An experimental assessment of the importance of substrate depth in the design of brown roofs: floral colonisation and community structure

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BSc Dissertation 2008

Abstract

This study aimed to find out how well brown roofs emulate the initial colonizing flora found on brownfields and how their design could be improved through changes in substrate depth. This was done by firstly researching the ecology of brownfields and green roofs and showing how brown roofs are seen as a mitigation tool for the loss of brownfield habitats. A controlled experiment was then set up with two brown roof designs of different substrate depths and control brownfield plots which were then seeded and left for 5½ months before being surveyed over two periods to define their plant community and structure.

The results showed that the treatments supported similar plant communities in respect of their species composition but there were significant differences between other dependant variables such as *biomass* and *species richness* and between the dominance of the key flora, which over time may lead the treatments onto divergent successional paths. Because of these reasons it is concluded that brown roof should be considered as a mitigation method for the loss of brownfield habitats but further development and analysis of their design is needed.

1 Introduction

Brownfield sites in the UK are becoming increasingly recognised as important urban ecosystems worthy of conservation (Harrison & Davies 2002) due to the unique and varied habitats often contained within them that can lead to rare assemblages of invertebrates (Eyre et al 2003; Gibson 1998), rich and diverse plant communities (Gilbert 1989) and rare birds and mammals using them for nesting and foraging (Gedge 2003; Donovan et al 2005). All of which means urban brownfield sites often have a higher ecological value when compared with protected rural Greenfield sites that are intensively managed for agriculture. However, despite the ecological value brownfield sites often have, they are feeling the brunt of development pressures due to the present governments housing and development policies (Communities and Local Government 2006). The idea of redeveloping these ‘wasting assets’ is seen as a step towards a more ‘sustainable’ model for urban living (reduction in travelling distances, more efficient energy use etc), which in itself should be encouraged but the loss of these habitats and the many environmental services they provide cannot be ignored.

Finding a resolution between these two worthy issues has become the focus for some urban ecologists and planners (Lorimer 2008) and has led to the development of green roofs which can provide some of the same environmental services that urban green spaces can, such as the production on cold air and the reduction of storm water run-off (Obendorfer et al 2007). A new development in this concept is the use of specifically designed green roofs aimed at emulating the habitats found in brownfield sites so that they can be used to replace brownfield sites when they are redeveloped, these roofs have become known as ‘brown roofs’.

This project will be looking at the initial colonising flora on these 'brown roofs' and comparing it with brownfield flora to see if brown roofs can indeed be used as a substitute for brownfield sites when they are developed. The design of brown roofs will also be analysed to see if changes in substrate depth will provide a better simulation of a brownfield habitat.

1.1 Defining a green roof

Also known as a nature, living or eco-roof, the term *green roof* as defined by English Nature (2003) will be used in this study to describe both intensive ornamental roof gardens and extensive roofs with more natural plants or self-established vegetation and the term *brown roof* will refer to a specific type of Biodiverse green roof which is extensive and designed to create a vegetation system similar to that found on a brownfield site (Emilsson, 2006).

The design of an extensive green roof (EGR) (including brown roofs) can vary, but they all have the same general components as shown in Fig. 1.1. The main difference brown roofs have compared with other green roofs is that their growing medium or substrate is designed to emulate brownfields so it is usually made up from crushed brick and cement (English Nature 2003).

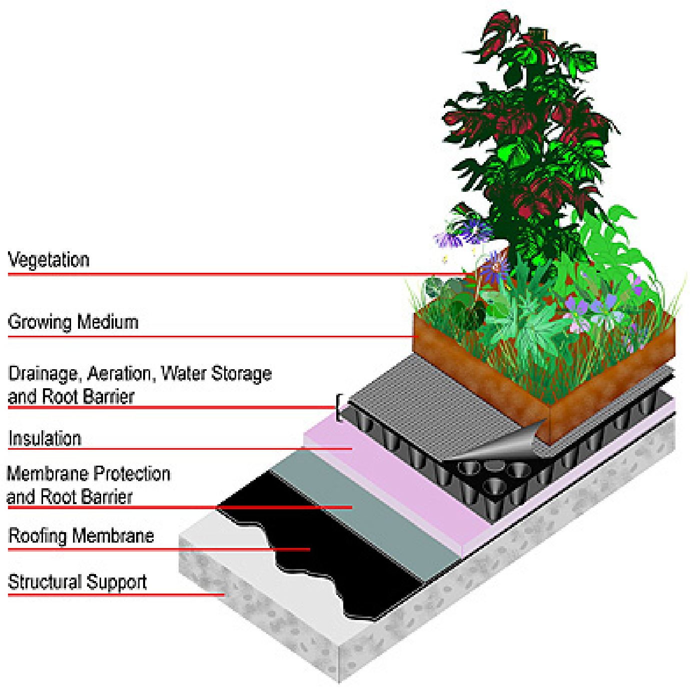


Figure 1.1 Typical design of an extensive green roof (Morgan, 2004)

1.2 Aims and objectives

Aim

The aim of this study is to establish if changes in the substrate depth of brown roofs help to provide a habitat more suited to brownfield flora.

Objectives

1. To develop a controlled experiment made up of brown roofs with various substrate depths and control brownfield sites.
2. Analyse the plot's floral communities for similarities between the various designs of brown roof and control brownfield sites, comparing their biodiversity, species composition and productivity.
3. Make recommendations for future brown roof designs from how well the differing substrate depths in the brown roofs emulated brownfield flora.

2 Literature review

2.1 Background to brownfield ecology and conservation

2.1.1 What are brownfields?

Brownfields comprise of landfills, industrial dumps, sand or gravel pits and former colliery and railway land, but are principally previously-developed land made up of demolished buildings such as houses and factories (Strauss & Biedermann 2006; Small et al 2003). The UK National Land Use Database estimates that there were over 64,000ha of brownfield land in the UK in 2004 (cited in Lorimer 2008). After demolition sites are usually flattened out as a domed expanse of brick rubble containing a lot of finer material including mortar. There tends to be a large variation in the stoniness of the substrate across a site and this variation in substrate also affects the pH and nutrient content of the substrate making brownfield very heterogeneous.

Artificial habitats such as brownfields have often been studied from a point of view which regards them as an impoverished version of some other more desired system (Gisbon 1998), however this attitude is changing as ecologists are becoming more aware of the fauna and flora in these habitats and are becoming concerned about the effects of humans on these ecosystems (Niemela 1999). Below is a summary of the ecology of brownfields.

2.1.2 Invertebrate communities

A significant amount of work has been put into studying invertebrate communities on brownfield sites (Small et al 2003; Eyre et al 2004; Strauss & Biedermann 2005; Gibson 1998; Whiteley 1994; Lazenby 1988) which have found that brownfield sites can be important for nature conservation as they support a high invertebrate species

richness. They also support a substantial amount of invertebrate species (313) that are nationally scarce and rare which is between 12-15% of the total nationally scarce and rare invertebrate species although this is considered as a 'gross underestimate' of the potential contribution brownfield sites make to the conservation of scarce and rare invertebrates (Gibson 1998). The main reason for this high species richness and significantly large amount of scarce and rare species appears to be due to the early successional state of most brownfield sites (Strauss & Biedermann 2006; Small et al 2003; Eyre et al 2003; Angold et al 2006), with the best sites being those which have patchy but species-rich vegetation which is kept in an open state for long periods because of nutrient, toxicity and/or disturbance limits on succession (Gibson 1998).

2.1.3 Other fauna found on brownfield sites

Rare birds in the Red Data Book (Batten et al 1990) such as the Black Redstart *Phoenicurus ochruros* and House Sparrow *Passer domesticus* are known to use brownfields for feeding and suitable built structures for nesting sites, along with the Linnet *Carduelis cannabina* and starlings *Sturnidae* spp. (Shaw et al 2008; Jones 2008; Donovan et al 2005). Sites in Sheffield are known to support breeding pairs of ground nesting species such as Meadow Pipit *Anthus pratensis* and Skylark *Alauda arvensis* (Gilbert 1989). Brownfields are also known to support foraging birds such as Feral pigeon *Columba livia* and in the late summer granivores such as goldfinches *Carduelis* spp., redpolls *Carduelis* spp. and Reed Bunting *Emberiza schoeniclus*.

Other urban wildlife such as the Red fox *Vulpes vulpes*, West European hedgehog *Erinaceus europaeus,* Norwegian rat *Rattus norvegicus* and the Common Pipistrelle bat *Pipistrellus pipistrellus* are known to use brownfields as foraging areas but they

tend not to take up residence due to lack of shelter. Once the grass stage has been achieved sites can support small mammals such as the Field vole *Microtus agrestis* and older sites may have the Wood mouse *Apodemus sylvaticus* and the Bank vole *Myodes glareolus* (Gilbert 1989).

2.1.4 Flora on brownfield sites

Brownfields, with perhaps a few exceptions such as unkempt pavements, constitute the only urban surface with spontaneous vegetation (Sukopp & Werner 1987) and can be of importance due to their high floristic diversity (Herbst & Herbst 2006; Muratet et al 2007; Angold et al 2006) and potentially large numbers of locally very rare species found on them (Muratet et al 2007). Muratet et al (2007) also found that 58% of the total areas flora species richness in the Greater Paris region was recorded on brownfield sites and their mean richness was 39 species per site, varying from 5 to 92 species. The most frequent group of plants on brownfields are ruderal perennials or species of ruderal mesoxerophytic grass lands with one study finding 54% of the species being mainly wind dispersed (Maurer et al 2000) but if left alone vegetation on brownfields tend to go through a series of successional stages which Gilbert (1989) describes in detail.

