"DEVELOPING BIODIVERSITY INDICATORS AND ECONOMIC VALUATIONS FOR CREATED GRASSLANDS IN THE UK"

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SUMMARY OF THESIS

TITLE: Developing biodiversity indicators and economic valuations for created grasslands in the UK

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The thesis is an investigation in to a quick and easy means of establishing the ecosystem service provision of a created grassland and applying an economic value to these services. Biodiversity indicators are first explored in a literature review. Common statistical techniques are then employed to identify relevant bio-indicators of created grasslands from first-hand data collected from sourced fieldwork study sites. Economic values of ecosystem service provision in grasslands are then extracted from papers sourced from a systematic review. These values, and their explanatory variables, are modelled to establish variation in economic estimates. Benchmarking figures of goal grassland ecosystem service provision are established based on theory. Crucially, a link between ecological data and economic values is ascertained. This allows an Excel model to be designed allowing users to estimate economic value of grasslands based on on-site recordings of identified bio-indicators.

Although this masks a lot of the complexity of this study, a diagrammatical representation of the main structure of this study and its findings is presented below

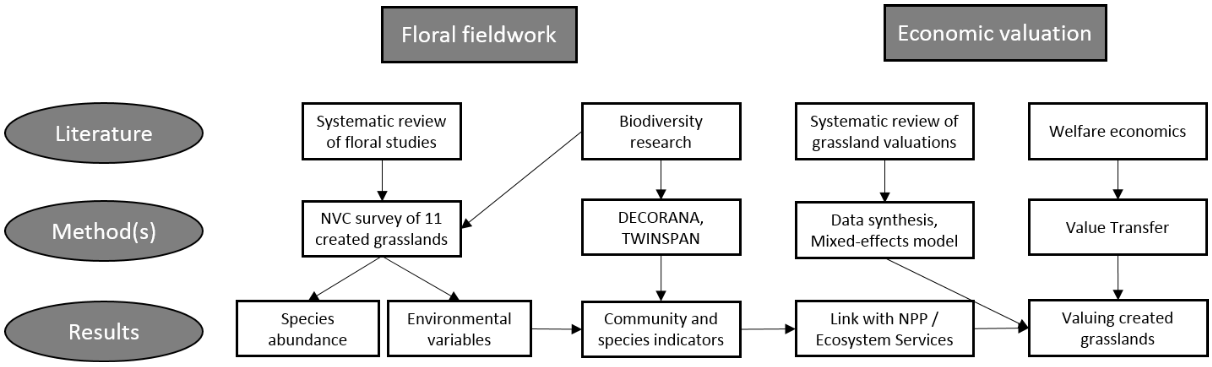

Figure i.1: Structure of thesis and main findings

Keywords: Bio-indicators; Non-market valuation; Habitat creation; Biodiversity; Ecosystem Services

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LIST OF ABBREVIATIONS

- AC – Avoided Cost
- BAP – Biodiversity Action Plan
- BSBI – Botanical Society for Britain and Ireland
- CBD – Convention on Biological Diversity
- CCA – Classical Confirmation Analysis
- CEH – Centre for Ecology and Hydrology
- CIEEM – Institute of Ecology and Environmental Management
- CVM – Contingent Valuation Method
- CVS – Countryside Vegetation System
- CWS – County Wildlife Site
- DCA – Detrended Correspondence Analysis
- DECC – Department of Energy and Climate Change
- DEFRA – Department for Environment, Food and Rural Affairs
- EDA – Exploratory Data Analysis
- FALP – Further Alterations to London Plan
- GDP – Gross Domestic Product
- GHG – Greenhouse gases
- GLM – Generalised Linear Model
- GWP – Gross World Product
- HAP – Habitat Action Plan
- HERR – Humanitarian and Emergency Response Review
- IPCC – Intergovernmental Panel on Climate Change
- IUCN – International Union for the Conservation of Nature
- JNCC – Joint Nature Conservation Committee
- LBAP – Local Biodiversity Action Plan
- LPI – Living Planet Index
- MA – Millennium Ecosystem Assessment
- MAVIS – Modular Analysis of Vegetation Information System
- NERC – Natural Environment and Rural Communities
- NPV – Net Present Value
- NUWS – Nottinghamshire Urban Wildlife Scheme
- NVC – National Vegetation Classification
- ONS – Office for National Statistics
- PFA – Pulverised Fuel Ash

- PPP – Purchasing Parity Power
- RC – Replacement Cost
- RSPB – Royal Society for the Protection of Birds
- SAP – Species Action Plan
- SCC – Social Cost of Carbon
- SINC – Site of Importance for Nature Conservation
- SNH – Scottish Natural Heritage
- SREX - Disasters to Advance Climate Change Adaptation
- SSSI – Site of Specific Scientific Interest
- TCM – Travel Cost Method
- TEEB – The Economics of Ecosystems and Biodiversity
- TEV – Total Economic Value / Valuation
- TWINSPAN – Two-Way Indicator Species Analysis
- UNESCO - The United Nations Educational, Scientific and Cultural Organization
- UNFPA – United Nations Population Fund
- WCPA – World Commission on Protected Areas
- WTP – Willingness to Pay
- WWF – World Wide Fund for Nature
- YWT – Yorkshire Wildlife Trust
- ZAP – Zero-Altered Poisson
- ZINB – Zero-Inflated Negative Binomial
- ZIP – Zero-Inflated Poisson

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CHAPTER 1 - INTRODUCTION

There has not been a more relevant time for a study in biodiversity[1] and sustainability measures. The global environment is in a rapid state of flux, and unfortunately not in a positive direction. The recent Living Planet Report, published by the World Wide Fund for Nature (WWF, 2012) highlights the many ways the environment has been degraded by humans. Its Living Planet Index (LPI), tracking over 10,000 species of mammals, birds, reptiles, amphibians and fish, has declined by 52% since 1970. According to the report's tracking of our "Ecological footprint", human demands on the Earth have exceeded its biocapacity[2] for 40 years. In essence, it concludes, we need 1.5 earths to support our yearly demands upon it. Recent extreme flooding in the UK could be seen as the beginnings of consequences of habitat[3] loss and increasing paved landscapes.

Despite this somewhat sombre view of the current state of our planet, the necessity of ecological services is starting to be understood. The 2015 General Election highlights a changing tide in UK public interest in environmental issues. The Green Party, specialising in championing sustainability, nearly quadrupled the number of votes they had achieved in 2010 to one million (The Independent, 2015). In support of this, a 2012 study by the Department of Energy and Climate Change (DECC), showed not only public support for greener energy and industry, but that a willingness to accept environmental issues may require financial backing. 79 % of responders indicated they supported renewable energy use, crucially with 35 % stating they would be willing to pay more to upkeep environmental services (2012).

[1] Biodiversity: "Biodiversity comprises all the millions of different species that live on our planet, as well as the genetic differences within species. It also refers to the multitude of different ecosystems in which species form unique communities, interacting with one another and the air, water and soil." (Swingland, 2001)
[2] Biocapacity: the capacity of an area's natural resources to support life within it
[3] Habitat: the natural environment of an organism

Perhaps most importantly to Governments and policy-makers is the recent realisation that the destruction of ecosystems has approached a point where long-term prosperity for humans is threatened. A number of reviews, including the Humanitarian and Emergency Response Review (HERR) led by Lord Ashdown (2011); Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (Intergovernmental Panel on Climate Change (IPCC), 2011) and Reducing Risks of Future Disasters: Priorities for Decision Makers (Government Office for Science, 2012) stress how our changing environment is producing very real chances of extreme weather events. While climate change could reduce global crop yields by 25%, it is estimated that 50% more food needs to be produced to feed the global population by 2020 (World Bank, 2015). A discussion on current biodiversity levels is discussed in Chapter 2.

As such, it is generally agreed that means must be sought to slow the destruction of natural resources. Where possible, we must strengthen and create ecological resources. Habitat restoration[4] and creation across a range of ecosystems is a new and lively field, with many calls for further research (see for example Hobbs, 2007; Helm, 2015; Hardman et al., 2015). A number of public agencies (for example RSPB, 2015; Natural England, 2013) are setting up, and providing advice for creation and restoration programmes. However, for such schemes to be fully integrated in policy and practice, the benefits received by ecosystems must first be understood and where possible quantified. These could include, for example, the aesthetic pleasure of viewing natural habitats, or mitigation from extreme weather. After consideration of the various means of quantifying these services, an Ecosystem Service[5] method was adopted. An ecosystem is defined here as a community[6] of connected organisms and their environment.

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[4] Restoration: the process of renewing damaged or destroyed habitats or ecosystems

[5] Ecosystem Service: "The direct and indirect contributions of ecosystems to human wellbeing." (TEEB, 2015)

[6] Community: "…all the plants occupying an area which an ecologist has circumscribed for the purposes of study" (Crawley, 2009)

In comparison to the study of ecology as a whole, the study of the services provided to humans is a relatively new concept. A search for the topic "Ecosystem Services" within the year 2000 revealed 189 papers on Web of Science, in contrast to 2,708 for the same search in 2014 (ISI Web of Knowledge, 2015). The concept is not only gaining ground in academia. The contribution of Ecosystem Services, it is argued, should be pivotal in decision making (Glaves, Egan & Harrison, 2009; Humphreys et al., 2014, in EGF, 2014).   Ecosystem services, and their contribution to human health, are discussed in Section 2.2.6.

It is widely accepted that quantitative assessment of Ecosystem Services may be problematic due to a lack of evidence base (Glaves, Egan & Harrison, 2009). Systematic reviews and analysis such as that employed here are particularly valuable in the current climate. Studies such as this help aggregate pre-existing knowledge and advance its use across paradigms. This can hopefully allow quicker evaluation of Ecosystem Service provision which could encourage further habitat maintenance, restoration, and creation.

Due to the complexity of ecological systems, this process must be undertaken at the finest scale possible to allow the full picture of services to be revealed. Attempting to draw conclusions from too broad a topic too quickly would most likely obscure key functioning and interactions. As such, this study focuses on one habitat type, grasslands, and more specifically, created grasslands in the UK. Through first-hand chronosequencing[7], a picture of created grasslands over time and under differing management[8] regimes was built. The data set could be studied further for factors outside of the remit of this study. This could include analysis of computed variables to further analyse succession.

[7] Chronosequence: "A set of sites formed from the same parent material or substrate that differs in the time since they were formed" (Walker, 2010)
[8] Management (ecology): Human measures taken to maintain or improve biodiversity and contextual ecosystem functioning (e.g. grazing, annual cut)

Grasslands were chosen for a number of reasons. Firstly, our industrial partner, Middlemarch Environmental Ltd. has seen increasing interest in the creation of grasslands and wetlands, reflected in their work at two of our fieldwork sites, North Cave and Whittleford Park. Also, so far there has arguably been more attention paid within the scientific community to other habitat types such as wetlands and forests. For example, in a Web of Science search, forests achieve 582,912 hits, while grasslands only achieve 77,618 hits (in a search under topic in all years). Understandably, these habitats are more generally lauded for their beauty and ecological importance. Beauty is especially appreciated in the publics' perception of value, which is discussed further in section 2.2.6. In light of this, a larger space to contribute to our understanding of ecological functioning exists around grassland habitats and their benefits. To our knowledge, no published studies of floral development on created grasslands exist.

Despite, perhaps, less attention being paid to grasslands than some other ecological features, the literature that exists is vehement in highlighting the importance of grasslands. The agronomic[9] aspects of grasslands are well-documented and represented in economic markets (e.g. AHDB, 2016). These services provide value to many cultures, and are still highly relevant in the UK. However, the less-studied non-market aspects of grasslands are of great interest across the ecological field and in policy-making. For example, the European Grassland Foundation (EGF) has been charting the usage and progression of grasslands since its inception in 1963. Its work has included yearly symposiums on the functioning and human use of grasslands. In its latest symposium (2014), EGF reflected on changes in grassland status since their paper on EGF History was published, also documenting "The Future" (Prins, 2004). In this document, it was noted that a real increase in interest in grassland function beyond agricultural use is taking place. This, it predicted, would herald further interest from non-agronomic researchers. "There is an increasing interest in how to meet the challenges of the various services which grassland provides for the human well-being and for its contribution to natural capital and environmental services" (EGF, 2014). It is imperative that collaborations exist

[9] Agronomic: Matters relating to agricultural aspects of ecology

between researchers and practitioners in ecology, economics, sociology and data modelling (EGF, 2014). This study contributes to this much-needed collaboration, with academic research being undertaken on the suggestion of, and with the support of, environmental consultants.

Although calls for any research into the field are strong and widespread, the logistical elements of such studies require much thought. The validity of whether to value previously non-market ecological functions and services in an economic sense is a divisive issue. Governments and policy-makers have been quick to include the idea in their environmental plans. The UK Government issued an "Introductory Guide to Valuing Ecosystem Services", focusing on the anthropocentric value of ecosystems. This, they argue, helps ensure that environmental issues are fully included in decision-making and the costs and benefits to ecosystems from policy are understood. The Treasury Green Book states that "the effects on the environment should be considered, including air and water quality, land use, noise pollution, and waste production, recycling and disposal" (HM Treasury, 2013).

Furthermore, the impact of Costanza's seminal 1997 paper "The Value of the World's Ecosystem Services and Natural Capital" cannot be understated. This attempted to value all known habitats, and was recently updated in 2014. This paper states that between 1997 and 2011, Ecosystem Services to the value of $4.3-$20.2 trillion per year have been lost.

As decision-makers infiltrate the notion of ecosystem valuation into our society, so increases the need for up-to-date and informed research on the applicability of these values. As the literature review shows (Chapter 5), quantitative measures of Ecosystem Services provision can be uncertain. Estimations of market value for these services are also varied.

This study is a contribution to the growing recognition of the necessity of services provided to humans by nature, by means of investigating indicators of biodiversity in created grasslands and structuring economic applications of value. A quick assessment for biodiversity is presented, the results of which inform a model which estimates economic value. Currently, if you wished to establish the biodiversity levels of a site, fieldwork such as that undertaken here would have to be completed. This is time-consuming and unachievable for most, especially those in charge of land use decisions. This assessment allows the decision maker to simply undertake a perfunctory look-over of the site, and all relevant calculations are completed in one Excel file.

This study covers a broad variety of themes. As such, each chapter attempts to introduce the reader to each concept first on a broad scale. Then the literature is examined for each further potential concept that could be of use. This can highlight current knowledge, but also any gaps in knowledge that could be filled. Methods and results then follow the same structure. Owing to the broad range of themes and technical terms, any potential unknown terms are defined in footnotes. This is in an attempt to introduce a theme of explicit definition and transparent method to the study. This can allow further replication of any aspect at a later date as further information becomes available.

The remainder of the study is concerned with addressing the following research problem. This problem was incepted by Middlemarch Environmental Ltd. and framed from literature scrutiny. Can the value of Ecosystem Service provision delivered by created grasslands in the UK be quickly and easily established by a non-ecologist?

A diagrammatical representation of the structure of the thesis and main findings is presented in Figure 1.1 below. This is followed by established research objectives, hypotheses and terms of reference. These were established with reference to the theory, and the empirical experience of Middlemarch Environmental.

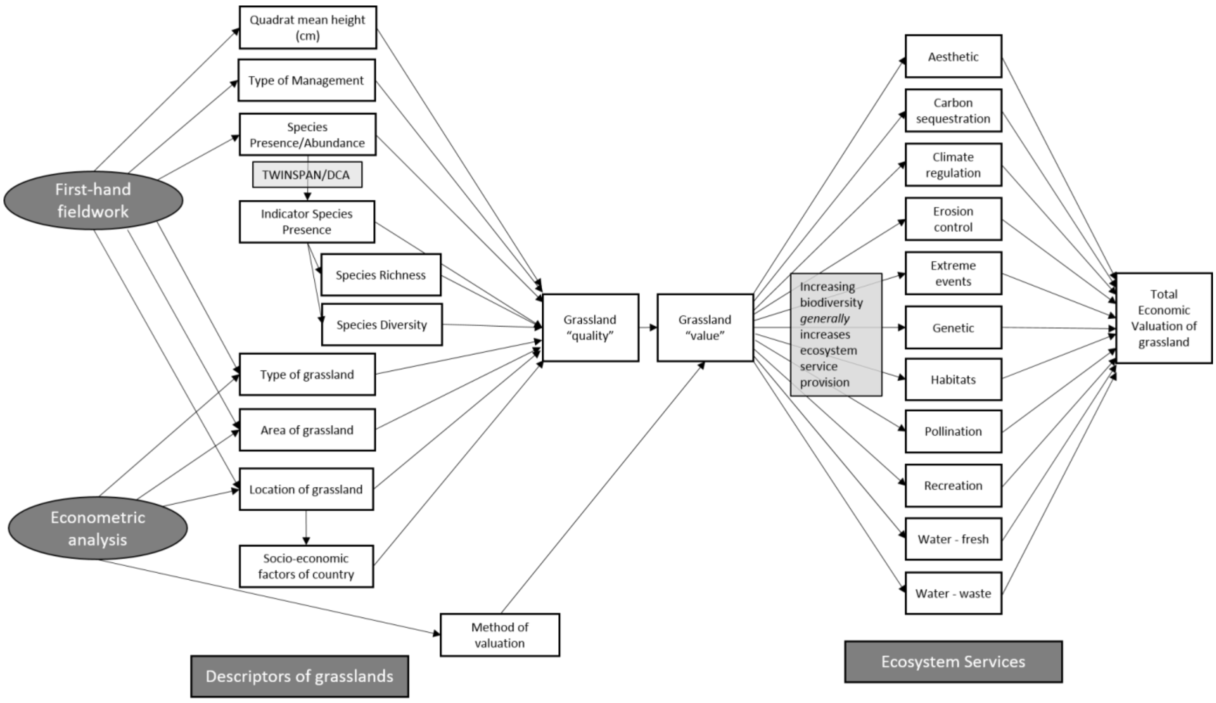

Figure 1.1: Diagrammatical representation of main findings

From our findings in the literature reviews, the following objectives and hypotheses are presented. These will be reiterated throughout the study and their successes discussed in the concluding chapter.

1. **Examine real-life created grasslands to establish assemblages** – Undertake fieldwork on a number of created grasslands at a range of ages since creation. This will give us first-hand data which can be analysed in an attempt to identify bioindicators with time since creation in mind.

   Hypothesis: Assemblages will vary with age since creation, but this link will be moderated by a number of different factors including soil type, and management regime.

2. **Using common ecological statistical tools, extract potential bioindicators of created grasslands. Compare these with known grassland bioindicators identified in literature review –** in line with original research objectives, these should, if possible, be relatively simple to identify, and cover the broadest possible range of grassland types

Hypothesis – As created grasslands are meant to mimic natural and semi-natural grasslands, current indicators of quality should transfer satisfactorily. Further biodiversity indicators will be sourced via common statistical tools.

3. **Identify the impact of management regimes on created grassland assemblages** – Do created grassland assemblages react to management regimes in line with natural and semi-natural grasslands?

   Hypothesis – Created grasslands will, on the whole, react to management regimes in line with natural and semi-natural grasslands.

4. **Use the systematic review process to identify grassland valuation papers within the inclusion criteria**

   Hypothesis – there will be high variation within grassland values. Ecosystem Service value estimates will vary widely.

5. **Using statistical analysis and modelling, attempt to identify the drivers of variation in grassland values**

   Hypothesis – Method of valuation will play a major part of explaining the variation in grassland value as discussed in Section 5.2.3. Ecosystem Service values will vary by grassland type due to differential delivery.

The following terms of reference, designed in conjunction with Middlemarch Environmental Ltd. are also presented below:

1. This research should not only be accessible to ecology academics, but also policy-makers, developers, and the interested public;

2. As it is not yet known what indicators could best signal created grassland quality over time, an inclusive fieldwork methodology should be followed to ensure vital components are not missed;
3. Indicators should, where possible, be identifiable by those without extensive botanical knowledge. This can help present a “quick” means of establishing grassland quality, much as the presence of bluebells in a woodland has become relatively common knowledge;
4. Indicators of the widest possible grassland types in the UK would be desirable. However, care will be taken to not over-generalise where possible.

The following section outlines the significance of this study, and its contributions to both the fields of ecology, and economics. Chapters 2 to 4 are concerned with the identification of bioindicators of created grasslands. Chapters 5-7 look at the application of economic values to grassland ecosystem services. Chapter 7 explores applying values to created grasslands using identified indicator reference levels. Conclusions are also made in Chapter 8 on the contributions made by the study, policy implications and recommendations for further work.

Contribution to knowledge

The complexity of ecology, and the economic system, means further study in both areas is almost always required. Governments are realising the necessity for conserving our natural habitats and creating more (DECC, 2012; HERR, 2011). 63% of surveyed planners in England stated they had targets for the restoration and creation of priority habitats (Lee, 2010). This is creating a trickle-down effect of interest in to both academia, and policy. This study is the result of collaboration between Middlemarch Environmental Ltd. and Aston University. Such collaborations are called for in order to allow further biodiversity gain (Cowling et al., 2008; Clark et al., 2001). The inception of this study came about after Middlemarch Environmental Ltd. saw a surge in interest in the concepts of Ecosystem Services, and maintaining and creating sustainable habitats. These are often on the sites of ex-industry, for example on some of fieldwork sites such as North Cave wetlands, Houghton Regis quarry, and Brandon Marsh Nature Reserve. However, without the assistance of a trained ecologist, the biodiversity on site could not accurately be judged. Even with the input of ecologists, units quantifying biodiversity such as species richness are not easily understood by developers or clients. As such, Middlemarch University Ltd. instigated a CASE studentship PhD attempting to provide a quick reference system for biodiversity of newly created habitats. This study is the product of this CASE PhD under the academic guidance of Aston University.

The resulting quicker and more understandable means of visualising these benefits could be used not only by Middlemarch Environmental, but by all manner of local and national authorities. Clearly, the complexities of ecological processes should not be overlooked, and an instant simple answer is unlikely. However a means of “getting out” the benefits of created grasslands will, it is hoped, encourage the creation of more. As these are studied, the process can be honed even further.

This study has responded to a large number of calls for further study and current gaps in knowledge. Indicators and predictors of biodiversity and ecological processes are widely used, but further research in to them is needed (Clark et al., 2001):

"...projects remain constrained by the need for quantifiable and 'objectively verifiable indicators' that allow regions to be compared" (Bell & Morse, 2003, pg. 2 in Fraser et al., 2008).

Although ecological research in to grassland functioning is historically large, literature on *created* grasslands is extremely limited. In contrast, the admission of our need for them is not limited. The RSPB claim created or restored habitats are one of the keys to fulfilling 2020 United Nations (UN) targets for biodiversity (Lee, 2010). However, the tying together of current knowledge on the subject is still poor. The Royal Society for the Protection of Birds' (RSPB) attempts to survey UK planners on created and restored habitats was "a disaster", with only 11 of England's 300 planning departments responding to repeated requests (2010). To our knowledge, no other extensive study of created grasslands over time in the UK exists.

Specifically, new and interesting results in to created grasslands in this study include:

- A systematic review of floral indicator species studies, both as a means to highlight issues in survey methodology, and to ensure rigorous methodology for this study;
- Fieldwork generating first hand floral data across 9 sites (16 sub-sites) chronosequencing 47 years of created grasslands;
- The identification of biodiversity indicator species (individual and community) for created grasslands;
- Insight in to the succession of communities across a chronosequenced time scale;
- Insight in to the effect of management on created grassland habitats;
- Addition to the pool of floral databases;
- Early development of a "quick" biodiversity indicator guide on created grasslands.

The services provided to humans by natural resources (hereto known as Ecosystem Services), and their means of relating complex ecological knowledge in to the public conscious, is a hot topic. The Ecosystem Service concept was almost as influential as ecological networks in a survey of UK planners (Lee, 2010). The potential for valuing these services is highlighted in the seminal Millennium Ecosystem Assessment (MA, 2000), and Costanza's global habitat valuation papers (1997; 2014), however comprehensive data and models are lacking (see for example Glaves, Egan & Harrison, 2009; Seppelt et al., 2011; Jakeman, Letcher & Norton, 2006). Although the contribution of grasslands to Ecosystem Services is well documented, what this means in terms of quality and value is not (Hancock, 2010). This study makes a large contribution to this field with:

- Identifying the crucial link between site variables (in this case indicators present) and Ecosystem Service value, through the use of NPP.
- A systematic review of all valuation studies of grasslands globally. To our knowledge, no other synthesis of grassland values has been undertaken, despite similar with wetlands (Brouwer, 2000; Woodward & Wui, 2001);
- A quantitative synthesis of this knowledge, and insight in to the drivers of grassland valuation;
- Highlighting the high variation that still exists in Ecosystem Service valuations;
- Applying a "quick" valuation system (attached Excel spreadsheet) for UK created grasslands that can be utilised by Middlemarch Environmental Ltd. and potentially other policy makers to assess the benefits created grasslands can make. This will hopefully encourage further created grasslands which are of benefit to overall biodiversity and human well-being.

Every attempt has been made to make this study accessible to those who are not well-versed in either ecology or economics. This should help the findings be utilised empirically as well as within an academic setting. This is in response to concerns in the literature that sophisticated articles in peer-reviewed journals are not working their way through to policy (Cowling et al., 2008). These contributions will be revisited in the concluding chapter to highlight, specifically, what has been found.

Summary of contribution to knowledge:

The original contribution to knowledge is presented:

- Fieldwork generating first-hand floral data across a number of created grassland sites at various ages since creation in the UK. In this context we define created grasslands as those allowed to populate or those seeded on land previously of a non-natural land use (e.g. industrial; quarrying).
- A number of identified bioindicators following common statistical techniques. The number of positive indicator species identified within a quadrat had a significant positive effect on quadrat species richness, a known cross-habitat indicator of biodiversity (Section 4.12).
- The mean vegetative height of the quadrat also had a significant effect on species richness (Section 4.12).
- A theoretically sound link between biodiversity levels on created grasslands and their Ecosystem Service provision was found. This was via an estimated species richness, and NPP, a measure of solar energy linked to Ecosystem Services.
- A comprehensive systematic review and subsequent analysis of grassland valuation studies. Similar studies have been published on wetland habitats, but no such analysis of grassland valuations. Method of valuation and socio-economic factors had the highest effect on variation within included grassland values.
- A quick biodiversity assessment method and usable model (Excel spreadsheet, Section 7.5) estimating created grassland value, informed by the number of present indicator species within the reference levels.

Chapter 2: Investigation of grasslands, created grasslands, and the indicators of their success

2.1 Introduction

The following chapter is the result of interrogation of the literature surrounding biodiversity and the relevance of grasslands within wider ecological processes. Threats to global natural resources are first discussed, along with consequences of their destruction. On a more local level, what constitutes a grassland is then discussed along with more specific threats to their survival. The means of structuring the benefits to humans (Ecosystem Services) by grasslands are then explored. These are pertinent to the study as a whole as these are commonly valued in ecological economics studies. Variables that can affect development of a grassland are then explored, followed by scrutiny of the literature to identify potential indicators of biodiversity. These results can inform the indicator selection study in Chapter 4.

2.1.1 Context

The overall goal of this study is to economically value created grasslands at various stages of development. This can allow non-ecologists to more accurately judge the improving biodiversity on site over time. Before this can be achieved however, a sense of what it is we are valuing and why must first be accomplished. Although grasslands have been extensively studied over time, these studies have mostly been confined to pre-existing or restored grasslands. As such, there is little sense of what standards grasslands should hope to achieve within relatively short timelines after creation, and how to accurately quantify these standards. The below graphic outlines the basic research question this section of the study is hoping to achieve.

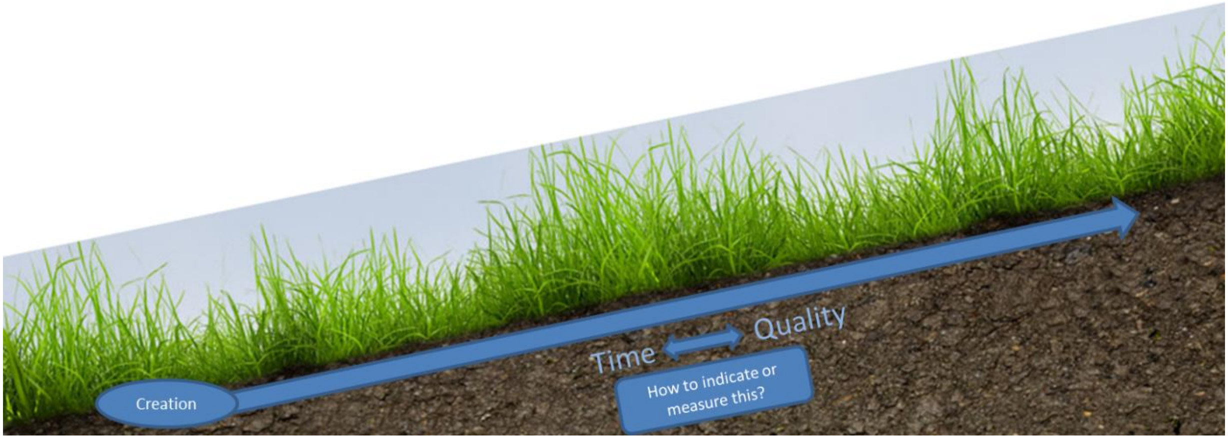

Figure 2.1: Graphical representation of research objective

Due to the complexities of ecological communities, methodologies and theories studying their development can vary widely in the field. A main objective of this study is encouraging the use of rigorous methods. As such, an extensive literature review has been undertaken. This investigates theories on community development, and methods of study to provide evidence for these. The current state of global biodiversity is first briefly discussed. Grassland habitats are then more specifically explored, with a discussion over the main processes within vegetation succession. The services provided to humans by these habitats are then examined. These are pertinent as this is the main link to an economic value.

In order to appropriately value ecological services, the level of service provision must be established. This study takes an indicator species[10] approach. The literature is therefore searched for pre-existing indicators of biodiversity in grasslands (hereon known as bioindicators). A systematic review of floral indicator species surveying and analysis methods is undertaken. This is then followed by methods and results of first hand data surveyed on created grassland. It is hoped that even beyond this analysis this data set will prove valuable.

[10] Indicator species: a species that describes the biodiversity and health of the study site

The following terms of reference, in conjunction with Middlemarch Environmental Ltd., should be kept in mind:

1. This research should not only be accessible to ecology academics, but also policy-makers, developers, and the interested public;
2. As it is not yet known what indicators could best signal created grassland quality over time, an inclusive fieldwork methodology should be followed to ensure vital components are not missed;
3. Indicators should, where possible, be identifiable by those without extensive botanical knowledge. This can help present a “quick” means of establishing grassland quality, much as the presence of bluebells in a woodland has become relatively common knowledge;
4. Indicators of the widest possible grassland types in the UK would be desirable. However, care will be taken to not over-generalise where possible.

2.1.2 Global biodiversity

Although the focus of this paper is created grassland and the value of their services provided to nature, no aspect of ecology is unconnected to another. Off-site effects, although under-studied, are of great importance (Seppelt et al., 2011). It has now been estimated with some confidence that there are approximately 8.7million species present in the world (Mora et al., 2011). This figure is much-honed from previous estimates of between 3 and 100 million (May, 2010, in Mora et al., 2011). It is unlikely any of these individual species exist outside of an ecological community. These communities are what give the importance of diversity in to biodiversity, and they exist at a multitude of different scales. Plant communities and their development are discussed further in Sections 2.3.

The vast loss of biodiversity from anthropogenic causes is now widely documented. The literature is replete with warnings and estimates of global habitat loss. The last five decades have seen an unparalleled loss of biodiversity, mostly attributed to increases in agricultural land use (Rahman et al., 2013; Willi et al., 2005; Hooper et al., 2005). Accurate estimates of the extent of habitat loss and species extinction are difficult to pin down. There are no direct estimates, as the time and effort involved in counting each and every species is prohibitive (Williams & Gaston, 1994). The most accepted method of estimation involves reversing species-area accumulation curves[11] back to smaller areas to estimate species loss (He & Hubbell, 2011). Estimates obtained from these methods have been widely at odds with real life species losses. At the high end of predictions, Dirzo and Raven estimated over 1000 extinctions per million species per year (2003 in Brockington, Duffy & Igoe, 2012). At the low end, Myers and Lanting estimated between 50 and 150 species a year are going extinct (1999 in Brockington, Duffy & Igoe, 2012). The implications of even the small end are high, and every effort needs to be taken to protect habitats.

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[11] Species accumulation curve: "The number of species found in 20-30 quadrats within a particular vegetation type is recorded and the results plotted against the number of samples. Where the curve levels off indicates the number of samples needed to describe most of the species in that vegetation type." (Kent, 2012)

The specific habitat under study here is created grassland habitats in the UK. The following section explores current threats to grassland habitats and the consequences of their destruction. Our current understanding of the definitions and classifications of grasslands is first discussed to provide context to the study.

2.2 Grasslands

2.2.1 Grassland definitions

A good working definition of grassland allows us to accurately assess their status, and quantify the benefits provided. A number of well-cited definitions exist, these are discussed below. Obviously, "grassland" is an umbrella term for a wide range of finer habitat types. As such, and in all grassland discussions, the wider sense is first discussed before being gradually unpacked in to finer detail.

A broad working definition of grassland ecosystems is "land covered with herbaceous[12] plants with less than 10 percent tree and shrub cover," and wooded grassland (or savannah) is "land covered with grassland and has 10–40 percent tree or shrub cover" (The United Nations Educational, Scientific and Cultural Organization (UNESCO), 1973 in White, 1983). This definition does not address any of the functions of grasslands, their formation or maintenance. In contrast, the following definition explicitly defines the maintenance structure of grasslands.

"PAGE (The Pilot Analysis of Global Ecosystems) analysts define grasslands as terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures." (White et al., 2000).

NatureServe's study of global grasslands favoured the UNESCO/White definition (Faber-Langendoen & Jossem, 2010). This is specifically due to its lack of emphasis on land-use by humans, instead focusing on the ecological aspects. This divide in emphasis, whether we are interested in

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[12] Herbaceous/herb: a plant with seeds and leaves without the presence of woody tissue

conservation for conservation's sake, or for the benefit of humans, is present throughout all aspects of the literature.

The main division in grassland types is between temperate and tropical grasslands. Temperate grasslands occur within temperate regions of the world (with hot and cold seasons), and are normally flat with few trees. These are the applicable grasslands to this study.

