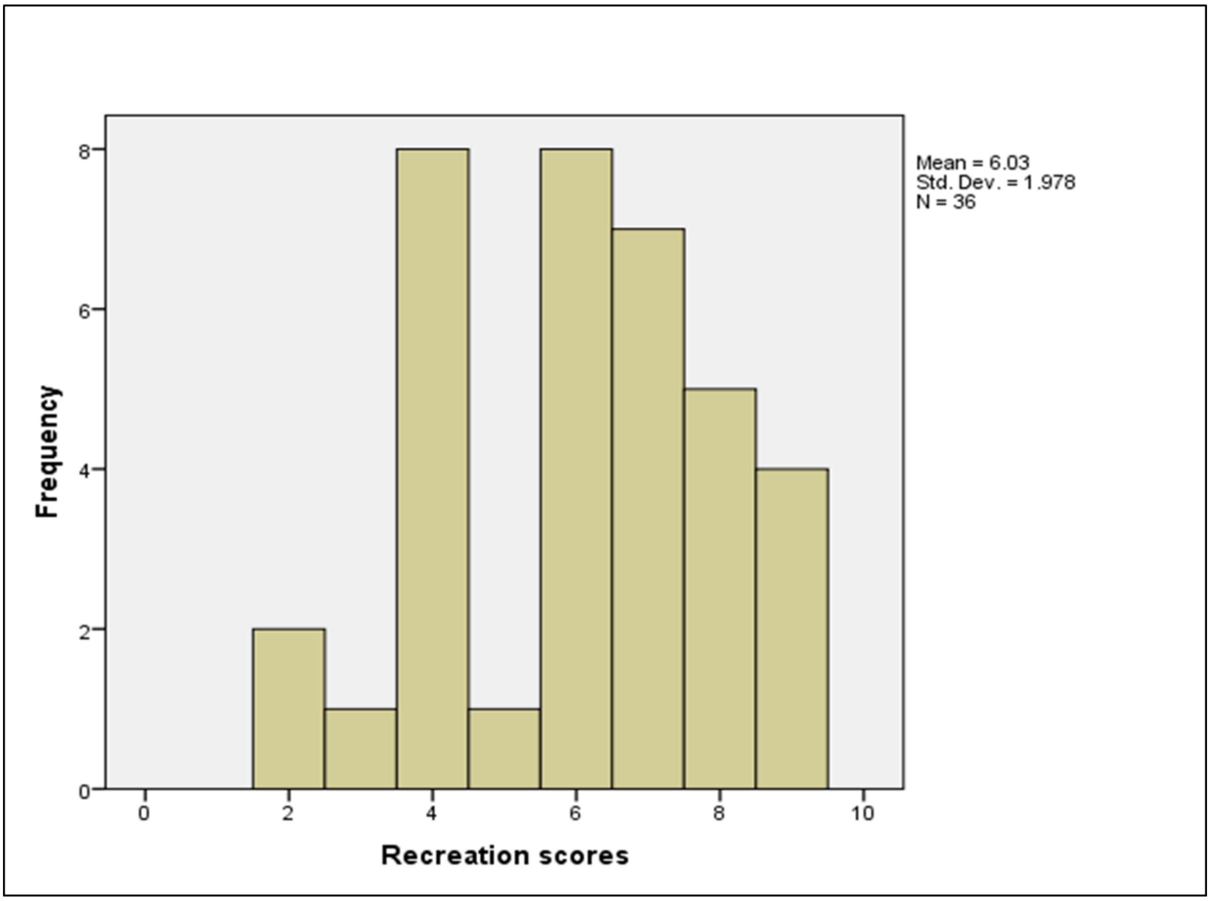

Figure 6.39 – A histogram of recreation scores for dog faeces rarely found on-site.

According the data in Figures 6.37 to 6.39, the distribution of recreation scores are all negatively skewed, with skewness values of -1.118, -1.014 and -0.299 respectively. Because of the skewness of the data shown in Figure 6.37 to 6.39, and also because variance are roughly homogenous after performing the Leven's test (p-value = 0.373, which is larger than 0.05), non-parametric Kruskal-Wallis analysis was performed to examine whether there is a relationship between the level of dog faeces coverage and recreation scores a site can obtain. The data in Table 6.33 illustrates the mean ranks for the level of dog faeces on-site and the Kruskal-Wallis results.

Table 6.33 – Mean ranks between the level of dog faeces and Kruskal-Wallis results

	Level of dog faeces	N	Mean Rank
Recreation scores	**frequent**	5	25.50
	occasional	8	32.50
	rare	36	23.36
	Total	49	
	Chi-Square	2.839	
	df	2	
	Asymp. Sig.	0.242	

According to Table 6.33, the Kruskal-Wallis test shows that p-value (asymp. sig.) of 0.242 is larger than 0.05. This implies that there is no significant difference between the levels of dog faeces coverage on-site compared with the recreational score each site gets, out of 49 sites surveyed. Therefore, the hypothesis concerning the level of dog faeces on-site cannot be linked to recreation ecosystem service generation, based on the 49 sites examined.

6.6.7. The influence of litter coverage on recreation scores

Another ecosystem disservice variable being used to examine the effect it has on recreation is he level of litter coverage on-site. The hypothesis is that if the level of litter on-site is high, then the recreation ecosystem service the site is able to provide is going to be low.

In order to test this hypothesis, the distributions of the recreation scores were examined to determine normality. It was found that the data was all skewed, but the variances are all roughly homogenous. Therefore, once again, the Kruskal-Wallis analysis was performed (see Table 6.34).

Table 6.34 – Mean ranks between the level of litter and Kruskal-Wallis results

	Level of litter	N	Mean Rank
Recreation scores	**frequent**	14	26.86
	occasional	9	24.61
	rare	26	24.13
	Total	49	
	Chi-Square	0.351	
	df	2	
	Asymp. Sig.	0.839	

According to the results in Table 6.34, the Kruskal-Wallis test shows that p-value (asymp. sig.) of 0.351, which is larger than 0.05. This implies that there is no significant different the between levels of litter coverage on-site compared with the recreational score each site gets, out of 49 sites surveyed. Therefore, the hypothesis concerning the level of litter on-site cannot be linked to recreation ecosystem service generation, based on the 49 sites examined.

6.7. Conclusion

Overall, this chapter presented results from the vegetation structure cover-abundance survey and the cultural ecosystem services and disservices variables appraisals. Ecosystem services scores (habitat for species, urban heat island mitigation, carbon sequestration, recreation and education) were produced for all 49 sites. These scores were analysed in accordance with different site area groups and different type of sites (aquatic or terrestrial). Analysis were also conducted to investigate the relationships between different ecosystem services (habitat for species versus recreation and education). Finally, the effects of ecosystem disservices variables (dog faeces and litter) were analysed to determine whether they influence the strength of the recreation ecosystem service. Chapter 7 will contain the discussion of the results presented in this chapter. Chapter 7 will also contain the conclusion for the entire research.

7. Discussion and main conclusion

Chapter 6 contained the results of the vegetation structure cover-abundance survey and cultural ecosystem services and disservices appraisals data analysis. The results of the two methods provide evidence for the validation of the SuDS Communication and Planning Framework. Therefore, that chapter satisfied the “outcome from research solution verification” component of the PhD research framework (Figure 1.1).

This chapter presents the discussion of the results from Chapter 6 and the conclusion of the entire research. The discussion will contain commentary on the research limitations.

The discussion will also contain commentary on the significance of the results on biodiversity and amenity of vegetation SuDS systems, and on the merit of integrating the Ecosystem Approach, using ecosystem services and disservices, to enhance the existing SuDS approach.

The conclusion will state the main findings, describe the novelty, further research ideas and contribution of the research.

7.1. Research discussion overview

At the beginning of the research, it was identified that climate change and increased urbanisation were associated with increased risk of flooding, and higher levels of urban diffuse pollution and habitat fragmentation (section 2.2 – Millennium Ecosystem Assessment, 2005; Intergovernmental Panel on Climate Change, 2007; Pitt, 2007; Woods-Ballard *et al.*, 2007; Defra, 2010; Cain *et al.*, 2011; Parliamentary Archives, 2012; Environment Agency, 2013b; Environment Agency, 2014; Joint Nature Conservation Committee, 2014a). Together these have a variety of negative effects on human and wildlife.

The SuDS stormwater management approach has the potential to mitigate the negative effects of climate change and increased urbanisation by offering a variety of ecosystem services (section 2.3.3 – Oberndorfer *et al.*, 2007; Woods-Ballard *et al.*, 2007; Scholz & Uzomah, 2013). However, the SuDS stormwater management approach has been criticised for failing to consider associated impacts on ecosystem amenity and biodiversity (Ellis, 2013).

The Ecosystem Approach was identified during the critical literature review stage (chapters 2 and 3) of this research to be an ideal tool for integration into existing SuDS stormwater management approach in order to bring about positive changes to the way biodiversity and amenity are dealt with during SuDS development processes. The Ecosystem Approach contains the ecosystem service(s) and disservice(s) concepts which contextualise and offer variables to measure biodiversity and amenity benefits that SuDS can offer, whilst also allowing possible negative issues to be considered (Ackerman, 2003; Secretariat of the Convention on Biological Diversity, 2004; Sparling *et al.*, 2004; Scher & Thièry, 2005; Viol *et al.*, 2009; Angelibert *et al.*, 2010; Coffman & Waite, 2011; Editorial, 2011; UK National Ecosystem Assessment, 2011b; Bastian, *et al.*, 2013; Briers, 2014; Baró *et al.* 2015; Van Mechelen *et al.*, 2015; von Döhren & Haase, 2015).

The result of the critical review was the creation of an innovative SuDS Communication and Planning Framework (section 3.4) highlighting the amenity and biodiversity related ecosystem services and disservices (Figure 3.5) which vegetated SuDS sites can produce, coupled with the identification of drivers affecting the production of each service and disservice (Figures 3.6 and 3.7).

Validation of the SuDS Communication and Planning Framework was then carried out using a combination of desktop studies, spatial analysis via satellite images, and biodiversity and amenity appraisals (section 4.2 and 4.3 for methods and chapter 6 for results). Within Greater Manchester 49 sites were chosen for the validation process (section 4.1).

Five ecosystem services were examined: habitat for species, urban heat island mitigation, carbon sequestration, recreation and education. On-site appraisal of vegetation structure coverage abundance, coupled with examination of satellite images, was carried out to examine habitat for species, urban heat island mitigation and carbon sequestration that each of the 49 sites can generate. Desktop studies on legal accessibility, evidence of educational use and proximity of educational establishments were carried out, couple with on-site appraisals of physical accessibility, recreational infrastructures and educational signs, in order to examine the recreation and education ecosystem services the 49 sites can generate. On-site appraisals of dog faeces coverage, litter coverage and presence of litter bins were also carried out to establish the extent of ecosystem disservices for the 49 sites (section 6.6.5).

The 49 sites selected for this research focus mostly on elements of urban green infrastructures. The reasons for this choice were discussed and justified in section 4.1.1. In summary, elements of urban green infrastructures were able to act as proxies for vegetated SuDS systems. Firstly, this is because they share many common biodiversity features (Hoffmann, 2005; Jackson & Boulte, 2008; Viol *et al.*, 2009; Kazemi *et al.*, 2011; Tonietto *et al.*, 2011; Ksiazek *et al.*, 2012; Demuzere *et al.*, 2014; Loder, 2014; Bell, 2015; Church, 2015; Hansen *et al.*, 2015; Matthews *et al.*, 2015; Norton *et al.*, 2015; Van Mechelen *et al.*, 2015). Secondly, they offer many site management and amenity values, in particular social and cultural, which can be implemented when conducting vegetated SuDS planning and design (Buri *et al.*, 2013; Krasny *et al.*, 2014; Church, 2015; Wolf, 2015). Finally, in recognising the seriousness of habitat fragmentation caused by increased urbanisation and climate change, there has been and continues to be international efforts to integrate vegetated SuDS systems into urban green infrastructure, in particular in North America and in the UK (US Environmental Protection Agency, 2007; Ashton *et al.*, 2010; Wise *et al.*, 2010; Natural England, 2011; Odefey *et al.*, 2012; Ellis, 2013; Graham *et al.*, 2013; Struck *et al.*, 2010 cited in Fletcher *et al.*, 2014).

Greater Manchester, as discussed in section 4.1.2, shares many similarities with other urban and post-industrialised cities across the world, therefore, new discoveries made in this city region can be applied to the rest of the world. The range of sites chosen for this research covered every element of green infrastructures that can be found within Greater Manchester. For instance, the distribution of the scores for habitat for species (Figure 6.13) illustrates that the 49 sites covered all possible vegetation structure coverage abundance scenarios, apart from the maximum possible score (a scenario that is not possible in reality, as explained in section 6.3). The range of sites also covered all legal accessibility scenarios encountered within Greater Manchester (section 6.6.1; Table E6).

In terms of the vegetation structure cover-abundance survey performed for this research, those sites that were smaller than (or marginally greater than) 2500m^2, were surveyed in their entirety. For larger sites a degree of structure in the placement of the 50m by 50m quadrates was introduced to ensure that key features in the sites were not missed.

The possibility of subjectivity in the visual estimation of the percentage of each observable vegetation layer was compensated for by determining the height of the upper canopy layer using the tree height measurement application (section 4.2.2; Figures 4.4 and 4.5), and the data collection sheet (Figure 4.7) included the height ranges and expected vegetation types for each vegetation layer, which acted as a guide whilst conducting on-site data gathering. The Braun-Blanquet scale (Figure 4.7) also acted as a guide when conducting on-site data gathering.

Satellite images were used to aid sample plot allocation and on-site vegetation structure cover-abundance survey (Section 4.2.5). However, when using the satellite images (Google, 2015) to conduct initial vegetation structure coverage abundance assessments, it was discovered that images for some sites were slightly out-of-date (typically by two to five years). This proved to be only a minor issue because the satellite images were used only to quantify the approximate location of each dominant vegetation layer on-site (Section 5.1). The images were also used as a verification tool to conduct sense checks on the percentage of each observed vegetation layer noted down on-site, in order to achieve higher accuracy.

Finally, photographs were taken whilst conducting on-site data gathering. These photographs acted as a verification tool to compensate for the limitation of the on-site vegetation structure cover-abundance visual estimates.

In terms of the cultural ecosystem services and disservices variables appraisal performed for this research, the possibility that the data gathered for dog faeces and litter coverage (Section 6.6.5) were subjective was compensated by the inclusion of rating definitions for other researchers to follow (Section 4.3.4.4 and Figure 4.16).

Pearson Chi-Square Test was used to test associations between two categorical variables (Tables 6.2 and 6.32). Its assumptions are as follows (Hinton, 2014):

- The test does not provide information with regards to the strength of the relationship or what the result means in terms of the entire population.
- Sample size should be large, typically more than 25.
- No cells should have expected count less than five.

In all cases when one or more of the Chi-Square test assumptions were violated, the Fisher's Exact Test results (Table 6.2) were used. This is because the Fisher's Exact Test does not depend on the above approximations.

Kruskal-Wallis Test (non-parametric, rank comparisons) was used as an alternative to one factor independent analysis of variance (parametric, means comparisons) (Tables 6.17, 6.20, 6.26, 6.28, 6.33, 6.34). Its assumptions are (Hinton, 2014):

- Sample sizes must be as close to equal as possible.
- Distributions of the groups being analysed are approximately equal.

With regards to the first assumption, equality (or close to equality) of sample sizes were ensured by grouping data into separate categories. For example, the education scores were group into three groups (group one – score 1 to 2, group two – score 3 to 4, group three – score 5 to 7) so that the number of sites were evenly distributed in order to satisfy the first assumption. The Levene's test for non-parametric data was performed to verify that the second assumption of the Kruskal-Wallis Test was followed before the actual test was carried to analyse the data.

Independent Sample T-test (parametric, means comparisons) was used to test for equal means of two samples (Tables 6.5, 6.7, 6.9, 6.11, 6.13 and 6.22). Its assumptions are sample data must be normal, and variances must be equal (Hinton, 2014). With regards to the first assumption, histograms were plotted (Figures 6.11, 6.12, 6.14 to 6.17, 6.20, 6.21, 6.25 to 6.35, 6.37 to 6.39) to examine the shape of the data distributions, and in particular, the skewness values for each cases to ensure they were not more than three. Kolmogorov-Smirnov normality test was also performed for each cases to verify normal distribution of data. With regards to the second assumption, the Independent Sample T-tests performed to analyse the data allowed the option of unequal variances to be chosen. Therefore, the assumption was overcome by choosing the equal variances not assumed option (Table 6.5, 6.7, 6.9, 6.11, 6.13 and 6.22).

7.2. Vegetated SuDS sites and biodiversity

The vegetation structure cover-abundance data provided evidence for habitat for species, urban heat island mitigation and carbon sequestration ecosystem services potential of vegetated SuDS sites based on the structural complexity of the vegetation on-site (Sections 6.1 to 6.5).