They start with a pioneer community in which R-strategists are favoured (Sukopp & Werner 1982), such as Oxford Ragwort *Senecio squalidus*, American Willowherb *Epilobium ciliatum*, knotgrasses *Polygonum* spp., Common Groundsel *Senecio vulgaris* and annual meadow grasses. Gilbert (1989) describes how a site cleared in January had by August accumulated 41 species, including the above. The second stage is made up of perennial herbs including Rosebay Willowherb *Epilobium*

angustifolium, wormwood *Artemisia absinthium*, Fennel *Foeniculum vulgare*, golden-rod *Solidago* spp. and Feverfew *Tanacetum parthenium*. The third stage is primarily perennial grasses before finally culminating in stage four consisting of scrub woodland mainly consisting of k-strategists. Sites can be disturbed at any point leading to their successional clock being set back and site conditions such as pollution or lack of nutrients can lead to a stunted successional climax so the age of site does not necessarily indicate what stage the site will be in (Gilbert 1989).

It is worth noting that all of the above are aspects of brownfield ecology; however they are known to have other benefits as well such as improving the quality of life of local residents due to their experiences with nature (Sukopp & Werner 1987). Kowarik (1993) suggests that vegetated wasteland sites may also be important for local climate by producing cold air (cited in Herbst & Herbst 2006) and brownfields are known to help slow down urban runoff (Pauleit 2004). There are however problems associated with brownfields such as soil contamination and fly tipping and they are often described as 'wasteland' due to their perceived lack of use and degradation.

2.1.5 Brownfield conservation and development

Despite their importance for urban biodiversity as illustrated above, UK Government policy recommends the redevelopment of derelict land as a measure to achieve 'beneficial' use from these 'wasting assets' and to prevent urban sprawl (Donovan et al 2005), with a national target of 60% of new houses to be built on brownfield land (Communities and Local Government 2006). This pressure for development means it is inevitable that brownfield sites of nature conservation value will be threatened with

development, whilst interviews with urban ecologists suggest that neither planners nor project managers of developments expect wasteland communities to be recreated as part of the development process (Harrison & Davies 2002).

The complexities of developing and manufacturing brownfield land are illustrated by Donovan et al (2005) who undertook a biodiversity audit of an area in Birmingham called the Eastside. An open-spaces survey found that part of the Eastside was made up of derelict sites that used to be industrial land but which had been left to go 'wild'. These classic brownfield sites consisted of a variety of different habitat types including:

- Bare soil and derelict buildings
- Ephemeral/short perennial and tall herb or fern communities
- Areas of scattered and dense scrub
- Neutral grassland
- Scattered and dense bracken and trees

These habitat types are all described by Gilbert (1989) as discussed earlier and show the successional process brownfield sites go through, Fig. 2.11 shows two of the Eastside sites which illustrate these different habitat types. The four brownfield sites Donovan et al (2005) surveyed had an average of 95 plant species and 134 insect species including 11 SoCCs (species of conservation concern). Over the whole area 37 species of bird were recorded, ten of which were SoCCs, including the Black Redstart *Phoenicurus ochruros*, and two species of bat were also found in the area.

Figure 2.11 Brownfield sites in Eastside: Jennens Road and New Bond Street (Donovan et al 2005).

Eastside was found to have three legally protected species and it was felt that wildlife issues should be considered in the very early stages of the planning process to ensure the protection and enhancement of some of the habitats. Suggestions for conservation include the use of ‘dead land’, brown roofs, and changing ground maintenance practices.

The lack of conservation or mitigation of brownfield development is in part due to the lack of recognition of brownfield habitats as a distinctive habitat and the fact that mitigation methods are seen as ‘highly experimental and without any guarantees of success’ (Harrison & Davies 2002). However one solution being put forward to mitigate against the loss of these habitats is to replicate them at roof level by creating ‘brown roofs’, (a type of green roof) a technique that has been used to some success in parts of Europe and some locations in the UK (Donovan et al 2005).

2.2 Green roofs

2.2.1 History of green roofs

Using plants on buildings has a long history stretching back from the Hanging Gardens of Babylon (Lundholm 2006), roof gardens on Roman villas and Viking earth sheltered huts, a technique still used today by some Scandinavians (English Nature 2003). In the 20th century Le Corbusier declared roof gardens to be an essential part of the future city in his manifesto for modern architecture (1926; cited in Emilsson, 2006) but it was not until the 1970s with the development of the modern style extensive green roofs in Germany and Switzerland along with growing environmental concern which saw the gradual growth in popularity of green roofs, particularly extensive green roofs. The industry has continued to grow rapidly in these countries so that in 2001 approximately 13.5 million square metres of green roof was laid in Germany (Oberndorfer et al 2007); this growth has been encouraged by many German cities introducing incentive programs to promote green roof technology. This growth in green roofs has started to spread to the rest of Europe and North America (English Nature 2003). However, in the UK green roofs still appear to be a novelty with most being built as showcase buildings or environmental centres, but the potential for green roofs in the UK is massive with an estimated 20,000 hectares (200 million m^2) of existing urban roofs in the UK which could be vegetated with little or no structural modification (Corus 2001).

2.2.2 Types of green roofs

The term 'green roof' can be used to describe three categories of vegetated roofs:

1) Intensive
2) Biodiverse

3) Extensive

Figure 2.21 An intensive green roof on Coast Plaza Hotel in Vancouver (Michigan State University 2008)

Intensive green roofs are often referred to as roof gardens which are basically the equivalent of parks and gardens at ground level so can include all their associated flora, need regular maintenance (Fig. 2.21) and have a substrate depth of 20cm or more (Oberndorfer 2007).

Extensive green roofs (EGRs) (Fig. 2.22) need little or no maintenance and irrigation, have a substrate depth of between 2-20cm (Oberndorfer 2007) and can consist of succulents, mosses, herbs and grasses (English Nature 2003). Biodiverse green roofs are designed specifically to increase biodiversity on the roof, they can be intensive but they tend to be extensive, however they vary from the usual EGRs because they are designed to create a varied habitat and they are often left to colonize with little external inputs such as fertilization or planting of sedums etc… (see Fig. 2.23). This study will only be looking at EGRs and more specifically biodiversity roofs as brown

Figure 2.22 An extensive Sedum green roof on Canary Wharf, London (Kadas 2006)

Figure 2.23 A newly built green roof on the Cantonal Hospital, Basel designed to increase biodiversity (Brenneisen 2006)

roofs are a version of these and intensive green roofs can have a completely different ecology.

EGRs can either be established on-site or by bringing prefabricated vegetation to the roof (Emilsson & Rolf 2005), and are usually vegetated using succulents belonging to the *Crassulaceae* family as they are able to withstand long periods without water (Emilsson & Rolf 2005). They can provide a variety of services including visual relief and accessible green space, stormwater retention (Mentens et al 2006, VanWoert et al 2005), increases in sound insulation, fire resistance (Oberndorfer 2007) and the longevity of the roof membrane (Porsche & Kohler 2003), reductions in building energy consumption (Del Barrio 1998) and in the urban heat-island (Getter & Rowe 2006), and habitat provision (Brenneisen 2006; Lundholm 2006).

2.2.3 Flora and Fauna found on green roofs

In the past EGRs have generally been considered relatively species poor, however studies in Basel, Switzerland show that low biotic diversity of green roofs is mainly due to their thin substrate (Brenneisen, 2006). Research has shown that a well-designed Biodiverse green roof with varying substrate depths creating different microhabitat conditions can provide habitat compensation for rare and endangered species. One study found an assemblage of 79 beetle and 40 spider species being supported on a green roof, of which 11 beetle and 7 spider species were classified in Red Data Books as endangered (Brenneisen 2006). This ecological-compensation potential of EGRs has been a focus for research (Kadas 2006; Jones 2002; Baumann 2006) as it would mean green roofs could be used in maintaining the UK's Constant Natural Assets (CNA) (O'Connor, 2000).

Brenneisen (2003) found that bird species such as the Black Redstart *Phoenicurus ochruros*, House Sparrow *Passer domesticus* and White Wagtail *Motacilla alba* use green roofs as food habitats for insects and seed (cited in Baumann 2006). In addition a study by Baumann (2006), also in Switzerland, found that the Northern Lapwing *Vanellus vanellus* (a ground-nesting bird) was using various green roofs for breeding although they were yet to be successful. Jones (2002) and Kadas (2006) in the UK have studied the invertebrate fauna of green roofs, Jones found several unusual and uncommon species but in general he found a relatively low species diversity that had little in common with brownfield sites (although none of the roofs studied had been built to emulate brownfields). Kadas however found a 'high abundance' of invertebrates with at least 10% of the species being designated nationally rare or scarce.

When studying EGRs in Berlin, Kohler (2006) found the average number of vascular plant species on the roofs were 15, although this varied year on year with numbers going as high as 64. Within an urban setting Kohler expects that rare plant species would have difficulty establishing on EGRs but in a rural setting there are examples of rare plants occurring on EGRs such as an old waterworks in Teufelsse where Heather *Calluna vulgaris* and Tussock grass *Deschampsia cespitosa* have become established, or on the more intensive roof of the Lake water plant in Wollishofen which has a remarkable biological diversity and is now one of the largest sites of the orchid *Orchis moris* in the area (Emilsson 2005).

2.2.4 Brown roof development

The use of Biodiverse green roofs as replacement habitats for brownfield flora and fauna has been a recent development (Donovan et al 2005) as brownfield sites have become increasingly recognised as important ecosystems. Conservationists have begun to look to green roofs to compensate brownfield site loss as parallels can be found between them due to the early successional state of their habitats; however Jones (2002) found little similarity between the invertebrate populations he studied on these two habitats. This lack of similarities between the flora and fauna of green roofs and brownfield sites has led to the development of Biodiverse green roofs specifically being designed to emulate brownfield sites, these are called *brown roofs.*

Brown roofs have been developed within the London area, specifically around Deptford Creek where two buildings have had brown roofs built on them (Fig. 2.24**)** (Grant 2006). They have been designed to provide a habitat for fauna and flora usually found on brownfield sites, including the protected Black Redstart *Phoenicurus ochruros* (Grant 2006) which are mainly found in urban areas within the UK.