Grasslands go by a number of different names across the world: "'steppes' in Asia; 'prairies' in North America; 'pampas', 'llanos' and 'cerrados' in South America; 'savannas' and 'velds' in Africa; and 'rangelands' in Australia." (WWF, 2014)

In terms of the UK, where the model developed in this study must be relevant for, grassland types can be further disaggregated. The following table outlines some accepted definitions of UK broad grassland types.

Grassland type	**Definition**
Natural Grasslands	Grasslands not modified by human activity (The Grassland Trust, 2014)
Semi-natural grasslands	Grasslands that have been altered by human activity (e.g. farming, burning etc.) (The Grassland Trust, 2014) These can be further disaggregated by soil type (Limestone/Calcareous; Marshy; Acid; Lowland Meadow and Pasture; Upland hay meadow)
Restored grassland	Areas of degraded grassland where diversity and richness are restored through management.
Created grassland	Areas of grassland artificially created on areas previously not grassland.
Semi-improved grasslands	Modified by agricultural activities, e.g. fertiliser and over-grazing. Has lower diversity than Improved Grasslands (The Grassland Trust, 2014)

Table 2.1: Main grassland types in the UK and their definitions (continues)

Grassland type	Definition
Improved grasslands	High species diversity[13] with few agricultural species. Never been subject to agricultural involvement (The Grassland Trust, 2014)
Unimproved grasslands	Low species diversity, with instances of rye grass and clover. Has been subject to fertiliser and heavy grazing. (The Grassland Trust, 2014)

Table 2.1: Main grassland types in the UK and their definitions (continued)

2.2.2 Threats to grassland habitats

The importance of this study rests on the degradation of grasslands and the importance of replacing lost habitats. A number of threats have historically existed from humans, and these have been magnified with large population rises of the last century.

Land use change

Globally, land use changes are the biggest contributing factor in grassland habitat loss. The main land uses that grasslands are often destroyed for are urban dwellings and agriculture.

Changes to urban landscapes

The world population of 7 billion in 2011 is set to increase to over 9 billion by 2050 (United Nations Population Fund (UNFPA), 2014). In London alone, the population is set to increase by 13% by mid-2022, in relation to an overall rise in England's population of 7% in the same time period (Office for National Statistics (ONS), 2014). This creates an intense pressure for housing and related infrastructure all over the world. In Scotland, the built environment increased by an estimated 46%, at the expense of mostly smooth grassland and arable farming (Scottish Natural Heritage (SNH), 2014). The Greater London Authority say it is set to build 424,000 new homes over a 10 year period starting in 2015 (London Assembly, 2015), and this surge in new homes is a global trend. In a study

[13] Species diversity: "measures the probability of 'any two individuals drawn at random from an infinitely large community belonging to a different species' (Simpson, 1949)" (Rawlinson, 2009)

focused on Mexico City, for example, grasslands on the urban fringe reduced from 2,562 ha in 1960 to 729 ha (López et al., 2001). A theoretical competition hierarchy for land-use was developed by Rounsevell et al. (2006). This highlights the current priorities for land owners and local authorities. This hierarchy indicates the preference for urban and agricultural landscapes over more natural landscapes such as grasslands or at least biocrops. This is likely in part due to the known financial reward from urban or agricultural land uses. This further encourages the valuation of natural resources to allow further integration with other land uses.

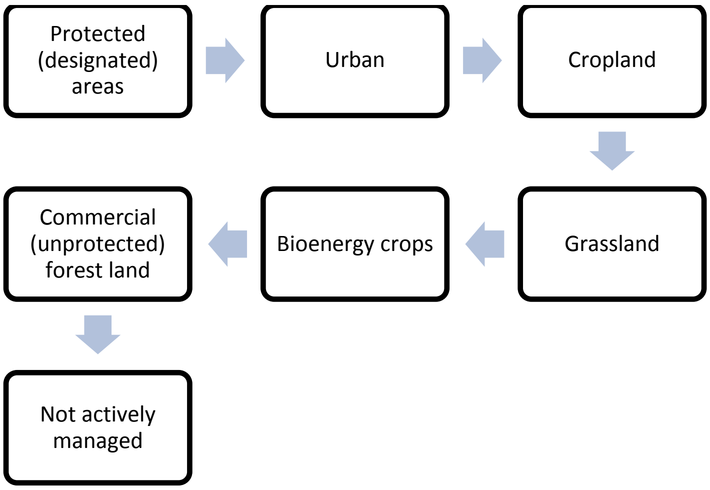

Figure 2.2: Theoretical hierarchy of land use (reproduced from Rounsevell et al., 2006)

Supported by the evidence of grassland loss previously mentioned, this hierarchy coupled with rising populations likely predicts further grassland loss. Urban landscapes are extremely unlikely to deliver the same Ecosystem Service provision as natural habitats such as grasslands.

Changes to agriculture

Increased populations have instigated a global surge in agriculture, and as such many grassland areas have been converted. In Britain, World War II sparked the need for sustainability, and the Twentieth Century showed a long-term reduction in grasslands. Although this decrease has reversed since 2000 in England, the amount of grassland is still lower than pre 1990 (Department for Environment, Food and Rural Affairs (DEFRA), 2010). 2007 and 2008 saw an increase of 6.1% in cropped land, fortunately at this stage seemingly not at the expense of permanent grassland (DEFRA, 2010). Scotland showed a similar trend, with increases in arable farming in the 1940s destroying improved pasture-land (SNH, 2014). With rising populations and food shortages, permanent grasslands may well give way to further agricultural use.

In addition to land use changes, agricultural increases can have further implications for grasslands. Even if the land is eventually turned back over to more natural habitats, over-fertilisation can leave the land difficult to recolonize due to excessive nitrates in the soil (Walker et al., 2009). Overgrazing also has a negative effect on semi-natural plant communities, potentially pushing the habitat in to a desertified state (Costanza, 2002).

Discussed threats have caused degradation and destruction to grassland habitats. The following section outlines the remaining extent of grasslands both globally and in the UK.

2.2.3 Extent of grasslands

Understanding the current extent of grasslands allows us to understand the need for more. Globally, grasslands cover approximately 40% of the earth (White et al., 2000, Gibson, 2009). This figure is hard to accurately quantify due to the differing definitions of grasslands, and blurring of boundaries between other land uses. Although the estimates of land cover and degradation differ, few argue against the notion that the habitat is swiftly declining. Hoekstra (2005) estimate while 4.6% of global grasslands are protected, 45.8% of total previous grassland coverage has been converted to a different land use. The effects of this land use change and its implications for this study were discussed in Section 2.2.2.

In 2011 the Centre for Ecology and Hydrology (CEH) created a land cover map based on satellite readings. This allows a greater understanding of the extent of grassland habitats in the UK. Perhaps surprisingly, only 6% of the UK is made up of urban regions. Figure 2.3 shows the location of different habitat types in the UK.

Aston University

Illustration removed for copyright restrictions

Figure 2.3: Map showing extent of different habitat types in the UK (CEH, 2011)

Despite this relatively positive look at Britain's habitats, much of the non-urban space is not the natural grasslands and woodlands that are most desirable. In fact, it is thought that 90% of the UK's semi-natural grasslands have been lost since 1945 (Bullock, 2011), gradually changing to more agriculturally-influenced land uses. Other papers provide less hopeful estimates, with Fuller estimating 97% of unimproved grassland has been lost in the UK (Fuller, 1987 in Critchley et al., 2003). This presents further problems as the areas that still exist are small and fragmented[14] (Joint Nature Conservation Committee (JNCC), 2014). This damages connectivity[15] for species.

The "Dig for Victory" and "The Great Harvest" campaigns spawned by necessity during the Second World War began the trend of converting unimproved grasslands to agricultural uses. This continued land-use change to agriculture did not stop, and it is widely believed this is the main driver behind grassland habitat loss (e.g. Plantlife, 2002; Haines-Young et al., 2000). A grassland with an obvious monetary potential has proven to be favourable to traditional, non-earning equivalents. Table 1.2 outlines the best estimates of what remains of each grassland type in the UK.

Grassland type	Area remaining (ha)
Unimproved neutral grassland	<8,500
Unimproved acid grassland	<26,750
Unimproved calcareous grassland	<40,000

Table 2.2: Estimates of remaining unimproved grassland types in the UK (Plantlife, 2002)

The extent of grassland degradation or loss seriously impacts the positive impacts such habitats have on humans. These positive impacts and their necessity are discussed further in Section 2.2.6. To mitigate this loss, restoration and creation efforts are underway. The following section describes what efforts are currently in place, including habitat creation.

2.2.4 Conservation and creation efforts

Global strategies are being put in place in an attempt to conserve what grassland remains. Currently, only 3.4% of the world's temperate grasslands are officially protected. This is even less than the next

[14] Habitat fragmentation: "the discontinuity, resulting from a given set of mechanisms, in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, or survival in a particular species" (Franklin et al., 2002)
[15] Connectivity: Connectivity: "the extent to which a landscape facilitates the movements of organisms and their genes" (Rudnick et al., 2012)

lowest protected habitat globally, Mediterranean forests and woodlands (International Union for Conservation of Nature (IUCN), 2014). Large-scale strategy groups have been put in place in an attempt to coordinate conservation programmes, including the Grasslands Specialist Group and the World Commission on Protected Areas (WCPA) Temperate Grasslands Specialist Group.

In the UK, groups such as the Grassland Trust and English Nature work to conserve grasslands. Various levels of protection exist in the UK for grasslands, these are summarised in Table 2.3.

Protection level	**Protection measure**
International Conventions	The Convention on Biological Diversity (CBD)
	The Convention on the Conservation of European Wildlife and Natural Habitats
European Directives	The EU Habitats Directive
	The EU Birds Directive
	The EU Water Framework Directive
UK legislation	The Wildlife and Countryside Act
	Natural Environment and Rural Communities (NERC) Act 2006
	UK Biodiversity Action Plan (BAP)

Table 2.3: Outline of relevant legislation surrounding grasslands

Probably most relevant to UK Grasslands on a more local scale is the UK Biodiversity Action Plan, a constantly evolving set of Habitat Action Plans (HAP) and Species Action Plans (SAP). Habitat Action Plans exist for all UK grasslands, and these have a demonstrable impact on planning applications which could negatively affect grasslands and other priority habitats (UK BAP, 2011).

Most relevant for this study are efforts to create habitats on sites previously used for other land uses. A number of Government agencies, policy-makers and ecological companies have been undertaking habitat creation. Although the creation of grasslands is by no means a new activity, the literature surrounding it is relatively sparse. It should be stressed that where possible, grassland creation should not be a substitute for conserving what semi-natural grasslands we have left. Under relatively short timescales, even expertly created grasslands cannot replicate ancient semi-natural grasslands. However, it could massively benefit biodiversity when compared with other potential land-uses, especially urban. This is especially pertinent for sites of ex-industry or landfill which would usually be built upon again.

2.2.5 Why are grasslands important?

The various threats to grassland habitats were discussed in Section 2.2.2. The consequent losses to grassland mean the services they provide to humans by nature (discussed in Section 2.2.6) are degraded. These services that grasslands provide to humans do not always only affect those living near them. In fact, local land-use decisions more often than not do not take off-site effects in to account (Seppelt et al., 2011). Instead, global grasslands contribute these services as a public good to all humans. As such, although this study is focused on the UK, the overall consequences of global grassland loss will be discussed. The following section attempts to summarise these threats.

Loss of species

Diminishing habitats have contributed to the reasons, sometimes unknown, why various species have become extinct in the recent past. "Waxcap" grasslands, so named because of the waxcap fungi species the nutrient-poor soils of these grasslands support, are of international importance (Natural England, 2010). Loss of even rare plant species within grasslands can have a wider effect on biodiversity. A study by Zavaleta and Hulvey (2004) compared patterns of species loss associated with various mechanisms from agriculture, biological invasions[16] and excess fertilisation with the capacity to resist invasion. This study found that resistance to invasion declined dramatically with losses of plant species in California grasslands, with wider applicability to global grasslands. Similar

[16] Biological invasion: "…a species' acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population." (Valéry et al., 2008)

studies by Selmants et al. (2012), and Hobbs and Huenneke (1992) affirm these findings. Although, to confuse matters, a certain amount of disturbance[17] is required to achieve optimal species diversity, following the disturbance curve shown in Figure 2.4. This perhaps suggests that even with the disturbance of land use changes etc., a diverse sward can be achieved as long as reasonable species richness is not lost.

Possibly the most worrying aspect of species loss is that we are likely to be unaware of its full consequences until too late. Species populations are so intrinsically linked that a loss of one could lead to loss of other, important species. This could affect our long term access to food via lack of pollinators. As 50,000-70,000 plant species are also harvested a year for modern and traditional medicines, loss of species could also have direct impacts on healthcare (WWF, 2016).

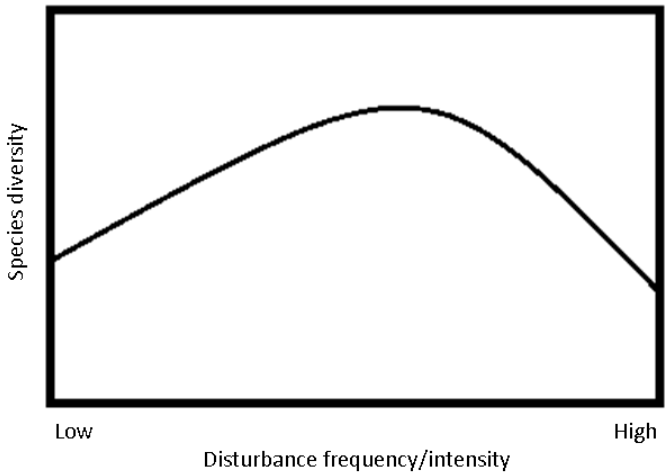

Figure 2.4: Species diversity within a given patch should be highest at intermediate frequencies or intensities of disturbance (Connell, 1978 in Hobbs & Huenneke, 1992)

Loss of Ecosystem Services

The discussed threats to grassland, and their subsequent destruction (Section 2.2.2), mean a reduction in ecological services provided to humans. In the field of conservation science, one of the

[17] Disturbance: where environmental or landscape conditions are changed, altering the ecosystem

main ways of describing and structuring these is the Ecosystem Services concept. Interest in this concept has increased dramatically in recent years. The following section explains the concept, and outlines the specific services provided by grasslands. This allows the reader to gain understanding of what we are attempting to indicate and value further in the study.

2.2.6 *What are Ecosystem Services?*

The background concept of Ecosystem Services has been known and discussed by scientists for decades. They are defined by The Economics of Ecosystems and Biodiversity (TEEB) as "The direct and indirect contributions of ecosystems to human wellbeing" (2014). Ecosystem Services as a term rose to prominence following the publication of the Millennium Ecosystem Assessment (MA, 2001). This involved the collaboration of thousands of scientists attempting to classify and quantify the services provided to us by nature. The following table outlines the Ecosystem Services that were agreed upon, and whether they are provided by grasslands. The services can be broken down in to four main categories depending on the type of service provided. A brief breakdown of the impact of grasslands on known Ecosystem Services is then presented. A vast quantity of literature is already available on the benefits of grasslands in a non-economic sense. Table 2.4 outlines Ecosystem Service and their presence in grasslands. These are then described in more detail below.

Ecosystem Service		**Ecosystem Service description**	**Can be present in grasslands?**
Provisioning	Food	Providing the conditions to grow or hunt for food.	✓
	Raw materials	Providing materials for construction and food including wood, biofuel and plant oils.	✓
	Fresh water	Regulating the global flow of water and purification.	✓
	Medicinal resources	Providing the plants used as traditional medicines and materials for use by pharmaceuticals.	✓

Table 2.4: Description of Ecosystem Services and their provision by grasslands (TEEB, 2014) (continues)

Ecosystem Service		Ecosystem Service description	Can be present in grasslands?
Regulating	Local climate and air quality	Shade and influence on rainfall from trees. Trees also remove pollutants from the atmosphere.	✓
	Carbon sequestration and storage	Sequestration[18] of greenhouse gases (GHGs) in plant tissues.	✓
	Moderation of extreme events	The buffers created by ecosystems against hazards including tsunamis, floods, avalanches and landslides.	✓
	Waste-water treatment	The filtering of human and animal waste. Pathogens are eliminated through activity of microorganisms and nutrients and pollution are limited.	✓
Habitat / Supporting	Habitats	Providing the things plants or animals need: water, food and shelter.	✓
	Maintenance of genetic diversity	Upkeep of the variety of genes between and within species groups. Helps promote commercial crops and livestock.	✓
Cultural	Recreation and mental and physical health	Providing space for leisure activities to improve physical and mental well-being.	✓
	Tourism	Providing tourism activities which improve the economic conditions of the area.	✓
	Aesthetic appreciation and inspiration for culture, art and design	The provision of inspiration for cultural pursuits.	✓
	Spiritual experience and sense of place	Many natural landmarks are held sacred in various areas of the world, and nature is often associated with local customs.	✓

Table 2.4: Description of Ecosystem Services and their provision by grasslands (TEEB, 2014) (continued)

[18] Sequestration: Storage of a chemical or compound

a. Ecosystem Service - Food and Raw materials

The products and raw materials grasslands provide are one of the few services that already have a structure of value attached. Grasslands provide crops, fodder, forage, fibres and biofuels. Numerous studies have indicated the link between higher species-richness and biodiversity of grasslands and the return of hay yields (Bullock, Pywell & Walker, 2006; Hooper et al., 2005; Jarvis, Padoch & Cooper, 2013).

Conversely, it has been speculated that production of biofuels could have an adverse effect on biodiversity. Natural vegetation is often cleared completely in larger scale biofuel plantations (von Maltitz & Staffor, 2011). However, the considerable reduction in greenhouse gases (GHGs)[19] versus fossil fuels is seen by many as an acceptable trade-off (CBD, 2012). This is compounded by hopes that biofuel production could help some global communities out of poverty. This success, however, is based on a variety of factors (for example which specific biofuels are pursued) (Peskett et al., 2007).

b. Ecosystem Service - Fresh water

Grasslands can have a significant impact on the provision of fresh water. Grasslands help filter out pollutants, reducing the reliance on man-made water treatment. A study carried out for DEFRA showed the pressures on grasslands from climate change and grazing could be reducing the grasslands' ability to filter water (Stevens et al. 2008). This could in turn require further spending to artificially recreate these services. These costs will be looked at in Section 5.2.3.

c. Ecosystem Service - Medicinal resources

This service is most relevant in countries or regions that do not have easy access to healthcare. As such, the availability of plants for use in traditional medicines is valued highly. Examples of medicinal

[19] Greenhouse gases (GHGs): any gas that contributes to climate change through absorption of radiation

use can be found widely in the literature (Stangeland et al., 2008; Barnes et al., 2003; Fabricant & Farnsworth, 2001).

d. Ecosystem Service - Local climate and air quality

Local climate and air quality issues are a priority in the UK. Health costs caused by PM10[20] pollution in the UK have been estimated at between £9.1 and 21.4 billion per year (Defra, 2007 in Forestry Commission, 2010). Although the strongest links to air quality are from woodland, there is compelling evidence for a positive effect on air quality and climate from grassland. For example, a 2009 study showed that scenarios comprising 75% grassland, 20% sycamore and 5% Douglas fir could remove 90.41 t of PM10 per year (Tiwary, 2009 in Forestry Research, 2010).

e. Ecosystem Service - Carbon sequestration and storage

Carbon sequestration and storage is one of the Ecosystem Services grasslands contribute most towards. Our effect on the global carbon cycle is increasing at an alarming rate (IPCC, 2011). As such the importance of this Ecosystem Service is also growing. Grassland soil in England store more carbon than any other land use (NEA, 2011). Arable areas are second, with 583 million tonnes (Bradley and others, 2005 in Natural England, 2010). This claim is countered by Dawson and Smith, 2007, who state that croplands in the UK lose on average 140 ± 100 kg of carbon/ha/year (in Ostle, Levy & Smith, 2009). Benefits to this Ecosystem Service are made when croplands are converted to grassland areas (Ostle, Levy & Smith, 2009). The Countryside Survey indicated that improved grasslands are also an excellent source of below-ground carbon (274 ± 25 million tonnes) (Countryside Survey, 2007).

[20] PM10: Particulate Matter up to 10 micrometers in size

f. Ecosystem Service - Moderation of extreme events

Grasslands can moderate extreme weather events. Alluvial meadows[21] can provide areas for flooding, while other grassland types can provide recharge of groundwater to help prevent run-off extremes (Hönigová et al., 2012; Wildlife Trusts, 2015). Recent extreme floods in the north of England have been cited as evidence of the consequences of natural habitat loss (Wildlife Trusts, 2016).

g. Ecosystem Service - Waste treatment

Although wetlands are arguably the habitat that provide this Ecosystem Service most highly, grasslands are also a valuable source of waste-water treatment under the right circumstances. In the USA, grasslands have been used in the Whole Farm Plans to help prevent toxic materials and sediments from reaching New York's water supply (Flaherty & Drelich, 1997). Other waste treatment can also be undertaken by grasslands. Biological activities allow them to act as waste cleaners for materials such as nitrogen compounds. Soil microbial processes convert ammonium (NH_4^+) and nitrate (NO_3^-) into N_2O (Hönigová et al., 2012)

h. Ecosystem Service - Habitats

Grasslands provide habitat for an enormous amount of important species worldwide. In UK semi-natural grasslands alone, 206 UK BAP species utilise them as habitat, including twite *Carduelis flavirostris* and marsh fritillary butterfly *Euphydryas aurinia* (Bullock, 2011; JNCC, 2014). In addition to important pollinators dealt with in "Pollination" Ecosystem Services, other invertebrates, birds, mammals, reptiles and amphibians use grasslands as habitat. There is evidence that increased agricultural intensification has contributed to massive bird loss (Vickery et al., 2001; JNCC, 2014]. Even without full habitat loss, the fragmentation of our remaining habitats causes further problems for biodiversity through lack of connectivity and isolation of habitat patches. This lowers the possibility of "rescuing" species under threat of extinction (Parker & MacNally, 2002).

[21] Alluvial meadows: grasslands located on riverbanks

i. Ecosystem Service - Maintenance of genetic diversity[22]

Similarly to providing habitats, grasslands provide the maintenance of genetic diversity. Higher per species genetic diversity has been found to maintain higher species diversity than those with lower genetic diversity (Booth & Grime, 2003 in Hughes et al., 2008). This in turn has positive effects on other Ecosystem Services (Prieto et al., 2014).

j. Ecosystem Service - Recreation and mental and physical health

Grasslands provide a number of possibilities for leisure and relaxation. Wildlife watching, hiking and other sports are all activities that can be undertaken on grasslands. Outdoor recreation has shown evidence for improving mental and physical health (Triguero-Mas et al., 2015). There are concerns that leisure activities such as those cited above could damage overall biodiversity (Tanner & Gange, 2005), but in moderation they are unlikely to cause large impacts.

k. Ecosystem Service - Tourism

Grasslands can provide a site for eco-tourism. PAGE analysts found that tourism to grassland systems is increasing, but grassland degradation could be harming this (2000). The Wildlife Trusts of the UK and the Grassland Trust provide detailed information on top grasslands for tourists.

l. Ecosystem Service - Aesthetic appreciation and inspiration for culture, art and design and Spiritual experience and sense of place

The aesthetic appreciation of grasslands is linked to the recreational aspects of grassland outlines above. Although spiritual experience and sense of place is a separate Ecosystem Service, the two are intrinsically linked which makes separation difficult. Lindemann-Matthies, Junge & Matthies (2010) found that people's aesthetic appreciation increased with grassland species richness, although this was potentially altered by the presence of particular species.

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[22] Genetic diversity – "any measure that quantifies the magnitude of genetic variability within a population" (Hughes et al., 2008)

Grasslands have played an important part of global and UK culture throughout history. Keleman and Kalóczkai discussed the aesthetic importance of grasslands amongst farmers. This revealed the importance of grasslands for providing a sense of place within humans, and the colours and beauty which can delight us (2013). This is especially linked to the innate beauty of a high proportion of wild flowers within a meadow.

Figure 2.5: Painting by Claude Monet depicting a meadow

2.2.7 Delivery of Ecosystem Services: Net Primary Productivity (NPP)

Although NPP will not be intensively studied in this thesis, its concept is important as a link to economic value in later chapters. NPP, a measure of solar energy driving a system, is a "key indicator" of Ecosystem Service provision (Costanza et al., 1998, Fig. 6). Studies have revealed strong links between NPP and biodiversity (using species richness as a proxy). This is despite some concerns this is due to "sampling effects" from the methodology (Aarssen, 1997; Grime, 1997; Huston, 1997; Wardle et al., 1997 in Costanza et al., 2007).

Through extensive analysis, a significant link was found between vascular species richness (as a proxy for biodiversity), and NPP. Where vascular species richness rises, the NPP also increasing, thus predicting a rise in Ecosystem Service provision. This was estimated as a 1-2% rise in Ecosystem Service provision for a 1% rise in vascular species richness. This was especially prevalent at high temperatures (0-25 degrees), although evidence suggests the relationship is only suppressed at low temperatures. There is already evidence that latitude effects NPP (Imhoff et al., 2004 in Costanza et al., 2007).

As the aim of this study is to link quick biodiversity assessment measures (e.g. indicator species presence) to the value of ecological services, this measure is very important. As species richness is an oft-used biodiversity measure, the link between this, NPP, and Ecosystem Service provision and therefore value is vital. As a challenge of this study was to link metrics of ecology and economics, this link could prove crucial in applying value to floral data obtained from created grasslands. In proceeding chapters, the relationships between biodiversity levels, NPP and value are explored further.

2.3 How do grasslands form?

The development of grassland communities has been studied extensively. Despite this, the complexity of the many relationships between species and environmental variables means that much remains unknown. The following section outlines the facets of community development pertinent to this study. First, a "mind map" outlining the main lines of enquiry in grassland successional research was drawn to structure themes of enquiry. These will be discussed along with an examination of species indicating these processes and their links to others.

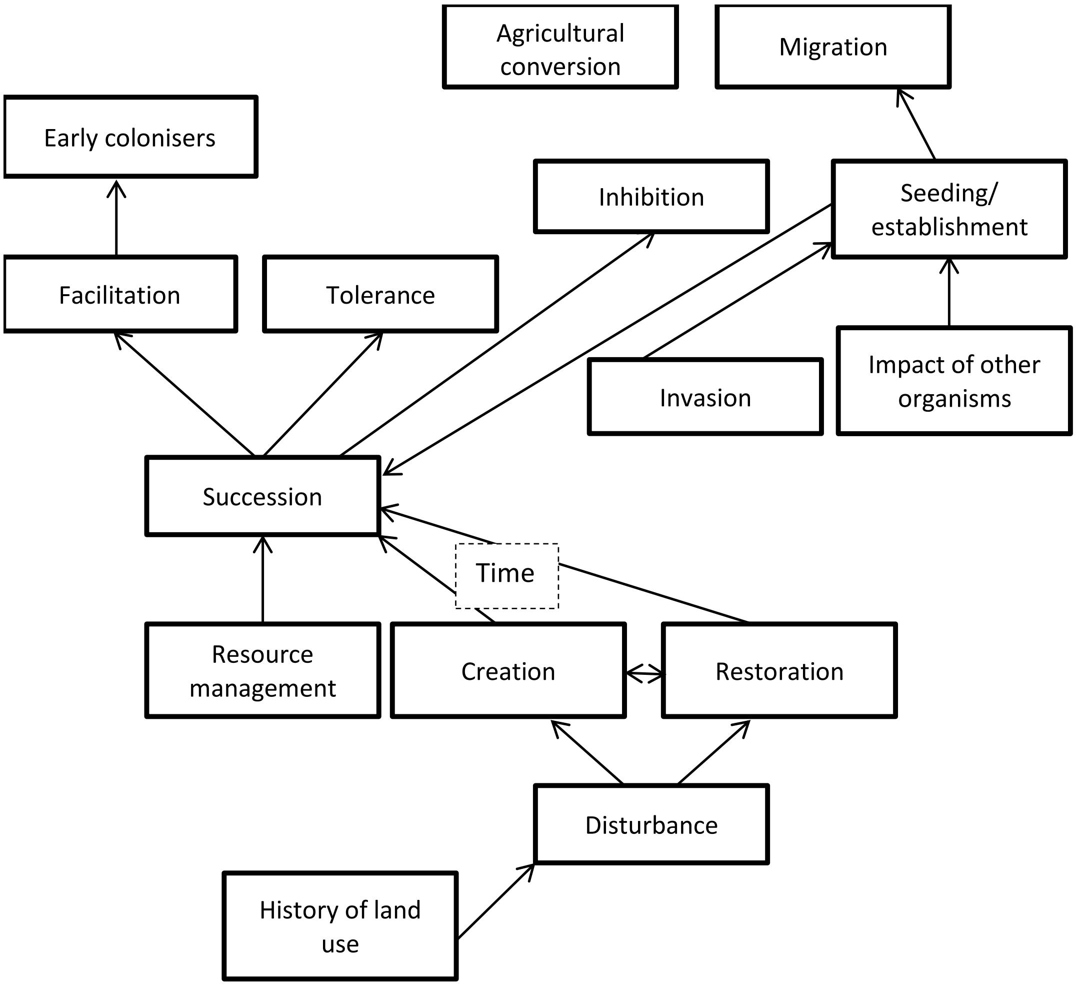

Figure 2.6: "Mind map" created by Sam Cruickshank of points for discussion in successional research

The above diagram was created by the author as a means of making sense of the topics covered in successional research. In the first instance, an original land use type can be subject to disturbance. This is followed by either restoration of habitat or creation of new ones. With appropriate resource management, succession of plant communities occurs. This leads to theoretical successional models such as tolerance, facilitation or inhibition. These are mitigated by seeding, invasive species, or the impacts of other organisms.

2.3.1 Time - succession

The time since creation of created habitats is both a dependent variable in this study and a potential bioindicator. As we are attempting to identify bioindicators of created grasslands, it makes sense that time may explain community changes. Chronosequencing[23] of sites allows us the effect of time without requiring years to undertake a study. As plant communities take time to establish and become stable, it follows that biodiversity could improve over time. In order to factor the effect of time in to this study, the following section discusses the important aspects of succession, and identifies other potential relevant indicators. Successional models are discussed for context, however this study will primarily be an indicator species study.

To our current knowledge, succession was first described by Clements in 1916 (Luken, 1990). However, his review highlighted ecological research in to succession dating back as far as 1685. It was recorded that Charles Darwin cleared areas of ground to study the competition of weeds recolonizing the area (Jordan, Gilpin & Aber, 1990). At an organism level, an individual arises, grows to maturity and eventually dies. The location and timing of this within a community depends on a variety of variables, including soil type, nutritive value, environmental factors and adjoining habitats. As such, the life cycle of a community mirrors the individuals within it, and the processes, however complex, can be mapped (Clements, 1916).

Clements' reasonably simple definition of succession, "the universal process of formation development" forms a starting point, but ultimately masks the complexity of the study. Other definitions describe succession as a process where "plant species are sorted along a gradient of resources", acknowledging the effect of external influences on assemblies (Luken, 1990, pp. 3). Although not explicit, one would assume that time is one of the resources stated. Other explanations are clearer on this, with studies of sand dunes as early as 1895 acknowledging the effect of time on plant communities (Warming, 1895; Cowles, 1899, in Walker, Walker & Hobbs, 2007). As such, perhaps a more robust definition would be "…community change where one group of organisms at a given site is replaced by others as time advances" (Wali, 1999).

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[23] Chronosequencing: establishing successional traits through surveying sites with similar attributes that are of different ages

Two main types of succession exist, primary and secondary. Primary succession occurs on land that has never previously been inhabited by vegetation, while secondary succession occurs on land previously inhabited by vegetation. Studies of primary succession include investigations of de-glaciated areas of Alaska (Chapin, Walker & Fastie, 1994) and volcanic areas of Hawaii (Vitousek et al., 1993). Secondary succession would include reclaimed industrial or agricultural land. Due to the relatively recent interest in habitat restoration and creation, fewer historic studies surrounding secondary succession exist. Examples include abandoned fields in tropical regions of Veracruz (Guevara, Purata & Van der Maarel, 1986), and on heathland ecosystems (Berendse, 1990). The vast majority of vegetation establishment in the UK revolves around secondary succession, and indeed this study focuses on this pathway. The data from fieldwork undertaken in this study could be useful for further successional research.

The importance of succession and attempts to understand its pathways are widely stated in the literature. A survey undertaken by the British Ecological Society (BES) of its members showed succession as the second most important concept at that time (Cherrett, 1989). Despite its long history of research, plant succession following disturbance remains an “intriguing mystery” (Walker & del Moral, 2009). The following sections attempt to track the major processes of succession from beginning to end. A discussion of theories pertinent to successional research is presented below. Understanding of this will help to inform the data analysis collected from chronosequencing secondary successional processes.

2.3.2 Succession - Seeding/colonisation

Establishment of plant communities can arise in a number of ways. Natural dispersal of plants’ reproductive units occurs, or often deliberate sowing of seeds is undertaken. Due to the economic status and necessity of agricultural plants throughout history, much more is known about the germination capabilities of these than of other species (Walker, Walker & Hobbs, 2007). From what is known of the requirements of seedlings, warmth; protection from herbivory; adequate water; and nutrients are the most important (Walker, Walker & Hobbs, 2007). An initial lack of these requirements does not guarantee lack of establishment. On the contrary, seeds can remain in a dormant state for many years until their environment is suitable (Wali, 1999). This is fortunate considering land following disturbance can be toxic and infertile (Walker & del Moral, 2009), especially following industrial use or mining (see for example Dudka et al., 1995).

Succession can take place through natural colonisation of a derelict site, or with deliberate seeding or relocation of desirable species. As an example of the former, the Woodland Education Centre, after clearing existing rhododendron plants and woody species, allowed the site to naturally colonise along 9 strips of differing management (2015). Similarly, an experiment was set up by the Field Studies Council (FSC) to establish how vegetation would naturally colonise an abandoned car park (2009). Despite a number of successes with colonisation without management, results can be unpredictable and success reliant on a specific and sometimes unknown set of conditions (Prach & Pysek in Walker & del Moral, 2009).

Management can also take place to encourage vegetative succession on a site (i.e. seeding, selective weeding), and colonisation can take a more structured path. Decisions can be made that will affect the future pathway of succession, for example introducing late stage successional plants immediately. This can be beneficial to particularly fertile sites but would potentially prove unfruitful otherwise (Whisenant, 2005 in Walker & del Moral, 2009). Such introduction of shrubs and trees can also protect further vegetation from disturbance such as grazing. However, a too quick ground cover by such plants or pioneers can inhibit colonisation by native species (Walker & del Moral, 2009).