In terms of vegetation structural complexity, it was discovered that the size of a site influences the coverage of upper (+16.763, $p = 0.005$; Table 6.2) and lower (+10.988, $p = 0.012$; Table 6.2) vegetation canopies (high and low trees). Both upper and lower canopy vegetation layers were found to be more prevalent on sites greater than 5500m^2 (Figures 6.1 and 6.2). Since all the sites chosen for this research were managed urban green spaces, it can be concluded that taller trees were deemed to be more suitable for larger sites. This is not surprising because trees provide habitats for many species and provide a greater number of ecological niches compared to other vegetation types (Cain *et al.*, 2011). As mentioned within the on-site appraisal results for Castle Irwell (section 5.1.2), there were sightings of at least one deer on-site. Common UK deer species, such as the roe deer (*Capreolus capreolus*), use woodlands as habitats (The British Deer Society, 2015). Other mammals (e.g. European badger (*Meles meles*), dormouse (*Muscardinus avellanarius*) and red squirrels (*Sciurus vulgaris*) and different birds (e.g. Eurasian bullfinch (*Pyrrhula pyrrhula*), chaffinch (*Fringilla coelebs*), and goldcrest (*Regulus regulus*)) also depend on woodlands as their habitats, as well as amphibians, reptiles, and many types of invertebrates (Woodland Trust, 2015). Indeed, several woodlands types are considered to be Priority Habitats under the UK Biodiversity Action Plan (Joint Nature Conservation Committee, 2013). Large sites, therefore, allow areas with a concentration of trees to form, which enable woodland conditions to prevail.

Trees are more effective at mitigating the urban heat island effect compared with other vegetation types, due to the amount of shading they provide and their superior moisture retention (Hall *et al.*, 2012). They also store more above ground carbon compared to other vegetation types (Dewar & Cannell, 1991; Perry, 1998; Waran, 2001; Delphin *et al.*, 2013), thus contributing to global carbon sequestration. Large sites allow more trees to grow, therefore, increasing urban heat island mitigation and carbon sequestration.

The size of a site was also discovered to influence the coverage of cropped or mown grass (+15.191, $p = 0.01$; Table 6.2). The cropped or mown grass vegetation layer was found to be more prevalent on sites smaller than or equal to 5500m^2 (Figure 6.5). Again, since all the sites chosen for this research were managed urban green spaces, it can be concluded that decisions were made at individual site management level to not allow grass to grow to any significant height.

Keeping vegetation short is an effective way of minimising unwanted animal species from using the vegetation as places to hide, forage and form habitats. An example would be the control of tick (Acarina) population by cutting down tall grass (Uspensky, 2014; Centers for Disease Control and Prevention, 2015). The fact that cropped or mown grass was found to be more common on sites up to 5500m^2 (Figure 6.5), site management decisions must have been made to mow the grass short to keep children safe and away from ticks, as sites up to 5500m^2 can potentially form informal or designated recreational spaces for children (Fields in Trust / National Playing Fields Association, 2008; Moseley *et al.*, 2013). The height of grass also dictates the type of recreational activities that can occur on-site. For example, football games require the grass to be mown short.

The size of a site influences the coverage of trees and cropped or mown grass, and it also has influence on the number of vegetation layers on-site (mean difference = -1.387, $p = 0.051$; Table 6.5). This is not surprising, since larger sites would tend to have more room horizontally to accommodate a higher number of vegetation structure layers, which implies a higher number of vegetation species. Also, this result indicates that larger sites allow greater horizontal vegetation structural diversity, which can provide multiple ecological niches for different organisms on-site (Cain *et al.*, 2011).

The data in Table 6.3 indicates that sites larger than or equal to 8000m^2 contain at least four vegetation layers. Even though statistically the size of the site has no influence on the number of vegetation layers on-site, larger sites do contain a greater number of vegetation layers on-site. So the trend of greater number of vegetation layers being observed for large sites merely reflects the fact that a larger quantity of vegetation was present on-site. This benefits a greater number of animal species because there are more opportunities to establish habitats, escape from predators and forage for food.

With regards to the habitat for species scores calculated for all 49 sites, it was discovered that the size of a site influences the habitat for species scores the site can achieve. Referring back to Figures 6.14 and 6.15, the mean habitat for species score for sites larger than 5500m^2 is greater than the mean score for sites smaller than or equal to 5500m^2. This is consistent with the findings for the overall vegetation structure layers coverage and the overall distribution of vegetation structure layers – larger sites are more structurally diverse than smaller sites, and hence offer greater potential for wildlife to establish habitats.

The conclusion that larger sites are better than smaller sites at generating ecosystem services can also be found when urban heat island mitigation and carbon sequestration scores were analysed in accordance with the size of site (Sections 6.4 and 6.5). It was discovered that the mean urban heat island mitigation and carbon sequestration scores for sites larger than 5500m^2 are greater than the mean scores for sites smaller than or equal to 5500m^2 (Figures 6.20, 6.21, and Table 6.12). This is again consistent with the findings for the overall vegetation structure layers coverage and the overall distribution of vegetation structure layers – larger sites have more room to allow large and tall trees to grow and water bodies to be constructed, hence they offer greater potential for mitigating the urban heat island effects (more shading by trees and higher evaporation rate) and greater potential for carbon sequestration and above ground carbon storage.

Comparing the habitat for species scores with the type of site (aquatic or terrestrial), it was discovered that whether a site is aquatic or terrestrial influences the habitat for species scores the site can achieve (mean difference = 10.896, p = 0.000; Table 6.9). Referring back to Figures 6.16 and 6.17, the mean habitat for species score for aquatic sites (31.43) is greater than the mean score for terrestrial sites (20.54). This indicates that sites with aquatic features can generate more habitat for species ecosystem service than sites with only terrestrial features. Ultimately, it can be concluded that sites with a mixture of aquatic and terrestrial features offer greater potential for wildlife to establish habitats. This confirms that vegetated SuDS sites, with their aquatic features used to treat surface water runoff, offer great habitat for species potential.

When the comparison of size of site, type of site and habitat for species scores was conducted (Figure 6.18), it was discovered that aquatic sites (large or small) generated higher habitat for species scores compared with terrestrial sites (large or small). The conclusion can be drawn that the diversity of aquatic features is the key driver that influences habitat for species scores. With this in mind, and also remembering the definitions of aquatic and terrestrial sites, as discussed in Chapter 6, it can be concluded that large sites with permanent aquatic features generate greatest habitat for species ecosystem service.

The conclusion that large sites with permanent aquatic features are better at generating ecosystem services can also be found when analysing the urban heat island mitigation and carbon sequestration scores. Referring back to Figure 6.22, the mean urban heat island mitigation score, 33, for aquatic sites larger than 5500m^2 is greater than the mean score, 24, for terrestrial sites larger than 5500m^2. The mean score of 33 is also greater than the mean scores for aquatic, 29, and terrestrial, 16, sites smaller than or equal to 5500m^2. This means that large sites with permanent aquatic features generate greatest urban heat island mitigation ecosystem service although aquatic sites smaller than or equal to 5500m^2 (mean score = 29) scored higher than terrestrial sites larger than 5500m^2 (mean score =

24). Therefore, permanent aquatic features on a site, irrespective of their size, enhances the site's urban heat island mitigation capacity.

Referring back to Figure 6.24, the mean carbon sequestration score, 22, for aquatic sites larger than 5500m^2 is greater than the mean carbon sequestration score, 11, for terrestrial sites of the same area range, 11. The mean score of 22 is also greater than the mean score for aquatic, 18, and terrestrial, 2, sites smaller than or equal to 5500m^2. This means that large sites with permanent aquatic features generate greatest carbon sequestration ecosystem service. However, having permanent aquatic features on a site, irrespective of their size, can enhance the site's carbon sequestration capacity. This is because aquatic sites smaller than or equal to 5500m^2 (mean score = 18) scored higher than terrestrial sites larger than 5500m^2 (mean score = 11).

With reference to the definitions of aquatic and terrestrial sites give in Chapter 6, a recommendation can be made that vegetated SuDS types with permanent aquatic features and site area greater than 5500m^2 have the potential to generate the most habitat for species, urban heat island mitigation and carbon sequestration ecosystem services. Consequently, the most desirable vegetated SuDS type, in terms of achieving the most habitat for species, urban heat island mitigation and carbon sequestration ecosystem services, is stormwater wetlands. This is because this SuDS type has permanent ponding, areas for trees to grow and concentrate, and tends to be designed to cover large area in order to function within the regional SuDS treatment train stage.

7.3. Vegetated SuDS sites and amenity

Results from the appraisal of cultural ecosystem services and disservices variables provided evidence of the recreation and education ecosystem services potential of vegetated SuDS sites.

In terms of recreation, it was discovered that the size of the site does not have any significant influence on the recreation ecosystem service the site can offer ($p = 0.943$; Table 6.17). That is surprising, since most recreational activities do depend on the size and shape of the site, and that is why Fields in Trust classified recreational grounds based on their size (Fields in Trust / National Playing Fields Association, 2008).

One explanation for this is that, generally speaking, no matter how a site is defined, people will find a way of using it to fit into their lifestyle. For instance, dog walkers were observed using site 8 (Brownfield site beside Asda Hulme petrol station) and site 22 (Littleton Road and Reading Street brownfield site). Both sites, when the observations were made, were derelict, abandoned, brownfield sites, with no defined recreational use. Children were also observed conducting recreational activities in sites 39, 40, 41 and 42 (Stamford Brook retention basins – an existing SuDS scheme within a new housing development, draining the new roads and acting as basins to temporary store flood water). Some children were observed using the inlet/outlet of the basins, where flood water will be diverted into the basins when the nearby stream breaches its capacity, as an informal recreation facility.

With regards to people's lifestyle and green space usage, another variable can be incorporated into the calculation of recreation scores. This variable can be combined with the proximity of neighbourhoods from the sites being studied and the social economic makeup of the people living in these neighbourhoods in order to illustrate the number and type of people who would use the site for recreation. This variable will allow more differentiation between sites which are closer to more populated neighbourhoods and neighbourhoods with more family and young children, in order to encourage children to use more of their local green space for recreational activities (Fields in Trust / National Playing Fields Association, 2008).

When comparing the recreation scores and the type of sites, it was discovered that there is no influence on the score a site can achieve whether it is an aquatic site or a terrestrial site (p = 0.181; Table 6.20). This is not surprising because there is no attempt to analyse different recreational activities in which people may participate, as recreational activities are influenced by the site conditions. For instance, if the site is a pond, then people may want to participate in angling, or feeding ducks. If the site is grassland, people may want to go for a walk, go for a run, walk their dogs or do some cycling. The influence of site conditions and activities people participate in are not investigated in this research, but can be conducted in future research projects.

However, when comparing habitat for species scores with recreation scores, it was discovered that there is a relationship between the two scores (p = 0.048; Table 6.22). The sites that achieved higher recreation scores tend to also achieve higher habitat for species scores according to the comparisons of the means between the two scores (Figures 6.29 and 6.30). Therefore, a site's vegetation structure diversity has a positive influence on the site's recreation potential. This is a significant finding because previous research indicated that spending time in green spaces can enhance people's physical as well as mental health (Millennium Ecosystem Assessment. 2005; Tzoulas *et al.*, 2007; Croucher *et al.*, 2008; Barton & Pretty, 2010; Konijnendijk, 2012; Maruthaveeran & Konijnendijk, 2014). English Nature even suggests a minimum distance of 300m for anyone to live from a two hectare size (minimum) green space (English Nature, 2003; Natural England, 2010). Consequently, future vegetated SuDS designs should ensure maximum vegetation structure diversity in order to achieve the most recreation potential for the sites concerned.

Unlike the clear relationship between habitat for species and recreation, the analysis of the data failed to show that there is any significant relationship between habitat for species and education. For instance, when comparing the education scores with the type of sites, it was discovered that there is no influence on the score a site can achieve whether it is an aquatic site or a terrestrial site (p = 0.838; Table 6.26). Additionally, when the habitat for species scores were directly compared with the education scores, it was discovered that there is no influence between the two scores (p = 0.929; Table 6.28).

One reason for this result is because the definition of "education" focuses on public exposure, engagement and education, instead of academic research. There are examples of education ecosystem service analysis being conducted through counting the number of academic research papers published on the site being examined (Welker *et al.*, 2010) but focusing solely on academic research is too exclusive, ignoring the potential contribution of the sites towards enhancing the general public's ecological and environmental awareness. In contrast, the focus on public engagement and education in this research enabled evidence to be gathered which indicated that vegetated SuDS sites should be associated with committed local groups as this resulted in better engagement by local people associated with the site (Section 6.63; Table E9, Appendix E). Enhanced engagement with local people also allows the management of these sites of nature to be a matter of societal choice (Secretariat of the Convention on Biological Diversity, 2004; Joint Nature Conservation Committee, 2014b). Therefore the focus on public engagement and education enabled the research result and future recommendations to be Ecosystem Approach compliant

These findings formed recommendations for new vegetated SuDS developments, so that the developers of these new SuDS sites can involve and encourage local communities to set up volunteering groups in order to maintain and care for the sites. Finally, as a future improvement on the education ecosystem service scoring system, a desktop study can be conducted to examine how each sites contributes to academic research (number of research papers published, value of grants allocated to the research) in order to gain an insight into the influence of the sites towards science research and higher education.

Referring back to the results of the education and habitat for species comparison suggests that biodiversity of the site has no significant influence towards enhancing the general public's ecological and environmental awareness. The remit of the research was not to conduct questionnaires and interviews on a sample population in order to find the influence the sites have on their ecological and environmental awareness; this work can be conducted in a future research project.

Other aspects of amenity that were examined were the coverage of dog faeces and litter, and the presence of bins on-site. Both dog faeces and litter coverage were used as ecosystem disservices indicators, whereas the presence of bins can influence community acceptance of the sites being examined.

With regards to dog faeces coverage, it was discovered that 74% of the sites surveyed were mostly free of dog faeces (Table 6.29). This result implies that the users of the sites were mostly considerate and civically conscious because in accordance with the UK law, it is an offence for dog owners to not clean up after their dogs have defecated in public places (Keep Britain Tidy, 2002; Clean Neighbourhoods and Environment Act, 2005). Alternatively, the sites were not or were seldom used by dog walkers.

With regards to litter coverage, it was discovered that 53% of the sites surveyed were mostly free of litter (Table 6.29). This result can be explained by three possible theories: firstly, litter was easier to identify on-site compared with dog faeces because litter stands out from the surrounding vegetation; secondly, the 46.9% of the sites surveyed where litter was frequently observed indicates users of those sites might be less considerate and civically conscious and there might be fly-tipping problems; thirdly, certain wild animals (grey squirrels (*Sciurus carolinensis*), magpies (*Pica pica*), or grey rats (*Rattus norvegicus*)) might be foraging in the bins situated within or nearby the sites, leaving litter lying around. One limitation of the dog faeces and litter coverage surveys is that cause and effects were not investigated. This is because investigating the cause and effects would involve conducting questionnaires and interviews on a sample population. This is beyond the remit of this research, but future research can be conducted to investigate further the cause and effects of dog faeces and litter coverage in urban green spaces.

The analysis was conducted to find the relationship between bin presence and dog faces and litter coverage. It was discovered that the presence of bins on-site influenced the coverage of dog faeces and litter (p = 0.001 and 0.000; Table 6.32).

The cross-tabulation of dog faeces and litter coverage verses presence of bins (Tables 6.30 and 6.31) shows that the presence of bins on-sites reduced litter and dog faeces coverage. Therefore, aside from civic consciousness, the presence of bins is also an important factor that influences whether a site is kept free of litter and dog faeces or not. Consequently, new vegetated SuDS sites should have bins located on-site in order to keep the sites clean and to enhance community acceptance of the sites.

When analysing the effects of dog faeces and litter coverage on recreation ecosystem service, it was discovered that both these variables do not have any significant influence on the recreation score ($p = 0.242$; Table 6.33, $p = 0.839$; Table 6.34). Unfortunately these two results suggest that while the cause and effects of dog faeces and litter coverage in urban green spaces were not investigated, it is impossible to know whether there is any effect on people's usage and enjoyment of the sites if they are frequently encountering dog faeces and litter on-site.

Cause and effects of the data gathered were not investigated during the research, therefore, the variables that contributed to the recreation and education ecosystem services scores (Sections 6.6.1 and 6.6.3) could not be weighted. For instance, the variable "legal accessibility" might be much more important compared with the variable "recreational infrastructure". In order to answer this question, questionnaires and interviews on a sample population would have to be carried out. This was not the research remit, but can be investigated in a future research project.