Figure 2.24 A brown roof on the Laban Dance centre, Deptford Creek (Kadas, 2006)

The substrate and design of a brown roof is very similar to an extensive green roof, the main difference being that the substrate can be made up of a mixture of broken bricks, cement and soil. Brown roofs are often seeded with an annual wild flower mix

(Grant 2006) then allowed to colonize on their own rather than using sedum mats or similar techniques to create the vegetation cover (English Nature 2003). The disadvantages of creating brown roofs like the one on the Laban Dance Centre (Fig. 2.24) is that because it is specifically designed to emulate a type of habitat, it can lose a lot of the other benefits a green roof provides. The substrate is heavier leading to increases in building costs, and vegetation can be sparse due to slow colonisation or poor habitat quality. Other Biodiversity green roofs such as the ones found on Shaw's Cottages shown in Fig. 2.25 and the one roof on Contonal Hospital (Fig. 2.23) are designed to provide more diverse habitats and so can have a greater diversity (Jones 2002; English Nature 2003). Although it is important to note that they do not necessarily provide the right habitat for brownfield flora as brown roofs should.

Figure 2.25 Part of the main roof at 11 Shaw's Cottages, South London (Grant 2006)

2.2.5 Potential relevance to BAPs

English Nature (2003) examined the UK, London and Birmingham Biodiversity Action Plans and the Biodiversity Audits for London and East Anglia to see which species of conservation concern may benefit from green and brown roofs. Plant species were not included as there are relatively few species of special conservation concern for which roofs are important although they noted green roofs could be designed for species of conservation concern when appropriate. Altogether 25 species

were thought to benefit from green roofs which included bats, several birds, beetles, flies, bees, wasps and spiders although as yet many of these benefits are yet to be proven.

2.3 Relevance of study

Along with London, Birmingham and Manchester have both developed brown roofs to mitigate for populations of Black Redstarts *Phoenicurus ochruros* (Jones 2008) as part of their BAPs (The Wildlife Trust for Birmingham and the Black Country 2000). Yet despite these developments, hitherto there are no controlled brown roof experiments aimed at establishing how well they emulate the flora on brownfields. Experiments with substrate depth have in the past found varying the depth can provide a more diverse habitat and so lead to increases in biodiversity (Brenneisen 2006; Jones 2002); however there have been no experiments with substrate depth and brown roofs to see if certain depths will provide a better emulation of brownfield habitats. This is due to the difficulty of making comparisons between *in-situ* brown roofs and brownfields because of the uniqueness of each site and the lack of good empirical data. But in general the ecology of brownfields and green roofs are an understudied area and with this in mind more work is needed to establish the potential of green and brown roofs to support populations of various wildlife (English Nature 2003). Brown roofs in particular need further research to establish their ecological benefits as they have many other disadvantages when compared to standard green roofs.

Developing an experiment that would help provide answers to both these research questions should help to give developers and ecologists increased confidence in using

brown roofs in the mitigation of brownfield development and go towards answering the four 'fundamental research & experimentation' areas that English Nature say studies are required in (2003), which include:

- Studies of patterns of colonisation and succession on green roofs of different types over a number of years and see the effects of different management strategies.
- Experimentation with different designs, orientations, substrate type and depth and micro-topographical detailing.

3 Method

3.1 Introduction

To fulfil the aims and objectives set earlier a controlled experiment was set up to test the design of brown roofs and compare them with brownfield sites under the same conditions. A controlled experiment was decided upon as it meant a few variables could be tested without the interference of other variables which would have occurred had real brown roofs and brown fields been used, although the artificially created plots can't produce results as true to reality it was felt stronger conclusions could be made from their data.

The experiment was made up of two types of self-contained 813x1220mm brown roof plots (Fig. 3.11), one with a substrate depth of 100mm as this is a more standard depth for EGRs known best to support *Sedum* species (Orberndorfer 2007;Dunnett & Nolan 2002) and one with 150mm as this is known to help support a more diverse mix of herbaceous perennials (Orberndorfer 2007), this should show if increasing the standard substrate depth would provide a better emulation of a brownfield habitat.

A control 813x1220mm brownfield plot was also built with a substrate depth of 150mm made up of the same type of substrate as the brown roof plots (Fig. 3.11). To reduce variables within the experiment the only difference was the brownfield plots

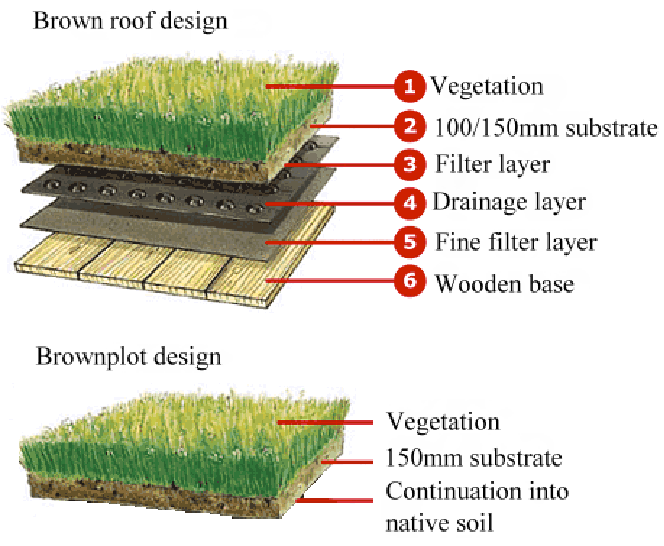


Figure 3.11 Cross section of brownplot and brown roof plots

had no drainage layer, thus enabling the plant roots access to unlimited substrate and so increasing their potential water and mineral resources. As the brownfield plots were designed to be the same as the brown roofs, apart from the drainage layer, they do not exactly replicate a normal brownfield site, so these control plots are called brownplots to avoid confusion.

Each of the plots was replicated five times to reduce the chance of a Type II error occurring during analysis. They were then left for around 5½ months over spring and summer with no irrigation or fertilization before being sampled using a 100 point quadrat and surveyed for floral species richness over two periods, one in early summer and the other in early autumn. Below is an account of where and how the experiment was set up before leading into what type of data was collected and how it was analysed.

3.2 Site description

The site for the experiment was an 'Ecopark' situated in a mix of urban residential land, playing fields and grassy flood plain (Fig. 3.21) and is run by the Birmingham and Black Country Wildlife Trust. It was chosen due to its relative isolation from human activity compared with many other sites in the Birmingham area, meaning the plots were not tampered with throughout the period of the experiment. The site is also a haven for flora and fauna giving the experiment access to a potentially large and diverse seed bank hopefully creating more chance of

Figure 3.21 Location of the ecopark (Google Earth 2008).

colonization that could occur naturally. A brief list of some of the flora and fauna found in the Ecopark is shown in Appendix 8.3.

Weather data for the period of the experiment is shown in Table 3.22 along with average temperatures and total rainfall for previous years. It is worth noting that the summer of 2008 was exceptionally wet for Birmingham as can be seen by the higher rainfall totals for all the months except June compared with the average for previous years, there was also an exceptionally high amount of rainfall for the first nine days in September (around triple the amount usually taken for the whole month!). It also wasn't a particularly hot summer with all the months except May falling below the average temperature. These unusual weather conditions will have affected growth on the plots as more water would have been available, potentially leading to less dehydration and more growth.

Month	Ave min wind speed (m/s)	Ave wind speed (m/s)	Ave max wind speed (m/s)	Ave air temp (°C)		Ave rel Humidity (%)	Total Rain (mm)		Ave solar Radiation (W m2)
				2008	2002-2007		2008	2002-2007	
April (from the 4th)	1.14	2.19	3.35	7.55	9.6	75.37	61.09	37.4	144.54
May	1.05	1.99	3.03	13.4	12.0	69.69	100.92	67.2	172.7
June	1.01	1.99	3.06	14.67	15.7	66.45	35.54	65.1	206.7
July	1.11	2.13	3.22	16.46	17.0	70.87	115.31	65.1	190.33
August	1.1	2.16	3.29	16.1	17.1	76.66	103.62	64.7	136.69
September (to the 9th)	1.27	2.37	3.55	13.25	15.1	85.35	122.65	44.9	85.01

Table 3.22 Weather data for the period of the experiment taken from the Watson building at the University of Birmingham's Edgbaston Campus (approximately 7.2km away from the site). Averages for the years 2002-2007 are taken from Met Office data from their Coleshill station (Latitude = 52.48 N Longitude =01.69 W). Averages are for the whole month.

3.3 Plot creation

The plots were created by building a wooden box with or without a floor depending on if it was for the brownfield plot or brownplot (Fig. 3.31 & 3.32). For the brownfield plots the wooden structure was then covered with pond liner and a plug hole put in one end for excess water to drain away (Fig. 3.33), a drainage and filter

layer was then put into the plot (Fig. 3.34) and finally a fine filter layer was fixed around the edge to prevent loss of the substrate down the sides (Fig. 3.35).

In all the plots a substrate made up of hydroleca (expanded clay) and sharp sand at a proportion of 2-1 was added, this is a common substrate mix used on extensive green roofs (Morgan 2004) rather than brown roofs which tend to use rubble made up of brick and cement. This choice of substrate was made to see if it was possible to produce brown roofs using this lighter material which would make them easier to produce on a larger scale and so more attractive to developers. A 10mm layer of topsoil from a brownfield site was spread on top (Fig. 3.36) as brown roofs are recommended to use soil from brownfields. Fifteen of these plots were created, five of each type, which were ordered one after another so that any environmental variables in the site would be spread across all three types of plot (Fig. 3.37). Each plot was then seeded with 2g of a wild seed mix made up of indigenous species (Zerbe et al 2003) which has been used on other local brownroof projects (see Appendix 8.2 for the break down of the seed mix).