Species' characteristics also help to predict their colonisation success. High seed production is beneficial, and larger seed size has often been shown to aid colonisation (Coomes & Grubb, 2003), for example in old field species (Gross, 1984 in Peart, 1989), and especially in dominant perennials. This success has been shown to be tempered by smaller seeds' ability to travel across greater distances to vacant sites (Coomes & Grubb, 2003). This trade-off may help to explain why both smaller and larger seeded species continue to coexist, especially within the same habitat. However, others have found no correlation between seed size and colonisation success (Fenner, 1978 in Peart, 1989). As with many of the other factors in this field, the evidence suggests colonisation success is dependent on number of factors in conjunction. Discussion of seeding in relation to this study's feedback is discussed further in Section 4.5.2.

2.3.3 Succession - Early colonisers/pioneers/ruderal species

Early colonisers, sometimes known as ruderal or pioneer species, hereon known as pioneers, are the first plants to arrive in a successional pathway, either primary or secondary. Competitive weed species generally fill this role, generally as their propagule availability is good in the local area (Bekker et al., 1997 in Van der Putten, 1999). In the UK, these include species such as Barren Brome *Anisantha sterilis,* Common nettle *Urtica dioica,* Cow parsley *Anthriscus sylvestris,* Ragwort *Senecio jacobeae* and Common Cleavers *Galium aparine*. This helps explain why these species are commonly seen on road sides and breaking through cracks in pavement. Grime's CSR method of plant description contains an index for assessing the ruderal nature of certain species (1979).

Competition in plant communities only occurs when a resource is not in excess for either plant (Went, 1973). However, this is often the case at any given time in a plant community. The potential competitive qualities of a species have been researched fairly extensively. Canopy height has been found to have a positive effect on above-ground competitive ability (Hodgson et al., 1999; Weiher et al., 1999 in Smart et al., 2005). In a regression analysis, 63% of variation in competitive ability was explained by biomass structure and plant height, with canopy diameter, canopy area and leaf shape explaining the majority of the residual variation (Gaudet & Keddy, 1988).

The condition of the soil in the area of interest can enhance or limit the success of colonisation. Remnant fertiliser from agricultural use, for example, can present a limitation in secondary succession. Where little soil is present, certain species, such as bird's-foot trefoil *Lotus corniculatus*, red bartsia *Odontites vernus*, common figwort *Scrophularia nodosa*, St John's-wort *Hypericum perforatum*, red clover *Trifolium pratense* and common and purple toadflax *Linaria vulgaris* and *Linaria purpurea* can all thrive as early colonisers (Bumblebee Conservation Trust, 2015). Early colonisers identified here were looked for in fieldwork data (see Section 4.5.1).

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Figures 2.7 and 2.8: Early colonising weeds Barren Brome *Anisantha sterilis* and Common Cleavers *Galium aparine* (Botanical Society for Britain and Ireland (BSBI), 2015; Kew, 2015)

2.3.4 Succession - Seedbank forming species

Seedbank forming species are important to build and sustain grassland biodiversity, and have implications on plant dispersal over time (Valkó et al., 2014; Vandvic et al., 2015). Table 2.5 presents a list of known seed-bank forming species in the UK. Seedbank forming species identified here were looked for in fieldwork data (see Section 4.5.2).

Common name	**Latin name**
Scarlet pimpernel	*Anagallis arvensis*
Common orache	*Atriplex patula*
Mouse-ear chickweed	*Cerastium fontanum*
Climbing corydalis	*Corydalis claviculata*
Common fumitory	*Fumaria officinalis*

Table 2.5: Common seed-bank forming species (continues)

Common name	Latin name
Red hemp-nettle	*Galeopsis angustifolia*
Cleavers	*Galium aparine*
Herb-robert	*Geranium robertianum*
Geranium sp.	*Geranium* sp.
Red deadnettle	*Lamium purpureum*
Nipplewort	*Lapsana communis*
Chamomile	*Matricaria recutita*
Medick spp.	*Medicago* spp.
Field forget-me-not	*Myosotis arvensis*
Common poppy	*Papaver rhoeas*
Common groundsel	*Senecio vulgaris*
Hedge mustard	*Sisymbrium officinale*
Sow thistle spp.	*Sonchus* spp.
Speedwell spp.	*Veronica* spp.
Common vetch	*Vicia sativa*
Field pansy	*Viola arvensis*

Table 2.5: Common seed-bank forming species (continued) – (Wilson, B.J. & Lawson, H.M., 1992)

2.3.5 Theoretical models of succession

As stated previously, models of succession have been being studied for the last few hundred years. However, to our knowledge few formal theoretical models were suggested until 1977. “Relay floristics” relate to the somewhat simplified concept that groups of plants establish, replace one another, and reach an eventual stable state. This concept has been in use for a number of years, but is considered a poor representation of real-life succession (Luken, 1990). Connell and Slatyer presented three theoretical models based on biotic interactions: facilitation; tolerance; and inhibition. These models, along with others presented in the literature, will be discussed further. An analysis of the full successional pathways of our communities is beyond the scope of this study. However, a background to this will help inform biodiversity indicator selection within this context.

a. *Facilitation*

Facilitation within succession occurs where a plant's presence encourages the success of other species during succession. Some early colonisers, or pioneer plants (discussed in Section 2.3.3), improve the nutrient status on site, allowing less competitive plants to succeed (Connell & Slatyer in Luken, 1990). Research in to facilitation is relatively sparse (Brooker et al., 2008). What evidence is in place shows a huge level of complexity in determining facilitative effects.

b. Tolerance

The tolerance model describes succession where early colonisers are successful, but the low-resource conditions limit further species thriving (Connell & Slatyer, 1977 in Luken, 1990). Real-world evidence of this process is very limited. Clearly, stress tolerance is an important facet of successional research. This is also pertinent to our study to highlight stress-tolerant species in newly created sites.

Species known for their stress tolerance (and under which stresses) are outlined below in Table 2.6. Unsurprisingly, many of these species known for stress tolerance are negative indicators for semi-natural grasslands and meadows. This will be taken in to account when analysing floral data.

Common name	**Latin name**
Brown bent	*Agrostis capillaris*
Hard fescue	*Festuca longifolia*
Sheep's fescue	*Festuca ovina*
Red fescue	*Festuca rubra*
Perennial rye-grass	*Lolium perenne*
Annual meadow-grass	*Poa annua*
Smooth meadow-grass	*Poa pratensis*

Table 2.6: Stress tolerant species – (Markham, Grime & Buckland, 2009; MacFillivray et al., 1995)

c. Inhibition

The inhibition model assumes that established species on a site inhibit the growth of new competitor species (Connell & Slatyer, 1977 in Luken, 1990; Peart, 1989). This is therefore only relevant on more established habitats in the successional process.

Studies of inhibition are relatively few, and further interest in the process during field studies would be beneficial. Analysis of inhibition models would be outside of the remit for this study, but inhibitor species will be noted in any results. This could aid further research in to the subject.

2.3.6 Invasive species

An invasive, or non-native species is defined as "those that have reached Britain by accidental human transport, deliberate human introduction, or which arrived by natural dispersal from a non-native population in Europe." (JNCC, 2012). Most non-native species have little to no impact on the receiving landscape globally, but others can spread disease, monopolise available resources, or encourage parasitism or hybridisation. In Hawaii, native forests were affected by the introduction of *Myrica faya,* a non-native nitrogen-fixing tree. The nitrogen inputs were raised so high that the habitat was permanently altered (Chapin et al., 2000). Halting this rise in invasive species is high on the UK agenda, highlighted by the "Environment for Europe" ministerial conference endorsing a resolution to "halt the loss of biodiversity at all levels by the year 2010" (CBD, 2010), including a reduction in invasive species. The increase in invasive species in Britain is highlighted in Figure 2.9.

Figure 2.9: Invasive species in Britain (CEH, British Trust for Ornithology, Marine Biological Association and the National Biodiversity Network Gateway, 2009)

The increase in invasive species has been seen as an indicator of a larger degradation of regulating Ecosystem Services (Carpenter et al., 2011). There are a number of means of dissuading invasive species from colonising created or restored grassland. Treating the soil with a carbon source, for example mulch or sawdust, can limit invasive species (Alpert & Maron, 2000 in Walker & del Moral, 2009). As discussed, species-rich swards appear to resist invasion better than species-poor areas (Elton, 1958; Vitousek et al., 1996; Van der Putten, 1999). This is linked to level of exposure and bare ground, which have also been linked to threat of invasion (Willi, Mountford & Sparks, 2005). Examining these effects on created grasslands would be beneficial. Further examples of invasive species in the UK sourced from the literature are presented in Table 2.7. These species are revisited in our floral analysis in Section 4.5.4.

Common name	Latin name
Garlic mustard	*Allaria petiolata*
Cow parsley	*Anthriscus sylvestris*
Burdock	*Arctium* sp.
Mugwort	*Artemisia vulgaris*
Belladonna	*Atropa bella-donna*
Musk thistle	*Carduus nutans*
Creeping thistle	*Cirsium arvense*
Marsh thistle	*Cirsium palustre*
Spear thistle	*Cirsium vulgare*
Hawksbeard sp.	*Crepis* spp.
Wild carrot	*Daucus carota*
Common foxglove	*Digitalis purpurea*
Wild teasel	*Dipsacus fullonum*
Willowherb	*Epilobium* spp.
Horsetail spp.	*Equisetum* spp.
Wood avens	*Geum urbanum*
Ground ivy	*Glechoma hederacea*
Common hogweed	*Heracleum sphondilium*
Hawkweed spp.	*Hieracium* spp.
White dead-nettle	*Lamium album*
Yellow melilot	*Melilotus officinalis*
Parsnip	*Pastinaca sativa*
Greater ribwort	*Plantago major*

Table 2.7: Invasive plants of disturbed habitats (Sage et al., 2009) (continues)

Common name	Latin name
Silverweed	*Potentilla anserine*
Cinquefoil spp.	*Potentilla* spp.
Lesser celandine	*Ranunculus ficaria*
Creeping buttercup	*Ranunculus repens*
Dock sp.	*Rumex* sp.
Ragwort	*Senecio jacobeae*
Dandelion agg.	*Taraxacum* agg.
Common nettle	*Urtica dioica*

Table 2.7: Invasive plants of disturbed habitats (Sage et al., 2009) (continued)

2.3.7 Climax and stable communities

The history of successional research tells us that no truly stable plant community exists (Cowles, 1899; Niering, 1987 in Connell & Slatyer, 1977). This is due to the inevitable influence of disturbance, both natural and anthropogenic. Despite this, a large amount of research has gone in to the concept of stable or climax communities. A "stable" community is often regarded as the goal for habitat creation or restoration (NAS, 1974 in Wali, 1999). Despite this, some evidence has emerged that biodiversity increases have a positive effect on productivity but a negative effect on stability (Pfisterer & Schmid, 2002 in Costanza et al., 2007).

What is considered a stable, or climax community, is disputed across the years of study. Wali (1999) states that a community where the removal of one species does not largely impact the remaining flora is probably stable, but this surely depends on the species that is removed. If the plant in question has particular qualities such as nitrogen fixing or being parasitic, the effect on the community could be much larger. Habitats which are often amongst the most stable in the UK include green lanes[24] (Croxton et al., 2005) and mature woodland (Rawlinson, 2009).

[24] Green lanes are defined here as tracks bounded by hedgerows (Walker et al., 2006)

The uncertainty around stable or climax communities complicates restoration or creation efforts owing to a lack of baseline data (Kennedy & Cheong, 2013). This can mean that the extent of disturbances remains unknown. The means of how to achieve stable communities are also well discussed (see for example Whittaker, 1972; Wali, 1999).

Table 2.8 highlights known species characteristic of stable communities. These species are revisited in our floral analysis in Section 4.5.5.

Common name	**Latin name**
Yarrow	*Achillea millefolium*
Moschatel	*Adoxa moschatellina*
Bugle	*Ajuga reptans*
Ramsons	*Allium ursinum*
Wood anemone	*Anenome nemorosa*
Fool’s-water-cress	*Apium nodiflorum*
Black horehound	*Ballota nigra*
Daisy	*Bellis perennis*
Red bryony	*Bryonia dioica*
Bellflower spp.	*Campanula* spp.
Nettle-leaved bellflower	*Campanula trachelium*
Bittercress spp.	*Cardamine* spp.
Sedge spp.	*Carex* spp.
Greater celandine	*Chelidonium majus*
Golden saxifrage	*Chrysosplenium oppositifolium*

Table 2.8: Species characteristic of a stable community in the UK (Sage, 2009) (continues)

Common name	**Latin name**
Enchanter's nightshade	*Circaea lutetiana*
Meadow thistle	*Cirsium dissectum*
Old man's beard	*Clematis vitalba*
Wild basil	*Clinopodium vulgare*
Pignut	*Conopodium majus*
Common dogwood	*Cornus sanguinea*
Common hawthorn	*Crataegus monogyna*
Wood spurge	*Euphorbia amygdaloides*
Meadowsweet	*Filipendula ulmaria*
Dropwort	*Filipendula vulgaris*
Wild strawberry	*Fragaria vesca*
Sweet woodruff	*Galium odoratum*
Galium spp.	*Galium* spp.
Mare's tail	*Hippuris vulgaris*
Bluebell	*Hyacinthoides non-scriptus*
St. John's wort	*Hypericum* spp.
Rush spp.	*Juncus* spp.
Yellow archangel	*Lamiastrum galeobdolon*
Common toadflax	*Linaria vulgaris*
Common honeysuckle	*Lonicera periclymenum*
Bird's-foot trefoil	*Lotus corniculatus*
Ragged robin	*Lychnis flos-cuculi*
Yellow pimpernel	*Lysimachia nemorum*

Table 2.8: Species characteristic of a stable community in the UK (Sage, 2009) (continues)

Common name	**Latin name**
Creeping Jenny	*Lysimachia nummularia*
Mint spp.	*Mentha* spp.
Dog's mercury	*Mercurialis perennis*
Water dropwort	*Oenanthe crocata*
Orchid	*Orchis* spp.
Oregano	*Origanum vulgare*
Broomrape	*Orobanche* spp.
Common sorrel	*Oxalis acetosella*
Hart's-tongue fern	*Phyllitis scolopendrium*
Burnet-saxifrage	*Pimpinella saxifrage*
Common tormentil	*Potentilla erecta*
Oxlip	*Primula elatoir*
Common cowslip	*Primula veris*
Primrose	*Primula vulgaris*
Common self-heal	*Prunella vulgaris*
Blackthorn	*Prunus spinosa*
Bracken	*Pteridium aquilinum*
Common fleabane	*Pulicaria dysenterica*
Meadow buttercup	*Ranunculus acris*
Lesser spearwort	*Ranunculus flammula*
Currant	*Ribes* spp.
Dog rose	*Rosa canina*
Rose spp.	*Rosa* spp.

Table 2.8: Species characteristic of a stable community in the UK (Sage, 2009) (continues)

Common name	**Latin name**
Bramble	*Rubus frucitosus* agg.
Raspberry	*Rubus idaeus*
Sheep's sorrel	*Rumex acetosa*
Salad burnet	*Sanguisorba minor*
Figwort	*Scrophularia nodosa*
White campion	*Silene alba*
Red campion	*Silene dioica*
Bladder campion	*Silene vulgaris*
Hedge woundwort	*Stachys sylvatica*
Greater stitchwort	*Stellaria holostea*
Devil's-bit scabious	*Succisa pratensis*
Comfrey	*Symphytum officinale*
Black bryony	*Tamus communis*
Woodland germander	*Teucrium scorodonia*
Red clover	*Trifolium pratense*
White clover	*Trifolium repens*
Common gorse	*Ulex europaeus*
Navelwort	*Umbilicus rupestris*
Dark mullein	*Verbascum nigrum*
Common mullein	*Verbascum Thapsus*
Violet spp.	*Viola* spp.

Table 2.8: Species characteristic of a stable community in the UK, (Sage, 2009) (continued)

2.3.8 Succession - Effects of Management on plant communities

It is said that management changes succession, not the state of vegetation itself (Luken, 1990). Rosenberg and Freeman (1984) discussed potential management models, Figure 2.10 highlights the interactions between these.

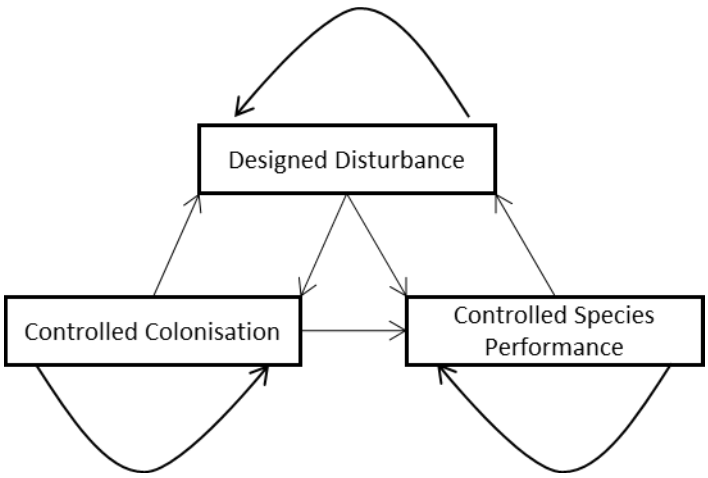


Figure 2.10: The three components of a successional management model. Straight arrows indicate sequential steps, curved arrows indicate repeated steps (Adapted from Rosenberg & Freeman, 1984)

Management alongside succession can create semi-natural grasslands, either with the help of seeding or reliance on local seed banks (Rahman, 2013). Some authors have advised where possible to allow natural colonisation along with minimal management, such as clipping and removing undesirable species, for example on capped landfills (Rahman, 2013). This is believed to allow establishment of local species, reduce the nutrient load (if applicable from prior use), and reduce competitive weeds. Further possible management regimes during succession include burning (Mallik and Gimmingham, 1983 in Luken, 1990); cabling[25] (Rippel et al., 1983 in Luken, 1990); grazing exclusion (Davis et al., 1985 in Luken, 1990); fertilisation (Heil & Diemont, 1983); grazing (Gibson et al., 1987); herbicide application (Marrs, 1987 in Luken, 1990); irrigation (Doerr & Redente, 1983 in

[25] Cabling: The strengthening of tree branches with metal cables

Luken, 1990); mowing (Vestergaard, 1985 in Luken, 1990); reducing soil fertility (Marrs, 1985 in Luken, 1990); selective cutting (Lowday, 1987 in Luken, 1990) and water level change (Bakker et al., 1987). The effects of various management schemes on vegetation composition have also been studied, for example those of grazing on grassland (Cooper & Huffaker, 1997), and of management on woodland (Barkham, 1992). The effects of management regimes on succession are, like many other variables, often difficult to quantify due to overlap with others (Smart, 2005), and a lack of detailed past management details (Marsland, 1989). Calls for further study on the effects of different management regimes on succession have been made (Rahman, 2013). The management regimes of any created grasslands under study here will be noted and taken in to account in any analysis.

2.4 Bioindicators of created grasslands

The previous sections outlined the importance of creating or maintaining high biodiversity habitats to ensure Ecosystem Service provision. It explored the ways grasslands form and factors that may influence their biodiversity. The following sections now explore how the biodiversity levels of a site can currently be established. A common ecological method of estimating this is the use of bioindicators[26]. These can take the form of indicator species, or community indicators. The following section explores the bioindicator concept. Potential indicators of biodiversity in created grasslands are discussed to inform indicator identification and analysis in Chapter 4.

2.4.1 Indicator species

What is an indicator species?

The need to describe different habitats arises often, for example to assess conservation status, to evaluate land-use planning options, or to assess the impact of external influences. It is unusual to

[26] Bioindicator: a variable that describes the biodiversity and health of the study site

see a description of a habitat without mention of the presence a specific species, or set of species (Dufrene & Legendre, 1997).

Both positive and negative bio-indicator species exist. These species, either by their presence or abundance on site, are known to indicate high or low levels of biodiversity. Any indicator should be relatively easy to identify, and tolerant to stress and disturbance (Grime, Hodgson and Hunt, 1988 in JNCC, 2004). Ease of identification is particularly pertinent in this study, as a research objective is that non-botanists can use this as a quick means of establishing biodiversity. Negative indicators should indicate disturbances such as grazing, high fertility etc. For example, the presence of scrub, bracken and woody species can indicate poor management.

Identified grassland indicators

Created grasslands are essentially attempting to mimic natural and semi-natural grasslands. As such it stands to reason that after a certain amount of time from creation, they will attract similar species. As such, a thorough literature search was conducted to identify established plant indicator species for grassland quality and environmental conditions. The following plants were identified from this search as commonly used indicators. Particular interest was given to indicators of the widest possible soil/grassland types. For brevity, these species are outlined in Table 2.9, but a full descriptive narrative of all species is presented in Appendix 4 with photographs. The table shows there is a wide range of potential indicators spanning a number of soil and habitat types. Clearly some species are more suited to indicating biodiversity of more niche habitat types. This applies to species such as ox-eye daisy *Leucanthemum vulgare* which is only deemed an indicator of newly created grasslands.

Common name	Latin name	Positive indicator	Positive grassland type	Negative indicator	Negative grassland type	Wet/moist grass	Abandoned/ latrine	Fertile soils	Disturbance	Poorly drained
Common agrimony	*Agrimonia eupatoria*	✓	All but strong acid							
Cow parsley	*Anthriscus sylvestris*			✓	Neutral	✓				
Kidney vetch	*Anthyllis vulneraria*	✓	Calcareous/Pulverised Fuel Ash (PFA)/Restored							
False oat-grass	*Arrhenatherum elatius*			✓	All (Over 10% abundance)		✓		✓	
Common knapweed	*Centaurea nigra*	✓	Most calcareous/neutral					✓		
Creeping thistle	*Cirsium arvense*			✓	Most			✓	✓	
Spear thistle	*Cirsium vulgare*			✓	Most				✓	
Cock's-foot	*Dactylis glomerata*			✓	Most (over 10% abundance)					
Wild carrot	*Daucus carota*	✓	Newly created							
Tufted hair-grass	*Deschampsia cespitosa*			✓	Neutral and marshy (over 10% abundance)	✓				
Common horsetail	*Equisetum arvense*			✓	Neutral and lowland meadows					
Cleavers	*Galium aparine*			✓	Most					

Table 2.9: Identified potential indicator species identified in the literature (continues)

Common name	Latin name	Positive indicator	Positive grassland type	Negative indicator	Negative grassland type	Wet/moist grass	Abandoned/latrine	Fertile soils	Disturbance	Poorly drained
Lady’s bedstraw	*Galium verum*	✓	Meadows; Undisturbed sites							
Common hogweed	*Heracleum sphondylium*	✓	Best quality grassland							
Yorkshire-fog	*Holcus lanatus*			✓	Most			✓		
Soft rush	*Juncus effuses*			✓	Lowland					✓
Meadow vetchling	*Lathyrus pratensis*	✓	Meadows/ some mesotrophic/calcareous					✓[a]		
Rough hawkbit	*Leontodon hispidus*	✓	Some mesotrophic/calcareous							
Oxeye daisy	*Leucanthemum vulgare*	✓	Newly created				✓			
Perennial rye-grass	*Lolium perenne*			✓	After 5 years from creation			✓	✓	
Bird’s-foot trefoil	*Lotus corniculatus*	✓	Characteristic of many grassland types							
Greater bird’s-foot trefoil	*Lotus pedunculatus*	✓	Some lowland			✓				

Table 2.9: Identified potential indicator species identified in the literature (continues)

Common name	Latin name	Positive indicator	Positive grassland type	Negative indicator	Negative grassland type	Wet/moist grass	Abandoned/latrin	Fertile soils	Disturbance	Poorly drained
Timothy	*Phleum pratense*			✓	In high abundances					
Rough meadow-grass	*Poa pratensis*			✓	In high abundances	✓		✓	✓	
Cowslip	*Primula veris*	✓	MG4/MG5; Best grassland quality			✓ [b]				
Meadow buttercup	*Ranunculus acris*	✓	Meadow					✓ [a]		
Creeping buttercup	*Ranunculus repens*			✓	Most				✓	
Yellow rattle	*Rhinanthus minor*	✓	Meadows/neutral grassland							
Bramble	*Rubus fruticosus agg.*			✓	All					
Ragwort	*Senecio jacobaea*			✓	All				✓	
White clover	*Trifolium repens*			✓	Most			✓		
Nettle	*Urtica dioica*			✓	All				✓	

[a] moderate fertility
[b] calcareous soils only

Table 2.9: Identified potential indicator species identified in the literature (continued)

2.4.2 Community bioindicators and metrics

As well as individual indicator species, there are a number of community-level variables that can indicate biodiversity. These are introduced below, and discussed in more detail in discussions of species metrics in Section 3.2.

What is a community in this context?

The definitions of plant communities and whether they even really exist have always been of interest in the field of Ecology (see for example Lortie et al., 2004). A simple working definition is "…all the plants occupying an area which an ecologist has circumscribed for the purposes of study" (Crawley, 2009). However, this implies that the community itself is defined by the ecologist looking at it, whereas other definitions give the community a boundary dependent on environmental or biotic conditions. Clements (1916, 1928 in Kent, 2012) discusses clearly recognisable communities that repeat with regularity across the Earth. In his 'organismic' concept, he describes how species make up communities which come together like the various parts of a human body, working separately and in conjunction with each other. In contrast, Gleason (1917; 1926; 1939 in Kent, 2012) viewed the combinations of plants in any one space and time as unique, with each species responding in its own way to environmental conditions. In more recent years, further models studying the levels between individual species and communities have emerged. Amongst the most notable are CSR (Grime, 1979; 2001), a model working around species strategies based on stress and disturbance (discussed below).

CSR community model

Grime's CSR model can be used as a community indicator of habitat health and the impact of disturbance. The competitive strategy (C), illustrates plants in a resource-rich environment and little to no stress or disturbance. Stress-tolerators (S) are plants that can still thrive in high-stress environments with little resources and low disturbance. Ruderals (R) are species that thrive with high resources but with high levels of disturbance. Tilman (1982, 1988, in Kent, 2012), introduced models depicting different combinations of the CSR concept.

The CSR model has been used widely as an indicator, especially to assess the impact of disturbance. Rahman (2013) used CSR as part of the analysis of differences between established habitats and created grasslands on capped landfill sites. CSR has also been used in analyses to assess the impact of agriculture on woodland (Willi, 2005); of human activity on high plant species (Smart, 2005); of drought (Morecroft et al., 2002); and of atmospheric pollution (Ling, 2003).

Although there was success in indicating the presence of agriculture through stress tolerators and ruderals (Willi, 2005), and human activity (Smart, 2005), other studies showed few significant results using the model (Morecroft et al., 2002; Ling, 2003). CSR would appear to be a useful complement to floral data analysis but should not be relied upon as an indicator on its own. The CSR of each quadrat was calculated prior to decisions made on indicator selection, and these figures will be presented as further material in Appendix 8. However, our research objectives (see Section 2.5) state potential indicators must be quick and easily calculated by a non-specialist. As such, due to the inability of the CSR method to be judged on site, and the requirement for computational analysis, this will be an unsuitable indicator. These figures could however be used for further study in to created grassland biodiversity.

Ellenberg Indicator Values

Ellenberg (1979, 1988, et al. 1992) devised the system of Indicator Values as a method of assigning plants along a scale according to a set of environmental variables (pH, soil moisture, nutrients, light, temperature, continentality, and salinity). As such, the species composition of an area can be used to estimate any of the above variables. Ellenberg values, like CSR discussed above, require specialist knowledge and specific software to calculate. As such, these values are also not suitable as a quick and easy indicator. However, like CSR, these figures are provided in Appendix 9 to potentially aid further study.

Herb to grass ratio

The proportional cover of grass species to forb[27] species can act as an indicator of grassland quality and health. A rough estimate benchmark figure is 40-80% forb for neutral and calcareous grasslands (JNCC, 2004), however in some cases this figure may alter or be skewed by the presence of *Trifolium repens* or *Cirsium arvense* which react favourably to nutrient loading. Wet and acid grasslands may have a higher grass proportion and still be considered good quality grasslands. This potential indicator is of particular interest to this study, as it could be assessed fairly easily by a person with virtually no knowledge of botany.

Functional groups - Quadrat mean height

The vegetative height of a site is potentially an indicator of biodiversity in grasslands. English Nature (2001) estimate that the mean height of vegetation should not exceed 80cm. This is especially pertinent, since undesirable grass species tend to be taller than desirable grass and forb species. As with herb to grass ratio, this is a metric easily established by a non-botanist.

Species richness

Species richness[28] is arguably the most commonly used measure of species abundance and biodiversity health (Dufrene & Legendre, 1997). Its wide usage is due to ease of measurement, comparability across communities when area is sufficiently specified, and ability to describe community and regional diversity. It is also praised for its ease of understanding to researchers, practitioners and the interested public (Hellman & Fowler, 1999; Magurran, 1988 in Gotelli & Colwell, 2001). However, its use has been criticised for failing to recognise the different properties of different species, and possible underestimation using simple richness measures (Gaston & Spicer, 2004; Hellman & Fowler, 1999).

[27] Forb: Herbaceous flowering plant not including grasses, sedges and rushes
[28] Number of different species present

Costanza et al. (2007) uses species richness as a “proxy” for biodiversity and NPP (Section 2.2.7). They tentatively claim that a 1% change in biodiversity (using species richness as a proxy), gives a 1-2% change in the value of Ecosystem Service delivery. This, they claim, is currently the best link between these facets. This may be particularly important in linking grassland metrics with Ecosystem Service valuation outputs.

2.4.3 Summary of biodiversity indicator literature review

There is a long history of literature regarding bioindicators, although they may not always have been called this. The previous section explained the need for bioindicators, and discussed the main indicators of biodiversity currently used in grasslands. This included an introduction to succession and the species used to understand this process. In addition to common statistical methods of identifying indicator species, instances of these indicators will be examined in the data and used to inform the overall study.

In order to establish indicators of created grasslands, a first-hand data set is to be created. This is due to a lack of data around created grasslands. In the following chapter, fieldwork methods are discussed to ensure appropriate methodologies are followed. This is informed by a systematic review of floral fieldwork surveys. This rigor is especially pertinent if the data set is to be used for further study.

2.5 Floral research objectives and hypotheses

The previous sections have outlined the most pertinent topics in the literature.

From our findings in the literature review, the following objectives and hypotheses are presented.

1. **Examine real-life created grasslands to establish assemblages** – Undertake fieldwork on a number of created grasslands at a range of ages since creation. This will give us first-hand data which can be analysed in an attempt to identify bioindicators with time since creation in mind.

   Hypothesis: Assemblages will vary with age since creation, but this link will be moderated by a number of different factors including soil type, and management regime.

2. **Using common ecological statistical tools, extract potential bioindicators of created grasslands. Compare these with known grassland bioindicators identified in literature review –** in line with original research objectives, these should, if possible, be relatively simple to identify, and cover the broadest possible range of grassland types

   Hypothesis – As created grasslands are meant to mimic natural and semi-natural grasslands, current indicators of quality should transfer satisfactorily. Further biodiversity indicators will be sourced via common statistical tools.

3. **Identify the impact of management regimes on created grassland assemblages** – Do created grassland assemblages react to management regimes in line with natural and semi-natural grasslands?

   Hypothesis – Created grasslands will, on the whole, react to management regimes in line with natural and semi-natural grasslands.

CHAPTER 3: FIELDWORK METHODS AND ECOLOGICAL DATA ANALYSIS

3.1 DISCUSSION OF FLORAL FIELDWORK METHODS AND JUSTIFICATION OF CHOSEN METHOD

Inspection of the literature highlighted the broad range of fieldwork methods and metrics employed in fieldwork surveys. Initially it appeared there was some discrepancy over definitions, terminologies and methods used. As a means of informing this study, a full systematic review of indicator species studies in the UK was undertaken. The systematic review process ensures reduction of author bias and the best opportunity for capturing relevant literature. The review parameters are first discussed, followed by its findings along with other relevant literature. Methodological choices employed are scrutinised, and the most relevant techniques extracted for use in this study. Following this, full fieldwork methodology is outlined before results are provided in Chapter 4.

3.2 SYSTEMATIC REVIEW OF FLORAL INDICATOR SPECIES STUDIES

3.2.1 Search strategy

Searching was conducted in February 2015. All searching was conducted by a single reviewer (SLC) with 25% blind checked by second reviewer (GL). Due to differences in available databases and search mechanisms, search terms varied accordingly. Non-English language searches were not conducted, as the product is intended to be relevant predominantly to the UK. Review outputs can be difficult to interpret owing to high quantities of references, so as much information as possible is presented graphically.

Scientific electronic resources: Relevant articles were identified through electronic database searching completed using the following five databases: ISI Web of Knowledge (including ISI Web of Science), JSTOR, Science Direct, Scirus (all journal sources), and Scopus. All references retrieved via these searches were examined for relevance. Various combinations of the following search terms were used for all electronic databases within title, abstract and keywords for all time periods to present: indicator; surrogate; flora, plants; vascular; vegetation; habitat assessment; UK.

Internet resources: Web-engine searches were completed using Google Scholar. Due to the large number of results decreasing in relevance, the first 5 pages of search were included (CEBC 2006). Search terms used were identical to those above.

Specialist websites: Specialist websites were also searched for relevant material, including: Botanical Society of the British Isles (BSBI); National Environmental Research Council (NERC); Joint Nature Conservation Committee (JNCC); Department for Environment, Food and Rural Affairs (DEFRA); Natural England/English Nature.

3.2.2 Inclusion criteria

Resources identified from the above search criteria were judged from title and abstract by a single reviewer (SLC). The review-specific criteria that articles had to meet for inclusion into the final stage of the systematic review were:

- Subject: Indicator species studies conducted in the UK (where flora is the indicator, either single species or communities)
- Intervention: All techniques implemented to monitor or test indicator species;
- Date range: No date cut off was used;
- Type of study: All studies utilising higher plant surveys with the goal of establishing results from indicator species were examined to establish methodological design, units of measurement and definition.

Articles were not accepted into the final review if they belonged to the following categories due to differences in methodological style:

- Studies of aquatic plants;
- Studies of only bryophytes[29];
- Review papers;

[29] Bryophyte: non-vascular plant such as mosses and lichens

- Studies of agricultural flora (crops), although studies examining effects of agriculture on other flora will be included;
- Studies undertaken in a controlled greenhouse environment.