7.4. Conclusion

There is a need to improve the SuDS stormwater management approach because it is currently too engineering focused and site specific. It is also currently failing to consider the effects of SuDS developments on the biodiversity and amenity in the ecosystem context. The Ecosystem Approach is the best way to appraise SuDS because the SuDS treatment train lies perfectly within the urban water cycle. However, one of the most common and persistent aspects that have always been missing with regards to the Ecosystem Approach is the failure to provide specific tools to implement solutions (Maltby, 2010). The aim of the research, therefore, was to create a SuDS Communication and Planning Framework by integrating the Ecosystem Approach, through ecosystem services and disservices, to appraise SuDS and to address the amenity and biodiversity knowledge gap within the existing SuDS approach.

Integrating the Ecosystem Approach into the existing SuDS approach to address the biodiversity and amenity gap proved to be a success. The first reason is because the research managed to successfully enhance the biodiversity objective of the current SuDS approach by providing a new and innovative way of analysing the biodiversity driven ecosystem services (habitat for species, urban heat island mitigation and carbon sequestration) of a site, before any retrofitting is being designed and built. The second reason is because the cultural ecosystem services and disservices appraisals managed to show the importance of sustained public engagement, local community groups management, and public education experiences, through the analysis of recreation and education variables (Section 6.6). The cultural ecosystem services and disservices appraisals also demonstrated that the SuDS Communication and Planning Framework is ecosystem compliant, and satisfies the all of the principles of the Ecosystem Approach (Table 3.1; Secretariat of the Convention on Biological Diversity, 2004).

Referring back to biodiversity, the ecosystem services analysis involved rapid assessment of vegetation structure layers coverage on-site, but the assessment also includes open water, aquatic plants and built surfaces coverage (Section 4.2, Chapter 4). Finally, three ecosystem services (habitat for species, urban heat island mitigation, and carbon sequestration) scores were calculated based on the vegetation structure layers data. This method of biodiversity assessment is an improvement on a previous method (Tzoulas & James, 2009), and the improvements are:

- The addition of the three aquatic features into the list of vegetation layers (Figure 4.7), enabling terrestrial and aquatic sites to be assessed by this method.
- The omission of a vegetation species list, focusing instead on the assessment of different habitat structures, in the form of the ten vegetation structure layers (Section 4.2.4, Figure 4.7). This enables multiple ecosystem services to be assessed, and also allows non-experts (people with no botanical training) to conduct ecosystem service assessments.

In line with established principles, the results from the biodiversity driven ecosystem services analysis enabled the recommendation to be made that large sites (greater than 5500m^2) with permanent aquatic features are best at preserving or even enhancing the biodiversity of the sites being considered for retrofitting. Large sites with permanent aquatic features also allow aquatic macroinvertebrates to take refuge, thereby, mitigating habitat fragmentation (Jackson & Boutle, 2008; Viol *et al.*, 2009; Natural England, 2011; Moore and Hunt, 2012; Ellis, 2013; Graham *et al.*, 2013; Briers, 2014). The results indicate that permanent aquatic features are able to enhance the biodiversity of sites irrespective of the size of the site. Therefore, placing permanent waterbodies onto green roofs (an example of a source control vegetated SuDS system) will potentially enhance their biodiversity potential.

Recreation (a key part of the amenity objective of the SuDS approach) was analysed using three variables: legal accessibility, physical accessibility, and recreation infrastructures. The results shows that having favourable and unrestricted accessibility is essential to promote recreational activities, such as horticulture opportunities, on vegetated SuDS sites. The results of the recreation analysis were also compared with the results from the habitat for species analysis. The habitat for species scores were statistically proven to have a positive influence on the recreation scores. This, therefore, demonstrates synergy between habitat for species and recreation ecosystem services (Section 3.3.4; Bennett *et al.*, 2009). This result also provided another evidence for the successful integration of the Ecosystem Approach into the existing SuDS approach. As a consequence of the synergy between habitat for species and recreation ecosystem services, a vegetated SuDS development recommendation can be made that future designs should ensure maximum vegetation structural diversity in order to achieve the most recreation potential for the sites concerned.

Education is a key part of the SuDS amenity objective. This ecosystem service was analysed using three variables: proximity of educational establishments, educational signs, and evidence of educational activities. The results provided evidence for the following recommendations to be made on future SuDS developments: (1) the provision of educational signs on-site can inform and educate local people with regards to the health and safety issues of vegetated SuDS; (2) locating SuDS sites within walking distance from schools can encourage children to use the sites for recreation and schools to use the sites for educational purposes, especially to learn about SuDS. Although these recommendations are established green infrastructure design and planning practises the application of them to SuDS design and planning is new. The result of the education ecosystem service appraisalenabled recommendations to be made that future vegetated SuDS development would benefit from involving local communities. For example by setting up local community groups by the SuDS developers so that the groups can manage and maintain the site in the future and act as focal points to engage local people towards caring about the SuDS sites they are responsible for

Referring back to Chapter 3, the existing SuDS approach details three principles for amenity: health and safety, visual impact, and amenity benefits. With regards to visual impact, the results from the litter and dog faeces coverage survey provided evidence of synergistic relationships with the presence of bins on-site. This research, therefore, has added more arguments to well established theory. This is because it was discovered that whenever there are bins present on-site, less litter and dog faeces were observed (Table 6.32; Section 6.6.5). Since bin provision is part of green space design (section 4.1.1) vegetated SuDS sites should also have bins on-site to maintain positive visual impact and promote community acceptance.

The next stage of the research would be to look at the cumulative evidence that the SuDS Communication and Planning Framework can be applied in a catchment area. For example, since a large part of Greater Manchester sits within the Irwell Catchment, the cumulative effects of different vegetated SuDS types can be examined to see what effects they have for that catchment as a whole.

The creation of the SuDS Communication and Planning Framework also enabled new, multi-disciplinary, research to be carried out. Further research ideas that can be studied are:

- Mosquito risk analysis and Lyme's disease analysis by monitoring tick population. These studies will be able to address the issues of physical health impact (disease carrying animals) of vegetated SuDS sites (Table 3.4; Figures 3.5, 3.6 and 3.7).
- Surveys of people consistently exposed to vegetated SuDS sites can be conducted in order to verify the links between contact with nature and people's mental health (Table 3.3; Figures 3.5, 3.6 and 3.7).
- The environmental design of vegetated SuDS sites can be critically reviewed to address issues of fear of crime and antisocial behaviours (Table 3.4; Figures 3.5, 3.6 and 3.7). This can be combined with interviews of users to examine what aspects people looks for in order to feel safety when using vegetated SuDS sites.
- The role of vegetated SuDS sites on social integration can also be analysed (Table 3.4; Figures 3.5, 3.6 and 3.7). The analysis can be combined with, firstly, socio-economics spatial analysis in order to gain an insight into the type of people using the sites. Secondly, interviews with site users can be conducted in order to examine what, if any, benefits the sites have in terms of social integration. Visits to local community groups attached to these sites can also be made in order to learn about the efforts they put into to promote social integration via their work on these urban green infrastructure sites.

Overall the findings of this research provide practical Ecosystem Approach methods for SuDS development decision making, utilising both qualitative and quantitative techniques. This proves that the incorporation of the Ecosystem Approach (by utilising the ecosystem services and disservices frameworks) into SuDS design and planning practises is the best way forward. The SuDS Communication and Planning Framework (Figures 3.5, 3.6 and 3.7) provides an innovative, easy to use tool to implement Ecosystem Approach compliant solutions.

The SuDS Communication and Planning Framework created as a result of this research can now be found in the second part of the UK National Ecosystem Approach, UK NEA follow-on (UK National Ecosystem Assessment, 2014). In this document, the framework is part of a series of Ecosystem Approach toolkits incorporated into the decision making processes for managing the urban environment in a sustainable way (Mak, 2014; UK National Ecosystem Assessment, 2014).

The findings can benefit stakeholders such as planners, developers, designers, researchers and policy makers to plan SuDS developments using the Ecosystem Approach, taking account of the positive and negative aspects of nature.

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Appendix A. Outline of SuDS techniques

Appendix A aims to provide a summary of all the standard SuDS techniques documented in existing SuDS literatures that are used to realise the SuDS treatment train concept, as shown in Figure 2.11.

Table A1 – Brief descriptions of each SuDS technique

Note: The treatment train stages each technique belongs to, and their water treatement processes are also included (Beard & Green, 1994; Pratt *et al.*, 2002; Ackerman, 2003; Ten Towns Great Swamp Watershed Management Committee, 2003; Scholz, 2006; Scholz & Grabowiecki, 2007; Smetak *et al.*, 2007; Woods-Ballard *et al.*, 2007; Collins *et al.*, 2010; Department of Planning and Local Government, 2010; Moore, 2011; Gonot, 2012; Moore & Hunt, 2012; US Environmental Protection Agency, 2014)

SuDS techniques	**Treatment train**	**Brief descriptions**	**Water treatment process**
Rainwater Harvesting	Source Control	Collects rainwater directly and coverts it into usable, even consumable, water for individual households. Can be in the form of individual devices such as a water butt, or systems with complicated arrangements and multiple parts.	Collection.

Continued…

Pervious pavements	Source control, site control	Capture, attenuate, and slow down the release of stormwater into natural water bodies. Target pollutants are hydrocarbons, heavy metals and nutrients such as nitrogen and phosphorous (Scholz & Grabowiecki, 2007). There are two types of pervious surfaces: permeable and porous. Permeable surfaces are made up of materials that do not contain any voids in itself. However, through surfacing arrangements, they allow water to infiltrate through the gaps in-between. An example would be concrete block paving (Pratt *et al.*, 2002). Porous surfaces are made up of materials that are full of inter-connected void spaces. Water passing over these surfaces can infiltrate through them and into the aggregate sub base below. Examples are grass, gravel, porous concrete, and porous asphalt (Pratt *et al.*, 2002). There are also three types of permeable pavement systems: total infiltration, partial infiltration, and no infiltration. Typical materials are sub-grade, geomembrane, aggregate, geotextile, and either impermeable pavement blocks or porous surfaces, depending on which of the two surface types is chosen to be used.	Attenuation, filtration, adsorption, sedimentation, biodegradation.
Filter strips	Source control, conveyance, site control	Reduce storm water flow by allowing water to flow through the vegetation growing on the strip. Generally found next to roads, car parks, and other small impermeable areas. Acts as a conveyance mechanism to connect other SuDS sites. Infiltration can be achieved depending on the soil type of the site. Different types of vegetation can grow on these filter strips, which enhances biodiversity and aesthetics.	Filtration, Sedimentation, infiltration.

Continued…

Swales	Source control, conveyance, site control	Shallow and wide ditch with dense vegetation cover, leads stormwater runoff from the drained surface to a storage or discharge system. Generally found next to roads, car parks, and other small impermeable areas. Three types of swales: • Standard conveyance swale – promote infiltration. • Dry swale – filter bed of prepared soil overlaying an under-drained system which promotes further water treatment and infiltration. • Wet swale – encourages wet and marshy conditions to form in the base which promote better water treatment. The main habitat for swales consists of Perennial Ryegrass (*Lolium perenne*) (Woods-Ballard *et al.*, 2007, p.10-9) or native plants. Similar to turf lawns (Moore, 2011, p.33). The main species that can be found in swales are non-pest invertebrates, including beetles, spiders, ants, nematodes and gastropods, and earthworms (Beard & Green, 1994, p.4-5, Smetak *et al.*, 2007).	Filtration, sedimentation, infiltration.

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Green roofs	Source control	Capture rainwater directly at source, hence prevents or minimises stormwater runoff into natural water bodies. Excellent biodiversity potential and offers a wide range of habitats for wildlife species. Typical components are: vapour barrier, insulation, waterproof membrane, aggregate or geo-membrane drainage layer, geotextile filter layer, substrate for plant growth. According to SuDS, BMP, LID and WSUD standards, there are three specific green roof types. They are extensive green roofs, intensive green roofs, and semi or simple intensive green roofs (Woods-Ballard *et al.*, 2007; Department of Planning and Local Government, 2010; US Environmental Protection Agency, 2014). SuDS literatures also included brown roofs (substrate laid on top of a waterproof membrane on a typically flat roof that is left to colonise naturally) and WSUD literatures included elevated landscapes (a new ground surface consisting of 600 millimetres or deeper growing medium). For this research, brown roofs and elevated landscapes are ignored and the term “green roofs” only applies to the three common types identified. The three green roofs types (extensive, intensive and semi intensive) are differentiated mainly by the depth of the growing medium. For extensive green roofs, the substrate is typically thin, either 125mm or less, as suggested by SuDS literatures (Woods-Ballard *et al.*, 2007), or six inches (approximately 150mm) or less, as recommended by BMP, LID and WSUD literatures (Department of Planning and Local Government, 2010; US Environmental Protection Agency, 2014). For intensive green roofs, the substrate is thick, either greater than 125mm, as suggested by SuDS literatures (Woods-Ballard *et al.*, 2007), or greater that six inches, as recommended by BMP, LID and WSUD literatures (Department of Planning and Local Government, 2010; US Environmental Protection Agency, 2014). Semi-intensive green roofs are a hybrid of extensive and intensive green roofs.	Collection, attenuation, filtration,

Continued…

Ponds	Site control, regional control	A SuDS pond consists of the following zones: • The sediment forebay – settlement of coarse sediments occurs. • The permanent pool – main treatment zone, where fine sediments are settled from suspension. • The temporary storage volume – provide flood attenuation. • The shallow zone (aquatic bench) – provide area for wetland plants, which acts as a biological filter and provide ecology, amenity and safety benefits. Examples of aquatic insects that can be found are odonates and hemipterans (Ackerman, 2003; Moore, 2011, p.30).	Sedimentation, filtration.
Infiltration devices	Source control, Site control	Normally found beside impermeable surfaces such as roads, pavements, and car parks. Treat stormwater through infiltration and percolation, before allowing groundwater recharge to occur. Can also act as temporary storage of storm water, hence slowing down discharge into natural water bodies. Typical components are geotextile, filter materials (sand or gravel), and overflow pipe at the top. With topsoil cover, infiltration devises can be made into bio-filtration devises. These have the potential to provide habitats for wildlife, which enhances biodiversity of an area (Gonot, 2012).	Infiltration, percolation, bio-filtration (under certain circumstances).

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Wetlands	Conveyance site control, regional control	There are six types of SuDS wetlands: shallow wetland, extended detention shallow wetland, pocket wetland, pond and wetland system, submerged gravel wetlands, and wetland channel (Woods-Ballard *et al.*, 2007). Design of stormwater wetlands "should minimize opportunities for short-circuiting and channelization" (Moore, 2011, p.15). Most stormwater wetlands in Europe are "soil or gravel based horizontal-flow systems planted with *T. Latifolia* and/or *P. Australis*" (Scholz, 2006, p.109). Ponds and wetlands support similar levels of macroinvertebrate diversity, though there are differences in community composition between the two habitat types (Moore & Hunt, 2012). Compared with ponds, wetlands have greater potential in providing carbon sequestration, vegetative diversity, and cultural ecosystem services (Moore & Hunt, 2012). However, a positive water balance (either by maintaining a constant baseflow or groundwater seepage) is needed so that the wetland will not die-off (Scholz, 2006, Woods-Ballard *et al.*, 2007).	Sedimentation, filtration, chemical sorption, chemical precipitation, microbial transformation, and assimilation by microbiota and aquatic plants (Moore, 2011)
Underground storage	Source control, Site control, Regional control	Underground storage includes: • Soakaways – designed to gather stormwater runoff from the surface, and "release it after a lag period to prolong the runoff hydrograph and to decrease the peak flow" (Scholz, 2006, p.273) • Geocellular/modular systems – plastic porous structures designed to contain water beneath ground surface.	Soakaways only – percolation and infiltration.

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Bioretention	Source control, site control	It is modelled after the biological and physical characteristics of an upland terrestrial forest or meadow ecosystem (Ten Towns Great Swamp Watershed Management Committee, 2003). Bioretention normally consists of the following parts: • Ponding area – plant uptake. • Mulch area – allows microorganisms to grow, which help degrade hydrocarbons and other organic pollutants. • Sand bed underneath – promote infiltration. • Trees, large shrubs, and grass channel – promote filtration and slow down storm water runoff rate. Several studies have indicated that bioretention is an effective way to remove nitrogen containing pollutants from storm water (Collins *et al.*, 2010). A study of bioretention swales shown that they can "host 65 different insect species on average" (Moore, 2011, p.32).	Filtration, evaporation, plant uptake, degradation, infiltration (depends on underneath soil condition)

Appendix B. Vegetation structure cover-abundance survey pilots

Appendix B contains the raw data and statistical analysis of the two vegetation structure cover-abundance survey pilots mentioned in sections 4.2.2 and 4.2.3. Table B1 contains the raw data for the first pilot (observed percentage cover vegetation layers by the three PhD researchers). Table B2 contains the Braun-Blanquet conversions of the raw data for the first pilot. Table B3 to B9 contains the cross tabulation analysis of PhD researcher subjects and vegetation layers Braun-Blanquet values. Table B10 to B16 contains the Chi-Square tests for PhD researcher subjects verse vegetation layers Braun-Blanquet values. Table B17 contains the raw data of the second pilot (observed percentage cover of vegetation layers by ecology undergraduate students). Table B18 contains the Braun-Blanquet conversions of the raw data for the second pilot.