Figure 3.31 Wooden structure of brownroofs


Figure 3.32 Wooden structure of brown plots


Figure 3.33 Structure covered with pond liner


Figure 3.34 Drainage layer added


Figure 3.35 Fine filter layer added

All the plots were at ground level as the environmental variables created by having the brownroofs on a roof and the brownplots at ground level would have effected the

resulting growth and species compostion. As the experiment is only looking at the variable of access to ground water (through substrate depth) is was not necessary to have the brownroof plots on a roof.

The plots were seeded on the 4th April 2008 and then were surveyed over two periods between the 3rd and 17th July 2008 (Period 1) and then again between 11th and 23rd September 2008 (Period 2).


Figure 3.36 Substrate added


Figure 3.37 Plots placed out evenly

3.4 Methods and problems of data collection

A square quadrat measuring 450 x 450mm with 50mm squares was used to gather information from 100 points. The quadrat didn't cover the whole plot; instead the corner of it was positioned 300x150mm away from the edge, this was to avoid measuring any edge effect there may have been. The information gathered from the 100 points was put into a table (see Appendix 8.1) and was made up of: the types of species present and whether it was present as an individual, stem or leaf (referred to as a 'hit'), if the individual was in flower or seeding and the length of the individual, although if a species was flowering and seeding at the same time, only the seeding was recorded which will have led to lower flowering species numbers. Other information put into the collection table included the maximum height of the plot and all the species present (Emilsson & Rolf 2005).

The identification of a species was done by using The Wild Flower Key (Rose, 2006) and Wild Flowers Of Britain And Ireland (Blamey, Fitter & Fitter, 2003), but this

process had many problems as a lot of the individuals were immature or dehydrated meaning their appearance was not always similar to the specimens in the books. This led to a large amount of initial detective work until enough knowledge was available to identify species in their various forms, which means it is likely that there are more errors in species identification than anticipated, especially early on in the process.

All grass species were grouped into a functional group (grasses) to reduce errors in species identification which will mean any measures of species richness are likely to be less than the true amount.

3.5 Methods and problems of data analysis

From the data collected six variables for each plot were compiled, which were: *Max. height* (height of the tallest plant), *species richness* (total species found on plot), *biomass* (total 'hits' including individuals, stems and leafs), *average length* (total length of all the individuals found under the points of the quadrat divided by amount of individuals)*, number of flowered species* and *number of seeded species*. These six dependant variables (DVs) have then been analysed for patterns and relationships with Treatment (depth of substrate) and Period (time when data was collected), using a Canonical Variate Analysis (CVA) to find where patterns are likely to occur, then a general linear model (multivariate), one-way ANOVA and Pearsons tests to define and explore any patterns and relationships found (see Fig.3.52).

After analysing the six dependant variables the top ten overall species were then worked out by using the total hits for a species in a plot to generate a percentage of the total composition for each species in each plot. The top ten species are shown in

Table 3.51 and include the invasive (not in the seed mix) Knotgrass *Polygonum aviculare*, Black Medic *Medicago lupulina*, White Clover *Trifolium repens* and grasses *Poaceae* spp, although grasses is not an individual species.

Top 10 plants	Total (%)
Biting stonecrop *Sedum acre*	21.88
Knotgrass *Polygonum aviculare*	11.48
Oxeye daisy *Leucanthemum vulgare*	7.48
Thale cress *Arabidopsis thaliana*	6.35
Black Medic *Medicago lupulina*	5.78
Hoary plantain *Plantago media*	5.53
Bladder campion *Silene vulgaris*	5.04
Wild carrot *Daucus carota*	4.94
White clover *Trifolium repens*	4.10
Grasses *Poaceae* spp.	3.65

Table 3.51 The top ten dominant species overall the plots

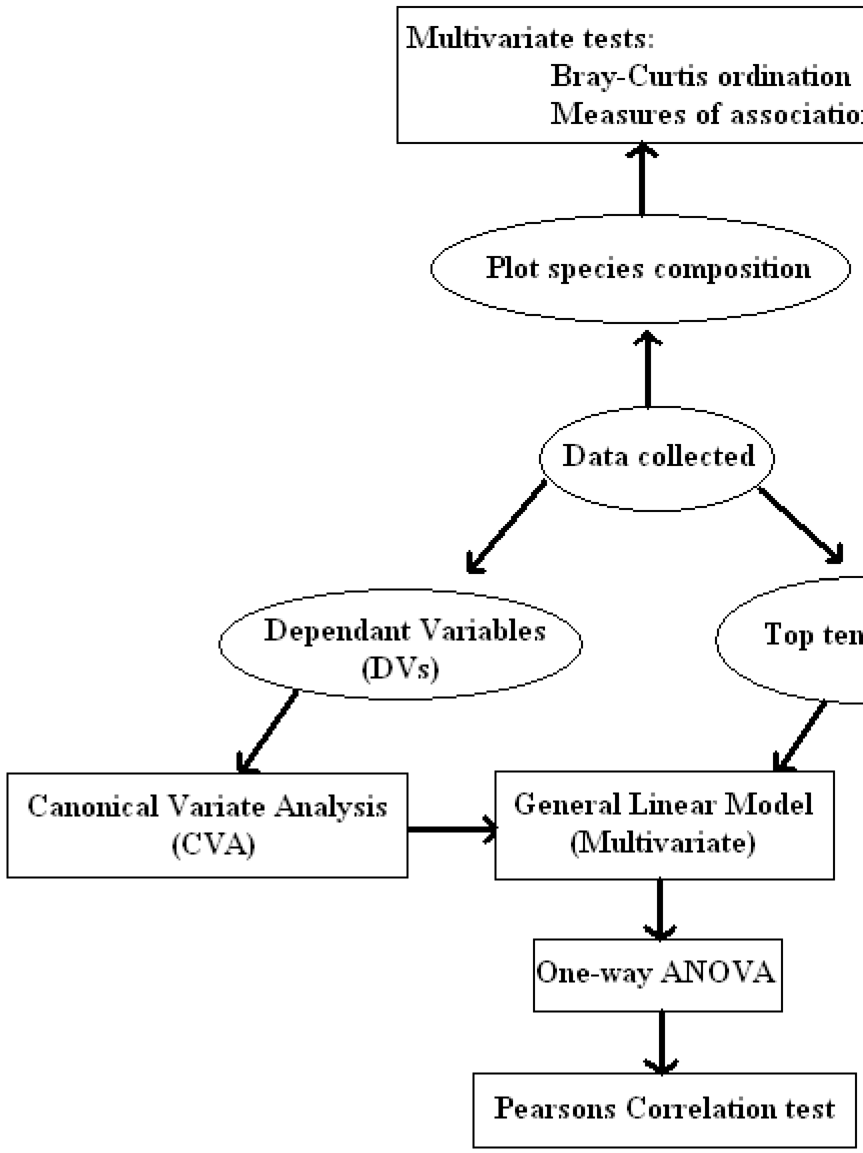


Figure 3.52 The analysis process for each type of data.

The data from these dominant species was then subjected to the same analysis as the dependant variables apart from no CVA was used (see Fig 3.52). Along with the changes in the top ten species amongst the treatments, two multivariate tests (Bray-Curtis ordination: Sorensens, and Measures of association: Jaccard) were used for the total species composition of each plot to get a broader sense of the similarities in the plant communities between treatments (see Fig. 3.52). These types of tests are often

used to compare fauna similarities in communities and are easily transferable to compare the plot flora communities (Scarsbrook 2002).

3.6 Substrate analysis

The substrate was analysed firstly for the moisture content using a sample from each plot by measuring the weight of the sample before and after it had been baked at 65º for 24 hours, the results were analysed using one-way ANOVA but there was no significant pattern (for results see Appendix 8.3). The organic content and fine particle content of the topsoil were analysed by baking in an oven until all the organic content was burnt off, then the sample was re-weighed, another sample of topsoil was wet sieved to find the fine particle content, and the results are shown in Table 3.61.

Organic Content		
	% mineral	% organic
Soil Sample	89.160	10.840
Fine Particle content		
	% sand	% fine particles
soil sample	66.411	33.589

Table 3.61 Organic and fine particle content of the sop soil used in the substrate.