3.2.3 Study assessment

A data extraction form was used to document details on each study that passed the inclusion stage, including methodological details, temporal and spatial details, along with a critical appraisal of study style. Units, such as species richness, were noted if discussed outside of results, as their mention is still relevant to results for comparability. Research objective and land cover type were standardised subjectively, and care was taken not to obscure details. Data were not collected, as although comparison will be made on methodology, specific studies will not be heterogeneous enough to compare. Therefore, comment will only be made on frequency of methodology usage and general success.

3.2.4 Systematic review findings

A total of 42 papers and reports fulfilled the inclusion criteria. All papers are summarised in Appendix 2. A range of land cover types and research objectives were included. Included papers are indicated in the references with "[a]". The following sections outline the main findings on methodologies and definitions within included floral indicator species surveys. These can assist in ensuring rigorous and replicable methods within fieldwork undertaken.

a. Systematic review findings - Quadrat size

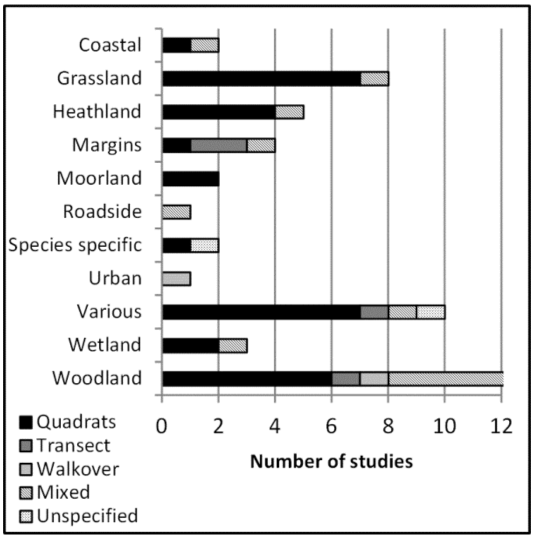
Methods of choosing quadrat size often seem to be arbitrary within the field of botany. A few more established techniques exist for specifying quadrat size. From the Braun-Blanquet school of vegetation classification comes a system starting with the smallest feasible size, and then continuing to double the size until no new species are recorded (Kent, 2012). This produces a "species-area curve". Of included papers, only one of 42 studies used this technique (Cantarello & Newton, 2008).

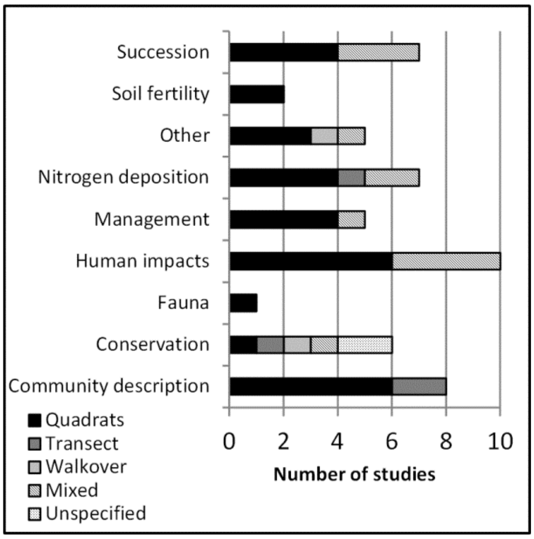
The use of species-area curves is often argued as a reason for the inaccuracy of the “break” in the curve (Rice & Kelting, 1955).

Quadrat size can have important consequences when analysing floristic data for relationships. If quadrat size is too small, false negative associations can be found, as two individuals of varying species cannot occupy the same small space (Kent, 2012). Conversely, an overly large quadrat could obscure all relationships. The National Vegetation Classification (NVC - example record card provided in Appendix 12), offers guidance on optimal quadrat size.

b. Systematic review findings - Sampling strategy (randomness of survey locations)

There are a number of factors to take in to account when deciding on the sampling strategy of a floral survey. In addition to quadrat size (above), the question of whether random sampling is appropriate is highly pertinent. The importance of random sampling is contextually dependent on what the effect under study is. In its strictest sense, random sampling should mean that every point within a site has an equal chance of survey as another (Kent, 2012). As part of this study, method of quadrat placement (clearly only if quadrat sampling was chosen), was reviewed. The results of this are shown in Figures 3.1 and 3.2. Quadrat placement is clearly the most popular methodological choice, across all land-use types and research objectives. However, certain land-use types or research objectives lend themselves better to other methods, such as transects on roadsides to follow the path of traffic and associated air pollution.





Figures 3.1 and 3.2: Distribution of sampling techniques amongst included papers in the ecological systematic review by habitat type and research objective

In some cases, the method of randomness was not specified (e.g. Tzoulas & James, 2010; Cullen et al., 1992), and this is indicative of a wider problem of insufficient definition of survey strategy. In some cases, the decision of non-random sampling strategy was contextually justified. Jones (2004) and Stevens et al. (2004) employed a line of non-random quadrats along a transect, in line with nitrogen deposition. This is justified in wishing to test plant responses to paths of deposition.

c. Systematic review findings - Ellenberg Indicator Values

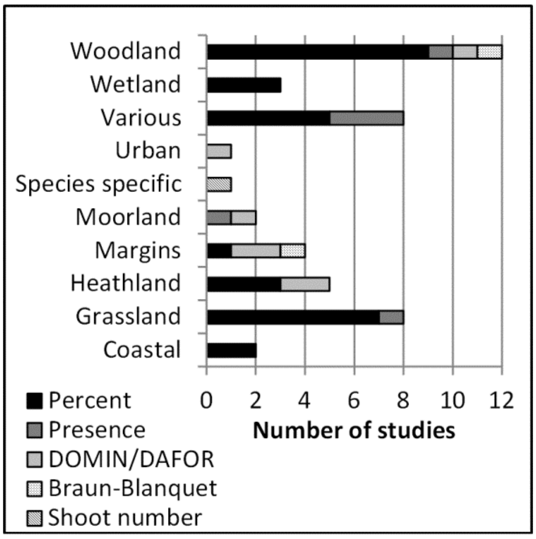
Ellenberg (1979, 1988, et al., 1992) devised the system of Indicator Values as a method of assigning plants along a scale according to a set of environmental variables (pH, soil moisture, nutrients, light, temperature, continentality, and salinity). As such, the species composition of an area can be used to estimate any of the above variables. Of our included papers, Ellenberg Values were utilised by 11 studies, with varying success. Rahman (2013) studied flora to test for differences between newly created grasslands on capped landfill sites and reference grassland sites. The Ellenberg values for soil fertility were highly significant between sites, but with no significant results for Ellenberg light. The ambiguity in these results is that it can be difficult to conclude whether the non-significant results are due to characteristics of the flora, or from deficiencies in the Ellenberg method. Southall, Dale &

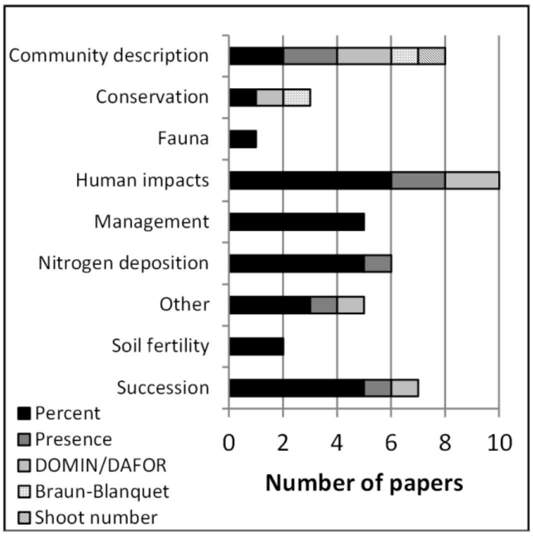
Kent (2003b) undertook a floral survey with an aim of assessing the usefulness of Ellenberg values. Their results showed that Ellenberg figures for some species were uncertain due to lack of information or a too-broad range of environmental conditions. Despite this, they concluded that even small plant compositional differences can reflect subtle differences in environmental variables. Ellenberg values would be an interesting addition to any analysis of floral data in this study, but is probably not usable by our industrial partner owing to further computational requirements.

d. Systematic review findings - Species metrics

When a decision has been made as to what flora to sample, and quadrat size/placement, a further decision on how to explain species presence and/or abundance must be made. The main examples of this were discussed as community indicators in Section 2.4.2.

The following graphs sum up the units estimation method in included papers by land cover type of study and reasons for study.



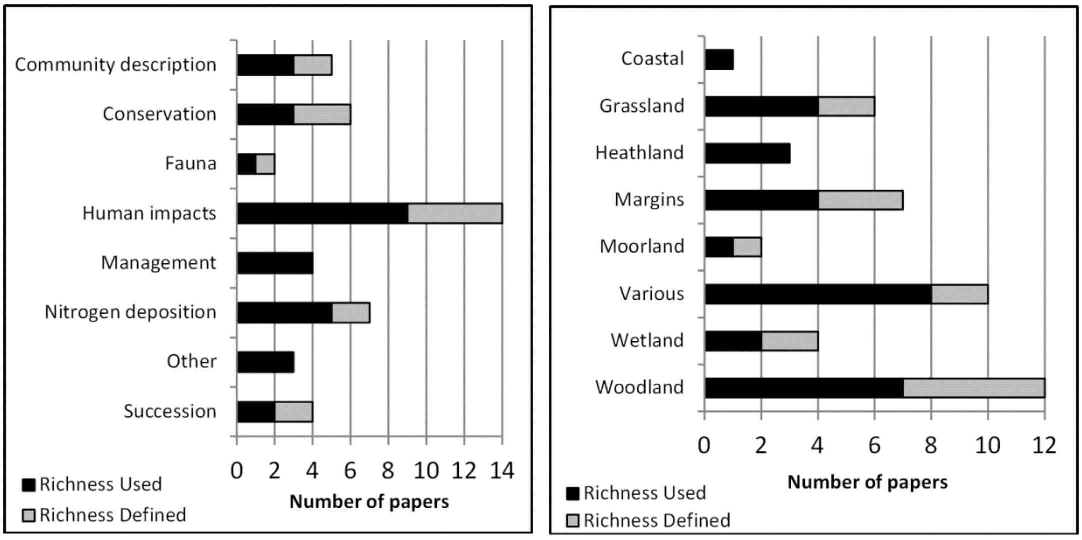


Figures 3.3 and 3.4: Graphs to show chosen unit of study for included papers studying floral surveys

A basic method is presence/absence of individual species. The advantages of this method are the speed of survey and a smaller chance of subjective sampler error in abundance weighting (Kent, 2012).

If a percentage cover of the habitat was taken, a number of methods exist on how to interpret this. The following sections sum these up and discuss use amongst included papers.

e. Systematic review findings - Species metrics - Species richness: As discussed in Section 2.4.2, species richness is arguably the most used metric in species abundance surveys. It has also been used previously as a proxy measure for biodiversity (Costanza et al., 2007). Figure 3.5 shows use of species richness and number of definitions by land cover type of study, Figure 3.6 shows use of richness and number of definitions by objective.



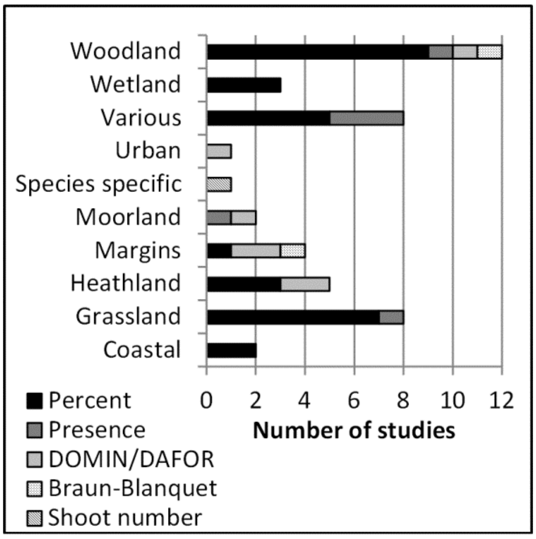
Figures 3.5 and 3.6: Plots showing use of species richness in included papers by land cover type and objective

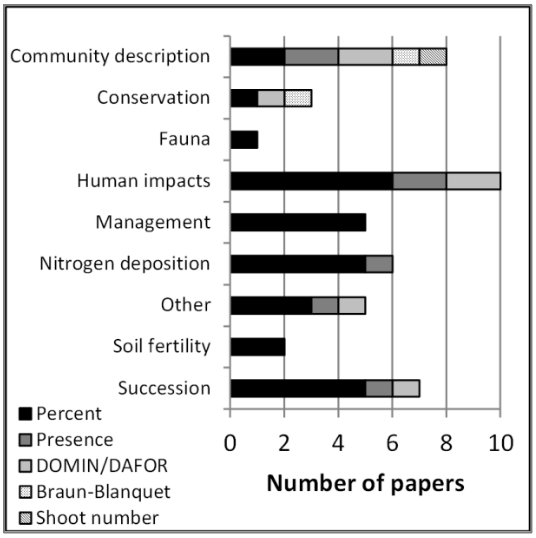
A large proportion of papers did not define their understanding of species richness. Reasoning for lack of definition may arise from a presumption that all authors mean the same thing. However, when species richness was defined, although it was often taken to mean "total number of species" (see for example Ling, 2003; Southall et al., 2003b; Willi et al., 2005), this was sometimes in conjunction with "per site/area/quadrat" (Kirby & Thomas, 2000; Natural England, 2000; Southall, Dale & Kent, 2003a). This was sometimes referred to as species density (for example tree count in Southall, Dale & Kent, 2003a). Stevens et al., 2007 defined richness as "mean number of species per quadrat". Despite Southall, Dale & Kent (2003a) defining species richness as "the average number of species per quadrat", later in the article "mean number of species per quadrat for each of the eight communities" is stated as part of the species diversity section. Sometimes the term "species richness" was not used, using instead "number of species" (Morecroft et al., 2002), or "species number" (Pitcairn et al., 2002). Gotelli and Colwell (2001), argue that averaging the species richness by any area reduces its usefulness, although many authors continue to practice this. This will be investigated further in Section 3.9.

f. Systematic review findings - Species metrics - Species abundance/frequency/composition

Species abundance/frequency/composition, or an unspecified unit of apparently similar methodology, was used or discussed by most authors. This was generally in line with Hubbell's well-cited definition of species abundance "how common or rare a species is relative to other species in a defined location or community" (2001), although this was often not explicitly defined.

The methods of survey used to achieve this were usually estimating the percentage cover by eye (Angold, 1997; Barkham, 1992; Britton & Fisher, 2007; Kirby & Thomas, 2000; Ling, 2003; Marshall & Arnold, 1995; Pitcairn et al., 2002; Rawlinson, 2009; Southall et al., 2003a; Wilson et al., 2001). The DAFOR scale was often used (Croxton et al., 2005), as well as the DOMIN scale (Hughes & Huntley, 1986; Mazzoleni, French & Miles, 1991; Webster & Kirby, 1988). These are explained further below. Figure 3.7 shows estimation method by land cover type, and Figure 3.8 by objective. Across most land-use types and research objectives, percent cover was the method most frequently employed. Attempts to describe communities attracted the highest variation in estimation methods, but reasons for this are unclear beyond preference of the individual author.





Figures 3.7 and 3.8: estimation method by land cover type and objective

Frequency was occasionally defined as the proportion of plots where the species was present, sometimes scaled up from presence/absence readings (Bennie et al., 2006; Jump & Woodward, 2003). In one case abundance was defined as "number of occurrences" (Pakeman et al., 2009). Abundance was once defined as "total number of plots occupied by a species" (Bennie et al, 2006), and once as "maximum density of individuals within a population" (sometimes shoots, sometimes clumps) (Jump & Woodward, 2003). Harmer et al. describe "low abundance and frequency", implying the two have differing definitions, but this is not explained (2001).

Species composition was used often as a generic term for the species make-up of a site without quantification. However, Stevens et al. (2011) used the term to mean all species recorded in all quadrats summed to make a full species list, similar to species richness.

Abundance can be surveyed in a number of ways. The most common are the percentage cover of each species, or using the DOMIN or Braun-Blanquet scales (based on percent). Table 3.1 outlines these cover scales. Also widely used is the DAFOR scale, weighting plant cover by Dominant (D); Abundant (A); Frequent (F); Occasional (O) or Rare (R). This is commonly used by ecological consultants as part of Phase 1 Habitat Surveys to quickly assess the vegetation of a site (Middlemarch Environmental, 2015).

Braun-Blanquet	DOMIN
<1% cover	Single individual
	1-2 individuals
	Several individuals, <1% cover
1-5% cover	1-4% cover
6-25% cover	5-10% cover
	11-25% cover
26-50% cover	26-33% cover
	34-50% cover
51-75% cover	51-75% cover
76-100% cover	76-90% cover
	91-100% cover

Table 3.1: Table outlining bandings of Braun-Blanquet and DOMIN scale

Fraser et al. (2008) recommends surveying at the smallest scale possible, allowing results to be aggregated or unpacked as needed. As such, percent cover to as small a banding as possible is desirable, as this could still be aggregated to be comparable with DAFOR/Braun-Blanquet, or for use as presence/absence.

g. Systematic review findings - Species metrics - Species density

It is also possible to survey flora by counting individual species within the quadrat. This is often known as density or per-quadrat richness (Kent, 2012). In the systematic review of floral surveys, species density was mentioned once as the number of tetrads that the species is recorded in (Jump and Woodward, 2003). This definition was also used for abundance in another paper (Bennie et al, 2006). Density was once explicitly defined as "'the number of individuals of a particular species per unit area' (Goldsmith et al., 1986)." (Rawlinson, 2009). Cherrill and Rushton (1993) used vegetation density as an "integrated measure of biomass and height", and Kennedy and Pitman (2004) as the mean distance between three closest trees. The main difficulty in this method of survey is that it can sometimes be difficult to identify an individual accurately. Some plants, especially grasses, are stoloniferous, meaning they are connected underground.

h. Systematic review findings - Species metrics - Other methodologies

The term species diversity was used in numerous studies, and was generally defined and justified extensively, such as Rawlinson's use of the Simpson diversity scale which "measures the probability of 'any two individuals drawn at random from an infinitely large community belonging to a different species' (Simpson, 1949)" (2009). This method was used in preference to the Shannon-Weiner index which can be sensitive to smaller sample sizes. The Shannon-Weiner index was used in other studies within the review (Cantarello & Newton, 2008; Cullen et al., 1998; Stevens et al., 2004; Tanner & Gange, 2005; Tzoulas & James, 2010). Diversity was also used in its more general sense, to imply a wide range of differing species, but without quantification.

Species turnover was only relevant in long-term studies, and used to indicate the difference in species occurrence across a time period (Barkham, 1992; Bennie et al., 2006; Kirby & Thomas, 2000). Presence/absence was used often in conjunction with other methods, except in larger scale studies, especially those using aerial imagery (Kennedy & Pitman, 2004; Morecroft et al., 2002; Sage et al., 2009).

i. Systematic review findings - Species metrics - Time

Time is potentially one of our most important variables, in fact, it is theoretically an indicator of biodiversity in itself, with management as an interaction. Included species in the systematic review also dealt with temporal elements in a number of ways. Figure 3.9 highlights the temporal elements of included studies by research objective. Successional studies, which one would think would benefit from long-term study, are still dominated by one-off studies. This perhaps suggests it is often unworkable to pursue a long term study due to time and economic constraints. Instead, studies of management and human impacts had a higher proportion of long-term studies, but these could still have been only spanning a small number of years. The graph also highlights the small number of studies which did not specify the temporal element of their study at all (Peterken, 1976; Pitcairn et al., 1998; Ratcliffe, Birks & Birks, 1993).

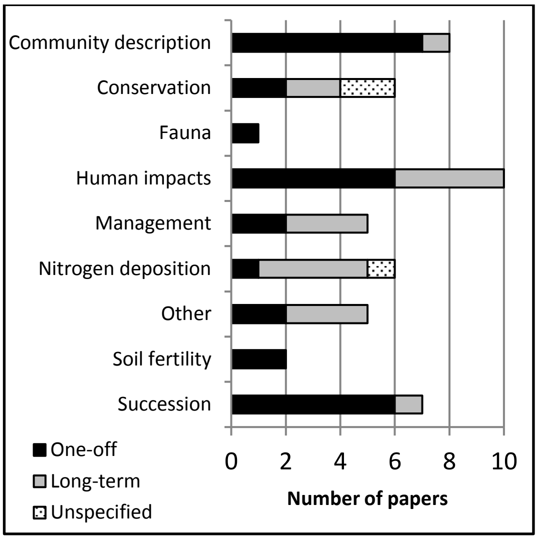


Figure 3.9: Temporal elements of included papers in systematic review

j. Systematic review findings - Species metrics - Functional groups

The large number of species often recorded during a floral survey can mean the outputted data is complex and difficult in which to detect trends (Kent, 2012). As such, the use of plant functional traits is becoming increasingly popular within the scientific community (see for example Díaz et al., 2002). A functional trait can be defined as "groups of plant species sharing similar functioning at the organismic level, similar responses to environmental factors and/or similar roles in (or effects on) ecosystems or biomes" (Cornelissen et al., 2003). At a seminal workshop held in Sorgue, France in 2000, scientists came together to attempt to agree on a minimal set of vascular plant functional traits that work at a number of scales (Cornelissen et al., 2003). Although a full analysis of functional traits is outside the remit of this study, more popular and easy-to-measure elements will be factored in. For example, mean quadrat height (discussed previously in section 2.4.2), is a functional trait which is easily measured by a non-ecologist.

k. *Systematic review findings - Species metrics - National Vegetation Classification (NVC)*

The NVC was started in 1975 as a means of classifying the UK's flora. The methodologies for each habitat type are explicitly defined and were established by ecological scientists. This includes habitat-dependent quadrat size, estimation methods and scale of estimation. An example NVC record card is provided in Appendix 12. The NVC method also includes means of calculating a classification of the site, based upon variables judged on site and key species sought. This classification is calculated using presence of particular species on site and indicates the estimated soil type and prominent species. Within the context of the systematic review papers, although the classifications of habitat were widely calculated and expressed throughout the included papers, the methodology, which includes guidance on quadrat size, and method of estimating species cover, was only utilised in three studies (Southall et al., 2003a; Southall et al., 2003b; Trivedi et al., 2008). The NVC method is used widely elsewhere, especially in consultancy and management. "This was considered to be the most suitable recording method, as percentage cover estimations are rapid, repeatable and cause minimal damage to the vegetation" (Kent & Coker, 1992 in Southall et al., 2003b, pg. 1431). Middlemarch Environmental Ltd. use the NVC classification as a descriptor for detailed floral site analysis.

3.2.5 Summary of findings from systematic review and further literature on fieldwork techniques

Findings were made which can inform fieldwork methodology and ensure further study is comparable. The systematic review highlighted a trend of authors not defining their understanding of terms and metrics. These could then be compared even though the figures are heterogeneous.

Species richness appears to be the most commonly used metric in biodiversity indicator studies. This, in addition to findings that species richness is linked to Ecosystem Service provision (Costanza et al., 2007), means this metric may be extremely pertinent in this study. Further species metrics (species diversity etc.) will be calculated, however due to further computational requirements these are not ideal community indicators in this context. Use of most functional groups will be beyond the scope of this study. However, vegetative height is a quick factor that can be surveyed without ecological skills and as such this will be collected.

The NVC classification is widely used amongst indicator studies, however the methodology is rarely explicitly followed. The NVC methods of fieldwork were however not employed, or if they were this was not explicitly stated. A lack of justification and method was a common theme throughout the review. The NVC method was developed by a large number of ecologists, and is employed across public bodies and ecological firms. As such this seems the most robust methodology to follow during fieldwork. Fieldwork methods stated in Section 3.7 are therefore adhering to NVC standards. There may be some aspects which are not relevant for this study. These will be stated where appropriate. NVC classifications are calculated and provided in Appendix 9.

The review highlighted how lack of definition or explicit methodology is prevalent amongst papers. Replication of many of the papers would be inadvisable due to this. Where specified, random quadrats were the preference in most cases unless the research problem lends itself to another process (e.g. transects along the path of nitrogen deposition). Species richness and species abundance were the most common forms of species monitoring, although these were on occasion mis-defined. The NVC's classification was commonly used, and its methodology followed if not stated. As such, this structure of methodology will be followed for simple replication where necessary.

Some of the papers in particular were of interest to inform this study. Rahman's investigation of grasslands on the site of ex-capped landfills was particularly relevant (2013). The results showed that differences between plant composition on semi-natural and restored grasslands are not as significant as first thought. This helps to support the theory that species indicators of good quality grasslands may be somewhat transferrable to created grasslands. Its other important finding was that soil variables are the most important when describing plant communities. This confirms soil type should be taken in to account when identifying potential indicator species. Similarly, Cullen's study of capped landfill sites showed landform sites can quite adequately replicate more natural grasslands (1998).

Papers by Southall (2003a; 2003b) are also highlighted as exemplars of rigorous methodology and explicit definition. The findings of this review will be considered as ecological fieldwork is undertaken and analysed.

3.3 *Discussion of Statistical analysis of floral species datasets and justification*

3.3.1 Introduction

As with any kind of fieldwork data, floral data can take forms that are difficult to analyse effectively. Care needs to be taken in exploration to ensure compatible modelling techniques are pursued. Fortunately various software options have been developed that are specifically targeted at floral datasets. These methods, along with others, are discussed here and their relevance to this study explored. The use of different kinds of analysis in included papers from the systematic review are presented. This will help inform the analysis of data retrieved from first hand fieldwork and ensure rigorous statistical outputs.

3.3.2 Issues in analysis of ecological and vegetative data

An issue inherent in the analysis of ecological and vegetative data specifically is redundancy. Certain species respond similarly to external influences and can share variation in analysis. Likewise, many sites and quadrats are similar to each other, and present replicate variation in an analysis (Kent, 2012). This "noise" can cause problems in modelling, creating too many degrees of freedom. This, in turn, has been argued to cause poor predictive power, and obscure significant findings (Jakeman, Letcher & Norton, 2006). Data and model reduction, as such, is an important part of the analysis process. This has also been argued in indicator species research (Heink & Kowarik, 2010).

Despite the obvious advantages of data and model reduction, care must still be taken not to remove an important facet of the biodiversity structure. The redundancy hypothesis, whereby there is a limit on species number contributing to overall biodiversity, above which no contribution is made, is discussed widely in the literature (see for example Perner & Malt, 2003 in Büchs, 2003; Walker, 1992). Despite this, the term “redundancy” can promote the sense of a lack of worth of species, especially to those unfamiliar with ecological complexities. In addition, without a full and complete understanding of habitat interactions, we may always be unsure which species, if any, are redundant. As such, a growing number of authors promote caution in use of this hypothesis (Gitay, Wilson & Lee, 1996; Ekins et al., 2003).

Another common problem in ecological data analysis is an abundance of zeros in the dependent variable. It is common to sample a large quantity of species across a number of sites, while some of these will be absent in a large proportion of quadrats. This problem can be identified by a large spike in a frequency graph of the dependent variable. In the past, only a few obscure functions in some mixed models allowed for zero-inflated data, but recent interest in the topic has spawned newer and better zero-inflated models such as zero-inflated Poisson (ZIP), zero-inflated negative binomial (ZINB), zero-altered Poisson (ZAP) and zero-altered negative binomial (ZANB) (Zuur et al., 2009). It is imperative we investigate the possibility of zero-inflation across our floral data.

The need for standardisation and transformation of data is common across ecological research. The scales of many common explanatory variables vary widely. In addition to this, significant variation in species data can occur if the contributions of abundant or rare species are not standardised (Kent, 2012). Without appropriate transformation, rare species can show a disproportionate significance, especially if using correspondence analysis techniques (Legendre & Gallagher, 2001). As such, transformation of species data occurs widely across the literature (see for example Wilson & Carpenter, 1999; Tanner & Gange, 2005; Sage et al., 2009). Removal of rare species can be beneficial (Bachand et al., 2014). Some ecological programs can perform this task as part of their overall analysis.

3.3.3 Exploratory data analysis (EDA)

New sets of data with no prior analysis or understanding require exploratory data analysis (EDA). This process is in line with the following flow diagram:

Figure 3.10: Data analysis flow diagram (reproduced from Kent, 2012)

This is in contrast to other types of data analysis which attempt to specify a model before analysing the data, such as Classical Confirmation Analysis (CCA) or Bayesian Analysis. On primary floristic data such as produced in this study, EDA is beneficial to fully examine any anomalies, outliers, or co-dependencies. This process is stressed in a number of high profile papers (Zuur, Ieno, & Elphick, 2010; Kent, 2012). They estimate a large quantity of ecological papers contain Type I or Type II statistical errors due to insufficient EDA prior to more sophisticated statistical methods.

The use of graphics as a preliminary step in EDA is widely supported in the literature. This was begun in part by Tukey (1977 in Ellison, 1993) and continued almost without argument (see for example Quinn and Keough, 2000 in Kent, 2012; Zuur, Ieno, & Elphick, 2010).

The following steps have been suggested by Zuur, Ieno, & Elphick (2010) as a robust means of conducted EDA. The reasons for the necessity of these are briefly discussed.

Step 1: Presence of outliers

If the incorrect statistical method is employed, outliers can skew the results of the test (Zuur, Ieno, & Elphick, 2010; Jackson & Chen, 2004). They can, for example, cause over-dispersion in a Generalised Linear Model (GLM). In other statistical methods, outliers can be included without influencing the result (Legendre & Legendre, 1998). The exclusion of extreme outliers prior to further statistical analysis occurs often in ecological data analysis. For example, English Nature excluded the extreme outlier *Brachypodium pinnatum* from further analysis when studying vegetation change in County Durham. As this species is atypical to the habitat of study, a priori knowledge of the habitat of study is clearly advantageous (English Nature, 2001).

Step 2: Homogeneity Y

The assumption of homogeneity in Y relies upon the dependent variable showing similar variance across all of its data points for an independent variable. When serious violations occur, model outputs can be highly unreliable (Fox, 2009 in Zuur, Ieno, & Elphick, 2010). Residual plots from any model should be examined for homogeneity.

Step 3: Normality

In linear regression and other similar statistical models, normality is important to ensure reliable outputs. Principal Component Analysis (PCA) or other similar analysis tools do not require normality to function.

Step 4: Abundance of zeros

An over-abundance of zeros is common in species data. However, these can produce incorrect parameter estimates and standard errors in a normal Poisson or negative binomial model (Zuur, Ieno, & Elphick, 2010).

Step 5: Collinearity

If correlation exists between the covariates, the significance of the explanatory variables can be unreliable. Collinear variables should be removed prior to modelling.

Step 6: Relationships

Studying the relationships between Y and X variables allows any unusual observations or relationships to be revealed. These can be investigated prior to modelling.

Step 7: Independence

In most statistical techniques, independence of the observations is required. In species data, where there is commonly a number of samples taken at one site, it is important to check for spatial dependence prior to modelling (Zuur, Ieno, & Elphick, 2010).

Spatial dependency, or spatial autocorrelation, is defined well by Ver Hoef et al. (2001, pg. 218, in Kent, 2012) as “the tendency for random variables to covary as a function of their locations in space”. Simply put, floral samples that are spatially and temporally close to one another are likely to share more traits than those far away. A number of papers have emphasised the importance of this, and the number of studies that ignore its effects (Legendre, 1993; Dormann, 2007). Only once has spatial autocorrelation has been tested for, and shown as not present in the data, should normal univariate or multivariate analysis be undertaken. Otherwise, a data analysis method that adjusts for the autocorrelation should be used (see Section 3.7 for further discussion and methods to adjust for this).

3.3.4 Floral data analysis techniques

Included papers from the systematic review on floral surveys were re-examined for statistical methods. This can help inform data analysis to ensure no pertinent species information is lost. Table 3.2 shows methods of statistical analysis used across included papers.

Statistical analysis used in included papers from systematic review

Statistical method employed \ Objective of study	Community	Conservation	Human impacts	Management	Nitrogen	Other	Soil fertility	Succession
ANOVA	1		2	2	1			2
CLUSTANGRAPH	1							
Cluster analysis			1					1
Correspondence Analysis (CA/CCA)		1						2
Detrended Correspondence Analysis (DCA) (CANOCO)					1		1	
DCA (DECORANA)	2		2	3		1	1	3
Ellenberg Indicator values	1					1	1	
General Additive model (GAM)			1					
Logistic regression			1					
Mixed-effects model			1		1			
Multiple regression					1	1	1	
Pearson Correlation		1						
Principle Component Analysis (PCA)	1							1
Principle response curve analysis (PRC)				2	1			
Restricted Maximum Likelihood (REML)			2					
Spearman rank correlation		1	1					
Tandy's Isovist						1		
t-tests		1				2		1
Two-Way Indicator Species Analysis (TWINSPAN)	3			2	1			5
u-tests						1		1
Wilcoxon signed rank sum test		1						

Table 3.2: Statistical analysis types used in included papers within systematic review. Numbers may seem inflated where single papers have used multiple analysis methods.

Evidence gleaned from the systematic review highlights the importance of Detrended Correspondence Analysis (DCA), usually undertaken in DECORANA, and Two-Way Indicator Species Analysis (TWINSPAN). These methods will be investigated further below.

3.3.5 Ordination – Detrended Correspondence Analysis (DCA)

DCA, often called DECORANA after its software, is a common statistical technique (English Nature, 2000) to explore species data sets. In particular, DCA can identify potential indicators of the site or environmental variables. The process works by identifying the dimensions of the species dataset, and "flattening" these in to axes. Oksanen, who developed the R package *vegan* to undertake DCA, estimates most species data sets have on average 2.5 dimensions (Oksanen, 2015). According to Gauch (1982): "Ordination primarily endeavours to represent sample and species relationships as faithfully as possible in a low-dimensional space".

DCA was developed in response to problems inherent in its predecessor, Reciprocal Averaging (RA). The most pressing issue was known as the "Arch Effect" or "Horseshoe Effect" (Kendall, 1971; Gauch et al., 1977, in Hill & Gauch, 1980). This effect arises from a second axis which is uncorrelated, but not independent of the first. DCA eliminated this effect by ensuring that after the first axis is drawn, the mean value of the subsequent axes is approximately zero at any point along the first axis.