Table B1 – Observed percentage cover of vegetation layers by three PhD researchers (Geographer, Ecologist and Engineer).

Note: S1, S2 and S3 represents the first, second and third PhD researchers respectively. HT = High trees, LT = Low trees, BU = Bushes, HGF = High grasses and forbs, LGF = Low grasses and forbs, GF = Ground flora, AQ = Aquatic

Sites	**Data collector**	**Subject**	**Date**	**Area (m^2)**	**Habitat type**	**HT (%)**	**LT (%)**	**BU (%)**	**HGF (%)**	**LGF (%)**	**GF (%)**	**AQ (%)**
Castle Irwell sample area one	S1	Geography	3-Mar-14	2500	Country park	0	1	1	49	49	0	0
Castle Irwell sample area one	S2	Ecology	3-Mar-14	2500	Country park	0	0	0	49	49	0	0
Castle Irwell sample area one	S3	Engineering	3-Mar-14	2500	Country park	0	0	0	100	0	0	0
Castle Irwell sample area two	S1	Geography	3-Mar-14	2500	Country park	5	10	10	70	15	0	0
Castle Irwell sample area two	S2	Ecology	3-Mar-14	2500	Country park	4	10	10	50	26	0	0
Castle Irwell sample area two	S3	Engineering	3-Mar-14	2500	Country park	6	15	10	67	2	0	0
Castle Irwell sample area three	S1	Geography	3-Mar-14	2500	Country park	1	5	5	84	5	5	0
Castle Irwell sample area three	S2	Ecology	3-Mar-14	2500	Country park	1	5	5	80	5	5	0
Castle Irwell sample area three	S3	Engineering	3-Mar-14	2500	Country park	1	8	5	80	5	10	0
Pendleton site 1a	S1	Geography	3-Mar-14	2500	Incidental green space	5	5	0	40	35	5	0

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Pendleton site 1a	S2	Ecology	3-Mar-14	2500	Incidental green space	1	3	1	55	40	5	0
Pendleton site 1a	S3	Engineering	3-Mar-14	2500	Incidental green space	1	3	3	40	40	5	0
Pendleton site 1b	S1	Geography	3-Mar-14	2500	Incidental green space	5	0	5	15	10	75	0
Pendleton site 1b	S2	Ecology	3-Mar-14	2500	Incidental green space	1	0	1	20	10	70	0
Pendleton site 1b	S3	Engineering	3-Mar-14	2500	Incidental green space	1	1	1	1	10	85	0
Pendleton site 1c	S1	Geography	3-Mar-14	2500	Incidental green space	5	15	15	10	30	60	0
Pendleton site 1c	S2	Ecology	3-Mar-14	2500	Incidental green space	4	3	4	10	10	80	0
Pendleton site 1c	S3	Engineering	3-Mar-14	2500	Incidental green space	5	5	3	80	25	20	0
Pendleton site 2	S1	Geography	3-Mar-14	16323	Incidental green space	40	20	5	10	10	90	0
Pendleton site 2	S2	Ecology	3-Mar-14	16323	Incidental green space	50	30	40	20	20	80	0

Continued…

Pendleton site 2	S3	Engineering	3-Mar-14	16323	Incidental green space	8	50	60	70	70	60	0
Pendleton site 3	S1	Geography	3-Mar-14	2160	Incidental green space	5	10	5	0	95	0	1
Pendleton site 3	S2	Ecology	3-Mar-14	2160	Incidental green space	0	2	2	2	90	5	0
Pendleton site 3	S3	Engineering	3-Mar-14	2160	Incidental green space	0	1	1	0	95	0	1
Three Sisters area one	S1	Geography	3-Mar-14	2500	Country park	0	10	0	0	0	45	55
Three Sisters area one	S2	Ecology	3-Mar-14	2500	Country park	0	10	5	10	25	15	80
Three Sisters area one	S3	Engineering	3-Mar-14	2500	Country park	5	20	15	10	30	5	80
Three Sisters area two	S1	Geography	3-Mar-14	2500	Country park	15	10	0	30	70	0	0
Three Sisters area two	S2	Ecology	3-Mar-14	2500	Country park	3	10	5	5	80	5	0
Three Sisters area two	S3	Engineering	3-Mar-14	2500	Country park	20	10	20	60	80	0	0

Table B2 – Braun-Blanquet values corresponding to the observed percentage cover of vegetation layers by PhD researchers (Geographer, Ecologist and Engineer).

Note: S1, S2 and S3 represents the first, second and third PhD researchers respectively. HT = High trees, LT = Low trees, BU = Bushes, HGF = High grasses and forbs, LGF = Low grasses and forbs, GF = Ground flora, AQ = Aquatic

Sites	**Data collector**	**Subject**	**Date**	**Area (m^2)**	**Habitat type**	**HT**	**LT**	**BU**	**HGF**	**LGF**	**GF**	**AQ**
Castle Irwell sample area one	S1	Geography	3-Mar-14	2500	Country park	0	1	1	3	3	0	0
Castle Irwell sample area one	S2	Ecology	3-Mar-14	2500	Country park	0	0	0	3	3	0	0
Castle Irwell sample area one	S3	Engineering	3-Mar-14	2500	Country park	0	0	0	5	0	0	0
Castle Irwell sample area two	S1	Geography	3-Mar-14	2500	Country park	1	2	2	4	2	0	0
Castle Irwell sample area two	S2	Ecology	3-Mar-14	2500	Country park	1	2	2	3	3	0	0
Castle Irwell sample area two	S3	Engineering	3-Mar-14	2500	Country park	2	2	2	4	1	0	0
Castle Irwell sample area three	S1	Geography	3-Mar-14	2500	Country park	1	1	1	5	1	1	0
Castle Irwell sample area three	S2	Ecology	3-Mar-14	2500	Country park	1	1	1	5	1	1	0
Castle Irwell sample area three	S3	Engineering	3-Mar-14	2500	Country park	1	2	1	5	1	2	0

Continued…

Pendleton site 1a	S1	Geography	3-Mar-14	2500	Incidental green space	1	1	0	3	3	1	0
Pendleton site 1a	S2	Ecology	3-Mar-14	2500	Incidental green space	1	1	1	4	3	1	0
Pendleton site 1a	S3	Engineering	3-Mar-14	2500	Incidental green space	1	1	1	3	3	1	0
Pendleton site 1b	S1	Geography	3-Mar-14	2500	Incidental green space	1	0	1	2	2	4	0
Pendleton site 1b	S2	Ecology	3-Mar-14	2500	Incidental green space	1	0	1	2	2	4	0
Pendleton site 1b	S3	Engineering	3-Mar-14	2500	Incidental green space	1	1	1	1	2	5	0
Pendleton site 1c	S1	Geography	3-Mar-14	2500	Incidental green space	1	2	2	2	3	4	0
Pendleton site 1c	S2	Ecology	3-Mar-14	2500	Incidental green space	1	1	1	2	2	5	0
Pendleton site 1c	S3	Engineering	3-Mar-14	2500	Incidental green space	1	1	1	5	2	2	0
Pendleton site 2	S1	Geography	3-Mar-14	16323	Incidental green space	3	2	1	2	2	5	0

Continued…

Pendleton site 2	S2	Ecology	3-Mar-14	16323	Incidental green space	3	3	3	2	2	5	0
Pendleton site 2	S3	Engineering	3-Mar-14	16323	Incidental green space	2	3	4	4	4	4	0
Pendleton site 3	S1	Geography	3-Mar-14	2160	Incidental green space	1	2	1	0	5	0	1
Pendleton site 3	S2	Ecology	3-Mar-14	2160	Incidental green space	0	1	1	1	5	1	0
Pendleton site 3	S3	Engineering	3-Mar-14	2160	Incidental green space	0	1	1	0	5	0	1
Three Sisters area one	S1	Geography	3-Mar-14	2500	Country park	0	2	0	0	0	3	4
Three Sisters area one	S2	Ecology	3-Mar-14	2500	Country park	0	2	1	2	2	2	5
Three Sisters area one	S3	Engineering	3-Mar-14	2500	Country park	1	2	2	2	3	1	5
Three Sisters area two	S1	Geography	3-Mar-14	2500	Country park	2	2	0	3	4	0	0
Three Sisters area two	S2	Ecology	3-Mar-14	2500	Country park	1	2	1	1	5	1	0
Three Sisters area two	S3	Engineering	3-Mar-14	2500	Country park	2	2	2	4	5	0	0

Table B3 – PhD researcher subjects and high trees Braun-Blanquet values cross-tabulation analysis

Specialised subject * High trees Braun-Blanquet value crosstabulation			High trees Braun-Blanquet value				Total
			less than 1%	1% to 5%	6% to 25%	26% to 50%	
Specialised subject	Geography	Count	2.0	6.0	1.0	1.0	10.0
		Expected Count	2.3	5.7	1.3	0.7	10.0
	Ecology	Count	3.0	6.0	0.0	1.0	10.0
		Expected Count	2.3	5.7	1.3	0.7	10.0
	Engineering	Count	2.0	5.0	3.0	0.0	10.0
		Expected Count	2.3	5.7	1.3	0.7	10.0
Total		Count	7.0	17.0	4.0	2.0	30.0
		Expected Count	7.0	17.0	4.0	2.0	30.0

Table B4 – PhD researcher subjects and low trees Braun-Blanquet values cross-tabulation analysis

Specialised subject * Low trees Braun-Blanquet value crosstabulation			Low trees Braun-Blanquet value				Total
			less than 1%	1% to 5%	6% to 25%	26% to 50%	
Specialised subject	Geography	Count	1.0	3.0	6.0	0.0	10.0
		Expected Count	1.3	3.7	4.3	0.7	10.0
	Ecology	Count	2.0	4.0	3.0	1.0	10.0
		Expected Count	1.3	3.7	4.3	0.7	10.0
	Engineering	Count	1.0	4.0	4.0	1.0	10.0
		Expected Count	1.3	3.7	4.3	0.7	10.0
Total		Count	4.0	11.0	13.0	2.0	30.0
		Expected Count	4.0	11.0	13.0	2.0	30.0

Table B5 – PhD researcher subjects and bushes Braun-Blanquet values cross-tabulation analysis

Specialised subject * Bushes Braun-Blanquet value Crosstabulation			Bushes Braun-Blanquet value less than 1%	1% to 5%	6% to 25%	26% to 50%	51% to 75%	Total
Specialised subject	Geography	Count	3.0	5.0	2.0	0.0	0.0	10.0
		Expected Count	1.7	5.7	2.0	0.3	0.3	10.0
	Ecology	Count	1.0	7.0	1.0	1.0	0.0	10.0
		Expected Count	1.7	5.7	2.0	0.3	0.3	10.0
	Engineering	Count	1.0	5.0	3.0	0.0	1.0	10.0
		Expected Count	1.7	5.7	2.0	0.3	0.3	10.0
Total		Count	5.0	17.0	6.0	1.0	1.0	30.0
		Expected Count	5.0	17.0	6.0	1.0	1.0	30.0

Table B6 – PhD researcher subjects and high grasses and forbs Braun-Blanquet values cross-tabulation analysis

Specialised subject * High grasses and forbs Braun-Blanquet value Crosstabulation			High grasses and forbs Braun-Blanquet value less than 1%	1% to 5%	6% to 25%	26% to 50%	51% to 75%	76% to 100 %	Total
Specialised subject	Geography	Count	2.0	0.0	3.0	3.0	1.0	1.0	10.0
		Expected Count	1.0	1.0	2.7	2.0	1.7	1.7	10.0
	Ecology	Count	0.0	2.0	4.0	2.0	1.0	1.0	10.0
		Expected Count	1.0	1.0	2.7	2.0	1.7	1.7	10.0
	Engineering	Count	1.0	1.0	1.0	1.0	3.0	3.0	10.0
		Expected Count	1.0	1.0	2.7	2.0	1.7	1.7	10.0
Total		Count	3.0	3.0	8.0	6.0	5.0	5.0	30.0
		Expected Count	3.0	3.0	8.0	6.0	5.0	5.0	30.0

Table B7 – PhD researcher subjects and low grasses and forbs Braun-Blanquet values cross-tabulation analysis

Specialised subject * Low grasses and forbs Braun-Blanquet value Crosstabulation			Low grasses and forbs Braun-Blanquet value						Total
			less than 1%	1% to 5%	6% to 25%	26% to 50%	51% to 75%	76% to 100 %	
Specialised subject	Geography	Count	1.0	1.0	3.0	3.0	1.0	1.0	10.0
		Expected Count	0.7	1.3	3.0	2.7	0.7	1.7	10.0
	Ecology	Count	0.0	1.0	4.0	3.0	0.0	2.0	10.0
		Expected Count	0.7	1.3	3.0	2.7	0.7	1.7	10.0
	Engineering	Count	1.0	2.0	2.0	2.0	1.0	2.0	10.0
		Expected Count	0.7	1.3	3.0	2.7	0.7	1.7	10.0
Total		Count	2.0	4.0	9.0	8.0	2.0	5.0	30.0
		Expected Count	2.0	4.0	9.0	8.0	2.0	5.0	30.0

Table B8 – PhD researcher subjects and ground flora Braun-Blanquet values cross-tabulation analysis

Specialised subject * Ground flora Braun-Blanquet value Crosstabulation			Ground flora Braun-Blanquet value						Total
			less than 1%	1% to 5%	6% to 25%	26% to 50%	51% to 75%	76% to 100 %	
Specialised subject	Geography	Count	4.0	2.0	0.0	1.0	2.0	1.0	10.0
		Expected Count	3.3	2.7	1.0	0.3	1.3	1.3	10.0
	Ecology	Count	2.0	4.0	1.0	0.0	1.0	2.0	10.0
		Expected Count	3.3	2.7	1.0	0.3	1.3	1.3	10.0
	Engineering	Count	4.0	2.0	2.0	0.0	1.0	1.0	10.0
		Expected Count	3.3	2.7	1.0	0.3	1.3	1.3	10.0
Total		Count	10.0	8.0	3.0	1.0	4.0	4.0	30.0
		Expected Count	10.0	8.0	3.0	1.0	4.0	4.0	30.0

Table B9 – PhD researcher subjects and aquatic Braun-Blanquet values cross-tabulation analysis

Specialised subject * Aquatic Braun-Blanquet value Crosstabulation			Aquatic Braun-Blanquet value				Total
			less than 1%	1% to 5%	51% to 75%	76% to 100%	
Specialised subject	Geography	Count	8.0	1.0	1.0	0.0	10.0
		Expected Count	8.3	0.7	0.3	0.7	10.0
	Ecology	Count	9.0	0.0	0.0	1.0	10.0
		Expected Count	8.3	0.7	0.3	0.7	10.0
	Engineering	Count	8.0	1.0	0.0	1.0	10.0
		Expected Count	8.3	0.7	0.3	0.7	10.0
Total		Count	25.0	2.0	1.0	2.0	30.0
		Expected Count	25.0	2.0	1.0	2.0	30.0

Table B10 – PhD researcher subjects and high trees Braun-Blanquet values Chi-Square Tests statistical analysis

High trees	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
	Pearson Chi-Square	4.903[a]	6	0.556	0.661
	Likelihood Ratio	6.307	6	0.390	0.614
	Fisher's Exact Test	4.664	NA	NA	0.628
	No. of Valid Cases	30	NA	NA	NA
	a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .67.				

Table B11 – PhD researcher subjects and low trees Braun-Blanquet values Chi-Square Tests statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Low trees	**Pearson Chi-Square**	2.759[a]	6	0.838	0.889
	Likelihood Ratio	3.340	6	0.765	0.889
	Fisher's Exact Test	3.197	NA	NA	0.889
	No. of Valid Cases	30	NA	NA	NA
	a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .67.				

Table B12 – PhD researcher subjects and bushes Braun-Blanquet values Chi-Square Tests statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Bushes	**Pearson Chi-Square**	7.071[a]	8	0.529	0.618
	Likelihood Ratio	7.379	8	0.496	0.623
	Fisher's Exact Test	6.514	NA	NA	0.641
	No. of Valid Cases	30	NA	NA	NA
	a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is .33.				

Table B13 – PhD researcher subjects and high grasses and forbs Braun-Blanquet values Chi-Square Tests statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
High grass and forbs	**Pearson Chi-Square**	9.950[a]	10	0.445	0.506
	Likelihood Ratio	11.547	10	0.316	0.590
	Fisher's Exact Test	9.183	NA	NA	0.544
	No. of Valid Cases	30	NA	NA	NA
	a. 18 cells (100.0%) have expected count less than 5. The minimum expected count is 1.00.				