4. Results

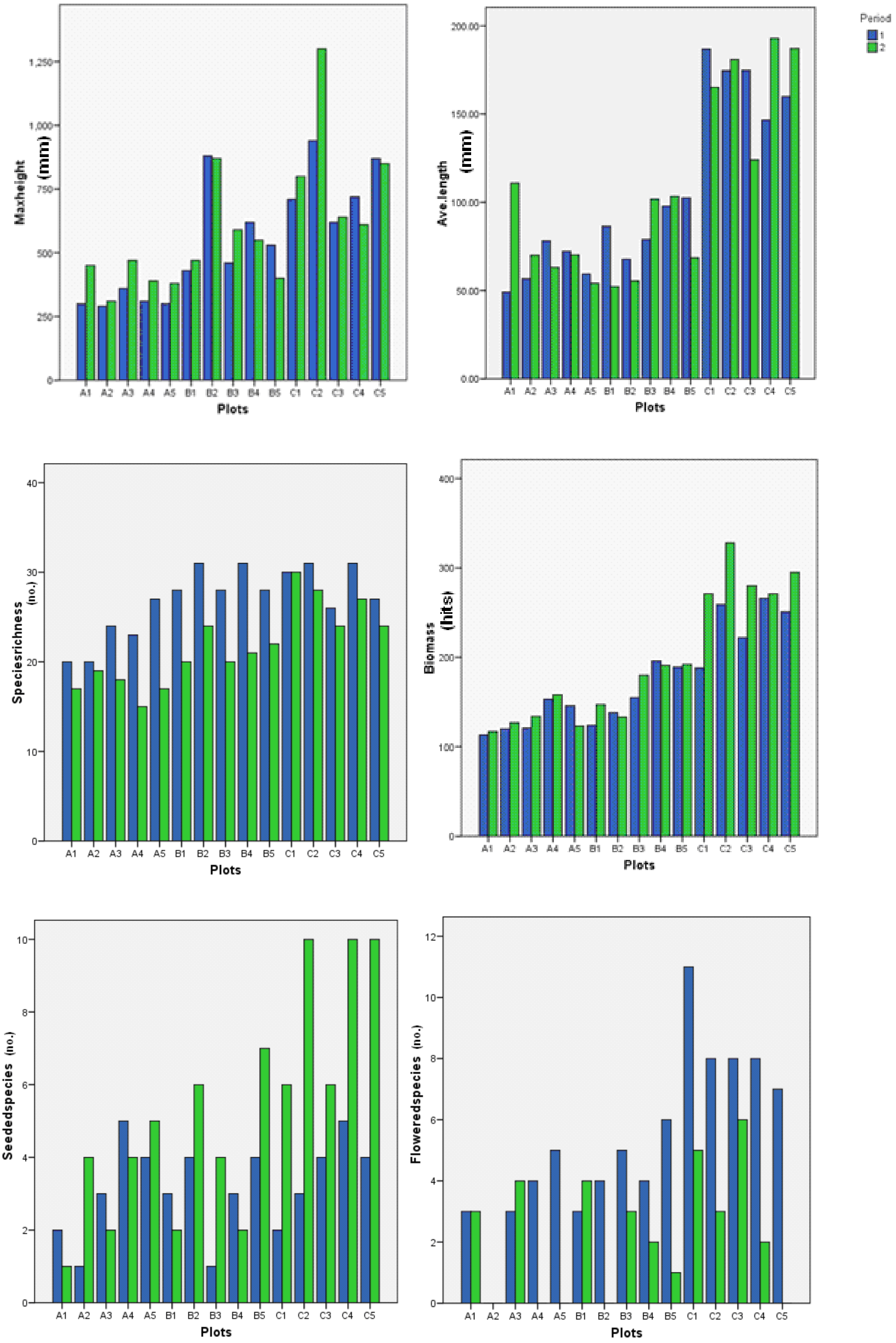


Figure 4.11 Each dependant variables total for all the plots. All the variables show a positive correlation with the depth of the plots and seededspecies, floweredspecies and speciesrichness show a pattern with period.

The following analysis is aiming to answer the following hypotheses:

Null hypothesis – There is no difference between the treatments floral biodiversity, species composition and productivity.

Alternate hypothesis – There are significant differences between the treatments floral biodiversity, species composition and productivity.

4.1 Overall variation between plots

Analysis of the data for the dependant variables (taken from Appendix 8.4) using CVA shows that there is indeed variation between treatments (Fig. 4.12) with treatment C (the brown plot) being clearly different from the other groups on the x-axis (made up of component 1). Component 1 explains 58.927% of the variance (Table 4.13) and is principally made up of the DVs; *ave.length* (.899), *biomass* (.919) and *max height* (.848) (Table 4.14) although all the DVs have a strong relationship to component 1. Component 2 explains 23.775% of the total variance and is mainly made up of *floweredspecies* (.798) and *seededspecies* (-.735) but there is no clear pattern in Fig. 4.12

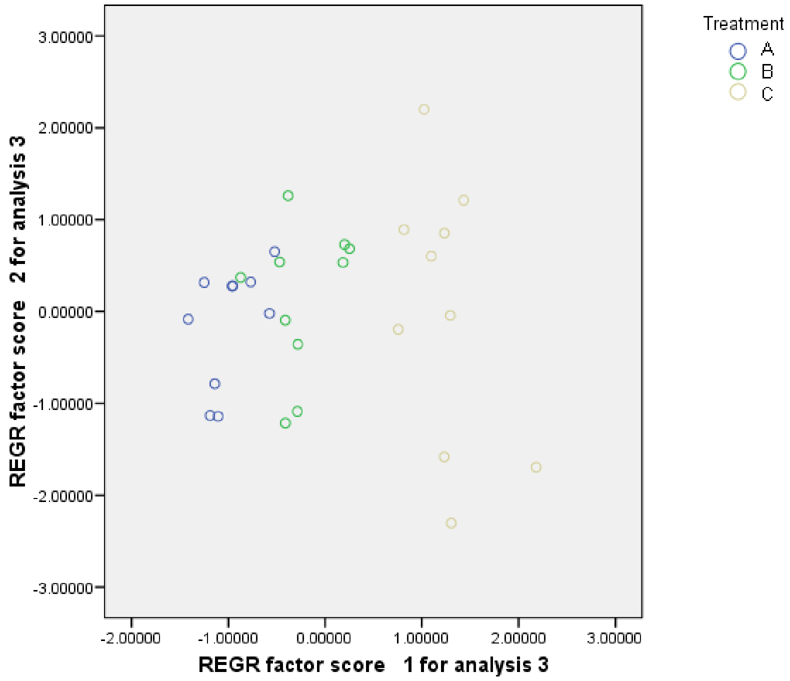


Figure 4.12 Individuals plotted according to their principal components using CVA. Treatments are colour coded and treatment C is clearly different to other the groups on the x-axis, but no clear pattern is shown on the y-axis.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.536	58.927	58.927	3.536	58.927	58.927
2	1.427	23.775	82.702	1.427	23.775	82.702

Table 4.13. Principal Component Analysis – Total variance explained: Showing the relative importance of each component, with component one and two explaining a total of 77.458% of the variance.

	Component	
	1	2
maxheight	.848	-.114
speciesrichness	.736	.430
Biomass	.919	-.226
ave.length	.899	.004
floweredspecies	.524	.798
seededspecies	.591	-.735

Table 4.14 Principal Component Analysis: Weightings for the measured variables for the two components. All the variables have a high positive weighting for component 1 whilst component 2 gives floweredspecies a high positive weight and seededspecies a high negative weighting.

Fig. 4.12 shows that overall, treatment C is different from the other two and slight differences between the other two treatments can also be identified. The data was then analysed in greater detail to attach significance to the variation and to see how it occurred, looking at each DV and the various independents that may have caused the variation.

4.2 Exploration for patterns in dependant variables (DVs) within treatments and periods.

Using multivariate tests each DV was analysed to see if there were significant patterns within the Treatment, Period or both. What can be seen from Table 4.21 is that there are two patterns within Treatment*Period, four of the DVs have patterns within Period and within Treatment all the DVs have significant patterns.

Source	**maxheight**		**Ave.length**		**Biomass**	
	F	Sig.	F	Sig.	F	Sig.
Treatment	18.601	***≤0.001***	74.081	***≤0.001***	72.608	***≤0.001***
Period	.671	.421	.005	.943	4.817	**.038**
Treatment*Period	.236	.792	.680	.516	2.900	.074
	Species richness		**Flowered species**		**Seeded species**	
	F	Sig.	F	Sig.	F	Sig.
Treatment	33.164	***≤0.001***	10.484	***≤0.001***	8.011	***.002***
Period	43.491	***≤0.001***	22.157	***≤0.001***	10.678	***.003***
Treatment*Period	3.854	**.035**	2.806	.080	4.878	**.017**

*Table 4.21 F-ratio and significance for all the variables compared with treatment, period and treatment*period. Data in bold and italics means the variables relationship with the source is significant to the 99% confidence level; data just in bold means the relationship is significant to the 95% level.*

The DVs that show a pattern in treatment and period together are *species richness* and *seededspecies* with the former being a negative relationship and the latter being positive which can be seen in Fig. 4.11. The patterns within Period were analysed further using a Pearson correlation test (see Appendix 8.5) which found a negative correlation for *Floweredspecies* (-0.549, sig. 99%), a positive correlation for *Seededspecies* (0.420, sig. 95%) and a negative pattern for *Speciesrichness* (-0.554, sig. 99%). After further analysis no significant relationship was found between *Biomass* and Period.

Having found significant patterns within Treatment for all of the DVs the next step was to look at patterns within the DVs between each treatment to see which treatments are significantly different from each other.

4.3 Exploration for patterns and relationships in dependant variables (DVs) between treatments.

Using one-way ANOVA and post-hoc tests (LSD) each treatment was compared against each other for each DV. The results that were significant at the 95% confidence level are in Table 4.31 and they show that treatment B (15cm substrate) was significantly different in each DV compared to treatment C apart from S*peciesrichness.* Treatment A (10cm substrate) was significantly different in each DV compared to treatment C, and compared to treatment B it was significantly different for half of the DVs (*Biomass, Maxheight* and *Speciesrichness*).

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Sig.	95% Confidence Interval	
			Lower Bound	Lower Bound	Upper Bound	Lower Bound
speciesrichness	A	B	-5.30(*)	≤0.001	-7.32	-3.28
	A	C	-7.80(*)	≤0.001	-9.82	-5.78
	B	C	-2.50(*)	0.017	-4.52	-.48
Biomass	A	B	-33.30(*)	0.007	-56.80	-9.80
	A	C	-131.90(*)	≤0.001	-155.40	-108.40
	B	C	-98.60(*)	≤0.001	-122.10	-75.10
maxheight	A	B	-224.00(*)	0.006	-376.27	-71.73
	A	C	-450.00(*)	≤0.001	-602.27	-297.73
	B	C	-226.00(*)	0.005	-378.27	-73.73
ave.length	A	C	-100.9180(*)	≤0.001	-119.5305	-82.3055
	B	C	-87.8600(*)	≤0.001	-106.4725	-69.2475
floweredspecies	A	C	-3.60(*)	≤0.001	-5.25	-1.95
	B	C	-2.60(*)	0.003	-4.25	-.95
seededspecies	A	C	-2.90(*)	0.001	-4.50	-1.30
	B	C	-2.40(*)	0.005	-4.00	-.80

* The mean difference is significant at the .05 level.

Table 4.31 Comparisons between each treatment for every dependant variable using one-way ANOVA with post-hoc tests (LSD).