DCA has a number of advantages that have led to it being one of, if not the, most frequently used means of floral data analysis. DCA has been used in the literature in a variety of habitats, including investigation in to soil fertility in British forests (Wilson et al., 2001); an analysis of *Cirsium* species (Jump & Woodward, 2003); and of vegetation on a reclaimed limestone quarry (Cullen et al., 1997). This last study was of particular interest due to its location of restored grassland. If a cluster exists in nature, this should be relatively easy to identify in the ordination. Likewise, no cluster should emerge in the ordination that does not exist in nature. It is an "elegant" method for mathematicians, and a relatively easily understandable method for practicing ecologists (Legendre & Legendre, 1998).

It also saves time through its use of a single multivariate analysis rather than numerous univariate analyses (Gauch, 1982). The graphical outputs, especially for the package developed for R, are intuitive visualisations of the community under study.

"Noise"* is also easier to deal with than in other applications as only the most important dimensions are considered (Gauch, 1982).

3.3.6 Two-Way Indicator Species Analysis (TWINSPAN)

TWINSPAN is a type of hierarchical clustering technique specially developed for identifying indicator species within a data set (Hill, 1979). The method is a mix of Zurich-Montpellier methods (characteristic species) and Uppsala methods (dominant species) (Leveque, 2003).

"An algorithm linear in the size of the dataset was achieved by, figuratively speaking, sending signals through the data matrix in search of resonances in which the species and samples sounded together, and then dividing the data accordingly. When the samples and subsequently the species were repeatedly divided, TWINSPAN resulted" (Hill, 1979, pg. 2).

Species are systematically split in to subsets according to their location along axes of a correspondence analysis ordination (CA or DCA). The method has been criticised for its possible inability to represent any secondary gradients beyond the initial one (Belin & McDonald, 1993 in Dufrene & Legendre, 1997). Also present is a concern that TWINSPAN fails to represent the natural process of species abundances (Dufrene & Legendre, 1997; McGeoch & Chown 1998 in De Cacres, Legendre & Moretti, 2010). As it focuses on relative species abundance, the natural formation of plant clusters could skew results. As such, it is advisable to use another method in conjunction to mitigate these issues.

The technique has been used across a number of habitats, including Willow carr (Southall et al., 2003a), field margins (Marshall & Arnold, 1995), and bogs (Large, 2001), often in conjunction with DCA as discussed in the last paragraph.

3.4 Site selection

Created grassland is defined for this study as a site previous used for non-natural land uses (e.g. industry, quarrying), allowed to develop naturally as grassland with management, or seeded. Relevant created grassland habitats were sourced via a number of methods. Suggestions were made from Middlemarch Environmental Ltd. of created grassland sites they have worked on. These are specifically Whittleford Park and North Cave Wetland although work has been undertaken at Brandon Marsh via Warwickshire Wildlife Trust. Warwickshire Wildlife Trust also recommended Ufton Fields as a potential site. Houghton Regis, Attenborough Nature Reserve, King's Meadow and Parc Slip were sourced through contacting the relevant Wildlife Trusts directly (Bedfordshire Wildlife Trust, Nottinghamshire Wildlife Trust and Welsh Wildlife respectively). Ryton Meadows was sourced through an internet search for created grasslands. Sites allowing the longest possible chronosequence were given preference. The sites were also selected to ensure different soil types were represented. Efforts were made to source a number of sites with various management types as an extra line of enquiry.

3.5 Environmental variables

3.5.1 Altitude

GPS altitude of each quadrat was recorded in m.

3.5.2 Species outside the sample but in the stand

Any species noted on a general walkover separate to the quadrats were noted.

3.5.3 Location

Quadrats were randomly placed around the site. Coordinates of the top right corner of the quadrats were identified using a random number checker. The 10 digit grid reference and latitude and longitude of the top right corner of each quadrat were checked on site. If the randomly generated location was unsuitable for sampling (e.g. area of open water; located on boundary between vegetation types), this location was skipped and the next quadrat location used.

3.5.4 Adjoining habitats

Habitat types adjoining the study site were noted.

3.6 Physiognomic/structural elements

This relates to the external features (i.e. size, morphology) of the species under study (see Section 2.4.2 of Literature Review).

3.6.1 Quadrat average height

The average height of the flora within the quadrat was estimated by eye using a metre rule held perpendicular to the ground. Height was recorded in cm.

3.6.2 Nomenclature

Nomenclature follows Stace (1997, 1999) for vascular plants as recommended by the NVC methodology. Bryophytes were not recorded as part of this study as they are particularly difficult to identify.

3.7 Floral sampling

Quadrat sampling was undertaken in accordance with the NVC monitoring standard. This was in response to information acquired during the systematic review of floral indicator species (see Section 3.2.5). An NVC record card is included in Appendix 12 which highlights variables collected on site. All sampling was undertaken in a 2 x 2m square quadrat in random locations discussed above. The percentage of each sub-species was estimated by eye and recorded on the relevant NVC record card (example in Appendix 12). Plant cover can feasibly exceed 100% because of structural overlap (Kent, 2012). Any doubtful specimens were checked by a referee(s) (academics at Leicester University

Botanical Garden), and/or checked using online resources (e.g. BSBI, 2015). To avoid damaging the habitat by removing samples, numerous high quality photographs of any unusual or doubtful specimens were taken where required. NVC methodology utilises the DOMIN scale (outlined in Table 3.3), however taking a percentage amount allows conversion to DOMIN to take place or more in depth analysis with percent if necessary.

DOMIN scale	Percentage scale
10	91-100%
9	76-90%
8	51-75%
7	34-50%
6	26-33%
5	11-25%
4	4-10%
3	<4% (many individuals)
2	<4% (several individuals)
1	<4% (few individuals)

Table 3.3: DOMIN scale compared to percentage cover

3.8 Data presentation

Data was initially entered in to Microsoft Excel 2010. Samples (quadrats) were arranged in rows, and all explanatory data arranged in columns. Species names were recorded in Latin using eight characters representing the first four letters of each word in the Latin name e.g. *Lolium perenne* is labelled Lolipere (Kent, 2012). No replication of species names occurred. Table 2.2 outlines initial explanatory variables recorded with description. Factor text variables were coded where possible. Details of coding are available in Appendix 7.

Variable name	Variable description	Variable type
Quadrat.number	Identification key variable	Integer
Location	Site (coded 1-9)	Integer
Location.2	Sub-site (coded 1-9 to one decimal place)	Integer
Site.info	Soil type (coded 1-3)	Integer
Management	Management of site/sub-site (coded 1-5)	Integer
Date.of.creation	Year grassland was created	Integer
Time.since.creation	Years since creation of grassland	Integer
Whole.Site.Area.(ha)	Area in hectares of full site	Number
Subsite.area	Area in hectares of sub-site	Number
Grid.reference	10 digit grid reference of quadrat (top right corner)	Factor
X	X coordinate of quadrat (top right corner)	Number
Y	Y coordinate of quadrat (top right corner)	Number
Latitude	Decimal latitude of quadrat (top right corner)	Number
Longitude	Decimal longitude of quadrat (top right corner)	Number
Date	Date of data collection of quadrat	Date
Grid.height	Altitude of quadrat	Number
GPS.altitude	Altitude of quadrat	Number
Sample.area	Quadrat size	Factor
Quadrat.mean.height.cm	Subjective estimate of mean height of all vegetation in quadrat in centimetres	Number
Species.outside.quadrat	Any species noted on walkover of site	Factor
Adjoining.habitats	Broad habitat type of areas adjoining site	Factor
Individual species	Percent cover of each species found on site. Each species represented by one column. Please see Appendix 11 for full species list.	Integer

Table 3.4: List and description of fieldwork variables and their variable type

Data was input from the fieldwork sampling sheets. All data was checked for input errors.

3.9 Community variables

a. Species richness

Species richness for each quadrat was calculated as the total number of species recorded per quadrat. Species richness, in reference to evidence obtained in the literature review (Section 3.2.4), was calculated in two ways, *total* site species richness and *mean* site species richness. Total species richness was calculated as the total species observed within the quadrats on the site. Mean species richness was the average species richness of all quadrats on site.

b. Species diversity

Species diversity was calculated as both Simpson's Index (D) and Simpson's Index of Diversity (1-D).

Equation 3.1: Simpson's Index is calculated as:

$$D = \sum (n - N)^2$$

Where n=the total number of organisms of a particular species and N=the total number of organisms of all species.

Due to problems in interpreting Simpson's Index, Simpson's Index of Diversity was also calculated (1-D).

c. Herb:grass ratio

The herb:grass ratio was calculated as:

Equation 3.2: Herb:grass ratio

$$Herb{:}\,grass\ ratio = \sum HP{:}\sum GP$$

Where HP is the percent of each herb species per quadrat and GP is the percent cover of each grass species per quadrat.

Due to difficulties in analysing ratios, this ratio was converted to percent herb as a proxy variable. This took in to account that total cover was over 100% in some cases.

Species not found in a quadrat were recorded as a 0 (NA would imply missing data).

d. Family groups

Individual species figures were aggregated per quadrat according to their family name defined by Stace (1997; 1999). The presence/absence of a family was distinguished using the variable family.pa while abundance in percent was distinguished using the variable family.abund, where family is the Latin family name without aceae (the word ending of plant family types).

3.10 Secondary variables

A number of secondary variables were calculated. Many of these were deemed unsuitable as bioindicators in the context of this study. This was mostly due to computational requirements outside of the remit of those likely to use this model. However, their inclusion in the data set could be useful for further study.

The Modular Analysis of Vegetation Information System (MAVIS) software was downloaded from the Centre for Ecology and Hydrology: Natural Environment Research Council. This is free software for analysing vegetation data using a variety of classification techniques. The following variables were calculated using each quadrat's species data in reference to the literature review.

a. CSR

Grime's (1979) CSR classifications were calculated for each quadrat. Results were outputted in number format to two decimal places.

b. Ellenberg Indicator Values

Ellenberg scores for Light, Fertility, Wetness and Ph. were calculated. Results were outputted in number format to one decimal place.

c. Countryside Vegetation System (CVS) class

The countryside classification of ITE Countryside Survey data for 1978 and 1990, called the CVS. Results were outputted in integer format.

d. NVC class

The National Vegetation Classification (NVC) was devised at the Unit of Vegetation Science, Lancaster University. First estimated NVC class, then second estimated NVC class, was calculated. Results were outputted as a factor according to NVC coding systems e.g. MG1b relates to a type of mesotrophic grassland, CG4 relates to a type of calcareous grassland.

3.11 Descriptive statistics

Descriptive statistics (mean, median, variance and standard deviation) were calculated using the sapply function in R. All code is presented in Appendix 7.

3.12 Exploratory Data Analysis

Data exploration steps follow Zuur, Ieno, & Elphick (2010), which is widely supported in the literature (see Section 3.3). These are outlined in Table 3.5.

Step	Aspects of data	Test
1	Outliers Y & X	Boxplot and Cleveland dot plot
2	Homogeneity Y	Conditional boxplot
3	Normality Y	Histogram or QQ-plot
4	Zero trouble Y	Frequency plot or corrgram
5	Collinearity X	VIF and scatterplots; Correlations and PCA
6	Relationships Y & X	(multi-panel) scatterplots; Conditional boxplots
7	Interactions	Coplots
8	Independence Y	ACF & variogram Plot Y vs time/space

Table 3.5: Aspects of data analysis identified in Zuur, Ieno, & Elphick, 2010

Step 1: Outliers Y & X

In order to identify outliers in Y and X, boxplots and dot charts were calculated for all included variables. Any identified outliers were then examined using a Cook's plot. Any data points over 1 will be considered for alteration to reduce risk of influential observations (Fox, 2002 in Zuur, Ieno & Elphick, 2014). Transformation of the data or removal of the outlier will be pursued if necessary. Removal of any data, however, will be avoided as recommended by Zuur, Ieno, & Elphick, 2010, although Gauch (1982) advises removal. This is due to concerns that a single 'outlier' in a relatively small dataset could be capturing an important, if rare, piece of information. Removal could impair full capture of ecosystem function.

Step 2: Do we have homogeneity of variance?

Step 2 (examining the residuals vs. fitted values for the model) can only be performed after modelling has taken place

Step 3: Are the data normally distributed?

Plots created as part of Step 1 (Outliers) were re-examined for evidence of non-normal distributions.

Step 4: Are there lots of zeros in the data?

Raw data was examined to establish number of zeros in the data. A corrgram was created to establish species pairs with common absences.

Step 5: Is there collinearity among the covariates?

Pairwise scatterplots were created assessing collinearity between each of the following types of variables:

1. Between-species correlation
2. Species – temporal/spatial variables correlation
3. Between-community variables correlation
4. Community-temporal spatial variables correlation.

As well as examining the scatterplots created, a Pearson correlation coefficient was created for each variable. A highly conservative cut-off of 0.3/-0.3 was set according to Zuur, Ieno, & Elphick (2010). Such a conservative figure was chosen due to evidence of collinearity issues in ecological studies.

Any species deemed to show auto-correlation were allocated to a Group B. This ensured no important information was lost due to the conservative cut off figure above. Group B species followed the proceeding methodologies. Any such species were marked as "Auto-correlation" in Table 3.3.

3.13 TWINSPAN (Two-Way Indicator Species Analysis) of species classification and indicator species

In this study, WinTWINS for Windows (Version 2.3 August 2005) was used to classify species identified in the field study. For each division in species classification, WinTWINS provides an eigenvalue which determines the significance of the division. A stronger separation (eigenvalue closer to 1.00) indicates sample groups with significant differences in species structure. In contrast, an eigenvalue closer to 0.00 signifies significant overlap in species composition. For each group, one or more indicator species of that group are revealed (at a pre-defined range of abundance).

WinTWINS was downloaded from http://www.canodraw.com/wintwins.htm. The adjusted quadrat dataset was uploaded in to the program. Cut levels were set to 4 on the recommendation of Šmilauer & Lepš (2014). Further levels were set at 0, 2, 5 and 10 with a weight of 1 in line with Hotanen (1990). Potential indicator species by group division was recorded. From Kent (2012), an "Indicator Score" for each pseudospecies of interest can be calculated with:

Equation 3.3: Indicator score (TWINSPAN analysis)

$$I_j = \frac{nj^+}{n_+} - \frac{nj^-}{n_-}$$

Where n_+ is the total quadrats on the positive side of the division, n_- is the total quadrats on the negative side of the division, nj^+ is the number of species on the positive side that contain the jth species and $nj^-$is the number of species on the negative side that contain the jth species (Kent, 2012).

Resulting output was examined for potential indicator species.

3.14 Detrended Correspondence Analysis (DCA)

DCA was run using the 'vegan" package in R (Oksanen, 2015). Full code and output is presented in Appendix 7. DCA was run on individual sites, as well as Group A and B data (if auto-correlation has occurred). Following Oksanen (2015), an *Indirect Gradient Analysis* was run as the community composition is of interest rather than solely environmental variables as with *Direct Gradient Analysis.* The axis length presented in the initial DCA analysis determines whether the further method will follow linear or unimodal analysis. In line with Šmilauer & Lepš (2014), if the largest value (or the longest gradient) is larger than 4.0, unimodal methods are advised (DCA, CA, or CCA).

3.15 *FURTHER INDICATOR TESTING*

Once statistical analysis has been run to establish bioindicators of created grassland, further testing will be undertaken to ascertain their usefulness. Bioindicators will be mapped against the sites to test their effectiveness. As the literature review identified the link between species richness as a proxy to biodiversity and NPP as a proxy for Ecosystem Service provision (Section 2.2.7), this relationship was explored.

A linear regression model was run to investigate the effect size and significance of our identified indicators against species richness. As not enough data points exist to run this at a sub-site level (n=11), species richness refers to total number of species per quadrat.

Equation 3.4 outlines the structure of the regression equation in notation form.

Equation 3.4: $$Y = \beta\_0 + \beta\_1 X\_1 + \beta\_2 X\_2 + \cdots + \varepsilon$$

Where Y is the dependent variable species richness, β_0 is the intercept term, $\beta\_1 X\_1$ etc. are a series of explanatory variables (Mean quadrat height (cm), Herb percent, Species diversity, No. positive indicator species present, No. negative indicator species present), and ε is the error term

Residual and leverage plots were examined for modelling violations.

CHAPTER 4: FIELDWORK RESULTS AND IDENTIFICATION OF INDICATOR SPECIES

4.1 INTRODUCTION

As discussed in the preceding chapters, ecological data, and economic analysis of non-market goods are inherently complex. As such, the range of methods available have been methodically researched and discussed. The first section of the Results chapter covers the first hand floral data retrieved surveying created grasslands. First a description of sites is presented, along with initial descriptive statistics. Extensive data exploration is first pursued following established methods. This is followed by Detrended Correspondence Analysis (DCA) and Two-Way Indicator Species Analysis (TWINSPAN). A number of indicators of grassland value are identified, both of individual species and community variables. This informs discussions of grassland value according to biodiversity level to be estimated in Chapter 7. This section utilises a rigorous systematic review of current valuation studies of grasslands. These results can then inform connecting bioindicators with estimated values in Chapter 8.

4.2 DESCRIPTION OF SITES

The next sections outline the sites used in the fieldwork study. Further information obtained from the owners or managers of the sites are provided in Appendix 1, along with permissions to sample on site where applicable.

Site 1 - Attenborough Nature Reserve, Nottingham

Site Overview

Attenborough Nature Reserve is a multi-habitat site owned and managed by Nottinghamshire Wildlife Trust, built on the site of a sand and gravel quarry just south of the conurbation of Nottingham. Situated at National Grid Reference SK 51326 34094, the site is dominated by open water, surrounded by grasslands, woodland and scrub. A popular bird-watcher destination, an ecofriendly visitor and education centre has been put in place. The site is scheduled as a Site of Specific Scientific Interest (SSSI).

Site Plan (specific area of study highlighted)

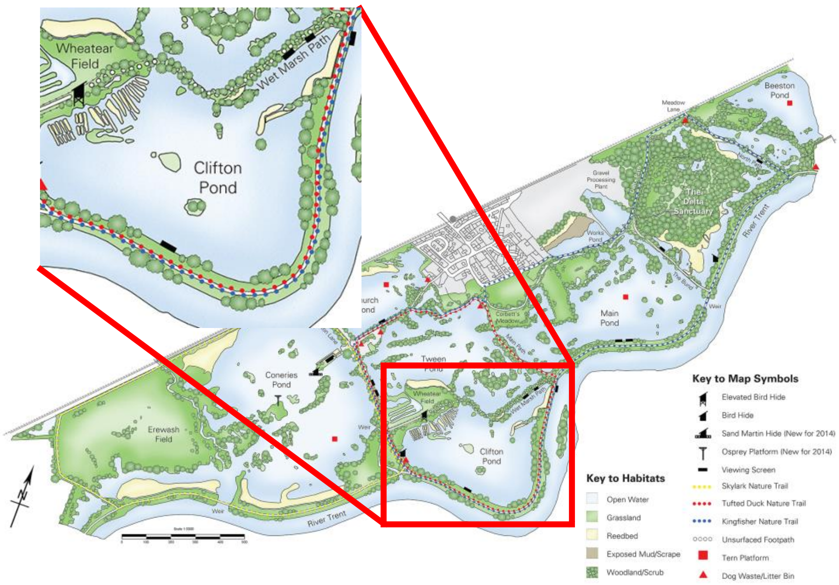


Figure 4.1: Site plan of Attenborough Nature Reserve

History of site

Extraction of sand and gravel in the area began in 1929, and continues to some extent today in regions close to the reserve. Prior to this extraction, the site mostly comprised wet meadows through which the Erewash, a tributary of the Trent, flowed. Leftover material from extraction formed peaks and troughs which went on to form the pools present at the Reserve. After establishment of the water pools and habitats on site, David Attenborough opened the reserve in 1966. Since then, further work has been undertaken to mitigate the pollution of the Trent by industrial works and further habitat creation

Geology of site

Due to the historic presence of the Erewash, the substrate of the site is dominated by mineral and organic alluvial deposits. Below this are glacial gravels and sands. The soil type of the site is mesotrophic, the common soil type of much of the UK. Breaching of the Erewash in 1972, while installing a barge channel, resulted in pollution of the river which inevitably impacted on the reserve's soil. Long-term work, including attempting to re-establish the original course of the Erewash, is attempting to rectify pollution of the reserve.

Site 2 – Brandon Marsh Nature Reserve

Site Overview

Brandon Marsh is a nature reserve with habitats ranging from open water and reed beds to woodland and grassland, situated in Coventry, West Midlands, at National Grid Reference SP 385 755 (centre of reserve). Developed on the site of an ex-sand and gravel quarry, conservation management began in 1967 and continues to this day, with the site being designated an SSSI in 1973.

Site Plan

Figure 4.2: Site plan of Brandon Marsh Nature Reserve including compartment designation

History of site

The area that is now Brandon Marsh Nature Reserve was originally farmland, with pools forming in pits caused by subsidence from Binley Colliery. Sand and gravel extraction occurred for over 35 years to 1989, however conservation management began in 1967 and the site was made a SSSI in 1973.

Geology of site

The bedrock of the site is Triassic Mercia Mudstone, forming an outcrop in various places across the site. Other than this, the geology is made up of The Wolston Stage of the Quaternary, at an age of approximately 200,000 years old (although recent evidence points towards a much earlier date), and the Triassic Bunter pebble beds.

Important habitats and known species

Fen and swamp; Ponds, lakes and reservoirs; Quarries and gravel pits; Reed bed; Rivers and streams; Scrub and carr; Woodland.

(Brandon Marsh Voluntary Conservation Team, 2005)

Site 3 – Houghton Regis Quarry

Site Overview

Houghton Regis Chalk Pit Nature Reserve is a 100 acre reserve located in Houghton Regis, Cambridgeshire, at National Grid Reference TL013 235. Managed by Bedfordshire, Cambridgeshire and Northamptonshire Wildlife Trusts, the site includes habitats such as chalk grassland, a limestone lake, broadleaved woodland and wetland. Houghton Regis Quarry is designated as a County Wildlife Site (CWS), while the Marl Lakes on site are a SSSI.

Site Plan

Figure 4.3: Site plan of Houghton Regis Quarry (Bedfordshire and Luton Biodiversity Recording and Monitoring Centre, 2012)

History of site

Previously agricultural land, Houghton Regis chalk quarry was established in 1926 supplying chalk to a cement works in Dunstable. The quarry was closed in 1971, and grass and scrub appropriated the area, along with Marl lakes developing. Bedfordshire Wildlife Trust now own and manage the site, with annual ragwort clearance being carried out.

Geology of site

Houghton Regis quarry, considering its excavation background, is unsurprisingly a chalk soil. The site sits on the West Melbury Marly Chalk Formation, with sedimentary bedrock formed around 94 to 100 million years ago (British Geological Survey, 2015).

Important habitats and known species

Lowland calcareous grassland and reed beds on site are Habitat Action Plans (HAP) for Bedfordshire and Luton. Houghton Regis quarry has a variety of dragonfly species, and characteristic plant species such as water horsetail *Equisetum fiuviatile*, lesser pond-sedge *Carex acutiformis*, and lesser bulrush *Typha angustifolia*.

Site 4 - King's Meadow Nature Reserve

Site Overview

King's Meadow is a nature reserve in central Nottingham, Nottinghamshire, at National Grid Reference SK 558 384. King's Meadow was leased to Nottinghamshire Wildlife Trust in 1995 for 21 years, and forms part of the King's Meadow Grassland Site of Importance for Nature Conservation (SINC). Developed on the site of the former Wilford Power Station site, wildlife conservation in its current form began in 1992 and now supports a wide range of flora and fauna.

Site Plan

Figure 4.4: Site Plan of King's Meadow (Nottinghamshire Wildlife Trust, 2012)

History of site

Prior to the Wilford Power Station's decommissioning in 1960, Pulverised Fuel Ash (PFA) was spread across the site. Orchids, including common spotted orchid *Dactylorhiza fuchsia* and southern marsh orchid *Dactylorhiza praetermissa*, began to colonise. In the late 1980's/early 1990's the area was earmarked for development, but following campaigning by Nottinghamshire Urban Wildlife Scheme (NUWS), King's Meadow was spread with trans-located vegetated ash turf and flora began to develop. In 1995 King's Meadow was leased to Nottinghamshire Wildlife Trust for 21 years and the area was designated a Site of Importance for Nature Conservation (SINC).

Geology of site

Underneath the industrial by-products forming much of the substrate to King's Meadow (PFA, vegetated ash turf, cinder and clinker), the bedrock belongs to the Mercia Mudstone Group.

Important habitats and known species

Habitats present within King's Meadow include scrub, dry grassland and tall ruderal. Notable species include southern marsh orchid *Dactylorhiza praetermissa* and locally uncommon wood small-reed *Calamagrostis epigejos*.

Site 5 – North Cave Wetlands

Site Overview

North Cave Wetland is a mosaic of wetland and wet grassland habitats in Northern England, at National Grid Reference SE 88293 32989. The initial site covered 38.8ha, with a second phase undertaken covering 42.5ha. The site is now frequented by a large range of bird species, and is popular with bird watchers.

Site Plan

Aston University

Illustration removed for copyright restrictions

Figure 4.5: Site Plan of North Cave Wetland (Yorkshire Wildlife Trust (YWT), 2013)

Site History

Previously a sand and gravel quarry, North Cave wetland was a site targeted for the site of a wetland and wet grassland, with the express purpose of creating an optimum bird habitat. Originally targeted for landfill after excavation stopped, this was heavily opposed by local residents and the site was bought by Yorkshire Wildlife Trust (YWT) in 2000. Initial stages of development were undertaken by 2003, with Phase 2 commencing in 2008 with ecological design and support undertaken by Middlemarch Environmental Ltd.

Site geology

Rocks formed on shallow seas, with Mudstone and Limestone Sedimentary Bedrock.

Important habitats and known species

North Cave Wetland has developed in to a prime bird-watching site, with 2015 sightings reported of species such as local Biodiversity Action plan (LBAP) and RSPB Amber Grey wagtail *Motacilla cinerea* and common bullfinch *Pyrrhula pyrrhula* subsp. *Pileata*. The site was the first recorded inland breeding of RSPB Amber List Avocet *Recurvirostra avosetta*. A number of protected bat species have also been noted on site, including NERC Act 2006 and UK BAP priority species Bechstein's bat *Myotis bechsteinii*.

The reed beds on site are a UK BAP priority habitat, and the deep water on site provides further refuge for waders and wildfowl (Yorkshire Wildlife Trust, 2015).

Site 6 – Parc Slip Nature Reserve

Site overview

Parc Slip Nature Reserve is a 121ha site comprising a mixture of wetland, grassland and woodland. The site is situated at National Grid Reference SS 881 841 near Bridgend, Wales. The site was previously a coal mine, with conversion to nature reserve occurring in the 1980's.

Site plan

Aston University

Illustration removed for copyright restrictions

Figure 4.6: Parc Slip Nature Reserve site plan

Site history

Parc Slip open-cast colliery pit was opened in the 1860's, closing in 1904. The site endured a number of tragedies due to explosion before its closure (Welsh Wildlife, 2012). After 1904, the site remained unused until the 1960's when British Opencast Coal extracted the remaining coal deposits. In the 1980's, excavation was completed and the site was filled to create the present Nature Reserve with multiple habitats.

Site geology

Parc Slip sits upon sedimentary bedrock comprising Mudstone, Siltstone and Sandstone. Previously mined for its coal deposits, the site currently stands on calcareous soil.

Important habitats and known species

Parc Slip Nature Reserve contains a number of habitats, including open water, wetland, wildflower meadows, and deciduous and coniferous woodland. Local BAP habitat reed beds are present, providing habitat for RSPB red status bird species Aquatic warbler *Acrocephalus paludicola* and Bittern *Botaurus stellaris*. Other important species noted on site include European protected great crested newt *Triturus cristatus,* and the previously-thought extinct Scarce Blue-tailed damselfly *Ischnura pumilio*.

Site 7 - Ryton Wood Meadows

Site Overview

Ryton Wood Meadows is a 12.4 hectare nature reserve on the outskirts of Coventry, England, situated at National Grid Reference SP 378 728. The site was previously used for sand and gravel extraction until the late 1980's when restoration of the site began. Numerous protected species have been recorded on site, notably UK BAP butterfly species dingy skipper *Erynnis tages* and moth species merveille du jour *Moma alpium*.

Site Plan

Figure 4.7: Site Plan of Ryton Meadows (Butterfly Conservation Warwickshire, 2012)

History of site

Until the 1960's, the area to the south east of the Leamington Road was a mix of farmland and woodland (Ryton Wood). After this, the site was purchased by Steetley Aggregates, and the area was mined for sand and gravel until the early 1990's. As the area quarried had contained 100 acres of Ryton Wood, by the end of extraction 40-60 acres of woodland had been lost.

In the late 1980's, restoration of the site began, with the north east of the site being filled with inert building waste, and the rest of the site in-filled with household rubbish and then sub-soil. The site was subsequently levelled in 1990/91 and in 1995 the landfill of the site was stopped and further restoration continued.

In 1990 transect surveys of the site began to assess possible importance of the site, and subsequently half the site was sown with wildflower mix. A further quarter of the site was left to colonise naturally while the remainder was left fallow. The reserve today boasts native hedgerows, a range of flora and fauna, and a range of management practices.

Geology of site

Bedrock comprises Mercia Mudstone Group sedimentary bedrock. Substrate provided by previously river deposits.

Important habitats and known species

This series of meadows and woodland areas have been managed specifically to provide habitat to butterflies, as well as other wildlife. Blackthorn *Prunus spinosa* hedges provide habitat for UK BAP priority species Brown Hairstreak *Thecla betulae*, while specially created stony banks support Grizzled skipper *Pyrgus malvae* and Dingy skipper *Erynnis tages*. Important plant species previously found on site include Penny royal *Mentha pulegium*, protected by Schedule 8 of the Wildlife and Countryside Act 1981 and a UK BAP priority species.

Site 8 - Ufton Fields

Site Overview

Ufton Fields is a 40.5ha area of mixed habitat including open water, scattered trees and grassland. Situated in Warwickshire, England, the site is located at National Grid Reference SP 38146 61690. Previously the site of limestone extraction, Ufton Fields is now a SSSI, hosting a number of priority plant and animal species.

Site Plan

Figure 4.8: Site Plan of Ufton Fields – surveyed areas are Compartments 10 and 13

History of Site

After a long history of extraction, Ufton Fields was sold to Warwickshire County Council in 1972 by Associated Portland Cement Manufacturers Limited. After this point, the site began to naturally colonise, with management being undertaken by Warwickshire County Council since 1980. Further parts of the site were reclaimed from farmland. A number of different management activities have been undertaken since conception, including grazing and scrub removal.

A series of pools, both permanent and temporary are present on site, as well as areas of woodland. These were, in contrast to the grassland areas, predominantly planted. These areas contain mostly non-native species.

Geology of site

The site stands upon a band of white Lias limestone, overlain with lower Lias clay, shales and mudstones. Quarrying and management has altered the composition of the site, with communities showing a distinctly mesotrophic structure.

Important habitats and known species

Ufton Fields contains a range of habitats, including woodland, open water and grassland, as well as boundary features. Although some of the habitats are non-optimal, including a high proportion of non-native or scrub species amongst the woodland and grassland, the site lays home to a number of important species. This includes priority bird species Turtle Dove *Streptopelia turtur*, Water Rail *Rallus aquaticus* and Spotted Crake *Porzana porzana*.

The SSSI status was granted mostly on the number of priority invertebrate species recorded on site. These include White-letter hairstreak, Grizzled Skipper *Pyrgus malvae* and Dingy skipper *Erynnis tages*, as well as 14 species of dragonfly.

The site also holds Great Crested Newt *Triturus cristatus*, and Grass Snake *Natrix natrix.*

Site 9 - Whittleford Park

Site Overview

Whittleford Park is a 43ha recreational area in an urban area of Nuneaton, West Midlands. Set at National Grid Reference SP 33909 92165, the park in its current form was created by Middlemarch Environmental Ltd. in 2009 after plans were drawn up by Warwickshire County Council in 2005. Previously a site of coal mining and tile making, the site now contains a number of habitats including open water, grassland and reed bed.

Site Plan

Figure 4.9: Site Plan of Whittleford Park, Nuneaton

Site History

The site was previously home to industrial pursuits, including Nuneaton Colliery, Stockingford Colliery, Ansley Hall Colliery, and Haunchwood Colliery. These were connected to each other and canal wharfs by a network of trams. The site also contained tile makers. The last factory was closed in 1970, and was demolished.

Warwickshire County Council announced plans to develop the site in to a public park in 2005. Middlemarch Environmental, in conjunction with Barrett Homes, began creation of a number of natural habitats in 2009. This was based upon development of ridge and furrow, allowing development of wet habitats and hay meadow. Clay Pool, now an area of open water, is the hole remaining from clay extraction for brick making.

Geological information

Whittleford Park lies on Triassic Rocks - Mudstone, Siltstone and Sandstone.

Important habitats and known species

New habitats on site contribute to Nuneaton and Bedworth's Habitat Action plans, including scrub and carr; ponds, lakes and reservoirs; a small amount of mature woodland and reed beds (Nuneaton and Bedworth Council, 2005).

The mature woodland is home to oak, birch and hazel, while a number of dragonflies and damselflies are present. These include Black Tailed Skimmer *Orthetrum cancellatum*, Emporer *Anax imperator* and Ruddy Darter *Sympetrum sanguineum*. Butterfly and moth species on site include Red Admiral *Vanessa atalanta*, Small White *Pieris rapae*, and Green-veined white *Pieris napi*.

Particular species of note are the Wildlife and Country Act (WCA) protected species Bee Orchid *Ophrys apifera* and Common Lizard *Zootoca vivipara*.

Note on seeding information

Although seeding information would have been desirable, this was not available for the majority of sites. With the exception of extensive records by Middlemarch Environmental on their design of Whittleford Park and North Cave; and some by Nottinghamshire Wildlife Trust on the design of Attenborough Nature Reserve, most sites do not have this information for analysis. As such, this study of indicator species will work on the assumption that seeding information is not known. This is broadly in line with our research objective of identifying indicators irregardless of soil type and without a comprehensive background of the site. Any positive or negative indicator species that emerge from the study can be used to inform future created grasslands and preferable seeding types. This could potentially speed up time from creation to well-functioning grassland.

4.3 Descriptive statistics

Descriptive statistics were extracted for each sub-site surveyed. These statistics are presented below in Table 4.1. Initial scrutiny of the descriptive statistics provide some potentially interesting lines of enquiry. The mean quadrat height is considerably higher at Attenborough Nature Reserve than the other sites. This was found in the literature to be a potential negative indicator (Section 2.4). English Nature (2001) recommends vegetative height should be no taller than 80cm. The mean at Attenborough (95cm) is considerably higher than this.