Table B14 – PhD researcher subjects and low grasses and forbs Braun-Blanquet values Chi-Square Tests statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Low grasses and forbs	**Pearson Chi-Square**	3.817[a]	10	0.955	0.991
	Likelihood Ratio	5.094	10	0.885	0.991
	Fisher's Exact Test	4.797	NA	NA	0.991
	No. of Valid Cases	30	NA	NA	NA
	a. 18 cells (100.0%) have expected count less than 5. The minimum expected count is .67.				

Table B15 – PhD researcher subjects and ground flora Braun-Blanquet values Chi-Square Tests statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Ground flora	**Pearson Chi-Square**	6.800[a]	10	0.744	0.849
	Likelihood Ratio	7.728	10	0.655	0.854
	Fisher's Exact Test	6.759	NA	NA	0.858
	No. of Valid Cases	30	NA	NA	NA
	a. 18 cells (100.0%) have expected count less than 5. The minimum expected count is .33.				

Table B16 – PhD researcher subjects and Aquatic Braun-Blanquet values Chi-Square statistical analysis

	Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Aquatic	**Pearson Chi-Square**	4.080[a]	6	0.666	1.000
	Likelihood Ratio	5.520	6	0.479	1.000
	Fisher's Exact Test	4.385	NA	NA	1.000
	No. of Valid Cases	30	NA	NA	NA
	a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .33.				

Table B17 – Observed percentage cover of vegetation layers by ecology undergraduate students.

Note: HT = High trees, LT = Low trees, BU = Bushes, HGF = High grasses and forbs, LGF = Low grasses and forbs, GF = Ground flora, AQ = Aquatic, BT = Built

Data Collector	Date of Pilot	HT (%)	LT (%)	BU (%)	HGF (%)	LGF (%)	GF (%)	AQ (%)	BT (%)
UG1	14-Mar-14	10	2	1	15	70	4	0	0
UG2	14-Mar-14	10	2	1	15	70	4	0	0
UG3	14-Mar-14	10	2	0.43	5	76	4	0.5	1
UG4	14-Mar-14	10	3	1	15	70	6	0	0
UG5	14-Mar-14	10	3	0.2	15	70	4	0	0
UG6	14-Mar-14	15.5	15.5	3	15	80	4	0	0.5
UG7	14-Mar-14	12	7	15	4	61	3	0	0
UG8	14-Mar-14	15.5	3	3	38	63	3	3	0
UG9	14-Mar-14	12	2	1	10	80	3	0	0
UG10	14-Mar-14	11	1	3	3	80	2	0	0

Table B18 – Braun-Blanquet values corresponding to the observed percentage cover of vegetation layers by ecology undergraduate students.

Note: HT = High trees, LT = Low trees, BU = Bushes, HGF = High grasses and forbs, LGF = Low grasses and forbs, GF = Ground flora, AQ = Aquatic, BT = Built

Data Collector	Date of Pilot	Braun-Blanquet values							
		HT	LT	BU	HGF	LGF	GF	AQ	BT
UG1	14-Mar-14	2	1	1	2	4	1	0	0
UG2	14-Mar-14	2	1	1	2	4	1	0	0
UG3	14-Mar-14	2	1	0	1	5	1	0	1
UG4	14-Mar-14	2	1	1	2	4	2	0	0
UG5	14-Mar-14	2	1	0	2	4	1	0	0
UG6	14-Mar-14	2	2	1	2	5	1	0	0
UG7	14-Mar-14	2	2	2	1	4	1	0	0
UG8	14-Mar-14	2	1	1	3	4	1	1	0
UG9	14-Mar-14	2	1	1	2	5	1	0	0
UG10	14-Mar-14	2	1	1	1	5	1	0	0

Appendix C. Cultural ecosystem services and disservices appraisals trials

Appendix C contains the raw data of the first and second trials at appraising cultural ecosystem services and disservices. Table C1 contains the raw data for the habitat for species and pollination ecosystem services gathered by PhD researchers. Table C2 contains the raw data for the recreation and education ecosystem services gathered by PhD researchers.

Table C1 – Habitat for species and pollination ecosystem services raw data gathered by PhD researchers.

Note: For "Subject": 1 = Geography. 2 = Ecology. 3 = Engineering. For "Confidence" and "Ranking Confidence": 2 = high. 1 = medium. 0 = low

				Habitat for Species				Pollination	
Sites	**Area (m^2)**	**Surveyor**	**Subject**	**1 = yes, 0 = no**	**Confidence**	**Ranking (see Figure 4.13)**	**Ranking Confidence**	**1 = yes, 0 = no**	**Confidence**
Castle Irwell sample area one	2500	S1	1	1	2	4	2	0	2
		S2	2	1	2	3	2	0	2
		S3	3	1	2	4	2	0	2
Castle Irwell sample area two	2500	S1	1	1	2	2	2	0	2
		S2	2	1	2	2	2	0	2
		S3	3	1	2	2	2	0	2
Castle Irwell sample area three	2500	S1	1	1	2	2	2	0	2
		S2	2	1	2	2	2	0	2
		S3	3	1	2	2	2	0	2
Pendleton site 1a	2500	S1	1	1	2	2	2	1	2
		S2	2	1	2	2	2	0	2
		S3	3	1	2	2	1	0	2

Continued…

Pendleton site 1b	2500	S1	1	1	1	4	1	0	1
		S2	2	1	2	4	2	0	2
		S3	3	1	2	2	1	0	2
Pendleton site 1c	2500	S1	1	1	2	2	2	1	2
		S2	2	1	2	3	2	0	2
		S3	3	1	2	2	1	0	2
Pendleton site 2	1632 3	S1	1	1	2	3	1	0	0
		S2	2	1	2	2	2	No data	No data
		S3	3	1	2	2	2	0	2
Pendleton site 3	2160	S1	1	1	1	4	2	1	1
		S2	2	0	2	4	2	0	2
		S3	3	1	2	2	2	0	2
Three Sisters sample area one	2500	S1	1	1	2	2	2	0	2
		S2	2	1	2	2	2	No data	No data
		S3	3	1	2	3	1	0	2
Three Sisters sample area two	2500	S1	1	1	2	2	2	1	2
		S2	2	1	2	4	2	No data	No data
		S3	3	1	2	4	2	1	2

Table C2 – Recreation and education ecosystem services raw data gathered by PhD researchers.

Note: *For "Subject": 1 = Geography. 2 = Ecology. 3 = Engineering. For "Confidence" and "Ranking Confidence": 2 = high. 1 = medium. 0 = low*

				Recreation				**Education**			
Sites	**Area (m^2)**	**Surveyor**	**Subject**	**1=yes, 0=no**	**Confiden -ce**	**Rank -ing**	**Ranking Confiden -ce**	**1=yes, 0=no**	**Confiden -ce**	**Rank -ing**	**Ranking Confiden -ce**
Castle Irwell sample area one	2500	S1	1	0	2	3	2	0	2	3	2
		S2	2	1	No data	3	2	1	No data	3	2
		S3	3	1	2	3	2	1	2	3	2
Castle Irwell sample area two	2500	S1	1	0	2	3	2	0	2	3	2
		S2	2	1	No data	3	2	1	No data	3	2
		S3	3	1	2	3	2	1	2	3	2
Castle Irwell sample area three	2500	S1	1	1	2	3	2	1	2	3	2
		S2	2	1	2	3	2	1	2	3	2
		S3	3	1	2	3	2	1	2	3	2
Pendleton site 1a	2500	S1	1	1	1	1.5	1	0	0	3	2
		S2	2	1	2	2	2	0	2	3	2
		S3	3	1	2	2	1	1	2	2	1
Pendleton site 1b	2500	S1	1	1	1	1.5	1	0	0	3	2
		S2	2	1	2	2	2	0	2	3	2
		S3	3	1	2	2	1	1	2	2	1

Continued…

Pendleton site 1c	2500	S1	1	1	1	1.5	1	0	0	3	2
		S2	2	1	2	2	2	0	2	3	2
		S3	3	1	2	2	1	1	2	2	1
Pendleton site 2	16323	S1	1	1	0	2	1	1	0	2.5	1
		S2	2	0	2	2.5	2	0	2	2.5	2
		S3	3	1	2	2	2	1	2	3	1
Pendleton site 3	2160	S1	1	1	2	1	2	0	2	3	2
		S2	2	1	2	2	2	0	2	2.5	2
		S3	3	1	2	2	1	1	2	3	1
Three Sisters sample area one	2500	S1	1	1	2	2	2	1	2	1.5	2
		S2	2	1	2	2	2	1	2	1.5	2
		S3	3	1	2	1	2	1	2	1	2
Three Sisters sample area two	2500	S1	1	1	2	2	2	1	2	1.5	2
		S2	2	1	2	2	2	1	2	1.5	2
		S3	3	1	2	1	2	1	2	1	2

Table C3 – Disease Carrying Animals and Biogenic Volatile Organic Compound (BVOC) Emissions ecosystem services raw data gathered by PhD researchers.

Note: For "Subject": 1 = Geography. 2 = Ecology. 3 = Engineering. For "Confidence" and "Ranking Confidence": 2 = high. 1 = medium. 0 = low

				Disease Carrying Animals				VOC Emissions	
Sites	**Area (m^2)**	**Surveyor**	**Subject**	**1=yes, 0=no**	**Confidence**	**Ranking**	**Ranking Confidence**	**1=yes, 0=no**	**Confidence**
Castle Irwell sample area one	2500	S1	1	1	2	3	2	0	2
		S2	2	1	No data	3	2	No data	No data
		S3	3	1	2	3	2	0	2
Castle Irwell sample area two	2500	S1	1	No data	No data	No data	No data	No data	No data
		S2	2	No data	No data	No data	No data	No data	No data
		S3	3	No data	No data	No data	No data	No data	No data
Castle Irwell sample area three	2500	S1	1	1	2	3	2	No data	No data
		S2	2	1	2	3	2	No data	No data
		S3	3	1	2	3	2	No data	No data
Pendleton site 1a	2500	S1	1	1	2	3	2	1	1
		S2	2	1	1	3	1	0	2
		S3	3	1	2	3	1	No data	No data
Pendleton site 1b	2500	S1	1	1	1	2	1	1	0
		S2	2	1	1	2	1	0	2
		S3	3	1	2	3	1	No data	No data
Pendleton site 1c	2500	S1	1	1	2	3	2	1	1
		S2	2	1	1	3	1	0	2
		S3	3	1	2	3	1	No data	No data

Continued…

Pendleton site 2	16323	S1	1	1	2	3.5	2	1	1
		S2	2	1	1	3	2	1	1
		S3	3	1	2	4	2	1	2
Pendleton site 3	2160	S1	1	1	1	2	2	1	1
		S2	2	0	1	2	2	0	2
		S3	3	No data	No data	No data	No data	No data	No data
Three Sisters sample area one	2500	S1	1	1	2	4	1	1	1
		S2	2	1	2	3	1	1	2
		S3	3	1	2	4	No data	No data	No data
Three Sisters sample area two	2500	S1	1	1	2	2	2	1	2
		S2	2	1	2	2	2	1	2
		S3	3	1	2	4	No data	No data	No data

Table C4 – Fear and Stress and Negative aesthetic ecosystem services raw data gathered by PhD researchers.

Note: For "Subject": 1 = Geography. 2 = Ecology. 3 = Engineering. For "Confidence" and "Ranking Confidence": 2 = high. 1 = medium. 0 = low

				Fear and Stress				Negative aesthetic			
Sites	**Area (m^2)**	**Surveyor**	**Subject**	**1=yes, 0=no**	**Confiden -ce**	**Rank- ing**	**Ranking Confiden -ce**	**1=yes, 0=no**	**Confiden -ce**	**Rank- ing**	**Ranking Confiden -ce**
Castle Irwell sample area one	2500	S1	1	1	2	4	2	0	No data	1	2
		S2	2	1	No data	4	No data	1	No data	1	No data
		S3	3	1	2	4	2	1	2	No data	No data
Castle Irwell sample area two	2500	S1	1	1	No data	4	2	0	No data	1	2
		S2	2	1	No data	4	No data	1	No data	1	No data
		S3	3	1	2	4	2	1	2	No data	No data
Castle Irwell sample area three	2500	S1	1	1	2	3	2	1	2	2	2
		S2	2	1	2	3	2	1	2	2	2
		S3	3	1	2	3	2	1	2	2	2
Pendleton site 1a	2500	S1	1	1	2	4	2	1	2	4	2
		S2	2	1	2	4	2	1	2	4	2
		S3	3	1	2	4	2	1	2	4	2
Pendleton site 1b	2500	S1	1	1	2	4	2	1	2	4	2
		S2	2	1	2	4	2	1	2	4	2
		S3	3	1	2	4	2	1	2	4	2
Pendleton site 1c	2500	S1	1	1	2	4	2	1	2	4	2
		S2	2	1	2	4	2	1	2	4	2
		S3	3	1	2	4	2	1	2	4	2

Continued…

Pendleton site 2	1632 3	S1	1	1	1	3.5	1	1	2	4	2
		S2	2	1	1	2.5	2	1	2	4	2
		S3	3	1	2	2	1	1	2	1	1
Pendleton site 3	2160	S1	1	1	2	1	2	1	1	2	1
		S2	2	0	2	1	2	1	2	1	2
		S3	3	1	2	2	2	1	2	4	2
Three Sisters sample area one	2500	S1	1	1	2	4	2	1	1	3	1
		S2	2	1	2	3	2	0	2	1	2
		S3	3	1	2	4	No data	1	2	1	No data
Three Sisters sample area two	2500	S1	1	1	2	4	2	1	1	3	1
		S2	2	1	2	3	2	0	2	1	2
		S3	3	1	2	4	No data	1	2	1	No data

Table C5 – Legal accessibility and physical accessibility choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low

		1. Legal Accessibility		**2. Physical Accessibility**	
Data collector	**Date**	**a) Access prohibited. b) Access by permission only. c) Open to public access.**	**Confidence (H, M, L)**	**a) Physically restricted. b) Physically accessible but not highly visible. c) Access to site is not restricted.**	**Confidence (H, M, L)**
UG1	14/03/2014	c	H	b	M
UG2	14/03/2014	c	H	b	M
UG3	14/03/2014	c	H	b	M
UG4	14/03/2014	c	H	b	H
UG5	14/03/2014	c	H	b	M
UG6	14/03/2014	c	H	b	H
UG7	14/03/2014	c	H	b	H
UG8	14/03/2014	c	H	c	H
UG9	14/03/2014	c	H	c	H
UG10	14/03/2014	c	H	b	H

Table C6 – Recreational infrastructures and proximity to public transport choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low

		3. Recreational Infrastructures		**4. Proximity to Public Transport**	
Data collector	**Date**	**a) Not present or so poorly maintained as to present safety hazard. b) Present but not well-maintained. c) Present and well-maintained.**	**Confidence (H, M, L)**	**a) No public transport links. b) Infrequent public transport links. c) Frequent public transport links.**	**Confidence (H, M, L)**
UG1	14/03/2014	b	H	a	No data
UG2	14/03/2014	b	H	a	No data
UG3	14/03/2014	b	H	No data	No data
UG4	14/03/2014	a	H	a	M
UG5	14/03/2014	b	H	No data	No data
UG6	14/03/2014	a	H	a	M
UG7	14/03/2014	a	M	a	H
UG8	14/03/2014	a	H	c	M
UG9	14/03/2014	a	H	c	M
UG10	14/03/2014	b	M	No data	No data

Table C7 – Ease of parking and education infrastructures choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low

Data collector	Date	5. Ease of Parking		6. Education Infrastructures	
		a) No parking nearby is allowed. b) Road parking is allowed. c) Car park on site.	**Confidence (H, M, L)**	**a) Not present. b) Present but poorly maintained. c) Present and well-maintained.**	**Confidence (H, M, L)**
UG1	14/03/2014	a	No data	No data	No data
UG2	14/03/2014	a	H	b	M
UG3	14/03/2014	a	H	b	H
UG4	14/03/2014	b	H	b	H
UG5	14/03/2014	No data	No data	No data	No data
UG6	14/03/2014	b	H	b	H
UG7	14/03/2014	b	H	b	M
UG8	14/03/2014	b	M	b	M
UG9	14/03/2014	b	H	b	M
UG10	14/03/2014	a	M	a	H

Table C8 – Dog faeces and street lights choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low, D = dominant, A = abundant, F = frequent, O = occasional, R = rare, N = none

Data collector	**Date**	**7. Dog Faeces**		**8. Street Lights**	
		D, A, F, O, R, or N	**Confidence (H, M, L)**	**F, O, R, or N**	**Confidence (H, M, L)**
UG1	14/03/2014	F	No data	N	No data
UG2	14/03/2014	F	H	N	H
UG3	14/03/2014	F	H	N	H
UG4	14/03/2014	F	No data	N	No data
UG5	14/03/2014	F	H	N	H
UG6	14/03/2014	R	M	N	H
UG7	14/03/2014	O	M	N	H
UG8	14/03/2014	O	No data	N	No data
UG9	14/03/2014	O	No data	N	No data
UG10	14/03/2014	F	No data	N	No data

Table C9 – Evidence of vegetation management and bins choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low, F = frequent, O = occasional, R = rare, N = none

		9. Evidence of Vegetation Management		**10. Bins**	
Data collector	**Date**	**WM = Well Managed. PM = Poorly Managed. NM = Not Managed.**	**Confidence (H, M, L)**	**F, O, R, or N**	**Confidence (H, M, L)**
UG1	14/03/2014	No data	No data	R	No data
UG2	14/03/2014	NM	H	R	H
UG3	14/03/2014	No data	No data	R	H
UG4	14/03/2014	PM	No data	N	No data
UG5	14/03/2014	NM	M	R	M
UG6	14/03/2014	PM	M	N	No data
UG7	14/03/2014	PM	H	N	H
UG8	14/03/2014	PM	No data	R	No data
UG9	14/03/2014	WM	No data	R	No data
UG10	14/03/2014	NM	No data	N	No data

Table C10 – Litter and flowers choices made by undergraduates and their confidence levels.