After finding patterns between the treatments and DVs, a Pearson Correlation test was used to look at the nature of the relationships, firstly looking at the relationship in each period separately and then seeing if it remained when both periods were put together. Table 4.32 shows these results and strong positive relationships between treatments and all the DVs are clear with the only two exceptions being *Seededspecies*

in July and *Floweredspecies* in September most likely due to the flora life cycles meaning the majority of the flora flowered in early summer (during period 1), and seeded in late summer (during period 2) meaning less data would have been available in the opposing periods. All these relationships are illustrated in Fig 4.11.

Treatment		**Maxheight**	**Species richness**	**Biomass**	**ave.length**	**Flowered species**	**Seeded species**
July (Period 1)	Pearson Correlation	.848(**)	.693(**)	.847(**)	.918(**)	.826(**)	.200
	Sig. (2-tailed)	.000	.004	.000	.000	.000	.474
	N	15	15	15	15	15	15
September (Period 2)	Pearson Correlation	.717(**)	.906(**)	.915(**)	.786(**)	.379	.730(**)
	Sig. (2-tailed)	.003	.000	.000	.001	.164	.002
	N	15	15	15	15	15	15
Together	Pearson Correlation	.772(**)	.670(**)	.864(**)	.850(**)	.526(**)	.482(**)
	Sig. (2-tailed)	.000	.000	.000	.000	.003	.007
	N	30	30	30	30	30	30

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

Table 4.32 A correlation test reveals a strong positive relationship for Treatment with all the variables except for Seededspecies in July and Floweredspecies in September.

4.4 Relationships between other independent variables and DVs.

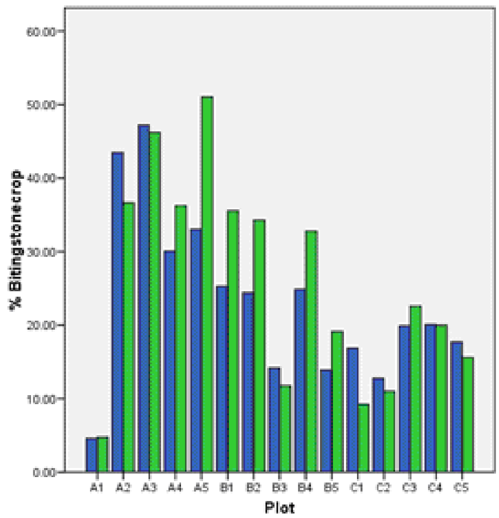
The location of each plot was graded and the DVs were tested for any significant relationships against this gradient. The only one that came up with a relationship was *Biomass* which had a positive relationship at the 95% confidence level (Table 4.41). The data was also graded depending on when it was taken within the two periods and tested for any patterns using one-way ANOVA, however no significant patterns were found.

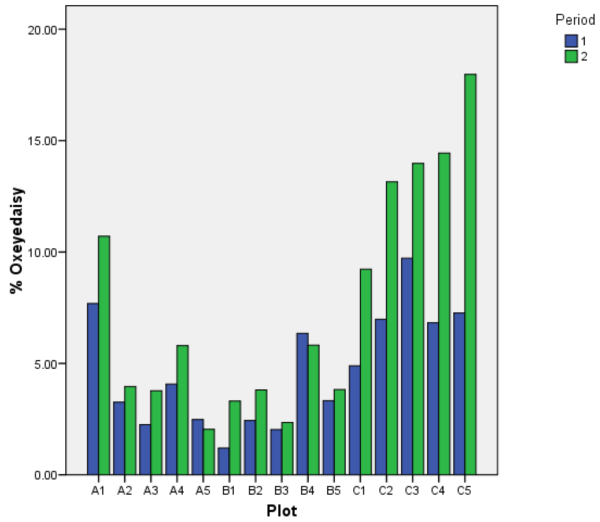
			Locationgrad
Spearmans Rank	Biomass	Correlation Coefficient	.418(*)
		Sig. (2-tailed)	.022
		N	30

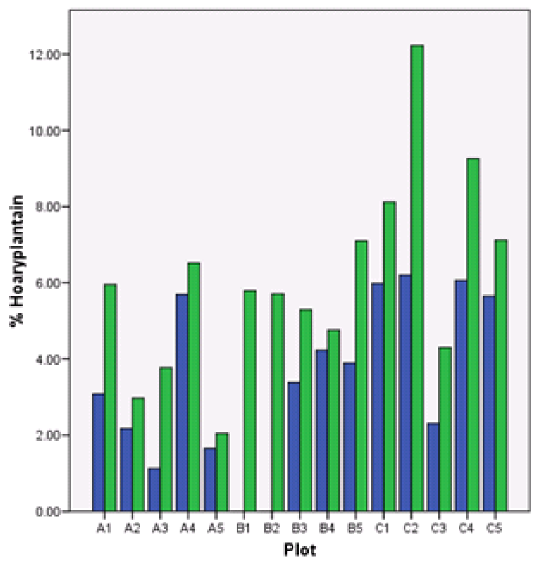
* Correlation is significant at the 0.05 level (2-tailed).

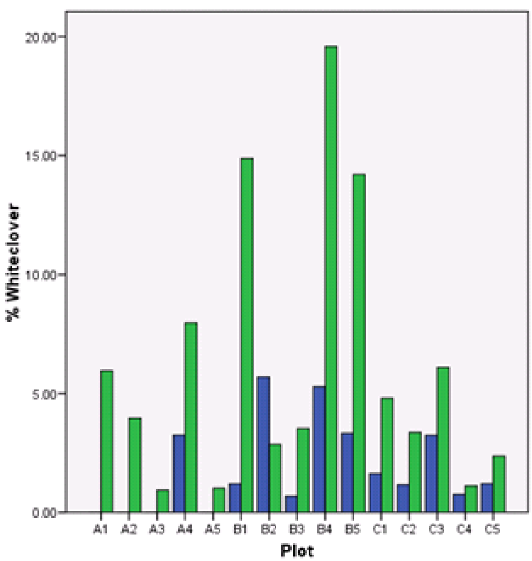
Table 4.41 Biomass was found to have a positive relationship with the location

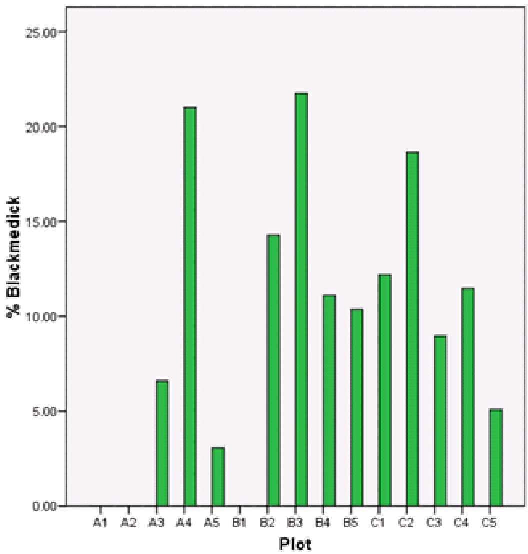
4.5 Exploration of patterns and relationships in key flora.

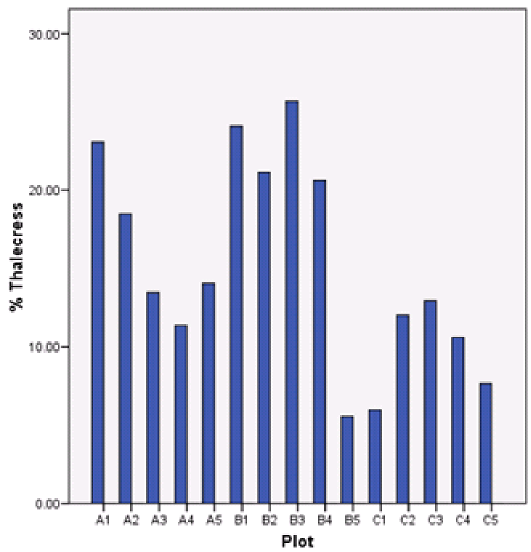












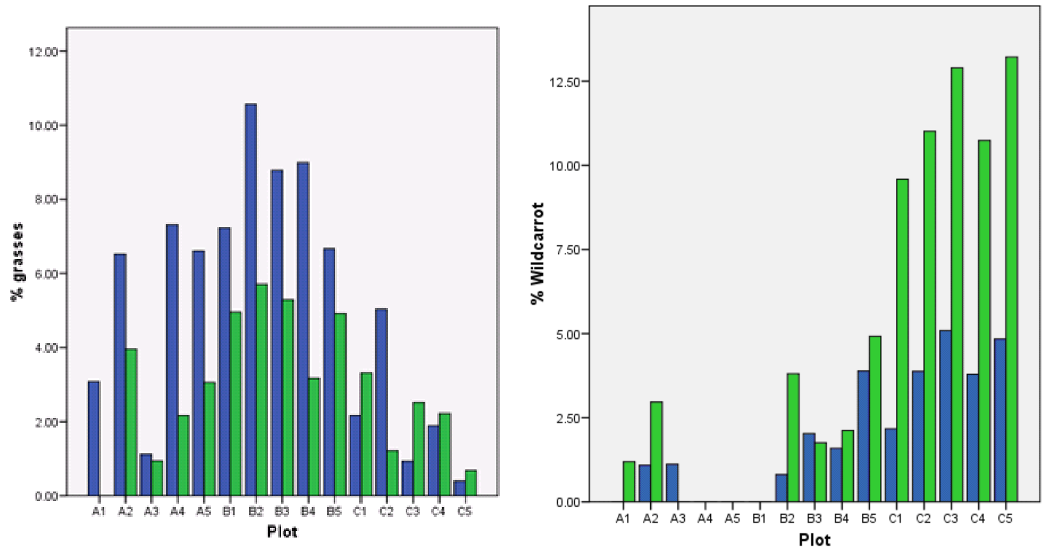


Figure 4.51 Graphs for the eight key flora that show patterns with either treatment or period (see Table 4.52). Each species percentage of total biomass is compared for all the plots and between periods. Patterns between periods and treatments are clear with species such as Thalecress only having values for period 1 and Wild Carrot has a strongly positive skewed appearance.