Species richness and species diversity show no initial correlation to time since creation. The highest species richness was found at Brandon Marsh, the second oldest site, and yet the oldest site showed one of the lowest. Unsurprisingly, Ellenberg wetness indicators were highest for wet grassland at Parc Slip.

Site name	Sub-site	Time since creation (years)	Soil/Substrate Type	Site area (ha)	Habitats on site	Mean quadrat height (cm)	Mean species richness*	Mean species diversity* (2.dp)	Mean Ellenberg* (light)	Mean Ellenberg (wetness)	Mean Ellenberg (pH)	Mean Ellenberg (fertility)	Mean "C"*	Mean "S"*	Mean "R"*	CVS classes	Top NVC classification
Attenborough Nature Reserve	NA	47	Mesotrophic	275	Running water; Open water; Scrub; Grassland and marsh; Boundaries; Scattered trees.	95	7.7	0.64	7	5.3	6.5	6.2	3.6	2.1	2.3	38; 28; 40; 43	MG1b
Brandon Marsh Nature Reserve	Comp. 4	24	Mesotrophic	4.31	Grassland and marsh; Scattered trees; Boundaries.	24	14	0.61	6.9	5.2	5.9	4.9	2.9	2.6	2.9	40; 30; 38; 27; 44	MG6
Brandon Marsh Nature Reserve	Grebe Pool	24	Mesotrophic	3.24	Open water; Grassland and marsh; Boundaries; Scattered trees.	25	10.7	0.83	7.2	5.1	6.1	4.9	2.8	2.6	2.8	47; 40; 30	MG11
Houghton Regis Quarry	NA	29	Calcareous	44	Bare ground; Grassland and scrub; Scattered trees.	16	11.4	0.75	7.3	4.7	6.5	3.7	2	3.5	2.3	44; 44; 56; 30; 23	CG4
King's Meadow	NA	21	Pulverised Fuel Ash (PFA)	1.05	Grassland; Scattered trees; Boundaries	45	14.1	0.76	7.2	5	6.7	4.6	2.6	2.3	2.9	9; 10; 14; 28; 30	OV23d

Table 4.1: Site descriptions and preliminary floral data by sub-site. All figures are presented to 1 d.p. unless specified otherwise (continues)

Site name	Sub-site	Time since creation (years)	Soil/Substrate Type	Site area (ha)	Habitats on site	Mean quadrat height (cm)	Mean species richness*	Mean species diversity* (2.dp)	Mean Ellenberg* (light)	Mean Ellenberg (wetness)	Mean Ellenberg (pH)	Mean Ellenberg (fertility)	Mean "C"*	Mean "S"*	Mean "R"*	CVS classes	Top NVC classification
North Cave Wetland	Butterfly Meadow	10	Mesotrophic	3.26	Grassland and Scrub; Scattered trees; Bare ground; Boundaries.	31	9.7	0.7	6.9	5.5	6.2	5.1	3	2.5	2.8	9; 27; 30; 38; 23	OV23c
North Cave Wetland	Central grassland	10	Mesotrophic	3.06	Grassland and scrub; open water; Grassland and marsh.	34	6.5	0.69	7	5.2	6.3	4.8	3.2	2.5	2.7	30; 14; 20; 40	MG11 a
North Cave Wetland	Phase 2	1	Mesotrophic	4	Grassland and marsh; Boundaries.	21	12.3	0.69	7.2	5.7	6.3	5.5	3.1	1.8	2.9	44; 34; 40	MG6a
Parc Slip Nature Reserve	Butterfly Meadow	28	Calcareous	0.23	Grassland; Boundaries	50	12.7	0.77	6.9	5.8	5.9	4.7	3.3	2.7	2.4	54; 48	MG9b
Parc Slip Nature Reserve	Met Field	28	Calcareous	1.59	Grassland; Boundaries	35	8	0.79	7	6.3	5.9	4.4	3.2	2.8	2.1	54	MG10 a
Parc Slip Nature Reserve	Canal Field	28	Calcareous	1.53	Grassland and Scrub; Scattered Trees; Boundaries.	26	9.3	0.79	7	6.7	5.8	4.1	3	2.8	1.7	54; 44; 40	MG10 a

Table 4.1: Site descriptions and preliminary floral data by sub-site. All figures are presented to 1 d.p. unless specified otherwise (continues)

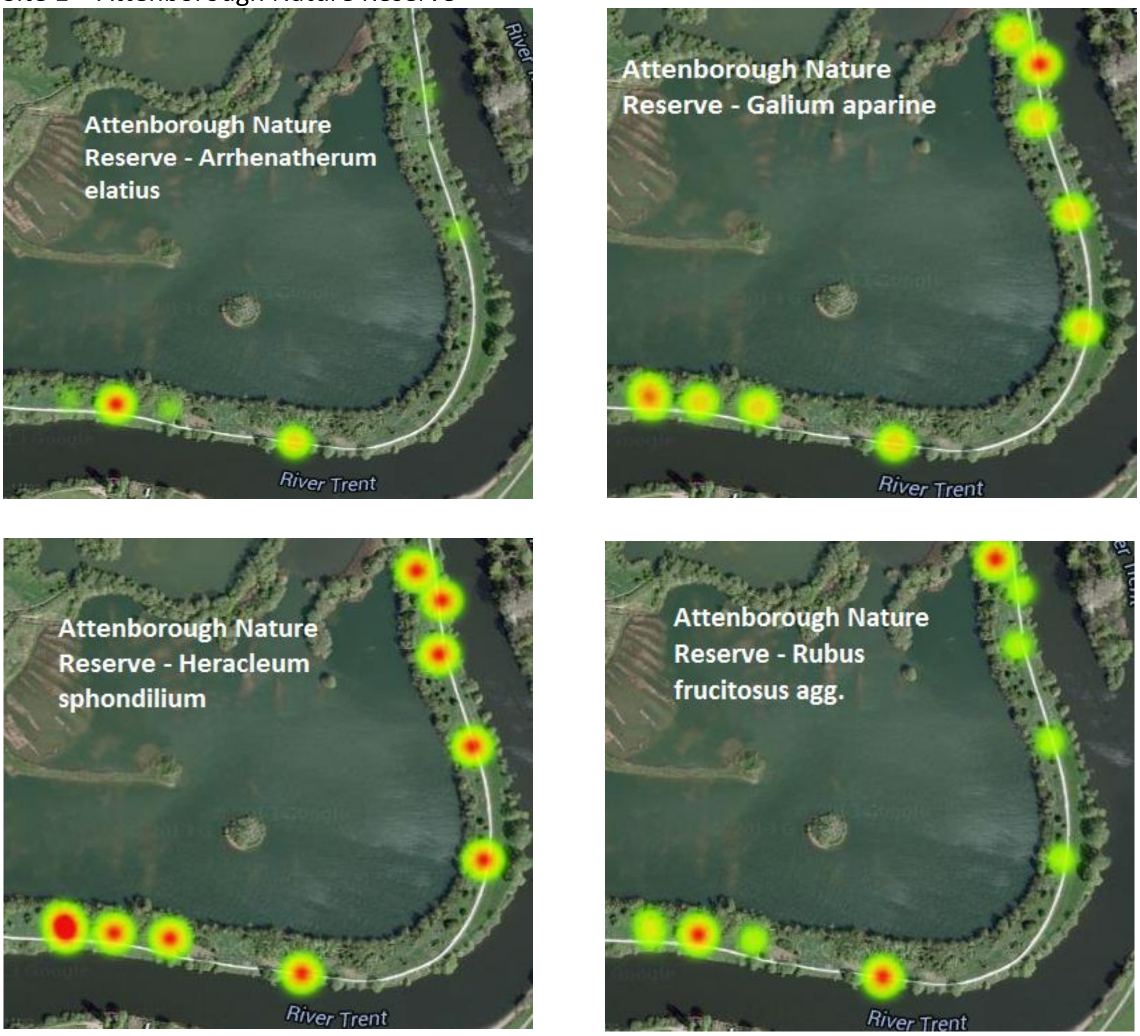
Site name	Sub-site	Time since creation (years)	Soil/Substrate Type	Site area (ha)	Habitats on site	Mean quadrat height (cm)	Mean species richness*	Mean species diversity* (2.dp)	Mean Ellenberg* (light)	Mean Ellenberg (wetness)	Mean Ellenberg (pH)	Mean Ellenberg (fertility)	Mean "C"*	Mean "S"*	Mean "R"*	CVS classes	Top NVC classification
Ryton Meadows	Area 1	18	Mesotrophic	0.4	Grassland; Boundaries.	45	8.3	0.76	7.1	4.8	6.5	4.4	3	2.6	2.5	23; 38; 47	MG1a
Ryton Meadows	Area 2	18	Mesotrophic	3.3	Grassland; Boundaries.	55	8.3	0.73	7	5.3	6.4	5.1	3.1	2.1	2.7	40;30	MG9
Ryton Meadows	Area 3	18	Mesotrophic	1.9	Grassland; Boundaries.	70	8	0.66	7	5.3	6.5	5.5	3.2	2.2	2.8	44; 38	MG9b
Ufton Fields	Snipe Meadows	41	Calcareous	3	Grassland and Scrub; Scattered Trees; Boundaries.	30	13.5	0.77	7.1	5.1	6.2	4.7	2.9	2.7	2.8	34; 40; 52; 47; 30; 27; 44	MG1a
Ufton Fields	Area 2	41	Calcareous	0.4	Grassland and Scrub; Scattered Trees; Boundaries.	27	9	0.68	7	5.1	6.7	5.8	3.4	2.2	2.6	23; 44	MG9b
Whittleford Park	NA	4	Mesotrophic	43	Grassland; Open water.	36	13.6	0.71	7.1	5.3	6.2	5.1	2.8	2.5	2.6	23; 44; 40; 20; 38	MG9b

Table 4.1: Site descriptions and preliminary floral data by sub-site. All figures are presented to 1 d.p. unless specified otherwise (continued)

4.4 Species maps

The following figures show relative abundance of potential indicator species (where applicable to site) according to the literature review undertaken, along with community indicators. The maps were generated using Google Fusion Tables (Google, 2016) which generate heat maps using imported spreadsheet data. The maps were then individually annotated with the variable under inspection. Only maps of note are shown here, further maps for all potential indicators are presented in Appendix 6.

Site 1 – Attenborough Nature Reserve



Figures 4.10 – 4.13: Relevant species maps for Attenborough Nature Reserve

Species maps generated for Attenborough Nature Reserve potentially show an abundance of undesirable species such as bramble *Rubus frucitosus agg.,* cleavers *Galium aparine,* and hogweed *Heracleum sphondilium.*

Site 2 – Brandon Marsh Nature Reserve

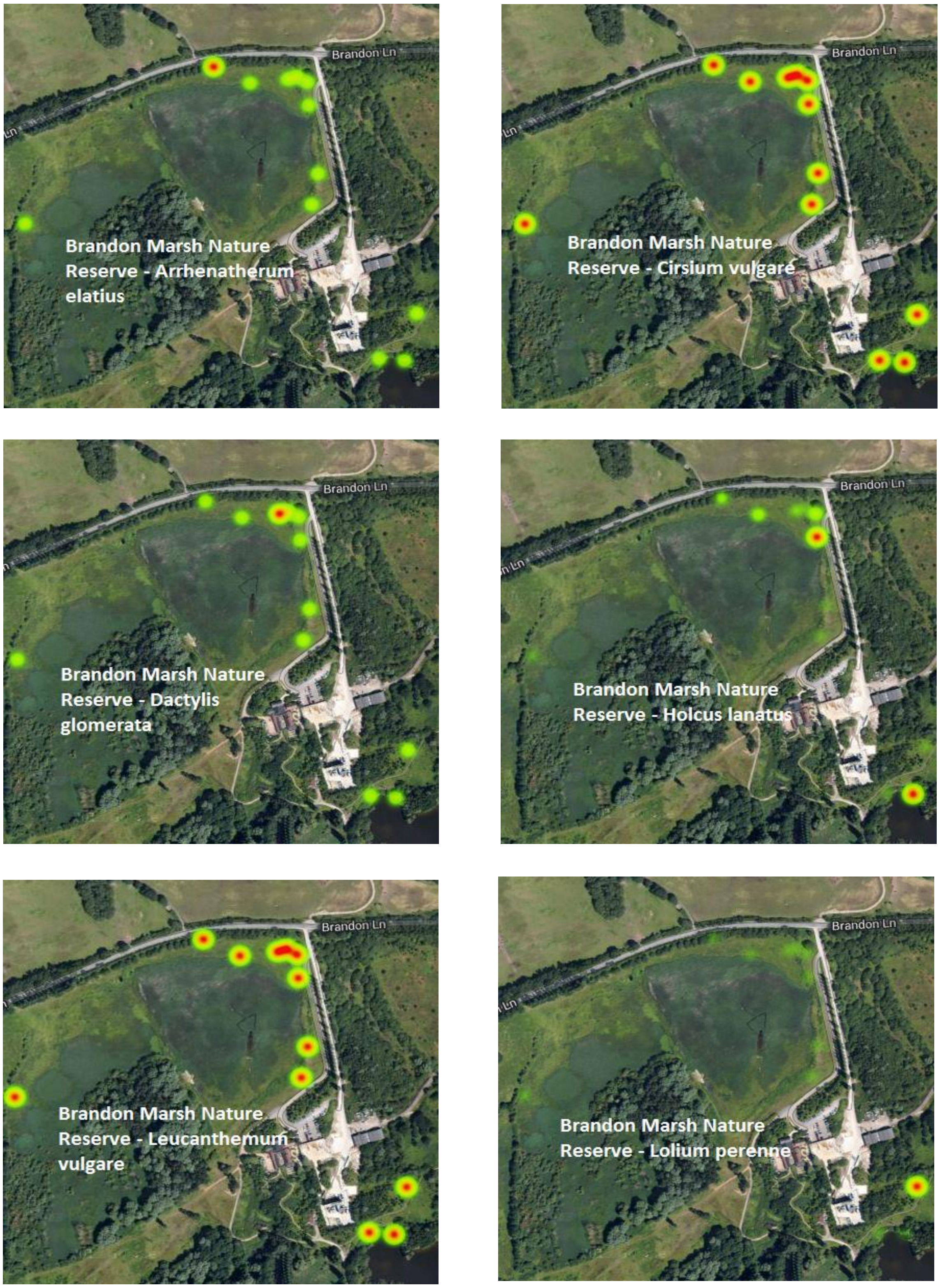
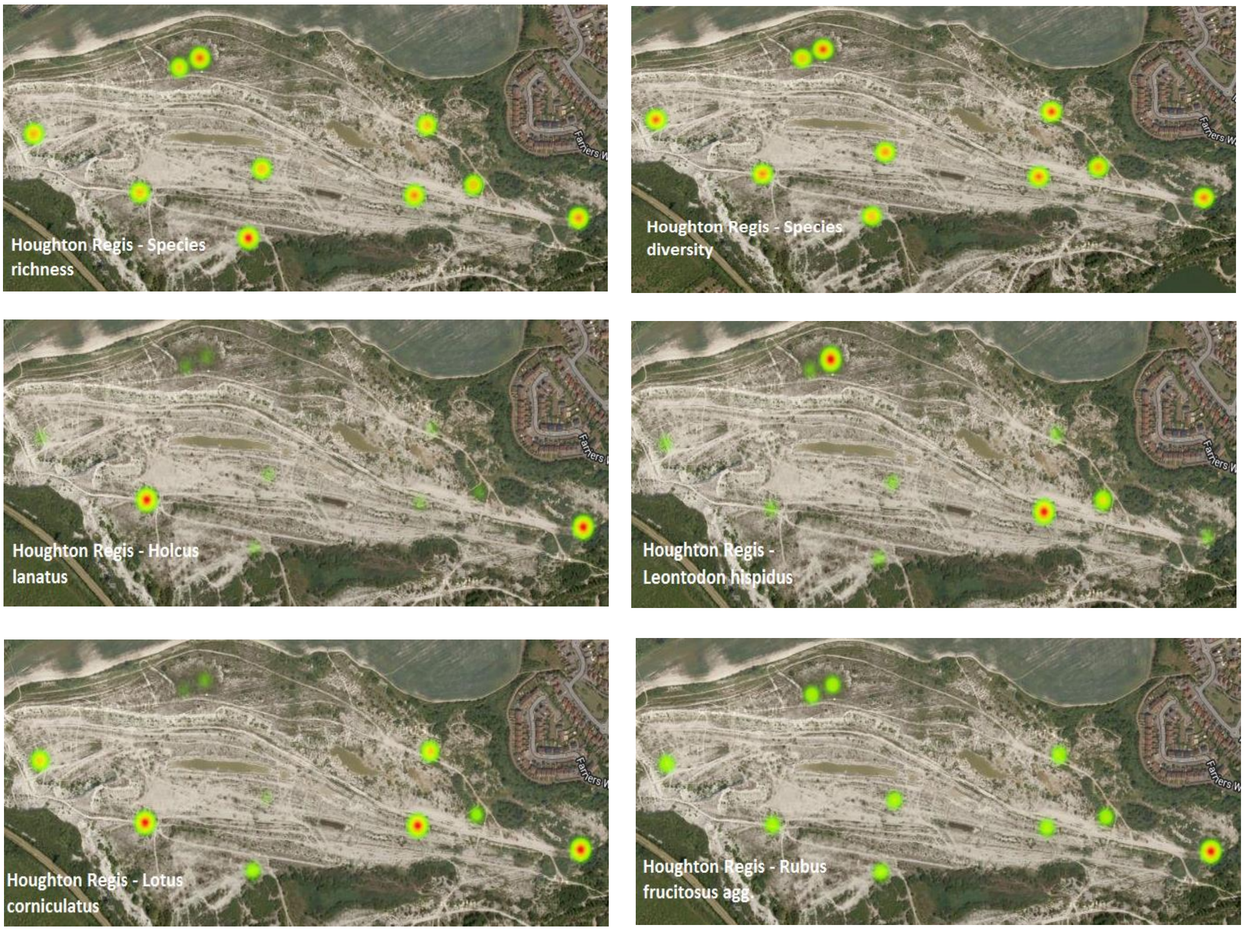


Figure 4.14 – 4.19: Relevant species maps for Brandon Marsh Nature Reserve

In contrast to Attenborough Nature Reserve, Brandon Marsh shows only low instances of undesirable species such as Perennial Rye-grass *Lolium perenne,* and bramble *Rubus frucitosus agg.*. Positive indicator species Ox-eye daisy *Leucanthemum vulgare* had particularly high abundance here. This positive indicator is normally more relevant in very newly created grasslands.

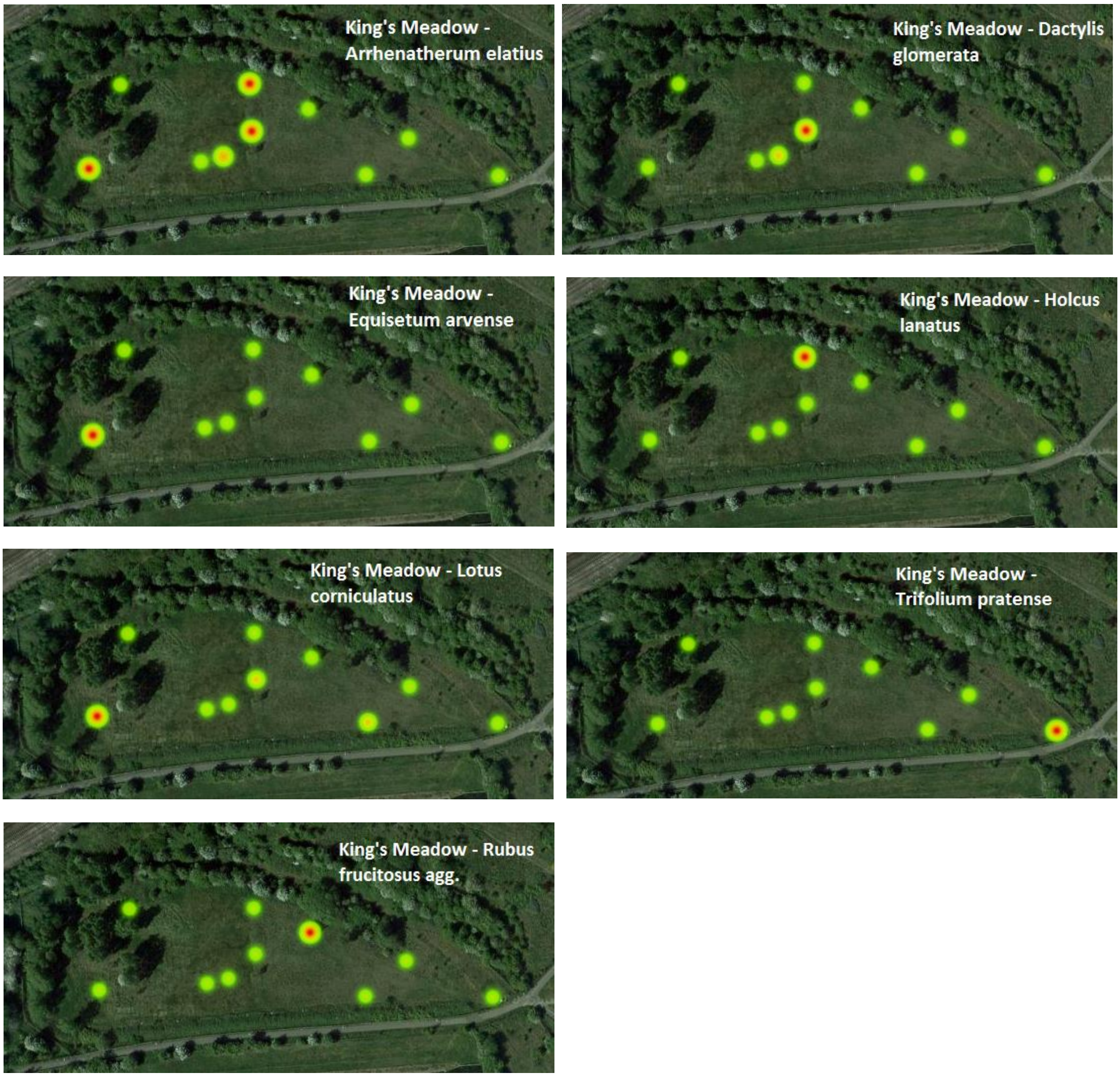
Site 3 – Houghton Regis



Figures 4.20 – 4.25: Relevant species maps for Houghton Regis Quarry

Species maps of Houghton Regis highlight numerous instances of undesirable Bramble *Rubus frucitosus* agg.. These were generally in low abundances highlighted by the lack of red in the heat map. Ragwort *Jacobaea vulgaris* is notably absent due to annual species clearance.

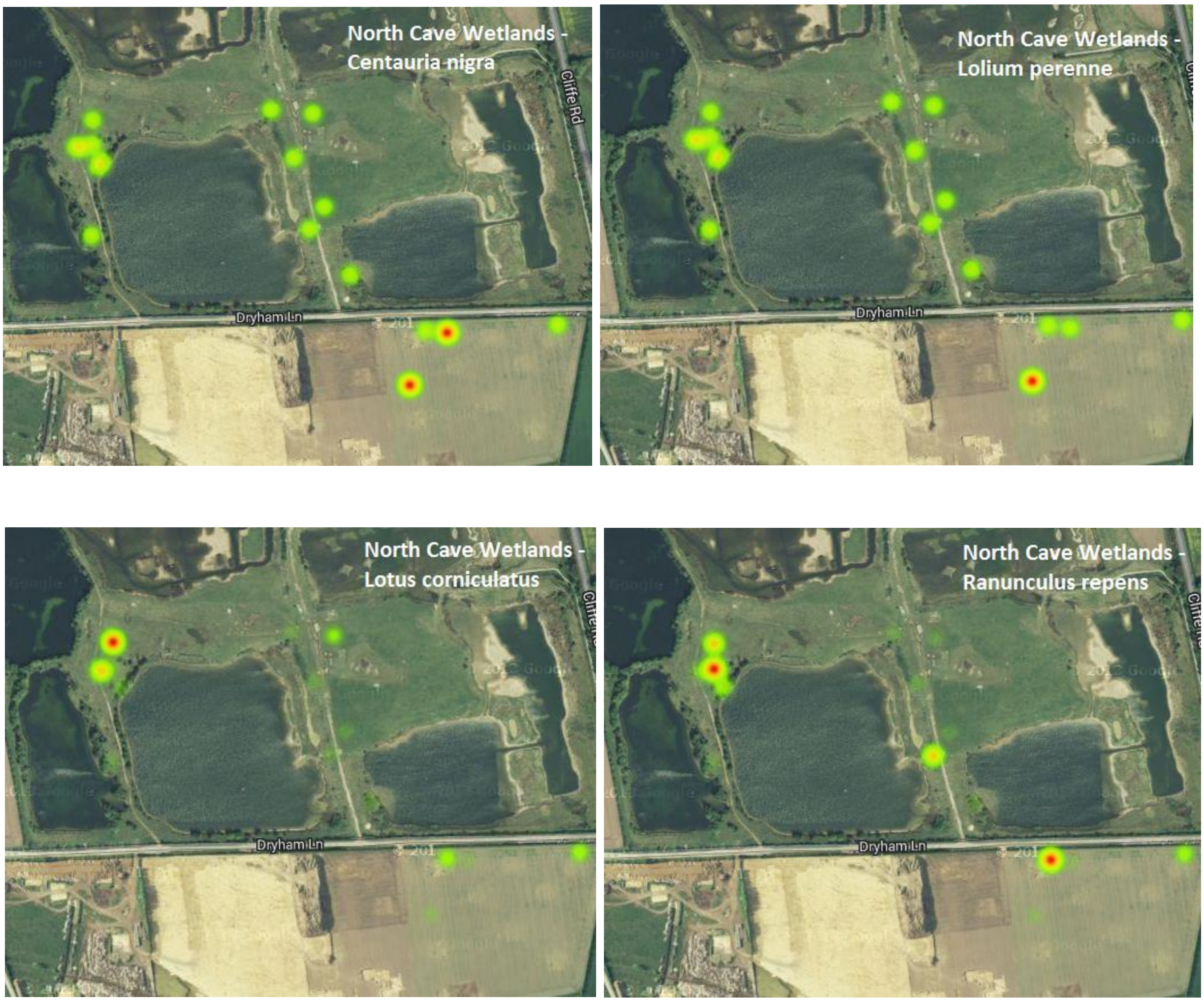
Site 4 – King’s Meadow



Figures 4.26 – 4.32: Relevant species maps for King’s Meadow

King’s Meadow appears to show a mix of positive (bird’s-foot trefoil *Lotus corniculatus* and red clover *Trifolium pratense*) and negative indicator species (e.g. bramble *Rubus frucitosus agg.;* false-oat grass *Arrhenatherum elatius)*.

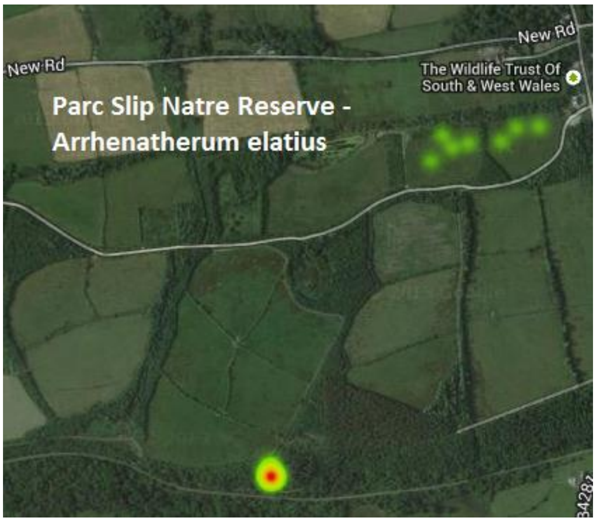
Site 5 – North Cave Wetlands

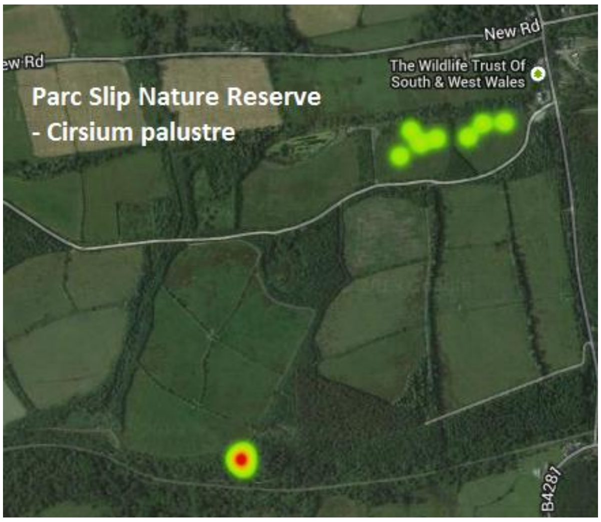


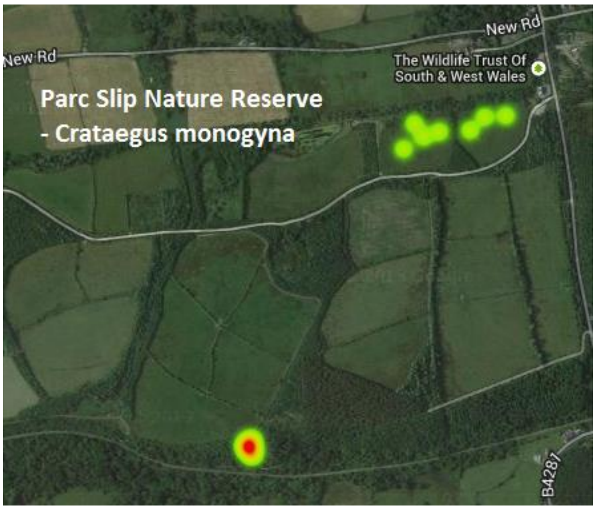
Figures 4.33– 4.36: Relevant species maps for North Cave wetlands

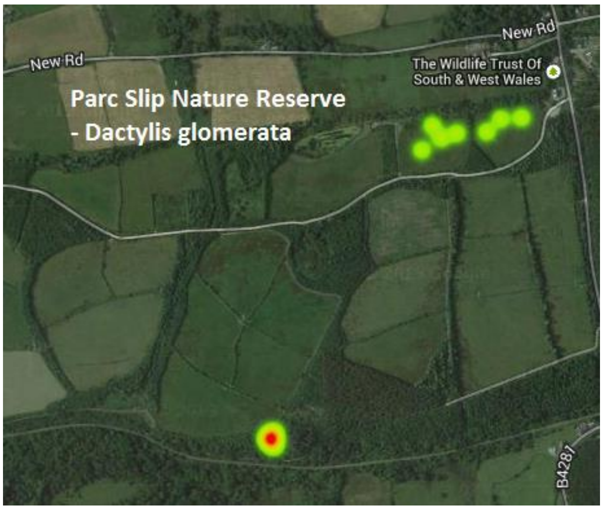
Despite its relatively new status, North Cave Wetlands show presence of positive indicator species such as Common knapweed *Centaurea nigra* and bird's-foot trefoil *Lotus corniculatus.* Unsurprisingly considering its age, there is a presence for competitive undesirable species such as creeping buttercup *Ranunculus repens* and Perennial Rye-grass *Lolium perenne.*

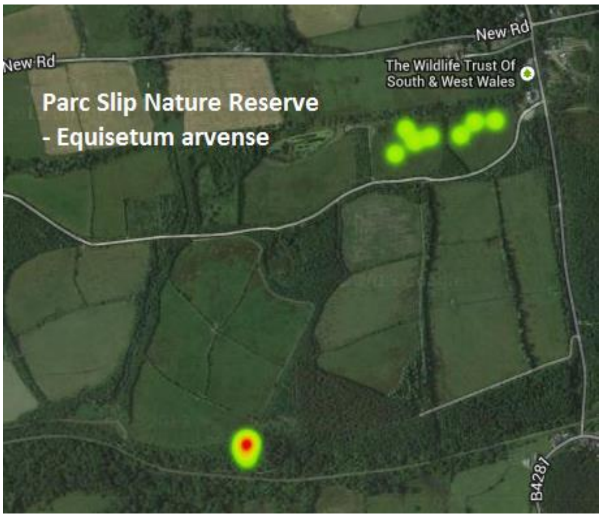
Site 6 – Parc Slip

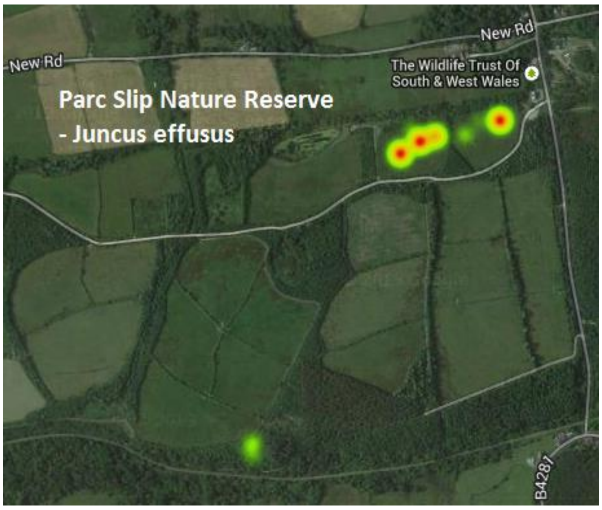












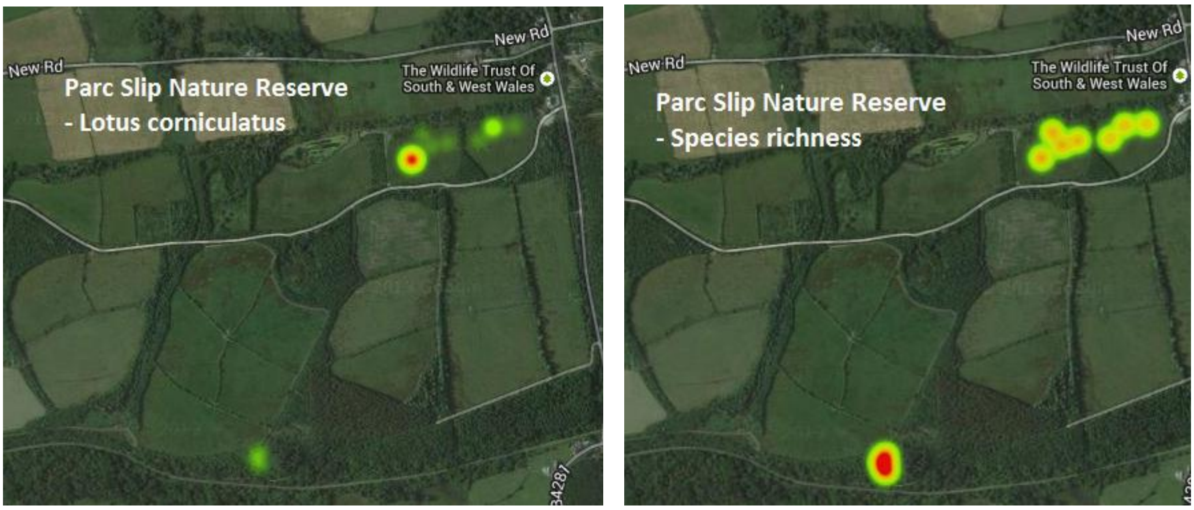


Figure 4.37 – 4.44: Relevant species maps for Parc Slip Nature Reserve

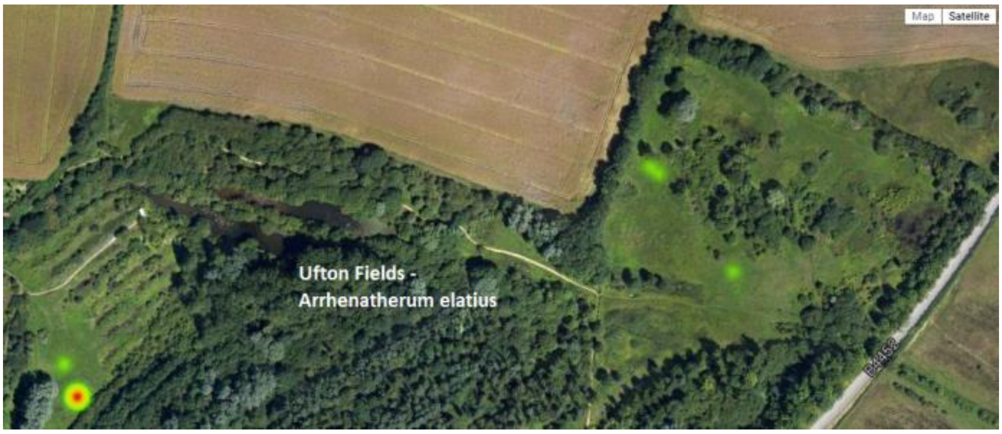
The differences between the two northern fields and the southern sub-site are highlighted in the heat maps. The north sub-sites were much wetter, and contained higher abundances of rush sp. *Juncus sp.*. The northern sub-sites also show a higher proportion of positive indicator species (bird's foot trefoil *Lotus corniculatus*). The southern sub-site, had a higher proportion of woody species hawthorn *Crataegus monogyna.* It also contained less desirable species such as Common horsetail *Equisetum arvense*, but showed higher species richness overall.