Note: H = high, M = medium, L = low, D = dominant, A = abundant, F = frequent, O = occasional, R = rare, N = none

Data collector	**Date**	**11. Litters**		**12. Flowers**	
		D, A, F, O, R, or N	**Confidence (H, M, L)**	**D, A, F, O, R, or N**	**Confidence (H, M, L)**
UG1	14/03/2014	R	No data	R	No data
UG2	14/03/2014	O	H	N	H
UG3	14/03/2014	R	H	N	H
UG4	14/03/2014	F	No data	R	No data
UG5	14/03/2014	N	M	N	L
UG6	14/03/2014	O	M	N	L
UG7	14/03/2014	F	M	A	M
UG8	14/03/2014	F	No data	N	No data
UG9	14/03/2014	F	No data	N	No data
UG10	14/03/2014	F	No data	N	No data

Appendix D. Castle Irwell vegetation structure cover-abundance

Appendix D contains the raw date for Castle Irwell. Table D1 contains the observed percentage cover of vegetation layers for sample plots 1 to 7 at Castle Irwell during June 2014. Table D2 contains Bran-Blanquet values corresponding to the raw data displayed in Table D1. The data contained in this appendix will be combined into the overall research results and analysis in Chapter 6.

Table D1 – Observed percentage cover of vegetation layers for sample plots 1 to 7 at Castle Irwell during June 2014.

Note: UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophyte; FH = Floating hydrophyte; BT = Built

Sample area	**Survey date**	**Area (m^2)**	**Relative positions**	**Observed percentage cover of vegetation layers**									
				1. UC (%)	**2. LC (%)**	**3. BW (%)**	**4. LBLG (%)**	**5. CMG (%)**	**6. GF (%)**	**7. OW (%)**	**8. EH (%)**	**9. FH (%)**	**8. BT (%)**
1	05/06/2014	2500	Edge of site	0	5	20	80	1	0	0	0	0	0
2	05/06/2014	2500	Middle of site	0	0	10	90	1	0	0	0	0	0
3	05/06/2014	2500	Middle of site	0	1	5	95	0	0	0	0	0	0
4	05/06/2014	2500	Middle of site	40	20	5	95	5	0	0	0	0	0
5	05/06/2014	2500	Edge of site	80	20	5	95	0	0	0	0	0	0
6	05/06/2014	2500	Edge of site	80	20	5	95	0	0	0	0	0	0
7	05/06/2014	2500	Edge of site	75	10	5	95	0	0	0	0	0	0

Table D2 – Bran-Blanquet values corresponding to the observed percentage cover of vegetation layers for sample plots 1 to 7 at Castle Irwell in June 2014.

Note: UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophyte; FH = Floating hydrophyte; BT = Built

Sample area	**Survey date**	**Area (m^2)**	**Relative positions**	**Braun-Blanquet values**									
				1. UC	**2. LC**	**3. BW**	**4. LBLG**	**5. CMG**	**6. GF**	**7. OW**	**8. EH**	**9. FH**	**8. BT**
1	05/06/2014	2500	Edge of site	0	1	2	5	1	0	0	0	0	0
2	05/06/2014	2500	Middle of site	0	0	2	5	1	0	0	0	0	0
3	05/06/2014	2500	Middle of site	0	1	1	5	0	0	0	0	0	0
4	05/06/2014	2500	Middle of site	3	2	1	5	1	0	0	0	0	0
5	05/06/2014	2500	Edge of site	5	2	1	5	0	0	0	0	0	0
6	05/06/2014	2500	Edge of site	5	2	1	5	0	0	0	0	0	0
7	05/06/2014	2500	Edge of site	4	2	1	5	0	0	0	0	0	0

Appendix E. SuDS Communication and Planning Framework validation results

Appendix E contains the results for the vegetation cover-abundance survey and the cultural ecosystem services and disservices appraisals. Table E1 contains the preliminary site information for all the 49 sites chosen for the framework validation. Table E2 contains the vegetation layers observed percentage cover for sites that deployed the 50m by 50m sample plots (site 24, 25, 29, 44 and 45). Table E3 contains the vegetation layers observed percentage cover for all 49 sites (mean percentage covers for site 24, 25, 29, 44 and 45). Table E4 contains the Braun-Blanquet conversions of the observed percentage cover of vegetation layers for all sites shown in Table E3. Table E5 contains the ranked data for all the cultural ecosystem services and disservices variables appraised (legal accessibility, physical accessibility, recreational infrastructures, educational signs, evidence for educational use, proximity of the nearest educational establishment, dog faeces, bins, and litter). Table E6 contains the ranked data for legal accessibility, evidence for the ranking and the evidence sources. Table E7 contains the ranked data for physical accessibility and reasons for the ranking. Table E8 contains the ranked data for recreational infrastructures and reasons for the ranking. Table E9 contains the ranked data for evidence for educational use, evidence for the ranking and the evidence sources. Table E10 contains the ranked data for proximity of the closest educational establishment and evidence for the ranking.

Table E1 – Preliminary site information

Note: Area group: 1 = less than 2500m^2; 2 = between 2500m^2 and 5499m^2; 3 = between 5500m^2 and 7999m^2; 4 = larger than or equal to 8000m^2. Type of site: 1 = aquatic characteristic or condition dominant; 2 = terrestrial characteristic or condition dominant.

Site ID	Name of site	Survey Date	Area (m^2)	Area group	Perimeter (m)	Type of site
1	Acorn Close allotments green roof	30/04/14	53	1	34	2
2	Adelphi House Car Park	06/03/15	2729	2	276	2
3	Alexandra Park pond	10/06/14	12787	4	529	1
4	Blackfish pond one	09/07/14	14480	4	593	1
5	Blackfish pond two	09/07/14	14046	4	473	1
6	Blackley New Road pond one	16/06/14	7594	3	424	1
7	Blackley New Road pond two	16/06/14	4633	2	279	1
8	Brownfield site beside ASDA Hulme petrol station	16/06/14	14290	4	492	2
9	Brownfield site beside houses behind Salford University	11/06/14	198	1	57	2
10	Canal Road pond	16/06/14	2779	2	214	1
11	Castle Irwell	05/06/14	171754	4	1677	2
12	Chorlton Water Park pond	10/06/14	269	1	65	1
13	Farner Norton Car Park	06/03/15	13322	4	463	2
14	Footpath beside David Lewis Sports Ground	11/06/14	9786	4	542	2
15	Green space behind old Salford Royal Hospital	06/03/15	906	1	143	2
16	Green space behind Salford Cathedral	06/03/15	2142	1	243	2

Continued…

17	Green space opposite David Lewis Sports Ground	04/03/15	5309	2	299	2
18	Heaton Park boating pond	09/07/14	49843	4	1117	1
19	Heaton Park Dell Garden pond	15/07/14	972	1	128	1
20	Heaton Park Western Pleasure Ground pond	09/07/14	2864	2	198	1
21	Hullard Park pond	30/05/14	1286	1	143	1
22	Littleton Rd and Reading St brownfield site	11/06/14	19433	4	562	2
23	Nan Nook Woods	07/08/13	77934	4	1438	2
24	Nutsford Vale	16/08/13	189424	4	2580	2
25	Old Trafford INCOM site	24/05/14	13795	4	537	2
26	Peel park cycle path	15/05/14	5704	3	426	2
27	Peel park Grass Pit	04/03/15	3928	2	252	2
28	Peel park area one	13/05/14	2500	2	200	2
29	Pendleton site one	16/05/14	40249	4	871	2
30	Pendleton site two	03/03/14	16323	4	704	2
31	Pendleton site three	03/03/14	2160	1	235	2
32	Platt Field pond	16/08/14	32697	4	736	1
33	Primrose Primary School pond	14/07/14	1251	1	188	1
34	Quays Reach business park pond	10/06/14	289	1	71	1
35	Range Road public garden	15/06/14	2283	1	193	2
36	Salford University garden	04/03/15	867	1	143	2
37	Salford University Woodland	06/04/14	10555	4	447	2
38	Scott Avenue allotments green roof	30/04/14	10	1	14	2
39	Stamford Brook retention basin one	28/05/14	2585	2	264	1
40	Stamford Brook retention basin two	28/05/14	7423	3	443	1
41	Stamford Brook retention basin three	28/05/14	3441	2	252	1

Continued…

42	Stamford Brook retention basin four	28/05/14	2977	2	221	1
43	Stevenson Square green roof	16/06/14	18	1	25	2
44	The Meadow	21/05/14	73409	4	1067	1
45	Three Sisters	03/03/14	50634	4	943	1
46	Trafford City Council office	28/05/14	235	1	151	1
47	Untrimmed vegetation area inside Hulme Park	16/06/14	1376	1	150	2
48	Whitworth Art Gallery green roof	25/08/14	281	1	101	2
49	Woodland walkway within Alexandra Park	15/06/14	21157	4	1000	2

Table E2 – Observed vegetation layers percentage cover of sample plots and the mean percentage cover for 24, 25, 29, 44 and 45.

Note: UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophytes; FH = Floating hydrophytes; BT = Built

Sample plot	**Observed percentage cover of vegetation layers**									
	1. UC (%)	**2. LC (%)**	**3. BW (%)**	**4. LBLG (%)**	**5. CMG (%)**	**6. GF (%)**	**7. OW (%)**	**8. EH (%)**	**9. FH (%)**	**10. BT (%)**
Site 24 (Nutsford Vale). Survey date = 16/08/2013. Area = 189424m^2. Perimeter = 2580m. Landuse = urban park. Eight 50m by 50m sample plots deployed.										
1	25	10	21	75	10	15	2	0	0	12
2	2	75	15	50	15	22	1	0	0	12
3	12	10	45	45	10	12	0	0	0	12
4	1	3	10	90	13	1	0	0	0	0
5	1	2	2	52	35	22	0	0	0	20
6	1	30	25	25	10	15	0	0	0	15
7	2	2	5	85	7	15	0	0	0	15
8	1	5	15	85	8	0	0	0	0	0
Mean	6	17	17	63	14	13	0	0	0	11
Std Deviation (+/-)	8.684	25.131	13.573	23.597	9.055	8.345	0.744	0.000	0.000	7.146
Site 25 (Old Trafford INCOM site). Survey date = 22/05/2014. Area = 13795m^2. Perimeter = 537m. Landuse = urban park. Two 50m by 50m sample plots deployed.										
1	2	8	2	40	35	90	0	0	0	4
2	5	20	26	60	20	80	0	0	0	0
Mean	4	14	14	50	28	85	0	0	0	2
Std Deviation (+/-)	2.121	8.485	16.971	14.142	10.607	7.071	0.000	0.000	0.000	2.828
Site 29 (Pendleton site one). Survey date = 16/05/2014. Area = 40249m^2. Perimeter = 871m. Landuse = urban park. Two 50m by 50m sample plots deployed.										
1	1	2	0	60	55	20	0	0	0	3
2	3	5	3	15	85	4	0	0	0	3
Mean	2	4	2	38	70	12	0	0	0	3
Std Deviation (+/-)	1.414	2.121	2.121	31.820	21.213	11.314	0.000	0.000	0.000	0.000

Continued…

Site 44a (The Meadow grassland area). Survey date = 21/05/2014. Four 50m by 50m sample plots deployed.										
1	0	0	0	0	95	0	0	0	0	5
2	5	15	18	5	90	0	0	0	0	5
3	1	3	5	50	45	5	0	0	0	5
4	3	5	15	15	90	0	0	0	0	5
Mean	2	6	10	18	80	1	0	0	0	5
Std Deviation (+/-)	2.217	6.500	8.426	22.546	23.452	2.500	0.000	0.000	0.000	0.000
Site 44b (The Meadow riparian area). Survey date = 21/05/2014. Four 50m by 50m sample plots deployed.										
1	50	30	80	10	1	0	0	0	0	0
2	50	30	80	10	1	0	0	0	0	0
3	50	1	50	10	0	0	0	0	0	0
4	60	2	85	10	0	0	0	0	0	0
Mean	53	16	74	10	1	0	0	0	0	0
Std Deviation (+/-)	5.000	16.460	16.008	0.000	0.577	0.000	0.000	0.000	0.000	0.000
Site 44c (The Meadow pond area). Survey date = 21/05/2014. One 50m by 50m sample plot deployed.										
1	0	1	0	84	0	0	18	8	0	0
Site 44mean (The Meadow). Survey date = 21/05/2014. Area = 73409m^2. Perimeter = 1067m. Landuse = country park.										
Grass-land area	2	6	10	18	80	1	0	0	0	5
Riparian area	53	16	74	10	1	0	0	0	0	0
Pond area	0	1	0	84	0	0	18	8	0	0
Mean	18	8	28	37	27	0	6	3	0	2
Site 45 (Three Sisters). Survey date = 03/03/2014. Area = 50634m^2. Perimeter = 943m. Landuse = country park. Two 50m by 50m sample plot deployed.										
1	5	20	15	10	30	5	40	5	0	1
2	20	10	20	60	80	0	0	0	0	0
Mean	13	15	18	35	55	3	20	3	0	0.5
Std Deviation (+/-)	7.506	5.000	2.517	25.000	25.000	2.517	20.000	2.517	0.000	0.500

Table E3 – Observed percentage cover of vegetation layers for all sites shown in Table E1.

Note: The mean percentage cover of sites 24, 25, 29, 44 and 45 are included in this table. ID = site ID. Date = date of survey. Area group: 1 = sites with aquatic features; 2 = sites with only terrestrial features. UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophytes; FH = Floating hydrophytes; BT = Built

ID	Date	Area group	Observed percentage cover of vegetation layers									
			1. UC	2. LC	3. BW	4. LB LG	5. CMG	6. GF	7. OW	8. EH	9. FH	10. BT
1	30/04/14	1	0	0	0	0	100	0	0	0	0	0
2	06/03/15	1	0	0	0	0	0	5	0	0	0	95
3	10/06/14	2	10	5	5	8	1	5	70	2	2	2
4	09/07/14	2	15	40	40	3	0	3	85	15	8	0
5	09/07/14	2	15	40	40	3	0	3	85	5	1	0
6	16/06/14	2	15	10	20	10	1	1	75	5	2	5
7	16/06/14	1	10	15	15	10	1	1	80	2	5	10
8	16/06/14	2	3	7	65	65	0	15	0	0	0	3
9	11/06/14	1	5	0	0	90	0	10	0	0	0	5
10	16/06/14	1	20	10	20	10	2	4	40	20	5	1
11	05/06/14	2	36	10	8	92	1	0	0	0	0	0
12	10/06/14	1	0	3	20	10	0	0	0	60	40	1
13	06/03/15	2	0	5	0	10	0	10	0	0	0	90
14	11/06/14	2	60	25	15	15	75	18	0	0	0	0
15	06/03/15	1	10	13	8	2	85	75	0	0	0	0

Continued…

16	06/03 /15	1	0	0	5	2	80	20	0	0	0	5
17	04/03 /15	1	60	10	10	5	80	53	0	0	0	2
18	09/07 /14	2	40	35	15	3	0	15	85	3	3	3
19	15/07 /14	1	40	15	15	15	0	15	3	80	0	3
20	09/07 /14	1	0	3	15	40	3	3	15	35	60	3
21	30/05 /14	1	40	1	10	80	20	15	1	5	0	30
22	11/06 /14	2	0	0	10	90	0	40	0	0	0	5
23	07/08 /13	2	60	15	10	5	15	40	1	0	0	0
24	16/08 /13	2	6	17	17	63	14	13	0	0	0	11
25	24/05 /14	2	4	14	14	50	28	85	0	0	0	2
26	15/05 /14	1	80	0	25	15	70	20	0	0	0	3
27	04/03 /15	2	40	1	7	10	85	7	0	0	0	10
28	13/05 /14	1	20	0	0	3	90	20	0	0	0	0
29	16/05 /14	2	2	4	2	38	70	12	0	0	0	3
30	03/03 /14	1	8	50	60	70	70	60	0	0	0	2
31	03/03 /14	2	0	1	1	0	95	0	1	0	0	1
32	16/08 /14	2	10	15	5	0	0	0	60	2	0	10
33	14/07 /12	1	0	1	2	80	2	0	30	20	1	5
34	10/06 /14	1	0	1	5	1	50	0	50	1	1	10
35	15/06 /14	1	85	0	60	0	60	55	0	0	0	10
36	04/03 /15	1	0	7	5	1	90	1	0	0	0	7
37	06/04 /14	2	90	5	5	80	0	45	0	0	0	0
38	30/04 /14	1	0	0	0	0	90	0	0	0	0	0

Continued…

39	28/05/14	1	0	12	12	1	58	1	1	18	1	2
40	28/05/14	1	1	10	3	1	73	1	1	15	1	2
41	28/05/14	1	0	2	2	1	82	1	1	14	0	1
42	28/05/14	2	0	1	1	1	85	1	1	13	0	1
43	16/06/14	1	0	0	0	90	0	0	0	0	0	0
44	21/05/14	2	18	8	28	37	27	0	6	3	0	2
45	03/03/14	2	13	15	18	35	55	3	20	3	0	1
46	28/05/14	1	0	0	0	90	0	0	2	5	0	0
47	16/06/14	1	0	0	55	60	0	0	0	0	0	0
48	30/04/14	1	0	0	0	0	95	5	0	0	0	0
49	15/06/14	2	90	0	15	80	15	2	0	0	0	0

Table E4 – Braun-Blanquet values corresponding to the observed percentage cover of vegetation layers for all sites shown in Table E3.