As in section 4.2 a multivariate test was used to find patterns in the composition of the top 10 species within treatments and periods. What can be seen from Table 4.52 is that the variation within 7 out of the ten species was significant between treatments and also between periods (although not all the same species were significant), however only three species were significant with Treatment*Period. The eight species that had significant patterns with treatment and/or period have been shown as graphs in Fig. 4.51. Thale Cress *Arabidopsis thaliana* and Blackmedic *Medicago lupulina* only have results for one period as they were not present during the other period; both Wild carrot *Daucus carota* and Oxeyedaisy *Leucanthemum vulgare* have strong positive correlations with the depth of the plots while Biting Stonecrop *Sedum acre* and Thale Cress *Arabidopsis thaliana* have negative correlations. Grasses *Poaceae* spp. have a more bell-shaped curve showing that the conditions in treatment B suit them the best but they also show a decrease in dominance from period one to two.

Source	**Bitingstonecrop**		**Knotgrass**		**Oxeyedaisy**		**Thalecress**	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Treatment	5.345	**0.012**	0.530	0.595	24.643	***≤0.001***	3.731	**0.039**
Period	0.371	0.548	0.405	0.530	10.998	***0.003***	108.28	***≤0.001***
Treatment*Period	0.307	0.738	0.769	0.475	4.595	**0.020**	3.731	**0.039**
	Hoaryplantain		**Wildcarrot**		**Whiteclover**		**grasses**	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Treatment	7.715	***0.003***	73.035	***≤0.001***	5.724	***0.009***	18.961	***≤0.001***
Period	13.376	***0.001***	33.547	***≤0.001***	11.061	***0.003***	12.628	***0.002***
Treatment*Period	0.646	0.533	20.846	***≤0.001***	1.812	0.185	3.005	0.068
	Bladdercampion		**Blackmedic**					
	F	Sig.	F	Sig.				
Treatment	0.691	0.511	0.849	0.440				
Period	0.056	0.814	25.645	***≤0.001***				
Treatment*Period	0.029	0.972	0.849	0.440				

*Table 4.52 F-ratio and significance for the top ten flora compared with treatment, period and treatment*period. Data in bold and italics means the variables relationship with the source is significant to the 99% confidence level; data just in bold means the relationship is significant to the 95% level.*

Three of the species have a significant pattern with treatment and period together, Fig. 4.51 shows that for Oxeyedaisy *Leucanthemum vulgare* and Wild Carrot *Daucus carota* both have a positive relationship with treatment*period whilst Thale Cress's *(Arabidopsis thaliana)* relationship is negative.

4.6 Exploration of relationships in key flora within periods.

Variation between treatments will be examined further in section 4.7**,** but it is also clear there was significant variation between periods as well with six out of the ten key flora having a significant relationship with Period (see Table 4.61). For example Thale Cress *Arabidopsis thaliana* constituted up to 25.68% (see Fig 4.51) of the biomass on the plots in July (period 1) but had completely disappeared from all the plots by September (period 2), giving it a strong negative relationship with period (see Table 4.61). Four out of the six have positive relationships while grasses *Poaceae* spp. along with Thale Cress *Arabidopsis thaliana* have negative relationships with period (see table 4.61).

		Thale cress	Black medick	Hoary plantain	Wild carrot	White clover	Grasses
Period	Pearson Correlation	-.858(**)	.695(**)	.497(**)	.370(*)	.470(**)	-.396(*)
	Sig. (2-tailed)	≤0.001	≤0.001	0.005	0.044	0.009	0.030
	N	30	30	30	30	30	30

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Table 4.61 A correlation test shows 6 species have a relationship with Period, two of which are negative.

4.7 Exploration of relationships in key flora within treatments.

Table 4.52 shows that 7 out of the 10 species have significant patterns within treatments; this was examined further using the same techniques as section 4.3 with each treatment being compared against each of the 10 species, Table 4.71 shows all the results that are significant.

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Sig.	95% Confidence Interval	
			Lower Bound	Lower Bound	Upper Bound	Lower Bound
Bitingstonecrop	A	C	16.75200(*)	0.002	6.5962	26.9078
oxeyedaisy	A	C	-5.84100(*)	≤0.001	-8.6458	-3.0362
	B	C	-6.99700(*)	≤0.001	-9.8018	-4.1922
Hoaryplantain	A	C	-3.22700(*)	0.005	-5.3934	-1.0606
	B	C	-2.70800(*)	0.016	-4.8744	-.5416
Wildcarrot	A	C	-7.08600(*)	≤0.001	-9.5221	-4.6499
	B	C	-5.63000(*)	≤0.001	-8.0661	-3.1939
Whiteclover	A	B	-4.81600(*)	0.018	-8.7467	-.8853
	B	C	4.55200(*)	0.025	.6213	8.4827
Grass	A	B	-3.15100(*)	0.003	-5.1173	-1.1847
	B	C	4.59100(*)	≤0.001	2.6247	6.5573

* The mean difference is significant at the .05 level
Table 4.71 Comparisons between each treatment for key species using one-way ANOVA with post-hoc tests (LSD).

These results show that 6 out of the 10 species vary significantly between treatments. All six are different when treatments A and B are compared with treatment C, with the majority of the change being negative. The clearest exception is Biting Stonecrop *Sedum acre* which has by far the largest difference between any of the plots and is more dominant on treatment A compared with treatment C. White clover *Trifolium repens* and grasses *Poaceae* spp. are also more dominant on treatment B than C,

however in treatment C Biting Stonecrop *Sedum acre*, White Clover *Trifolium repens* and grasses *Poaceae* spp.decrease in dominance whilst others increase.

4.8 Exploration for parallels between treatments species composition.

Using the data from each treatments total species composition (see Appendix 8.6), Bray-Curtis ordination and Measures of association were used to produce Fig. 4.81 and 4.82.

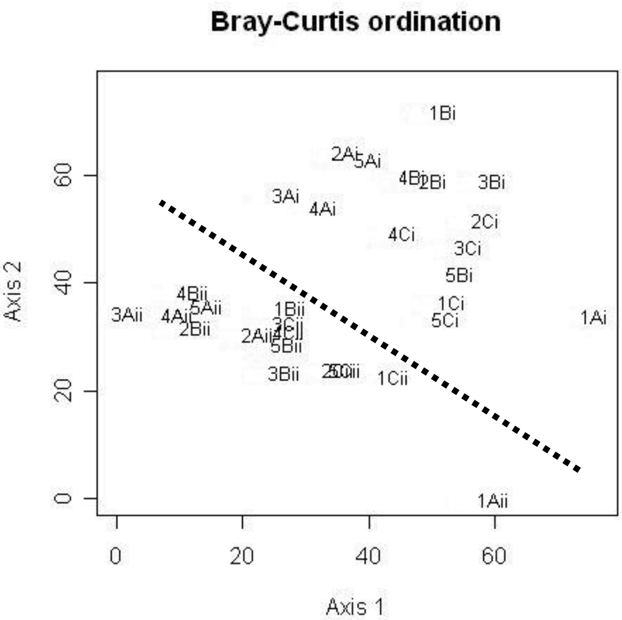


Figure 4.81 Bray-Curtis analysis of plot species composition. The dotted line shows the clear distinction between period 1 and 2.

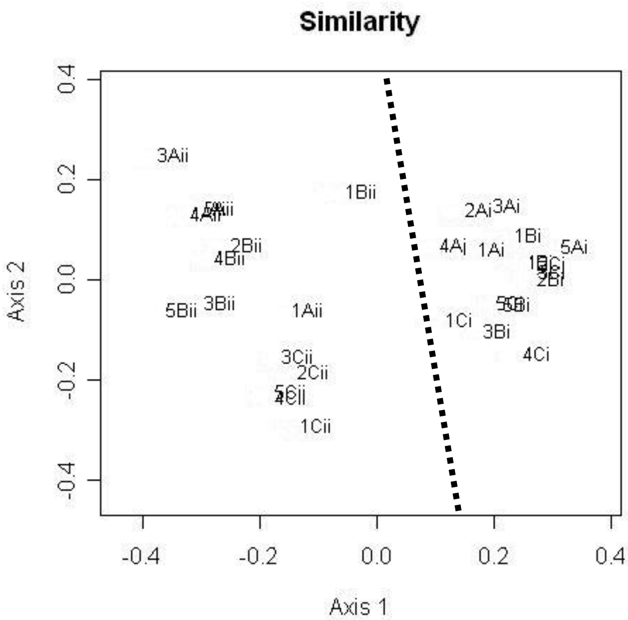


Figure 4.82 Measure of association analysis of plot species composition.The dotted line shows the clear distinction between period 1 and 2.

Two things are clear from these analyses, firstly there is no clear distinction between the three treatments species composition, and secondly there is a clear distinction between the two Periods species composition, which the dotted lines on the graphs highlight.

5. Discussion

This experiment has found significant variation in the floral communities between brown roof treatments and between the brown roof treatments and the brownplots so the null hypothesis can be disregarded and the alternate hypothesis accepted. The question now is how different are the communities, is it detrimental to the use of brown roofs and how can they be improved?

5.1 Variation in dependent variables between treatments.

5.1.1 Biomass (including *max. height & ave. length*)

This is where the greatest variation occurred between the different treatments with all three variables. Table 4.31 shows that that there were significant differences with the three variables between each of the treatments except *ave. length* which didn't have a significant relationship between plots A and B. As no significant relationship was found between the water content of the plot substrate samples (see section 2.6) it can be surmised that the extra growth on the plots is due to the amount of substrate available rather than the type, more substrate will allow for more stored water (VanWoert 2005) and less chance of frost damage or desiccation (Oberndorfer et al 2007; Emilsson & Rolf 2005). Treatment C (the brown plot) had 150mm substrate but the plant roots also had substrate below that available to them made up of compacted gravel and earth which will have provided more water and anchorage for roots allowing for further growth.