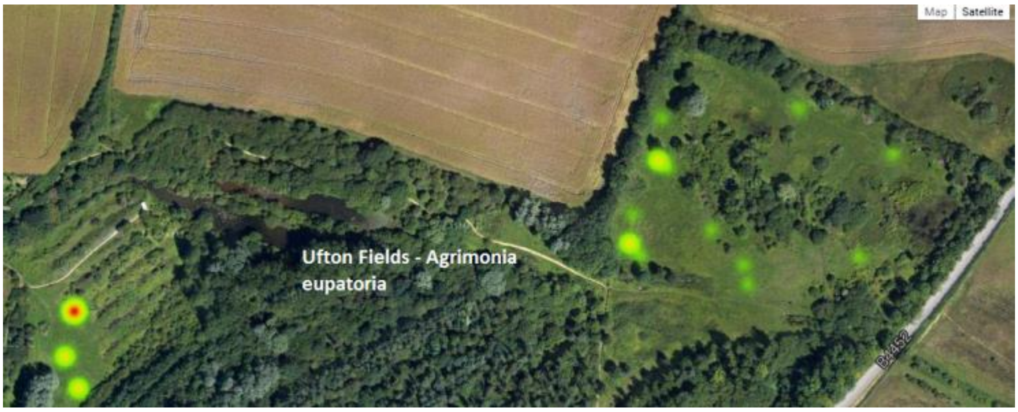
Site 7 – Ryton Meadows

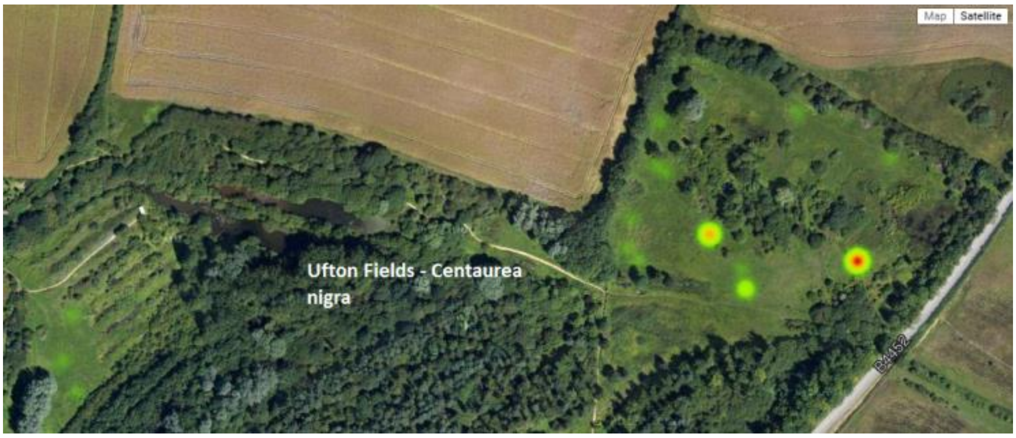
Figure 4.45 – 4.54: Relevant species maps for Ryton Meadows

The difference in management and time since creation of various areas around Ryton Meadows is potentially picked up in the species maps. Bird's-foot trefoil *Lotus corniculatus* for example, has a much stronger presence in Area 1 (top right of map) which could suggest differences in species composition due to management.

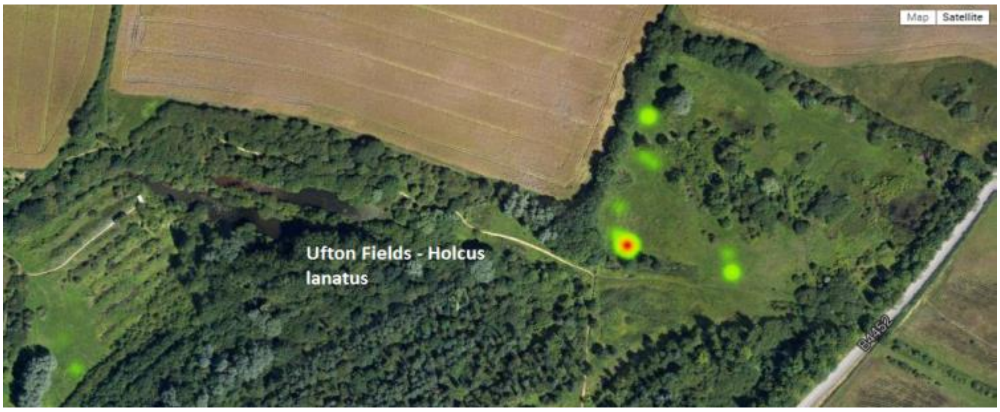
Site 8 – Ufton Fields

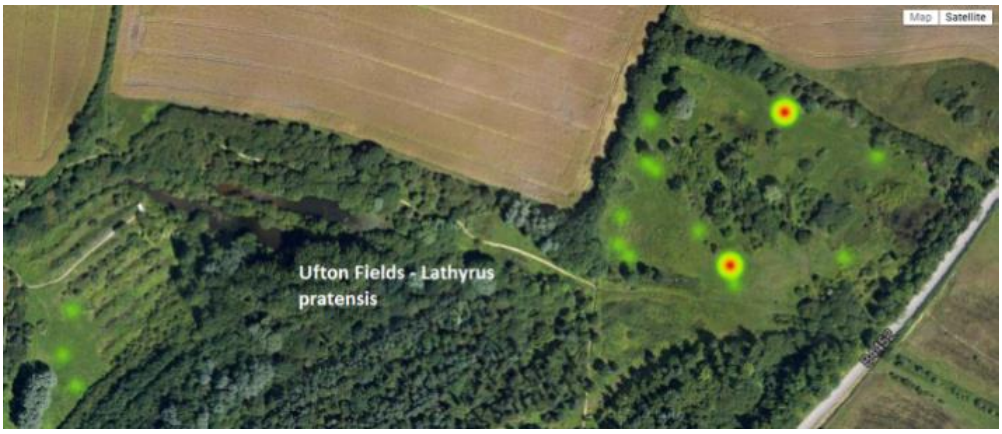

Map
Satellite
Ufton Fields -
Arrhenatherum elatius
B4452


Map
Satellite
Ufton Fields - Agrimonia
eupatoria
B4452

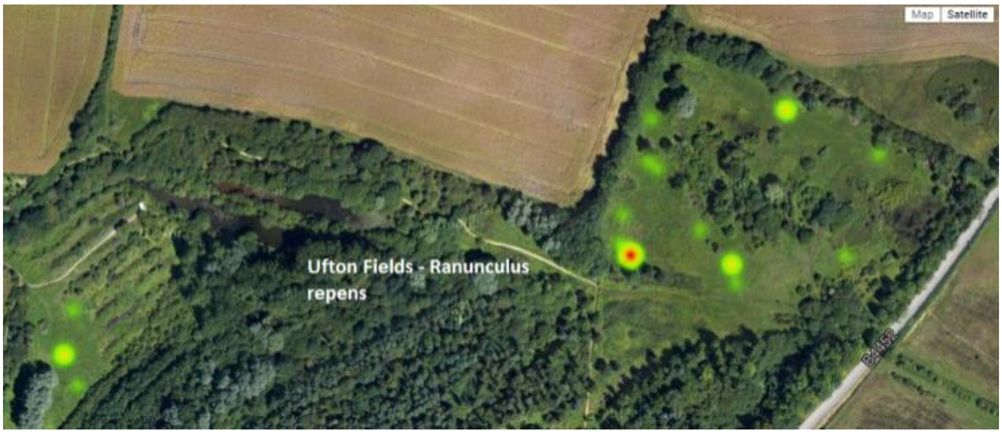

Map
Satellite
Ufton Fields - Centaurea
nigra
B4452

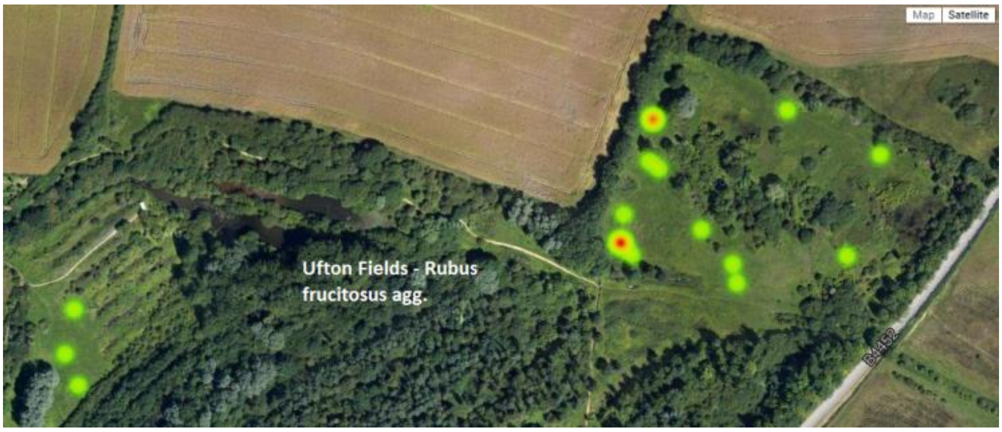

Map
Satellite
Ufton Fields - Galium
verum
B4452


Map
Satellite
Ufton Fields - Holcus lanatus


Map
Satellite
Ufton Fields - Lathyrus pratensis


Map
Satellite
Ufton Fields - Lolium perenne


Map
Satellite
Ufton Fields - Ranunculus repens



Figures 4.55 – 4.64: Relevant species maps for Ufton Fields

It is clear from the maps that Compartment 10 (Snipe Meadow) has a higher proportion of both negative and positive indicator species than Compartment 13. Compartment 13 has undergone less management and this is reflected through its higher species richness.

Site 9 – Whittleford Park

Figures 4.65-4.69: Relevant species maps for Whittleford Park

Although Whittleford's short time since creation is reflected in the presence of competitive grass species such as Yorkshire fog *Holcus lanatus.* However, a number of key positive indicator species are already present on site with abundance, such as Bird's-foot trefoil *Lotus corniculatus.*

4.5 Description of species and community data

A full descriptive analysis of the sites and their species composition was completed, to allow full understanding of the current states of the sites and accurate conclusions to be drawn. A preliminary look at the species composition of the sites in reference to important topics from the literature is first presented. This includes successional theories such as inhibition or tolerance of particular species. An overview of each site is provided (by sub-site), along with physiological traits and further preliminary floral information (Section 3.3). Habitats are classified according to Phase 1 Broad Habitat Classifications (JNCC, 2015). A full species list is provided in Appendix 11.

4.5.1 Early colonisers/pioneers

As discussed in Section 2.3.3, a number of species are known to be pioneers of succession on a site. Fieldwork data was examined for these species.

Despite having one of the older grasslands, Attenborough Nature Reserve still contained early coloniser species, such as small quantities of Barren brome *Anisantha sterilis*, cow parsley *Anthriscus sylvestris,* cleavers *Galium aparine,* and larger quantities of common nettle *Urtica dioica*. Conversely, the newest site (Phase 2 of North Cave wetland), contained no instances of any of these species. Whittleford Park, the second closest to completion, only had a single occurrence of cleavers and nettle. Within the context of our study, these species have not acted as early colonisers. This is likely down to the focused creation of the early sites and the lack of management in Attenborough Nature Reserve's grassland.

4.5.2 Seed-bank forming species

Formation of a seed-bank can have positive implications for long-term biodiversity of a site. Some of the seed-bank forming species identified in the literature review are undesirable species overall. For example cleavers *Galium aparine,* present in small quantities across the sites, can take over easily. Other more favourable seed-bank forming species were present in a number of the sites. Black medick *Medicago lupulina* and Veronica sp. *Veronica* sp. were noted on sites over 10 years old. These were particularly prevalent at Brandon Marsh Nature Reserve, which had one of the higher species richnesses. A higher abundance of seed-bank forming species may have encouraged higher species richness.

4.5.3 Stress tolerators

The presence of stress tolerators is not always desirable. Although they allow a site to be colonised after disturbance, in the context of a created grassland, they may encourage an undesirable sward. For example, an identified stress tolerators was also in the list of identified potential negative indicators (Perennial Rye-Grass *Lolium perenne).* This species was present to some extent on most sites but was most prevalent early on in time (Whittleford Park) and at the latest time scale (Attenborough Nature Reserve).

Conversely, one of the identified stress tolerators was also in the list of potential positive indicator species. Annual meadow-grass *Poa annua* was present to some extent in most sites. This was also the case for other stress-tolerators such as red fescue *Festuca rubra* and smooth meadow-grass *Poa pratensis.* Red fescue had some of the higher abundances of the grass species encountered, perhaps showing its colonising ability.

4.5.4 Invasive species

Identified invasive species, which could threaten to overrun a habitat, were also highlighted in the literature as positive or negative biodiversity indicators. Horsetail spp. *Equisetum* spp. , common nettle *Urtica dioica* and ragwort *Senecio jacobeae* were all potential negative indicators, and these do exist across the sites. These species rarely formed a large part of the quadrat, with the exception of a 70% abundance of Equisetum sp. at Brandon Marsh Nature Reserve.

Of the identified invasive species which were also identified as positive indicators, a similar pattern emerges. Wild carrot *Daucus carota* was identified as a positive indicator in newly created grasslands, while marsh thistle *Cirsium palustre* was identified as a positive indicator on wet grasslands. Neither of these species ever reached an abundance of over 5% of the quadrat. If then these species can be invasive, in these instances they have failed to over-colonise the sites.

Only one of the identified potential invasive species had high abundances across a number of sites. Cinquefoil spp. *Potentilla* spp. was present in the form of Creeping cinquefoil in 4 sites, with an average abundance of between 5 and 40% of the quadrats.

4.5.5 Stable communities

A number of the identified indicators of stable communities were found across the sites. As there were a number of these identified, identified indicators of stable communities and their presence on the sites are presented in Table 4.2. Identified indicators not found on any site have been deleted.

Common name	Latin name	1	2	3	4	5	6	7	8	9
Yarrow	*Achilea millifolium*		✓		✓	✓		✓	✓	✓
Daisy	*Bellis perennis*		✓			✓				
Sedge spp.	*Carex* spp.			✓			✓			
Pignut	*Conopodium majus*			✓						
Common hawthorn	*Crataegus monogyna*		✓	✓	✓		✓		✓	
Galium spp.	*Galium* spp.	✓								
Rush spp.	*Juncus* spp.		✓				✓			✓
Bird's-foot trefoil	*Lotus corniculatus*		✓	✓	✓	✓	✓	✓	✓	✓
Common cowslip	*Primula veris*							✓		
Common self-heal	*Prunella vulgaris*		✓	✓		✓	✓	✓	✓	
Common fleabane	*Pulicaria dysenterica*						✓			
Meadow buttercup	*Ranunculus acris*		✓			✓	✓		✓	
Dog rose	*Rosa canina*		✓	✓			✓		✓	
Rose spp.	*Rosa* spp.		✓	✓		✓	✓		✓	
Bramble	*Rubus frucitosus* agg.	✓	✓	✓	✓				✓	✓
Sheep's sorrel	*Rumex acetosa*									✓
Salad burnet	*Sanguisorba minor*								✓	
Hedge woundwort	*Stachys sylvatica*	✓								
Devil's-bit scabious	*Succisa pratensis*								✓	
Red clover	*Trifolium pratense*		✓	✓	✓			✓	✓	✓
White clover	*Trifolium repens*		✓		✓	✓		✓	✓	✓
Total		3	12	9	6	7	9	6	12	7

Table 4.2: Identified indicators of stable communities and their presence on site

Brandon Marsh Nature Reserve and Ufton Fields are showing the most indicators of stable communities. Attenborough Nature Reserve, despite being the oldest site, shows the least indicators of stable communities. The indicators it does have represented are more undesirable, such as the scrubby Bramble *Rubus frucitosus agg.,* Hedge woundwort *Stachys sylvatica* and Galium spp. *Galium* spp.

Unsurprisingly the wetter grasslands, such as Brandon Marsh, Parc Slip and North Cave present more sedge sp. *Carex* sp. and rush *Juncus* sp.

4.6 Species data preparation

Table 3.3 shows all species recorded during field work. Species present in less than 5% of the quadrats have been removed. This is as recommended by Bachand et al. (2014). This resulted in 78 species being removed from the dataset. In a study of general community data this would not always be required but rare species across all sites are unlikely to serve as an adequate indicator.

Species removed at this stage are greyed out in the below table.

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Achimill	*Achillea millefolium*	Yarrow				A	13	4.2
Agrieupa	*Agrimonia eupatoria*	Common agrimony			✓	A	13	3.3
Agrocani	*Agrostis canina*	Velvet bent	✓	<5% occurrence	-	-	1	1.0
Agrocapi	*Agrostis capillaris*	Common bent		Auto-correlation		B	14	8.2
Agrogiga	*Agrostis gigantea*	Black bent		Auto-correlation		B	6	5.2
Agrostol	*Agrostis stolonifera*	Creeping bent				A	37	6.3
Alopprat	*Alopecurus pratensis*	Meadow foxtail		Auto-correlation		B	8	3.3
Anisster	*Anisantha sterilis*	Barren brome	✓	<5% occurrence	-	-	3	2.3
Anthodor	*Anthoxanthum odoratum*	Sweet vernal grass	✓	<5% occurrence	-	-	2	3.0
Anthsylv	*Anthriscus sylvestris*	Cow parsley		Auto-correlation	✓	B	5	1.0
Anthvuln	*Anthyllis vulneraria*	Kidney vetch			✓	A	7	6.0
Arrhelat	*Arrhenatherum elatius*	False oat-grass		Auto-correlation	✓	B	46	9.9
Artevulg	*Artemisia vulgaris*	Mugwort	✓	<5% occurrence	-	-	2	3.0
Bare.Earth	*Bare Earth*	Bare earth				A	19	7.1
Bellpere	*Bellis perennis*	Common daisy	✓	<5% occurrence	-	-	3	7.0
Betupend	*Betula pendula*	Silver birch	✓	<5% occurrence	-	-	4	2.0
Blacperf	*Blackstonia perfoliata*	Yellow-wort	✓	<5% occurrence	-	-	2	1.0
Brizmedi	*Briza media*	Quaking-grass	✓	<5% occurrence	-	-	1	1.0
Bromhord	*Bromus hordeaceus*	Soft brome	✓	<5% occurrence	-	-	1	1.0
Calapige	*Calamagrostis epigejos*	Wood small-reed	✓	<5% occurrence	-	-	2	4.0
Calysepi	*Calystegia sepium*	Hedge bindweed	✓	<5% occurrence	-	-	1	1.0
Carduxstan	*Carduus x stangii*	Carduus crispus x nutans	✓	<5% occurrence	-	-	1	5.0
Caredist	*Carex distans*	Distant sedge	✓	<5% occurrence	-	-	1	2.0
Careflac	*Carex flacca*	Glaucous sedge	✓	<5% occurrence	-	-	2	3.0

Table 4.3: Initial exploration of species data (continues)

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Carenigr	*Carex nigra*	Common sedge	✓	<5% occurrence	-	-	2	20.0
Caresp	*Carex sp.*	Sedge sp.	✓	<5% occurrence	-	-	3	1.0
Centnigr	*Centaurea nigra*	Common knapweed			✓	A	16	5.6
Centeryt	*Centaurium erythraea*	Common centaury	✓	<5% occurrence	-	-	4	1.0
Cerafont	*Cerastium fontanum*	Common mouse-ear		Auto-correlation		B	13	1.3
Chamangu	*Chamerion angustifolium*	Greater willow-herb		Auto-correlation		B	8	6.3
Cirsacau	*Cirsium acaule*	Dwarf thistle	✓	<5% occurrence	-	-	4	2.0
Cirsarve	*Cirsium arvense*	Creeping thistle		Auto-correlation	✓	B	28	2.3
Cirspalu	*Cirsium palustre*	Marsh thistle		Auto-correlation		B	8	1.5
Cirssp	*Cirsium sp.*	Thistle sp.	✓	<5% occurrence	-	-	1	1.0
Cirsvulg	*Cirsium vulgare*	Spear thistle		Auto-correlation	✓	B	6	1.0
Conomaju	*Conopodium majus*	Pignut	✓	<5% occurrence	-	-	1	1.0
Cratmono	*Crataegus monogyna*	Hawthorn		Auto-correlation		B	11	3.2
Crepcapi	*Crepis capillaris*	Smooth hawksbeard				A	6	1.7
Crepvesi	*Crepis vesicaria*	Beaked hawksbeard		Auto-correlation		B	6	1.0
Cruclaev	*Cruciata laevipes*	Crosswort	✓	<5% occurrence	-	-	2	3.0
Cynocris	*Cynosurus cristatus*	Crested dog's-tail				A/B	8	5.0
Cypesp	*Cyperaceae sp.*	Sedge sp.	✓	<5% occurrence	-	-	1	1.0
Dactglom	*Dactylis glomerata*	Cock's-foot			✓	A/B	31	4.0
Dactfuch	*Dactylorhiza fuchsii*	Common spotted orchid	✓	<5% occurrence	-	-	2	1.0
Dauccaro	Daucus carota	Wild carrot		Auto-correlation	✓	B	9	1.0
Desccesp	*Deschampsia cespitosa*	Tufted hair-grass		Auto-correlation	✓	B	5	4.8

Table 4.3: Initial exploration of species data (continues)

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Descflex	*Deschampsia flexuosa*	Wavy hair-grass	✓	<5% occurrence	-	-	1	1.0
Dipssp	*Dipsacus sp.*	Teasel sp.	✓	<5% occurrence	-	-	4	2.0
Elytrepe	*Elytrigia repens*	Couch grass		Auto-correlation		B	5	5.8
Epilpalu	*Epilobium palustre*	Marsh willowherb	✓	<5% occurrence	-	-	2	1.0
Epilsp	*Epilobium sp.*	Willowherb sp.	✓	<5% occurrence	-	-	1	1.0
Equiarve	*Equisetum arvense*	Common horsetail			✓	A	6	2.3
Equisp	*Equisetum sp.*	Horsetail sp.	✓	<5% occurrence	-	-	1	7.0
Erodcicu	*Erodium cicutarium*	Common storksbill	✓	<5% occurrence	-	-	1	1.0
Euphoffiagg	*Euphrasia officinalis agg*	Eyebright	✓	<5% occurrence	-	-	1	1.0
Festovin	*Festuca ovina*	Sheep’s fescue	✓	<5% occurrence	-	-	2	1.0
Festprat	*Festuca pratensis*	Meadow fescue	✓	<5% occurrence	-	-	2	1.0
Festrubr	*Festuca rubra*	Red fescue				A	41	7.1
Galialbu	*Galium album*	White bedstraw	✓	<5% occurrence	-	-	3	3.7
Galiapar	*Galium aparine*	Cleavers			✓	A	10	1.1
Galipalu	*Galium palustre*	Marsh bedstraw	✓	<5% occurrence	-	-	2	1.0
Galiulig	*Galium uliginosum*	Fen bedstraw	✓	<5% occurrence	-	-	1	1.0
Galiveru	*Galium verum*	Lady’s bedstraw			✓	A	15	11.9
Gentamar	*Gentianella amarella*	Autumn gentian	✓	<5% occurrence	-	-	2	1.0
Geramoll	*Geranium molle*	Dove’s-foot crane’s-bill	✓	<5% occurrence	-	-	1	1.0
Heraspho	*Heracleum sphondylium*	Common hogweed		Auto-correlation	✓	B	8	1.5
Holclana	*Holcus lanatus*	Yorkshire-fog			✓	A	72	9.0
Holcmoll	*Holcus mollis*	Creeping soft-grass	✓	<5% occurrence	-	-	1	1.0
Hordmuri	*Hordeum murinum*	Wall barley	✓	<5% occurrence	-	-	1	5.0
Hyporadi	Hypochaeris radicata	Cat’s-ear		Auto-correlation		B	1	1.8

Table 4.3: Initial exploration of species data (continues)

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Juncarti	Juncus articulatus	Jointed rush	✓	<5% occurrence	-	-	3	3.7
Junceffu	Juncus effusus	Soft rush		Auto-correlation	✓	B	6	15.7
Juncinfl	Juncus inflexus	Hard rush		Auto-correlation		B	7	5.1
Junctenu	Juncus tenuis	Slender rush	✓	<5% occurrence	-	-	1	1.0
Knauarve	Knautia arvensis	Field scabious	✓	<5% occurrence	-	-	3	1.0
Lactserr	Lactuca serriola	Prickly lettuce	✓	<5% occurrence	-	-	1	1.0
Lapscomm	Lapsana communis	Nipplewort	✓	<5% occurrence	-	-	1	1.0
Lathapha	Lathyrus aphaca	Yellow vetchling	✓	<5% occurrence	-	-	1	15.0
Lathprat	Lathyrus pratensis	Meadow vetchling			✓	A	15	3.9
Leonautu	Leontodon autumnalis	Autumn hawkbit	✓	<5% occurrence	-	-	4	3.0
Leonhisp	Leontodon hispidus	Rough hawkbit			✓	A	11	3.9
Leucvulg	Leucanthemum vulgare	Ox-eye daisy			✓	A	11	5.4
Linucath	Linum catharticum	Fairy flax			✓	A	11	1.8
Lolipere	Lolium perenne	Perennial rye-grass		Auto-correlation	✓	B	19	6.4
Lotucorn	Lotus corniculatus	Bird's-foot trefoil			✓	A	41	8.0
Lotupedu	Lotus pedunculatus	Greater bird's-foot trefoil		Auto-correlation	✓	B	6	5.2
Medilupu	Medicago lupulina	Black medick		Auto-correlation		B	18	4.3
Myosramo	Myosotis ramosissima	Early forget-me-not		Auto-correlation		B	5	1.0
Odonvern	Odontites vernus	Red bartsia	✓	<5% occurrence	-	-	1	1.0
Pershydr	Persicaria hydropiper	Water-pepper	✓	<5% occurrence	-	-	1	1.0
Phleprat	Phleum pratense	Timothy			✓	A	7	2.1
Picrhier	Picris hieracioides	Hawkweed oxtongue	✓	<5% occurrence	-	-	2	1.0
Pilooffi	Pilosella officinarum	Mouse-ear hawkweed	✓	<5% occurrence	-	-	4	3.0
Planlanc	Plantago lanceolata	Ribwort plantain				A	61	7.9

Table 4.3: Initial exploration of species data (continues)

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Planmajo	Plantago major	Greater plantain	✓	<5% occurrence	-	-	2	3.0
Poaannu	Poa annua	Annual meadow-grass		Auto-correlation		B	12	1.8
Poaprat	Poa pratensis	Smooth meadow-grass		Auto-correlation		B	8	2.0
Poatriv	Poa trivialis	Rough meadow-grass		Auto-correlation	✓	B	5	1.8
Polyavic	Polygonum aviculare	Common knotgrass	✓	<5% occurrence	-	-	1	1.0
Poteanse	Potentilla anserina	Silverweed	✓	<5% occurrence	-	-	2	3.0
Poterept	Potentilla reptans	Creeping cinquefoil				A	14	8.9
Potesp	Potentilla sp.	Cinquefoil sp.	✓	<5% occurrence	-	-	1	5.0
Primsp	Primula sp.	Primrose sp.	✓	<5% occurrence	-	-	1	1.0
Primveri	Primula veris	Cowslip			✓	A/B	1	1.0
Prunvulg	Prunella vulgaris	Self-heal		Auto-correlation		B	15	3.9
Pulidyse	Pulicaria dysenterica	Common fleabane	✓	<5% occurrence	-	-	3	11.7
Quersp	Quercus sp.	Oak sp.	✓	<5% occurrence	-	-	1	15.0
Ranuacri	Ranunculus acris	Meadow buttercup		Auto-correlation	✓	B	13	3.2
Ranurepe	Ranunculus repens	Creeping buttercup			✓	A	3	5.9
Rhinmino	Rhinanthus minor	Yellow rattle			✓	A/B	12	10.5
Rosaarve	Rosa arvensis	Field rose	✓	<5% occurrence	-	-	1	1.0
Rosacani	Rosa canina	Dog rose		Auto-correlation		B	9	1.4
Rosapimp	Rosa pimpinellifolia	Rose burnet	✓	<5% occurrence	-	-	3	1.0
Rubufrutagg	Rubus fruticosus agg.	Bramble			✓	A	23	2.6
Rumeacet	Rumex acetosa	Common sorrel	✓	<5% occurrence	-	-	2	1.0
Rumeacet	Rumex acetosella	Sheep sorrel			✓	A	2	1.0
Rumecris	Rumex crispus	Curly dock	✓	<5% occurrence	-	-	4	2.0
Rumeobtu	Rumex obtusifolius	Broad-leaved dock	✓	<5% occurrence	-	-	3	1.0
Rumesp	Rumex sp.	Dock	✓	<5% occurrence	-	-	1	1.0

Table 4.3: Initial exploration of species data (continues)

Variable name	Latin name	Common name	Excluded from final data set?	Reason for exclusion	Indicator	Group Allocation	Instances	Mean abundance (%)
Sangmino	Sanguisorba minor	Salad burnet	✓	<5% occurrence	-	-	1	1.0
Seneeruc	Senecio erucifolius	Hoary ragwort	✓	<5% occurrence	-	-	3	1.0
Senejaco	Senecio jacobaea	Ragwort		Auto-correlation	✓	B	24	3.2
Silelati	Silene latifolia		✓	<5% occurrence	-	-	2	3.0
Stacoffi	Stachys officinalis	White campion	✓	<5% occurrence	-	-	2	1.0
Stacsylv	Stachys sylvatica	Hedge woundwort	✓	<5% occurrence	-	-	1	1.0
Succprat	Succisa pratensis	Devil's bit scabious	✓	<5% occurrence	-	-	2	3.0
Tanavulg	Tanacetum vulgare	Tansy	✓	<5% occurrence	-	-	2	3.0
Taraoffiagg	Taraxacum officinale agg	Dandelion	✓	<5% occurrence	-	-	4	1.0
Tragprat	Tragopogon pratensis	Goat's beard	✓	<5% occurrence	-	-	4	1.0
Trifcamp	Trifolium campestre	Hop trefoil	✓	<5% occurrence	-	-	1	1.0
Trifprat	Trifolium pratense	Red clover				A/B	18	5.6
Trifrepe	Trifolium repens	White clover			✓	A/B	25	5.3
Trifsp	Trifolium sp.	Clover sp.	✓	<5% occurrence	-	-	1	1.0
Tripinod	Tripleurospermum inodorum	Scentless mayweed	✓	<5% occurrence	-	-	1	1.0
Trisflav	Trisetum flavescens	Yellow oat-grass	✓	<5% occurrence	-	-	3	1.0
Unidentified	Unidentified	Unidentified				A	6	1.7
Urtidioi	Urtica dioica	Nettle			✓	A	1	2.5
Verocham	Veronica chamaedrys	Germander speedwell				A	6	12.5
Veroserp	Veronica serpyllifolia	Thyme-leaved speedwell	✓	<5% occurrence	-	-	4	1.0
Vicicrac	Vicia cracca	Tufted vetch		Auto-correlation		B	11	3.7
Vicisati	Vicia sativa	Common vetch	✓	<5% occurrence	-	-	1	1.0

Table 4.3: Initial exploration of species data (continued)

4.7 Exploratory Data Analysis – floral data

Step 1: Identification of outliers in X and Y

A boxplot and dot chart were made for the dependent variable, Time Since creation, and all spatial/temporal variables, as well as all species variables. Charts were examined for potential outliers. All code is presented in Appendix 7.