Note: ID = site ID. UC = Upper canopy; LC = Lower canopy; BW = Bush (woody); LBLG = Low bush and long grass (non-woody); CMG = Cropped or mowed grass; GF = Ground flora; OW = Open water; EH = Emergent hydrophytes; FH = Floating hydrophytes; BT = Built. Braun-Blanquet values: 0 = 0% cover; 1 = less than 1% cover; 2 = 1 to 5% cover; 3 = 6 to 25% cover; 4 = 26 to 50% cover; 5 = 51 to 75% cover; 6 = 76 to 100% cover

	Braun-Blanquet values									
ID	**1. UC**	**2. LC**	**3. BW**	**4. LBLG**	**5. CMG**	**6. GF**	**7. OW**	**8. EH**	**9. FH**	**10. BT**
1	0	0	0	0	6	0	0	0	0	0
2	0	0	0	0	0	2	0	0	0	6
3	3	2	2	3	2	2	4	2	2	2
4	3	4	4	2	0	2	6	3	3	0
5	3	4	4	2	0	2	6	2	2	0
6	3	3	3	3	2	2	5	2	2	2
7	3	3	3	3	2	2	6	2	2	3
8	2	3	5	5	0	3	0	0	0	2
9	2	0	0	6	0	3	0	0	0	2
10	3	3	3	3	2	2	4	3	2	2
11	4	3	3	6	2	0	0	0	0	0
12	0	2	3	3	0	0	0	5	4	2
13	0	2	0	3	0	3	0	0	0	6
14	5	3	3	3	5	3	0	0	0	0
15	3	3	3	2	6	5	0	0	0	0
16	0	0	2	2	6	3	0	0	0	2
17	5	3	3	2	6	5	0	0	0	2
18	4	4	3	2	0	3	6	2	2	2
19	4	3	3	3	0	3	2	6	0	2
20	0	2	3	4	2	2	3	4	5	2
21	4	2	3	6	3	3	2	2	0	4
22	0	0	3	6	0	4	0	0	0	2
23	5	3	3	2	3	4	2	0	0	0
24	3	3	3	5	3	3	1	0	0	3
25	2	3	3	4	4	6	0	0	0	2
26	6	0	3	3	5	3	0	0	0	2
27	4	2	3	3	6	3	0	0	0	3
28	3	0	0	2	6	3	0	0	0	0
29	2	2	2	4	5	3	0	0	0	2
30	3	4	5	5	5	5	0	0	0	2

Continued…

31	0	2	2	0	6	0	2	0	0	2
32	3	3	2	0	0	0	5	2	0	3
33	0	2	2	6	2	0	4	3	2	2
34	0	2	2	2	4	0	4	2	2	3
35	6	0	5	0	5	5	0	0	0	3
36	0	3	2	2	6	2	0	0	0	3
37	6	2	2	6	0	4	0	0	0	0
38	0	0	0	0	6	0	0	0	0	0
39	0	3	3	2	5	2	2	3	2	2
40	2	3	2	2	5	2	2	3	2	2
41	0	2	2	2	6	2	2	3	0	2
42	0	2	2	2	6	2	2	3	0	2
43	0	0	0	6	0	0	0	0	0	0
44	3	3	4	4	4	1	3	2	0	2
45	3	3	3	4	5	2	3	2	0	2
46	0	0	0	6	0	0	2	2	0	0
47	0	0	5	5	0	0	0	0	0	0
48	0	0	0	0	6	2	0	0	0	0
49	6	0	3	6	3	2	0	0	0	0

Table E5 – Cultural ecosystem services and disservices appraisal summary for all sites.

Note: Area group: 1 = smaller than 2500m^2; 2 = between 2500m^2 and 5500m^2; 3 = between 5500m^2 and 8000m^2; 4 = larger than or equal to 8000m^2. Cultural services and disservices variables – (1) LA (legal accessibility): 0 = access prohibited; 1 = access by permission only; 2 = open to public access. (2) PA (physical accessibility): 0 = physically restricted and/or not visible to public; 1 = physically accessible but not highly visible to public; 2 = access to site is not restricted and is completely visible to public. (3) RI (recreational infrastructures): 0 = not present or so poorly maintained as to present safety hazard; 1 = present but not well-maintained; 2 = present and well-maintained. (4) ES (educational signs): 0 = not present; 1 = present but poorly maintained signs which explains only one or two aspects of the site and/or not easily readable or visible; 2 = present and well-maintained signs which explain multiple aspects of the site. (5) PEE (proximity of the closest education establishment to sites): 0 = >1000m; 1 = 401m to 1000m; 2 = 101m to 400m; 3 = ≤100m. (6) EEU (evidence of educational use): 0 = no evidence; 1 = evidence of past educational activities; 2 = evidence of on-going educational activities. (7) DF (dog faeces): 0 = frequent; 1 = occasional; 2 = rare. (8) B (bins): 1 = present; 0 = not present. (9) L (litter): 0 = frequent; 1 = occasional; 2 = rare.

Site ID	Sites	Date	Area (m^2)	Area group	Cultural services and disservices variables								
					1. LA	2. PA	3. RI	4. ES	5. PEE	6. EEU	7. DF	8. B	9. L
1	Acorn Close allotments green roof	30/04/14	53	1	0	1	2	0	2	1	1	2	2
2	Adelphi House Car Park	06/03/15	2729	2	1	2	0	0	2	0	0	2	2
3	Alexandra Park pond	10/06/14	12787	4	2	1	2	2	3	2	2	3	2
4	Blackfish pond one	09/07/14	14480	4	2	1	2	0	1	0	0	1	1
5	Blackfish pond two	09/07/14	14046	4	2	1	2	0	1	0	0	1	1
6	Blackley New Road pond one	16/06/14	7594	3	1	2	2	0	1	0	0	1	2
7	Blackley New Road pond two	16/06/14	4633	2	1	0	2	0	2	0	0	2	2

Continued…

8	Brownfield site beside ASDA Hulme petrol station	16/06/14	14290	4	2	1	0	0	2	0	0	2	0
9	Brownfield site beside houses behind Salford University	11/06/14	198	1	2	2	0	0	2	0	0	2	0
10	Canal Road pond	16/06/14	2779	2	2	1	0	0	2	0	0	2	1
11	Castle Irwell	05/06/14	171754	4	2	2	1	0	2	2	2	2	2
12	Chorlton Water Park pond	10/06/14	269	1	2	2	2	2	1	2	2	1	2
13	Farner Norton Car Park	06/03/15	13322	4	1	2	0	0	3	0	0	3	2
14	Footpath beside David Lewis Sports Ground	11/06/14	9786	4	2	2	2	0	1	2	2	1	2
15	Green space behind old Salford Royal Hospital	06/03/15	906	1	2	2	0	0	2	0	0	2	2
16	Green space behind Salford Cathedral	06/03/15	2142	1	2	2	0	0	2	0	0	2	2
17	Green space opposite David Lewis Sports Ground	04/03/15	5309	2	2	2	2	0	2	2	2	2	2
18	Heaton Park boating pond	09/07/14	49843	4	1	0	2	0	1	2	2	1	2
19	Heaton Park Dell Garden pond	15/07/14	972	1	2	2	2	0	1	2	2	1	2
20	Heaton Park Western Pleasure Ground pond	09/07/14	2864	2	2	0	2	0	1	2	2	1	2
21	Hullard Park pond	30/05/14	1286	1	2	2	2	1	2	0	0	2	2
22	Littleton Rd and Reading St brownfield site	11/06/14	19433	4	2	2	0	0	2	0	0	2	1
23	Nan Nook Woods	07/08/13	77934	4	2	1	2	1	2	2	2	2	2
24	Nutsford Vale	16/08/13	189424	4	2	2	2	1	2	2	2	2	1
25	Old Trafford INCOM site	24/05/14	13795	4	2	2	0	0	1	0	0	1	0
26	Peel park cycle path	15/05/14	5704	3	2	2	2	1	3	2	2	3	2
27	Peel park Grass Pit	04/03/15	3928	2	2	2	2	1	3	2	2	3	2
28	Peel park area one	13/05/14	2500	2	2	2	2	1	3	2	2	3	2

Continued…

29	Pendleton site one	16/05/14	40249	4	2	2	0	1	2	0	0	2	0
30	Pendleton site two	03/03/14	16323	4	2	2	1	0	2	0	0	2	0
31	Pendleton site three	03/03/14	2160	1	2	2	0	2	2	0	0	2	2
32	Platt Field pond	16/08/14	32697	4	2	2	2	2	2	2	2	2	1
33	Primrose Primary School pond	14/07/12	1251	1	0	0	2	2	3	2	2	3	2
34	Quays Reach business park pond	10/06/14	289	1	0	2	2	0	2	0	0	2	2
35	Range Road public garden	15/06/14	2283	1	2	2	2	0	2	0	0	2	2
36	Salford University garden	04/03/15	867	1	2	2	2	2	2	1	1	2	2
37	Salford University Woodland	06/04/14	10555	4	2	2	0	0	1	1	1	1	1
38	Scott Avenue allotments green roof	30/04/14	10	1	0	0	2	0	2	2	2	2	2
39	Stamford Brook retention basin one	28/05/14	2585	2	2	2	2	0	2	1	1	2	2
40	Stamford Brook retention basin two	28/05/14	7423	3	2	2	2	0	2	1	1	2	2
41	Stamford Brook retention basin three	28/05/14	3441	2	2	2	2	0	2	1	1	2	2
42	Stamford Brook retention basin four	28/05/14	2977	2	2	2	2	0	1	1	1	1	2
43	Stevenson Square green roof	16/06/14	18	1	2	2	2	0	2	2	2	2	2
44	The Meadow	21/05/14	73409	4	2	2	2	2	2	2	2	2	2
45	Three Sisters	03/03/14	50634	4	2	2	2	2	3	2	2	3	2
46	Trafford City Council office	28/05/14	235	1	0	2	2	0	2	0	0	2	2
47	Untrimmed vegetation area inside Hulme Park	16/06/14	1376	1	2	2	2	0	2	0	0	2	1
48	Whitworth Art Gallery green roof	25/08/13	281	1	0	2	2	2	2	2	2	2	2
49	Woodland walkway within Alexandra Park	15/06/14	21157	4	2	2	2	1	3	2	2	3	2

Table E6 – Legal accessibility (LA) ranking evidence and sources

Note: 0 = access prohibited; 1 = access by permission only; 2 = open to public access.

Site ID	LA ranks	Evidence	Sources
1	0	Manchester City Council owned. Access for people who paid to rent plots to grow food.	Association of Manchester Allotment, 2015
2	1	University of Salford owned. Payment of permits for access to park.	University of Salford, 2015
3	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015a
4	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015b
5	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015b
6	1	King William IV Fishing Pond (locally known as Bottom Billys). Operated by the King William IV Angling Society. Payment of permits (in the form of day tickets) for fishing access.	King William IV Angling Society, 2010
7	1	King William IV Fishing Pond (locally known as Bottom Billys). Operated by the King William IV Angling Society. Payment of permits (in the form of day tickets) for fishing access.	King William IV Angling Society, 2010
8	2	Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015
9	2	Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015

Continued…

10	2	Timperley Flood Storage Basin. Open to public access, in accordance with the right to roam and public rights of way.	Dixon, 2012; O'Callaghan *et al.*, 2010
11	2	University of Salford owned former racecourse. Open to public access.	Irwell Valley Sustainable Communities Project, 2014; Gardiner *et al.*, 1998
12	2	Part of the Chorlton Water Park Local Nature Reserve. Open to public access. Payment for permits for course fishing.	Manchester City Council, 2015c
13	1	University of Salford owned. Payment of permits for access to park.	University of Salford, 2015
14	2	Part of Peel Park. Open to public access.	Salford City Council, 2015
15	2	Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015
16	2	Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015
17	2	Part of Peel Park. Open to public access.	Salford City Council, 2015
18	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015b
19	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015b
20	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015b
21	2	Public park, managed by Trafford Council.	Trafford Council, 2015; Lancashire Gardens Trust, 2009
22	2	Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015

Continued…

23	2	A site of Biological Importance (grade B). Open to pulic access, in accordance with the right to roam and public rights of way.	Manchester City Council, 2015d;
24	2	Public park, managed by Red Rose Forest and local Friends of groups. Open to public access.	Northwest Regional Development Agency & Forestry Commission, 2012; Manchester City Council, 2015e
25	2	Green space beside Alphacom Telecommunication office. Open to public access, in accordance with the right to roam and public rights of way.	Natural England, 2015
26	2	Part of Peel Park. Open to public access.	Salford City Council, 2015
27	2	Part of Peel Park. Open to public access.	Salford City Council, 2015
28	2	Part of Peel Park. Open to public access.	Salford City Council, 2015
29	2	Green space. Open to public access.	Salford City Council, 2015b; Salford City Council, 2015c; BBC, 2013
30	2	Green space. Open to public access.	Salford City Council, 2015b; Salford City Council, 2015c; BBC, 2013
31	2	Green space. Open to public access.	Salford City Council, 2015b; Salford City Council, 2015c; BBC, 2013
32	2	Public park, managed by Manchester City Council and Friends of Platt Fields.	Friends of Platt Fields, 2015; Manchester City Council, 2015e
33	0	SuDS pond in a public primary school. Access to pond for staffs and students only.	Primrose Hill Primary School, 2012; Urban Vision, 2007
34	0	Privately owned business park. Access prohibited.	No information.
35	2	Green space, open to public access.	No information.

Continued…

36	2	Salford University owned green space. Open to public access.	No information.
37	2	Salford University owned green space. Open to public access.	University of Salford, 2014; University of Salford, & Google, 2012
38	0	Manchester City Council owned. Access for people who paid to rent plots to grow food.	Manchester City Council, 2015f; Association of Manchester Allotment, 2015
39	2	SuDS system within a new-build estate. Managed by the National Trust and other key stakeholders, including community/citizens. Open to public access.	Kazmierczak & Carter, 2010
40	2	SuDS system within a new-build estate. Managed by the National Trust and other key stakeholders, including community/citizens. Open to public access.	Kazmierczak & Carter, 2010
41	2	SuDS system within a new-build estate. Managed by the National Trust and other key stakeholders, including community/citizens. Open to public access.	Kazmierczak & Carter, 2010
42	2	SuDS system within a new-build estate. Managed by the National Trust and other key stakeholders, including community/citizens. Open to public access.	Kazmierczak & Carter, 2010
43	2	Green roof planted by Red Rose Forest as part of their effort to turn Stevenson Square from grey to green. Open to public access and the herbs and fruit plants grown on the green roof are edible.	Red Rose Forest, 2013b; 2013b
44	2	Crescent Meadow is a local park. Open to public access. Managed by Red Rose Forest and Salford City Council.	Salford City Council, 2014; Northwest Regional Development Agency, & Forestry Commission, 2012b
45	2	A Site of Biological Importance managed by the Salford Ranger team, Salford City Council. Open to public access.	Salford City Council, 2014
46	0	SuDS system within an office complex.	Mara, 2013

Continued…

47	2	Public park. Open to public access.	Manchester City Council, 2015e
48	0	Green roof for maintenance access only.	Red Rose Forrest, 2010; University of Manchester, 2015; Drivers Jonas, 2012; Red Rose Forest, 2013a
49	2	Public park, managed by Manchester City Council.	Manchester City Council, 2015a

Table E7 – Physical accessibility (PA) ranking and reasons.

Note: 0 = physically restricted and/or not visible to public; 1 = physically accessible but not highly visible to public; 2 = access to site is not restricted and is completely visible to public.