5.1.2 Species Richness

An increase of *species richness* with the depth of substrate is clear when both periods are considered, however it is worth noting that Fig. 4.22 shows treatment B actually

had similar levels of *species richness* in period one compared with treatment C, if not slightly more, it was the drop in *species richness* in period two that gave treatment B its negative relationship with treatment C. The increase in species richness with the depth of substrate is a pattern that has been found in other studies such as Brenneisen (2006) who found varying the depth of the substrate increased species richness. Orbendorfor et al (2007) and Dunnett & Kingsbury (2004) suggest increasing the substrate depth to increase diversity, although they warn this can introduce unwanted weeds.

5.1.3 Flowered and seeded species

Table 4.31 shows that these two variables were similar between the two brown roof treatments but were significantly different compared to the brownplots indicating that fewer species went through their whole life cycle on the brown roof plots. Although this study is only looking at the initial colonizing flora on these treatments, if fewer species were able to go through their life cycle then the successional state of the treatments will be set back (Jones 2002), leading to decreases in species richness unless their seed banks are refreshed regularly. The difference in levels of *seeded* and *flowered species* and treatments will also affect the invertebrate communities the treatments can sustain (Jones 2002).

5.2 Variation in dependant variables between Periods

The negative correlation found in *flowered species* and the positive correlation found in *seeded species* are not surprising as it was expected that the fauna would flower earlier and seed later in the summer, more surprising is the negative pattern in *species richness*. The reduction of species richness over time occurred on all treatments, but

most significantly on the brown roofs plots. This could be due to various reasons linked with the harsher conditions found on these treatments, such as the premature death of seedlings, competitive advantage of a few hardier species (Orbendorfer et al 2007) and shortening of life cycles for the species found on these plots such as Thale cress *Arabidopsis thaliana* (Nakamura 2008). This pattern is a worrying one and deserves further studying as brownfield sites are known for their diversity and if brown roofs become dominated by a few species they would no longer be able to compensate for this attribute of brownfields. Other studies have found green roofs have needed maintenance to ensure a high species diversity (Kohler 2006).

5.3 Composition of the flora communities

Out of the 25 species seeded at the beginning, 7 of them did not appear on any of the plots and 5 were classed as key species. A total of 29 invasive species (not in the seed mix) were found on the plots, five of which were classed as key species. This highlights the importance of the seed bank found in the substrate and the availability of incoming seeds to create a species rich community and how they will directly effect the composition of the plant community. Therefore if a brown roof is being used as a replacement for a brownfield site then using the top soil from the brownfield on the roof will help to generate a similar community (Brenneisen 2006) and locating it in close proximity to the developed brownfield will help the roof have access to similar incoming seeds. This is important as most brownfields and brown roofs can be classed as urban ‘islands’ for nature due to the isolation and barriers created by their urban location, meaning the theory of island biogeography (MacArthur & Wilson 1967) is applicable to them (Niemela 1999).

5.4 Variation in key flora between treatments

Table 4.71 shows that six out of the ten key species vary significantly between treatments and all of the six vary significantly when treatments A and B are compared with treatment C although the relationships are different between species. This shows how the treatments provide slightly different habitats and so allow certain species to become more dominant. Biting Stonecrop *Sedum acre* increases in dominance with the thinner substrates which is due to the competitive advantage sedums have in drier, harsher conditions, hence their use on normal extensive green roofs (Dunnett & Kingsbury 2004; Oberndorfer 2007). The increase in dominance for White Clover *Trifolium repens* and grasses *Poaceae* spp. on treatment B may also be due to their competitive advantage in this slightly less harsher treatment; however any advantage these three species had must be reduced in treatment C because other species increase in dominance while they reduce.

Each treatment seems to have a slightly different community structure. With the dependant variables mentioned earlier treatment B was often a compromise between the harsher conditions of treatment A and the more resource rich treatment C, however with the species composition of the communities there was often no graded response between the treatment, with grasses *Poaceae* spp. and White Clover *Trifolium repens* showing an increase in dominance on treatment B when compared with the other treatments.

This variation between treatments is significant and shows that brown roofs will not be exactly the same communities that would be found on a brownfield site. Having said this though if the top ten species for each treatment are listed separately (rather

than the top ten of all the treatments which is what has been used so far), then seven out of the ten species are found in all the treatments (see Table 5.41). So despite the variation found between the treatments, the plant communities can be viewed as similar with the slight changes in habitat conditions only changing the dominance of certain species. These similarities in the community structure were evident when the total species composition of each plot were analysed using Bray-curtis and no clear distinction between the treatments were found (see Fig. 4.81 & 4.82).

	Treatment A (%)	Treatment B (%)	Treatment C (%)
1	Biting Stonecrop (33.33)	Biting Stonecrop (23.62)	Biting Stonecrop (16.58)
2	Knotgrass (13.42)	Knotgrass (10.09)	Knotgrass (12.56)
3	Thale Cress (8.05)	Thale Cress (9.91)	Oxeye Daisy (10.44)
4	Bladder Campion (5.95)	**White Clover** (7.12)	**Wild Carrot** (7.72)
5	**Moss** (4.74)	**Grasses** (6.63)	Hoary Plantain (6.72)
6	Oxeye Daisy (4.60)	Black Medick (5.75)	Black Medick (5.64)
7	Hoary Plantain (3.50)	Bladder Campion (5.56)	Thale Cress (4.92)
8	**Grasses** (3.48)	Hoary Plantain (4.02)	Bladder Campion (4.44)
9	Black Medick (3.07)	Oxeye Daisy (3.45)	**Cornflower** (3.70)
10	**White Clover** (2.31)	**Moss** (2.66)	**Common Poppy** (3.41)

Table 5.41 The top 10 species in each treatment. This shows 7 species are dominant in all treatments with 6 species not occurring in all of them (highlighted in bold).

Over time the variations in dominance within the treatments may lead to significant differences in the treatment communities (Gilbert 1989) but this study can only comment on the initial colonizing community.

5.5 Variation in key flora between Periods

It is unsurprising to find significant variation between periods as both growth and decline of species throughout the summer is expected due to competition and the lifecycle of the species. For example the loss of Thale Cress *Arabidopsis thaliana* from all of the plots in period two was due to the completion of its lifecycle before September; the majority of the individuals had already seeded by July so they had died back by September. The decline of grasses *Poaceae* spp. may impart be due to

lifecycle reasons as some of the individuals seeded in July, but there were more seeding individuals by September so it may be due to a lack of competitive advantage in these conditions (Dunnett & Kingsbury 2004).

The increase of the other four species (see Fig. 4.61) could be due to a competitive advantage over the other species so they increasingly became dominant within the plots (Kohler 2006). However, it is worth noting that because the species composition is worked out as a percentage, a decrease in a particular species over time does not necessarily mean the loss of individuals, it could mean an increase of other species. Because of this, a decrease in one species dominance may be due to an increase in another species dominance due to its ability to reproduce quicker and/or colonize empty ground quicker (giving it its 'competitive advantage'). These species are known as pioneer species or R-specialists (Sukopp & Werner 1982) and are abundant within the communities found on the plots, over time as the plots are covered the lack of empty ground will lead to the loss of these species competitive advantage so leading to the dominance of other species and the gradual succession of the plots (Gilbert 1989).

Changes in the community structure over time have already occurred on the plots as the Bray-Curtis and measure of association tests show (see Fig. 4.81 & 4.82). They both highlighted a clear distinction in the community structure between the two periods of data collection, which shows how the lifecycle of species can alter community structure over a short period of time but may also give some indication of how over a larger period of time the community structures of the different treatments may change and develop (Gilbert 1989)

5.6 Limitations

This is the first controlled experiment to test these hypotheses so the results have no precedent in which to follow making them extremely interesting but also difficult to assess their validity by comparing them with similar data, it is hoped that this study will inspire future experiments which will provide the results needed to do this. The design of the experiment also means that direct comparisons with the flora of true brownfields and brown roofs are limited as the treatments were not exact replicas of their real-life counterparts.

The size of the study limits the strength and range of the conclusion; further studies should look into a broader range of variables for brown roof design and consider more elements of the ecosystems created on these roofs such as invertebrate communities when they are comparing them with brownfield ecosystems.

However the main limitation in this study is time, a plant community in this type of habitat will take years to stabilise (Kohler 2006) if that is at all possible as this type of habitat will make plants exceptionally vulnerable to extreme weather events. Long-term studies comparing the ecology of brown roofs with brownfields are needed to see if brown roofs are indeed a long-term solution to the loss of brownfield habitats.

6. Conclusion

This study has given an indication that brown roofs do not provide exactly the same habitat as brownfields meaning the initial colonising plant communities will be different in many respects, but they can support plant communities with very similar species compositions and for this reason they should be considered for use as mitigation against brownfield development.

Although the species compositions of the plant communities are similar, there are distinct differences between the various dependant variables such as *biomass* and *species richness* and between the dominance of key flora, which over time means the species composition and succession of the plots may take divergent paths. The lack of water and substrate depth in brown roofs leads to the premature death of seedlings and a lack of species fulfilling their life cycle which in turn leads to an arrested succession. This is a brown roofs strength and weakness as it should help keep the plant community in an early successional stage with high floral biodiversity similar to that of brownfields, but they will have to be designed specifically to provide the habitat needed to replace a lost brownfield. The depth of the substrate should be a major consideration when aiming for a certain community as this experiment has illustrated how the amount of substrate directly affects the floral community, limiting its successional stage.

Brown roofs have shown that they are far better at supporting brownfield ecology when compared with other green roof designs, however there is a definite need for more development and analysis of brown roofs to find the optimal design and help to tailor brown roofs to the brownfield site they are replacing so they can provide the

best habitat for the ecology present. The newly developed brown roofs such as those in Deptford Creek will in the future provide a great resource from which we can study the ecology of these types of roofs and make conclusions about their suitability for long-term mitigation of brownfield sites, but as more of these roofs are being built, their designs and suitability should be tested before their development.