Site ID	PA ranks	2. Physical Accessibility reasons
1	1	Green roof requires a ladder for access. Tall fence and locked gate prevent access.
2	2	No issues.
3	1	Pond has fence around it, but it's low enough to easier climb over.
4	1	Pond situates behind dense understorey.
5	1	Pond situates behind dense understorey.
6	2	No issues.
7	0	Pond is behind tall fence and a locked gate, where permission is required in order to access go behind the gate.
8	1	There are tall fence on three sides of the site, therefore no accessible via the three sides. It can be accessed via the side that does not have a fence. But due to overgrown vegetation, access is not easily visible.
9	2	No issues.
10	1	Pond situates behind dense understorey.
11	2	No issues.
12	2	No issues.
13	2	No issues.
14	2	No issues.
15	2	No issues.
16	2	No issues.
17	2	No issues.
18	2	No issues.
19	2	No issues.
20	0	Fence around pond which prevents access to the pond.
21	2	No issues.

Continued…

22	2	No issues.
23	1	Dense understorey.
24	2	No issues.
25	2	No issues.
26	2	No issues.
27	2	No issues.
28	2	No issues.
29	2	No issues.
30	2	No issues.
31	2	No issues.
32	2	No issues.
33	0	Tall fences and locked gate prevent access.
34	2	No issues.
35	2	No issues.
36	2	No issues.
37	2	No issues.
38	0	Green roof requires a ladder for access. Tall fence and locked gate prevent access.
39	2	No issues.
40	2	No issues.
41	2	No issues.
42	2	No issues.
43	2	No issues as the roof is low.
44	2	No issues
45	2	No issues
46	2	No issues
47	2	No issues
48	2	No issues as access is via second floor of the gallery, which is accessible by steps or elevator.
49	2	No issues.

Table E8 – Recreational infrastructures (RI) ranking and reasons.

Note: 0 = not present or as poorly maintained as to present safety hazard; 1 = present but not well-maintained; 2 = present and well-maintained.

Site ID	RI ranks	Reasons
1	2	The allotment provide opportunities for people to grow their own food.
2	0	No evidence.
3	2	People can observe wildlife (ducks, geese etc) and practise fishing at clearly marked out places at the edge of the ponds. Well maintained benches and footpaths.
4	2	People can observe wildlife (ducks, geese etc) and practise fishing at the edge of the ponds.
5	2	People can observe wildlife (ducks, geese etc) and practise fishing at the edge of the ponds.
6	2	People can observe wildlife (ducks, geese etc) and practise fishing on the fishing platforms provided on-site.
7	2	People can observe wildlife (ducks, geese etc) and practise fishing on the fishing platforms provided on-site.
8	0	No evidence.
9	0	No evidence.
10	0	No evidence.
11	1	Benches and footpaths (created by differential mowing) are available but not well maintained.
12	2	Well maintained benches, viewing platform and footpaths.
13	0	No evidence.
14	2	Well maintained footpath and grassed sport pitches immediately beside the site.
15	0	No evidence.
16	0	No evidence.
17	2	Well maintained green and grassed sport pitches immediately space the site.
18	2	Hired boats are available for rowing in the pond. Café next to the pond.
19	2	Well maintained benches, viewing platform and footpaths.
20	2	Well maintained benches and footpaths.

Continued…

21	2	Well maintained benches, viewing platform and footpaths.
22	0	No evidence.
23	2	Well maintained footpaths.
24	2	Well maintained benches and footpaths.
25	0	No evidence.
26	2	Well maintained cycle path and grassed pitch immediately beside the site.
27	2	Well maintained footpaths, benches and children’s play area.
28	2	Well maintained footpaths, benches and children’s play area.
29	0	No evidence.
30	1	Poorly maintained footpaths.
31	0	No evidence.
32	2	People can observe wildlife (ducks, geese etc) at the edge of the ponds. Well maintained benches and footpaths.
33	2	Well maintained benches, viewing platform and footpaths.
34	2	Well maintained benches, picnic tables and footpaths.
35	2	Well maintained benches and footpaths.
36	2	Well maintained benches and footpaths.
37	0	No evidence.
38	2	The allotment provide opportunities for people to grow their own food.
39	2	Well maintained benches and footpaths.
40	2	Well maintained benches and footpaths.
41	2	Well maintained benches and footpaths.
42	2	Well maintained benches and footpaths.
43	2	Many restaurants and cafes immediately beside the site.
44	2	Well maintained benches and footpaths
45	2	Well maintained benches and footpaths
46	2	Well maintained benches and footpaths
47	2	Well maintained benches and footpaths
48	2	The gallery is well equipped with fine art, café and rest areas.
49	2	Well maintained benches and footpaths.

Table E9 – Evidence of educational use (EEU) ranking, evidence and sources.

Note: 0 = no evidence; 1 = evidence of past educational activities; 2 = evidence of on-going educational activities.

Site ID	EEU ranks	Educational use and community acceptance evidence	Sources
1	1	This roof was erected in 2011 and it was part of the Red Rose Forest's Little Green Roofs project to educate people about climate change. No information was found to indicate whether this project is still on-going or not.	(Red Rose Forest, 2011a, 2012)
2	0	No evidence.	
3	2	The main website of Alexandra Park provides information (history, ecology, interactive map etc.) of the site. There is a learning centre specifically to tailor lessons for the children that use the park. The pond itself has a secure education zone. There is also a Friends of Alexandra Park (a local resident group) caring for the park. These programs are on-going.	(Alexandra Park CLC, 2013; Manchester City Council, 2015a)
4	0	No evidence.	
5	0	No evidence.	
6	0	No evidence.	
7	0	No evidence.	
8	0	No evidence.	
9	0	No evidence.	
10	0	No evidence.	
11	2	The Irwell Valley Sustainable Communities Project details the site's flood basin development plans. The project itself is designed to support local residents to adapt to climate change and live more sustainably. This group is on-going. Gardiner *et al.* (1998) written about the site in their fieldwork guide to Greater Manchester.	(Gardiner *et al.*, 1998; The Irwell Valley Sustainable Communities Project, 2015)

Continued…

12	2	The site features in the Manchester City Council's Wild About Manchester website, which is a biodiversity educational tool. RSPB and Manchester City Council ran biodiversity educational events at the site in the summer of 2015. A local conservation group (Sale and Altrincham Conservation Volunteers) also run educational events in and concerning the site. Educational activities and local group are on-going.	(Sale and Altrincham Conservation Volunteers, 2013; Manchester City Council, 2015e, 2015b)
13	0	No evidence.	
14	2	University of Salford students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university. The site is part of Peel park, which has a Friends of group for organising community volunteering events. The Friends of group is on-going.	(University of Salford & Google, 2012; Du Preez, 2014; Salmon & Baldry, 2014; University of Salford, 2014)
15	0	No evidence.	
16	0	No evidence.	
17	2	Salford University students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university. The site is part of Peel park, which has a Friends of group for organising community volunteering events. The Friends of group is on-going.	(University of Salford & Google, 2012; Du Preez, 2014; Salmon & Baldry, 2014; University of Salford, 2014)
18	2	Heaton Park has designated daily educational programmes for Foundation Stage and Key Stage 1 and 2 children. The park also has guided woodland walks, nature trials, wildlife walks, history trials and farm tours. Community groups (Friends of Heaton Hall, Heaton Park Trust) dedicate themselves in preserving, managing and maintaining the site, and also educating and engaging local people about the site. All activities mentioned are ongoing.	(Manchester City Council, 2015b, 2015c, 2015e)
19	2	Heaton Park has designated daily educational programmes for Foundation Stage and Key Stage 1 and 2 children. The park also has guided woodland walks, nature trials, wildlife walks, history trials and farm tours. Community groups (Friends of Heaton Hall, Heaton Park Trust) dedicate themselves in preserving, managing and maintaining the site, and also educating and engaging local people about the site. All activities mentioned are on-going.	(Manchester City Council, 2015b, 2015c, 2015e)

Continued…

20	2	Heaton Park has designated daily educational programmes for Foundation Stage and Key Stage 1 and 2 children. The park also has guided woodland walks, nature trials, wildlife walks, history trials and farm tours. Community groups (Friends of Heaton Hall, Heaton Park Trust) dedicate themselves in preserving, managing and maintaining the site, and also educating and engaging local people about the site. All activities mentioned are on-going.	(Manchester City Council, 2015b, 2015c, 2015e)
21	0	No evidence.	
22	0	No evidence.	
23	2	The site is part of Wythenshawe Park. The park has a variety of educational programs concerning the biodiversity of the park and its woodlands. There are three community groups formed by local residents for the management, maintenance, education and general community engagements. All activities are on-going.	(Wythenshawe Parks Watch Association, 2012; Friends of Wythenshawe Hall, 2013; Manchester City Council, 2015f, 2015f; Parks and Gardens Data Services Ltd., 2015)
24	2	Red Rose Forest started the Nutsford Vale engagement project in 2011 to educate and engage local people on topics such as woodland management and habitat protection. There is also a community group called the Nutsford Vale Park Project, which was formed by local residents for the management and maintenance of the site. The community group is on-going.	(Nutsford Vale Park Project, 2010; Red Rose Forest, 2011b)
25	0	No evidence.	
26	2	Friends of Peel Park organises volunteering events to engage and educate local people about the park and its biodiversity. University of Salford students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university. The Friends of group is on-going.	(University of Salford & Google, 2012; Du Preez, 2014; Salmon & Baldry, 2014; University of Salford, 2014)

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27	2	Friends of Peel Park organises volunteering events to engage and educate local people about the park and its biodiversity. University of Salford students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university. The Friends of group is on-going.	(University of Salford & Google, 2012; Du Preez, 2014; Salmon & Baldry, 2014; University of Salford, 2014)
28	2	Friends of Peel Park organises volunteering events to engage and educate local people about the park and its biodiversity. The Friends of group is on-going. Salford University students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university.	(University of Salford & Google, 2012; Du Preez, 2014; Salmon & Baldry, 2014; University of Salford, 2014)
29	0	No evidence.	
30	0	No evidence.	
31	0	No evidence.	
32	2	Friends of Platt Fields is a community group started by local residents for the management, maintenance of the site, and also for the education and engagement of local people with regards to the use of the site and the biodiversity it offers. The Friends of group is on-going.	(Friends of Platt Fields, 2015)
33	2	The site situates within the Primrose Hill Primary School, serving as an ecological education tool for the students of the school. The pond is still being used as an educational tool for students in the school. But people outside of the school requires permission to access the site. Schools are community assets.	(Primrose Hill Primary School, 2012)
34	0	No evidence.	
35	0	No evidence.	
36	1	Salford University students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university. The site was also recently been left intentionally overgrown, and an educational sign was erected to inform people of wildlife that can be observed due to the change of vegetation maintenance regime.	(University of Salford & Google, 2012; University of Salford, 2014)

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37	1	Salford University students performed biodiversity baseline surveys and compiled an interactive, web-based, map and a report showing the biodiversity of lands (including this site) surrounding the university.	(University of Salford & Google, 2012; University of Salford, 2014)
38	2	Feeding Manchester is a group that promotes and educate people about sustainable food in Greater Manchester. Scott Avenue allotment features as one of the many places in Manchester that fit into the sustainable food source criteria. Feeding Manchester is still on-going.	(Kindling Trust, 2015)
39	1	This site has become a reference to other new residential building projects with regards to the way it was designed to mitigate against floods and has also become a reference to how a new estate can be built in a flood risk area. The design reference might be superseded. Public engagement efforts with local communities were made prior to the development, but no evidence were found for on-going community engagements. Details on past engagements cannot be found.	(Kazmierczak & Carter, 2010)
40	1	This site has become a reference to other new residential building projects with regards to the way it was designed to mitigate against floods and has also become a reference to how a new estate can be built in a flood risk area. The design reference might be superseded. Public engagement efforts with local communities were made prior to the development, but no evidence were found for on-going community engagements. Details on past engagements cannot be found.	(Kazmierczak & Carter, 2010)
41	1	This site has become a reference to other new residential building projects with regards to the way it was designed to mitigate against floods and has also become a reference to how a new estate can be built in a flood risk area. The design reference might be superseded. Public engagement efforts with local communities were made prior to the development, but no evidence were found for on-going community engagements. Details on past engagements cannot be found.	(Kazmierczak & Carter, 2010)

Continued…

42	1	This site has become a reference to other new residential building projects with regards to the way it was designed to mitigate floods and has also become a reference to how a new estate can be built in a flood risk area. The design reference might be superseded. Public engagement efforts with local communities were made prior to the development, but no evidence were found for on-going community engagements. Details on past engagements cannot be found.	(Kazmierczak & Carter, 2010)
43	2	Red Rose Forest (a community forest based in Greater Manchester) created this green roof as part of the project to transform Stevenson Square (central Manchester) from grey to green. The community forest is also in charge of the maintenance of the roof. A residents group called New Leaf was also involved with the construction and are now involved with the maintenance of the roof. The resident group is still on-going.	(Red Rose Forest, 2013b; A New Leaf, 2015)
44	2	Red Rose Forest was involved in the creation of this site as a new urban meadow for wildlife conservation. It is also involved with the management and maintenance of the site. This involvement is on-going.	(Northwest Regional Development Agency & Forestry Commission, 2012)
45	2	The Salford Rangers regularly organises volunteer conservation sessions on-site. This is ongoing.	(Michaels, 2014)
46	0	No evidence.	
47	0	No evidence.	
48	2	Red Rose Forest was involved in the building of the green roof. Whitworth Art Gallery is a public gallery, providing the public with arts expeditions and education. The gallery is free entry and expeditions are on-going.	(Red Rose Forrest, 2010; AECOM *et al.*, 2011; Red Rose Forest, 2013a)
49	2	The main website of Alexandra Park provides information (history, ecology, interactive map etc.) of the site. There is a learning centre specifically to tailor lessons for the children who use the park. The pond itself has a secure education zone. There is also a Friends of Alexandra Park (a local resident group) caring for the park. All the activities mentioned are on-going.	(Alexandra Park CLC, 2013; Manchester City Council, 2015a)

Table E10 – Proximity of the closest educational establishment (PEE) ranking and evidence.

Note: 0 = >1000m; 1 = 401m to 1000m; 2 = 101m to 400m; 3 = ≤100m.

Site ID	PEE ranks	Closest educational establishment to site
1	2	210.92m (Rodney House School)
2	2	120.77m (Salford University Adelphi Building)
3	3	68.59m (St Bede's College)
4	1	819.68m (Bowker Vale Primary School)
5	1	819.68m (Bowker Vale Primary School)
6	1	718.77m (Bowker Vale Primary School)
7	2	217.30m (Bear Necessities)
8	2	190.79m (Rolls Crescent Primary School)
9	2	241.97m (fourquarters Accessible Web Design Consultancy)
10	2	309.59m (Brentwood School)
11	2	278.15m (Brentnall Primary School)
12	1	406.42m (Southern Cross School)
13	3	16.09m (Salford University Adelphi Building)
14	1	406.285m (Charlestown Community Primary School)
15	2	153.63m (Salford University Adelphi Building)
16	2	184.01 (Manchester Midi school)
17	2	191.50m (fourquarters Accessible Web Design Consultancy)
18	1	593.32m (Bowker Vale Primary School
19	1	992.44m (St Hildas C Of E Primary)
20	1	853.85m (St Hildas C Of E Primary)
21	2	355.12m (St Alphonsus RC Primary School)
22	2	379.38m (Albion High School)
23	2	389.45m (Button Lane Primary School)

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24	2	157.00m (Saint Richard's Roman Catholic Primary School)
25	1	708.09m (Salford University Mediacity campus)
26	3	85.592m (Peel Building at Salford University)
27	3	360.48m (Salford University Newton Building)
28	3	150.40m (Salford University Newton Building)
29	2	159.35m (St Pauls Cross Lane C Of E Primary School)
30	2	236.07m (St Pauls Cross Lane C Of E Primary School)
31	2	201.36m (Lark Hill Community Primary School)
32	2	298.35m (Manchester High School For Girls)
33	3	0m (Primrose Primary School)
34	2	192.21m (Salford City College's Mediacity Future Skill)
35	2	168.00m (St Bede's College)
36	2	210.57m (Salford University Newton Building)
37	1	459.18m (Charlestown Community Primary School)
38	2	316.36m (St Hilda's C Of E Primary School)
39	2	251.35m (Broadheath Primary School)
40	2	202.26m (Broadheath Primary School)
41	2	365.44m (Broadheath Primary School)
42	1	403.45m (Broadheath Primary School)
43	2	223.86m (Manchester College Of Higher Education & Media Technology)
44	2	212.086m (Peel Building at Salford University)
45	3	88.73m (Chatsworth High School)
46	2	239.69m (Trafford College)
47	2	146.84m (St Wilfrid's R C Primary School)
48	2	224.50m (Manchester Hospital School)
49	3	66.23m (St Bede's College)