Time since creation

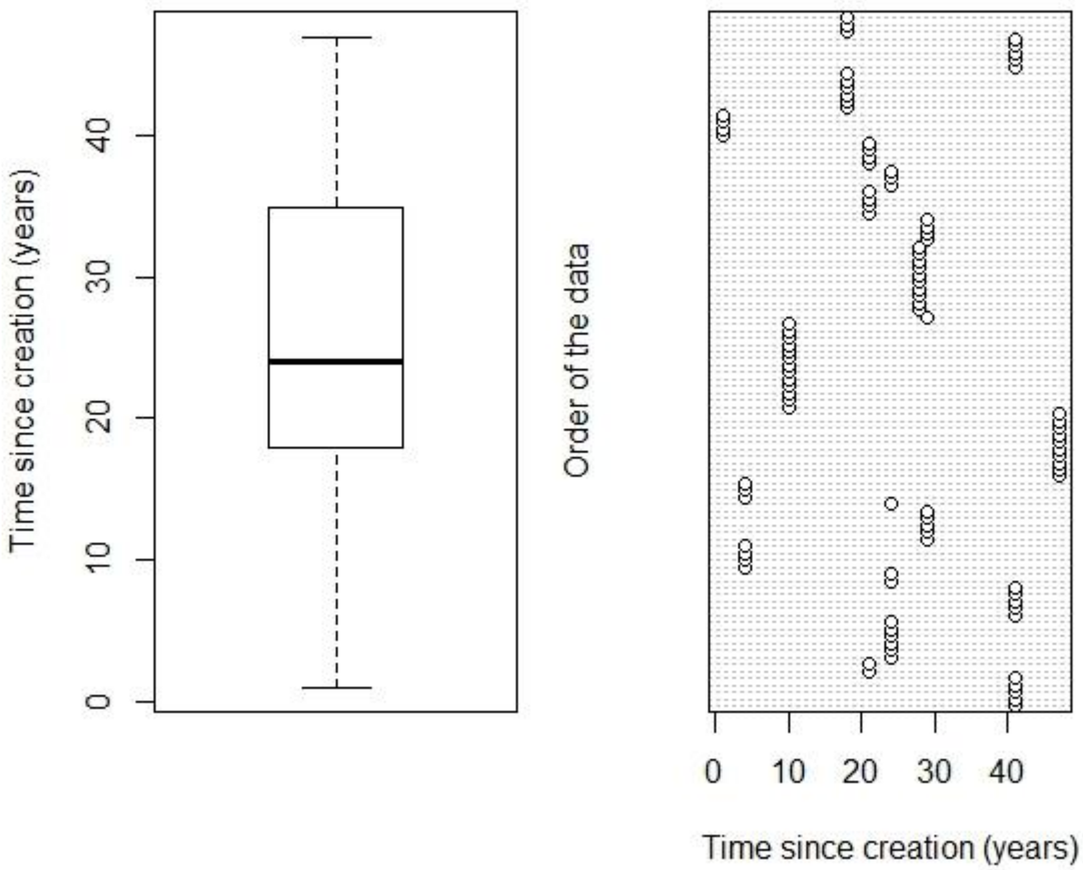


Figure 4.70: Box plot and scatter plot for Time since creation (years)

The boxplot for Time since creation shows a fairly even variance around a central point. The organisation of the scatter plot is due to the time since creation variable constituting a series of intervals through time.

Location

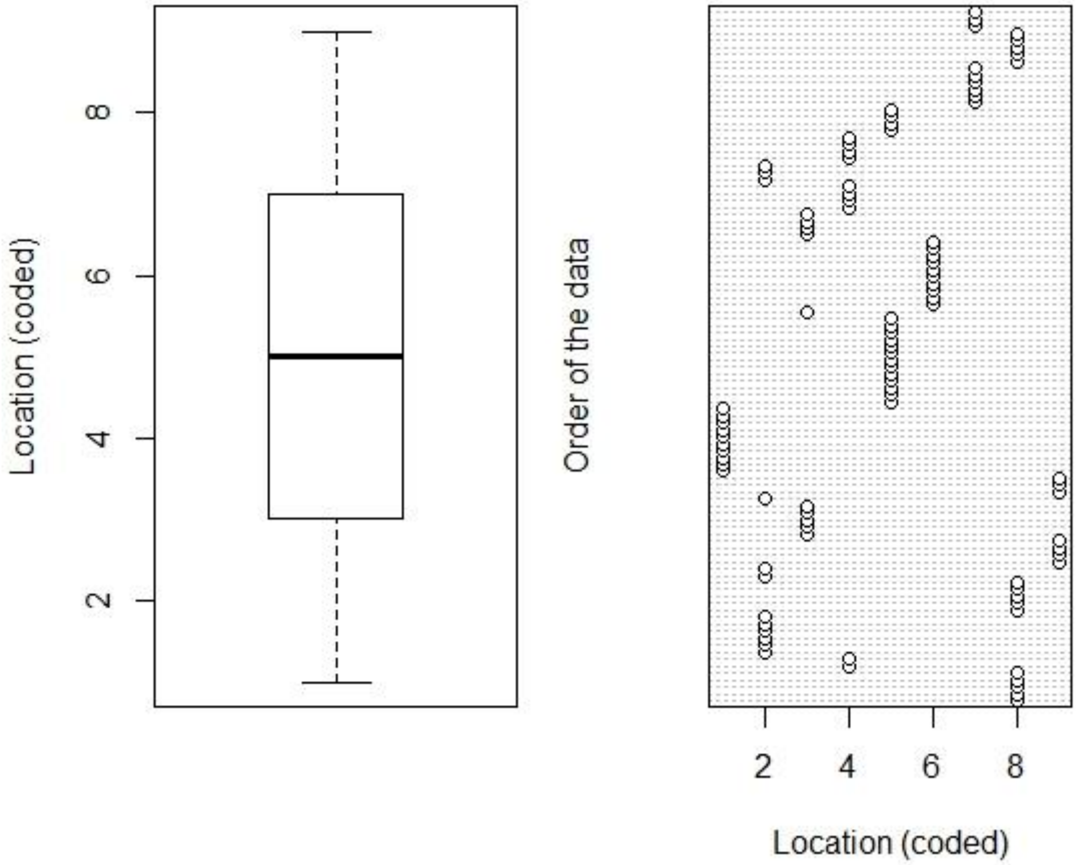


Figure 4.71: Box plot and scatter plot for Location of site

Location shows a good spread of data around the median point. Further analysis of the spatial aspect of the quadrats is dealt with later (Section 4.7).

Site info (soil type)

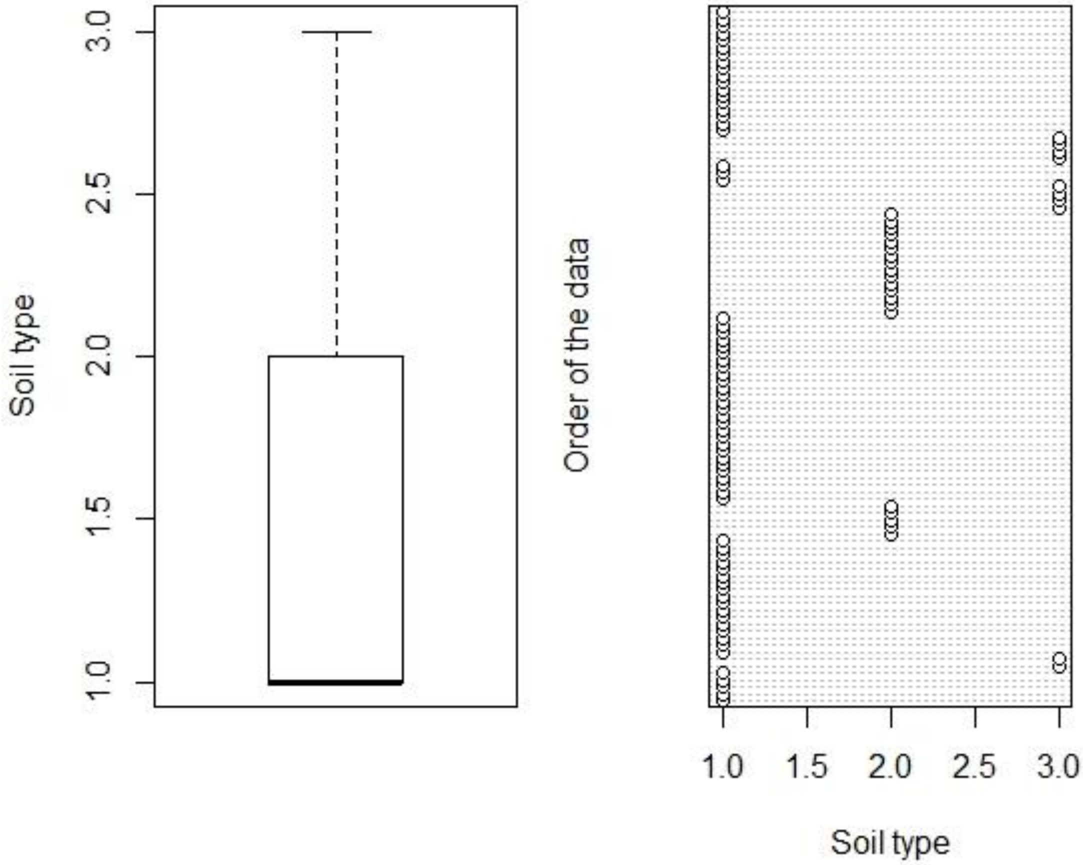


Figure 4.72: Box plot and scatter plot for Soil type

This boxplot indicates a floor effect. This is not a concern in this context as more sites are mesotrophic in line with ratios of soil type in the UK. A number of calcareous sites are also present. Indicators will be specified if only applicable to certain soil types.

Management

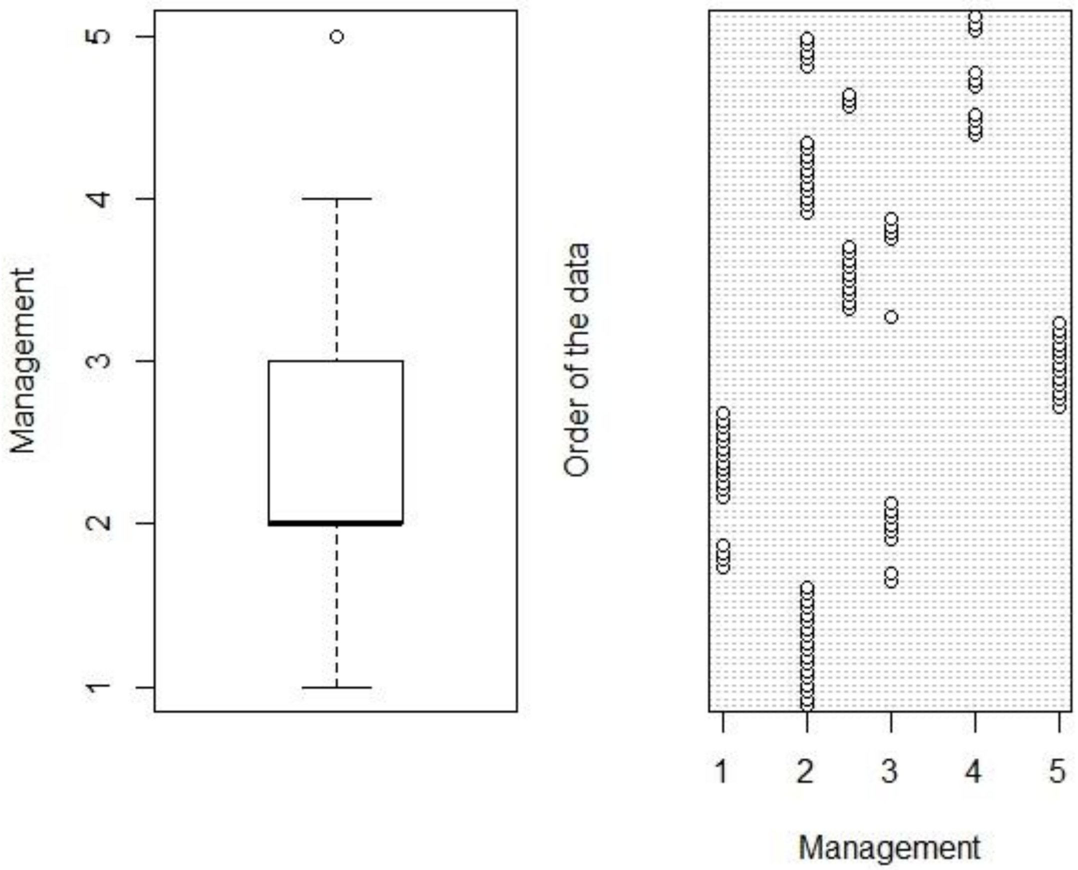
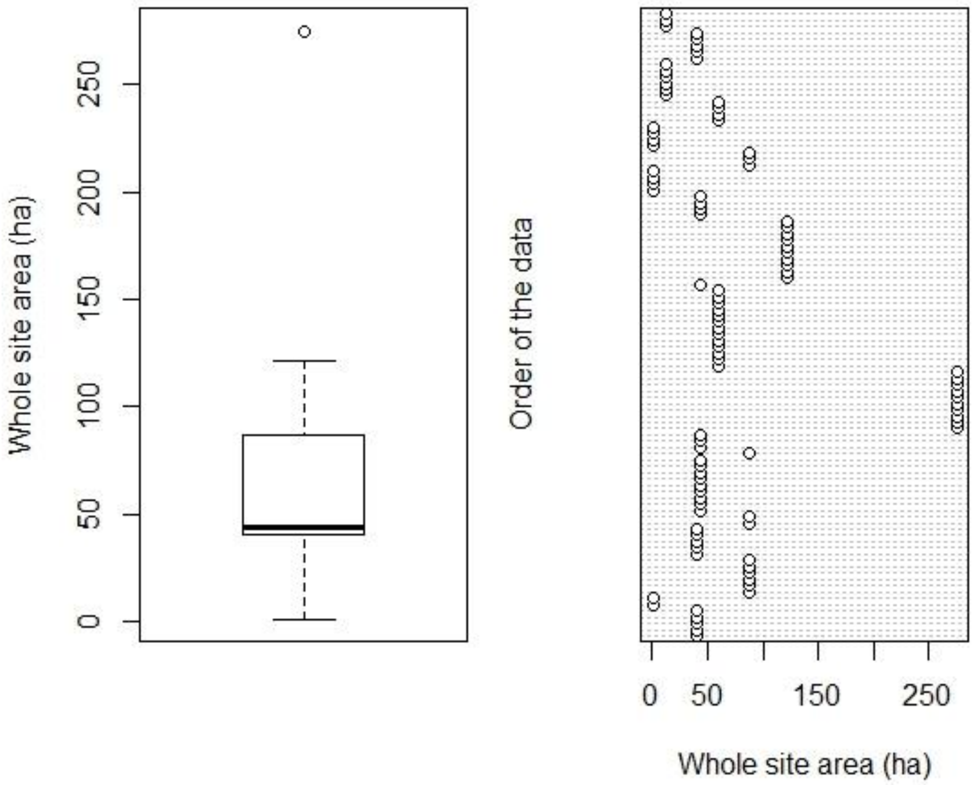
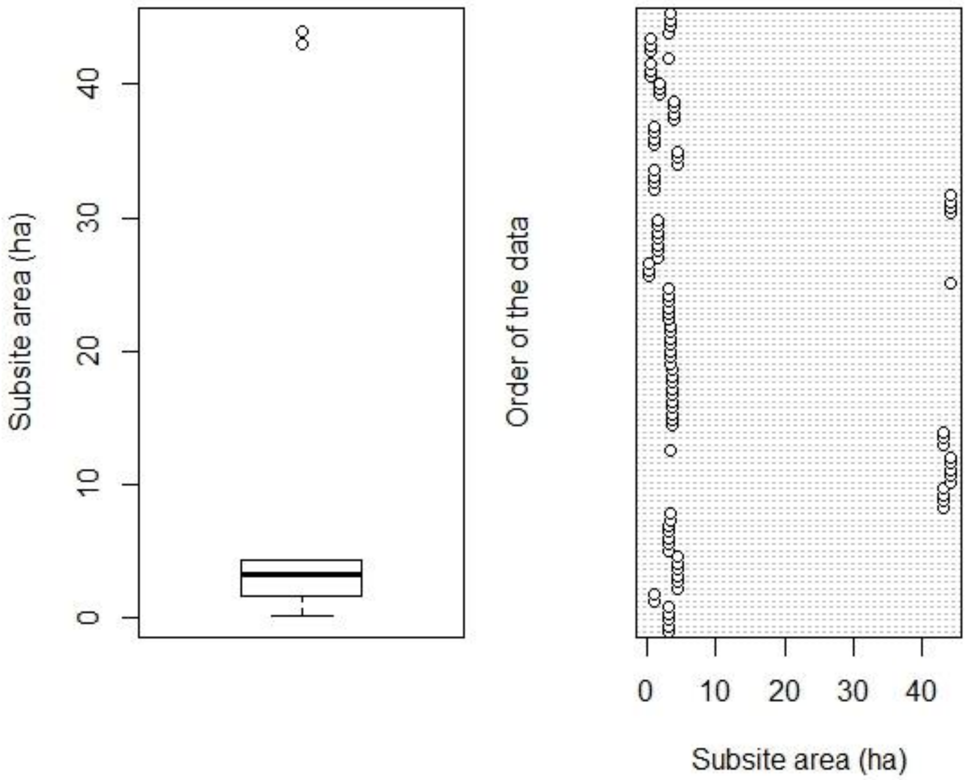


Figure 4.73: Box plot and scatter plot for Management

A limited number of types of management are generally used, most are represented across the range of sites.

Whole site area (ha) *Sub-site area (ha)*





Figures 4.74 and 4.75: Box plots and scatter plots for Whole site area (ha) and Sub-site area (ha)

Attenborough Nature Reserve has a particularly large area in contrast to the other sites (275 ha). This is not considered a concerning outlier as it reflects usual variation in site size. Sub-site area data looks somewhat skewed as some sites did not have sub-site(s). Due to this, sub-site area will not be included in further analysis owing to heterogeneity amongst sites.

Quadrat mean height (cm)

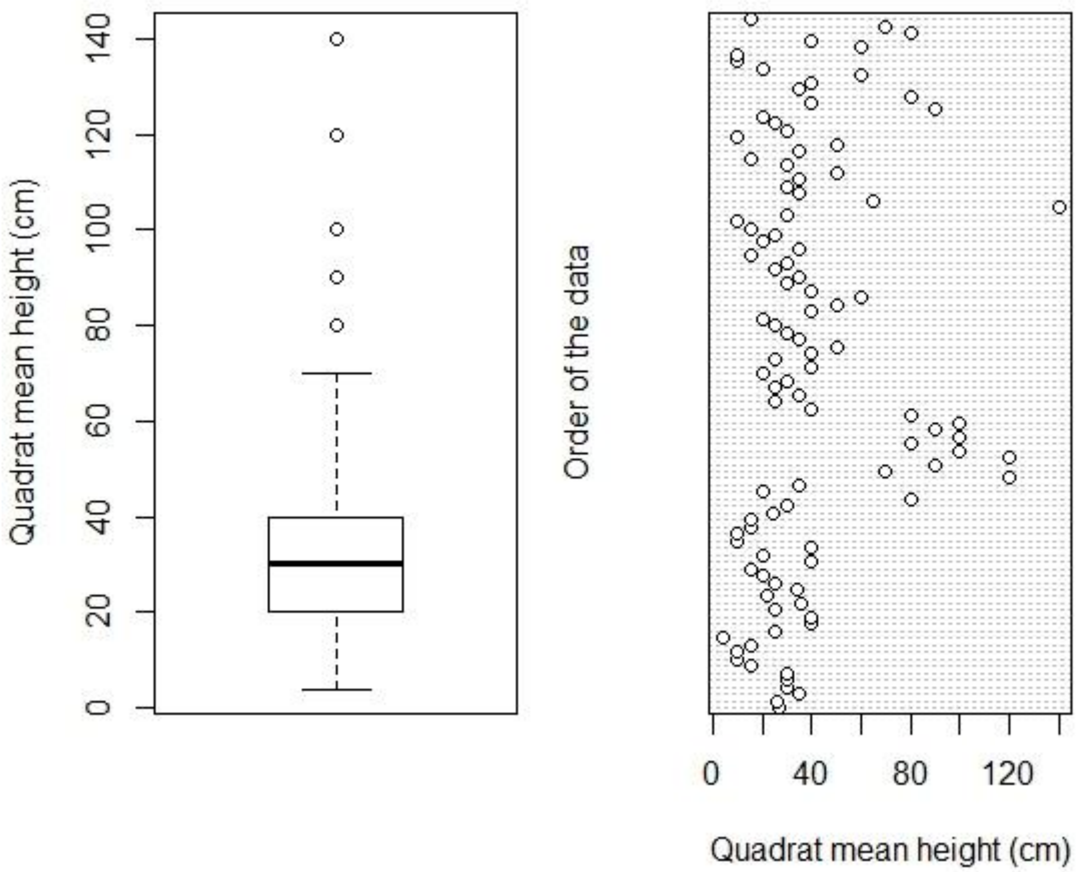


Figure 4.76: Box plot and scatter plot for Quadrat mean height of vegetation (cm)

Particularly tall grasses at the site at Attenborough Nature Reserve cause the distribution shown in the above plots. Transformation may obscure this actual representation of the sites.

Step 2: Do we have homogeneity of variance?

Variance is explained through eigenvalues extracted from ordination.

Step 3: Are the data normally distributed?

Boxplots created as part of Step 1 (Outliers) were re-examined for evidence of non-normal distributions. Sub-site area benefitted from transformation. All other variables appeared to show a normal distribution.

Step 4: Are there an abundance of zeros in the data?

A corrgram was created to establish joint zeros in the data (Zuur, Ieno, & Elphick, 2010). Figure 4.77 shows the corrgram created for all species variables.

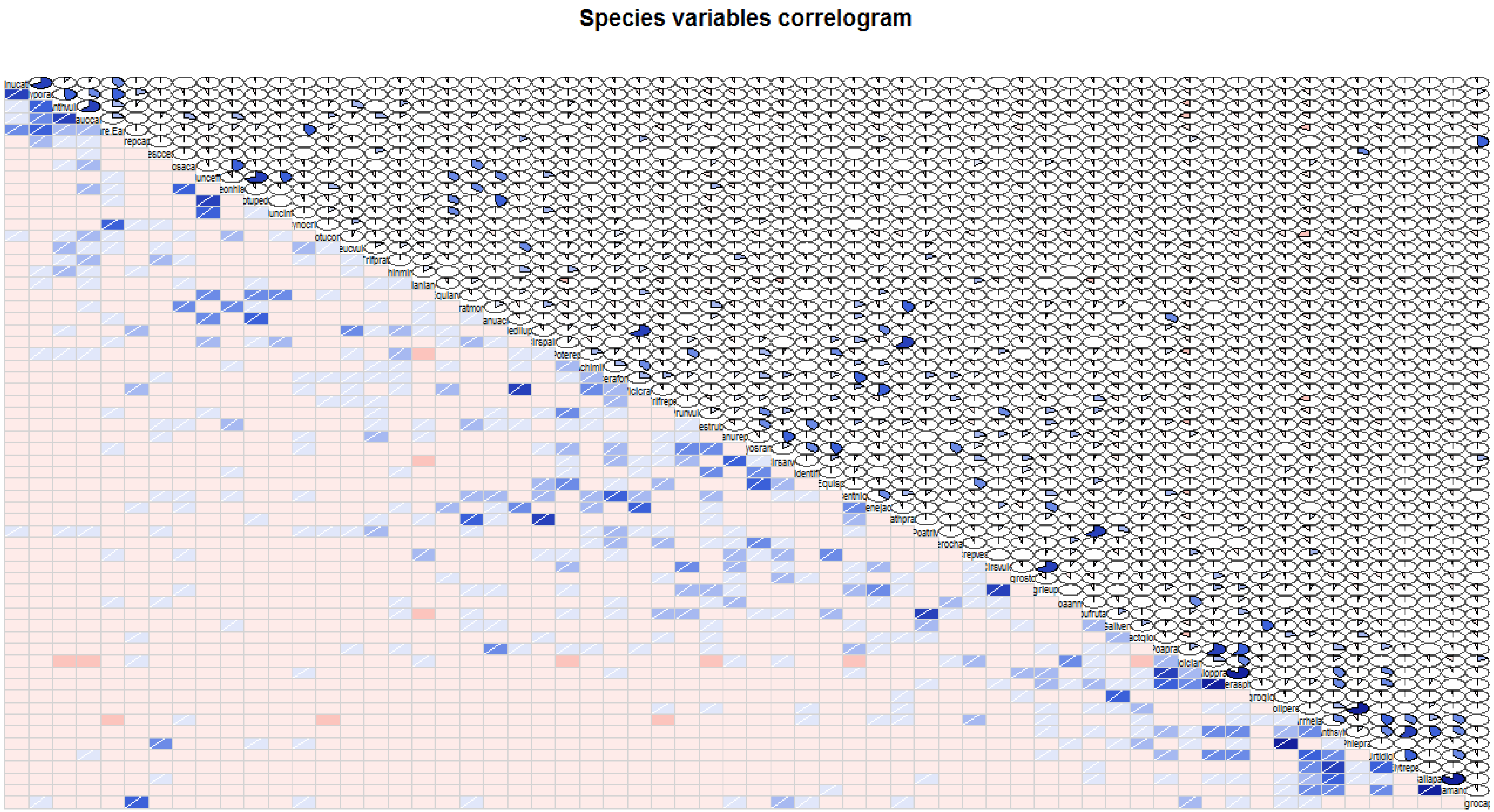


Figure 4.77: Corrgram (examined in zoomed sections) showing joint zeros within the floral data.

The corrgram, created in R, is difficult to reproduce in high definition due to its size. A zoomed in version was examined for any species pairs showing joint zeros. The following species pairs were identified as having high joint zeros (over half the "clock"):

Fairy flax *Linum catharticum* – Cat's ear *Hypochaeris radicata*

Kidney vetch *Anthyllis vulneraria* – Wild carrot *Daucus carota*

Soft rush *Juncus effusus* – Greater bird's foot trefoil *Lotus pedunculatus*

Black medick *Medicago lupulina* – Tufted vetch *Vicia cracca*

Marsh thistle *Cirsium palustre* – Meadow vetchling *Lathyrus pratensis*

Spear thistle *Cirsium vulgare* – Common agrimony *Agrimonia eupatoria*

Rough meadow-grass *Poa trivialis* – Bramble *Rubus fruticosus agg.*

Smooth meadow-grass *Poa pratensis* – Meadow foxtail *Alopecurus pratensis*

Meadow foxtail *Alopecurus pratensis* – Common hogweed *Heracleum sphondylium*

Perennial rye-grass *Lolium perenne* – Timothy *Phleum pratense*

Cow parsley *Anthriscus sylvestris* – Couch grass *Elytrigia repens*

Cleavers *Galium aparine* – Greater willow-herb *Chamerion angustifolium*

Step 5: Is there collinearity among the covariates?

1. Between-species correlation
2. Species – temporal/spatial variables correlation
3. Between-community variables correlation
4. Community-temporal spatial variables correlation.

A Pearson correlation coefficient matrix was created for each variable. This was examined to assess between-species correlation. A highly conservative cut-off of 0.3/-0.3 for exclusion was set according to Zuur, Ieno, & Elphick (2010). This level was discussed in Section 3.12.

Figure 4.78 indicates variables that show a >0.3/-0.3 correlation with one or more other variables.

Variable name	Achimill	Agrieupa	Agrocapi	Agrogiga	Agrostol	Alopprat	Anthvuln	Arrhelat	Centnigr	**Chamangu**	Cirsarve	Cirspalu	Cratmono	Crepvesi	**Dauccaro**	Desccesp	**Elytrepe**	**Equiarve**	Festrubr	**Galiapar**	**Galiveru**	**Heraspho**	Holclana	**Hyporadi**	Juneffu	**Leonhisp**	Leucvulg	Linucath	Lolipere	Lotucorn	**Medilupu**	**Myosramo**	Phleprat	Planlanc	**Poaprat**	Prunvulg	**Ranuacri**	**Ranurepe**	Rubfrutagg	Rumeacet	**Senejaco**	**Urtidioc**	**Vivicrac**	Number of adverse reactions	Ease of identificatio
Anthsylv						0.4		0.4		0.4							0.6			0.4																						0.4		6	M
Cerafont									0.5																																			1	M
Chamangu								0.4																																				1	M
Cirsvulg		0.7																																										1	M
Crepcapi			0.5																																									1	M
Dauccaro							0.6																																					1	M
Elytrepe								0.4																																				1	H
Equiarve														0.4											0.3																			2	M
Galiapar										0.8																																		1	E
Galiveru				0.5																																								1	E
Grid height		0.3																																										1	NA
Heraspho						0.8																																						1	M
Hyporadi							0.5								0.3													0.7																3	M
Juncinfl																		0.3							0.4																			2	H
Lathprat												0.6	0.4																															2	M
Leonhisp													0.3																															1	M
Lotupedu																		0.4							0.7												0.5							3	M
Management					0.4									0.3																				0.4				0.3						4	NA
Mean height								0.5		0.3										0.3													0.3											4	NA
Medilupu																											0.4																	1	M
Myosramo																			0.4																	0.3								2	M
Phleprat																0.3													0.7															2	M
Poaannu																							0.4																					1	H
Poaprat						0.6																																						1	H
Poatriv																					0.3																0.3		0.6					3	H
Poterept																																0.3				0.4								2	E
Ranuacri																									0.4										0.3									2	M
Ranurepe											0.5																																	1	M
Rosacani													0.4		0.3											0.5																		3	E
Senejaco		0.4							0.4																						0.4													3	E
Site info							0.3								0.3									0.3							0.5										0.3		0.3	6	NA
Subsite area															0.4	0.3										0.4		0.3		0.4										0.3				6	NA
Urtidioc								0.4		0.4							0.5					0.3																						4	E
Verocham																																0.4												1	M
Vicicrac	0.4																														0.7										0.5			3	M
Whole site area								0.4		0.4							0.4			0.3									0.5		0.3		0.4									0.3		8	NA
Number of adverse reactions	1	3	1	1	1	3	3	6	2	5	1	1	3	2	4	2	3	2	1	3	1	1	1	1	4	2	1	2	2	1	4	2	2	1	1	2	2	1	1	1	2	2	1		
Ease of identification	M	E	H	H	H	M	E	M	M	M	M	M	E	M	M	H	H	M	M	E	M	M	M	M	H	M	E	E	M	M	M	M	M	E	H	M	E	E	E	M	M	E	M		

Figure 4.78: Pearson correlation coefficient matrix was created for each species variable

To select species to remove out of species-pairs showing autocorrelation or double zeros, the following criteria were utilised in the subsequent order:

1. Species pairs with the highest Pearson correlations were scrutinised first, working backwards.
2. If one species is a known indicator and the other is not, the latter was removed;
3. If both or neither species is a known indicator, the species which is the most difficult to identify was removed.
4. If both species are of the same difficulty, the species with the highest incidence of data violations and/or further high Pearson correlations was removed.

To ensure no important information was lost, removed species were placed in to a Group “B”, to be analysed along with all uncorrelated species. Details of species removed are presented in Table 4.3.

A pairs correlation matrix was created using Pearson correlation figures to assess any auto-correlation between explanatory community variables. Figure 4.79 presents the output from this. No concerning auto-correlation exists between explanatory community variables despite the conservative cut-off of +/- 0.3 (Zuur, Ieno, & Elphick, 2010).

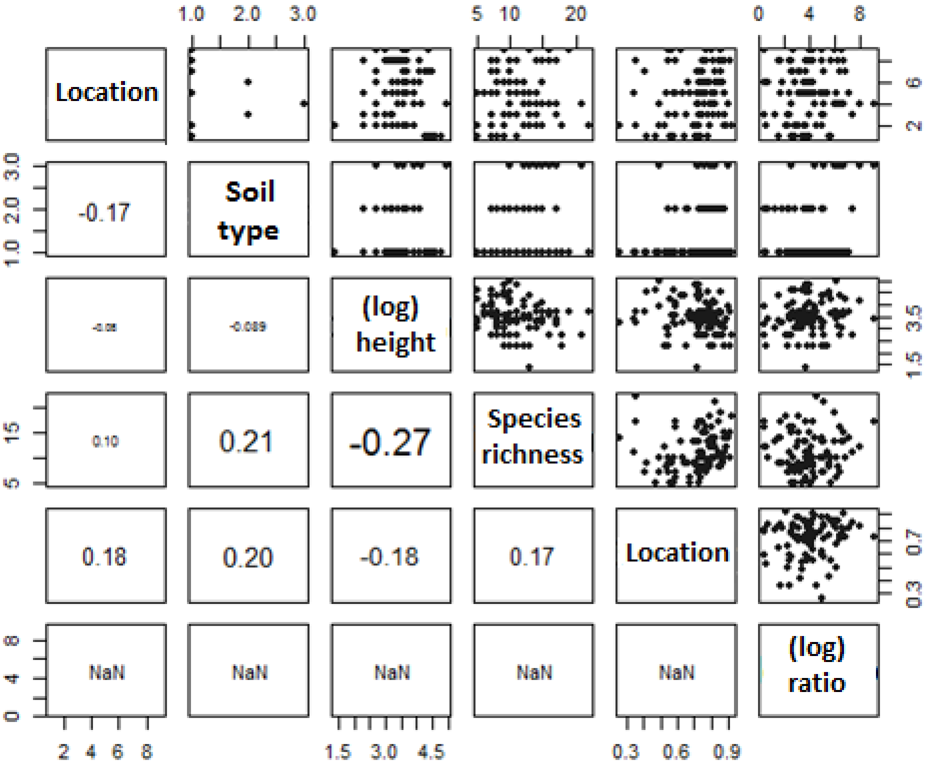


Figure 4.79: Pairs plot showing Pearson correlation between explanatory community variables.

As would be expected, species richness and species diversity show a positive correlation with each other. Both are potential indicators of grassland quality. These could also, in different sites, be high due to over-fertilisation of the soil in past agriculture, but this is unlikely to be relevant in post-industrial sites. The mean height of the vegetation shows a negative correlation with species richness and species diversity. As vegetative height could potentially be a negative indicator of quality, this could support that hypothesis.

Step 6: What are the relationships between Y and explanatory variables?

Figure 4.80 shows the relationship between Y and the explanatory community variables. From a visual perspective, the log ratio of herb to grass appears to have a negative relationship with time since creation, which is contrary to our hypothesis (Section 2.5). Quadrat mean height shows a sudden rise towards the end of the sample, this is representing Attenborough's particularly tall grasses. Site.info (Soil type) trend line should be treated with some caution due to small sample size.

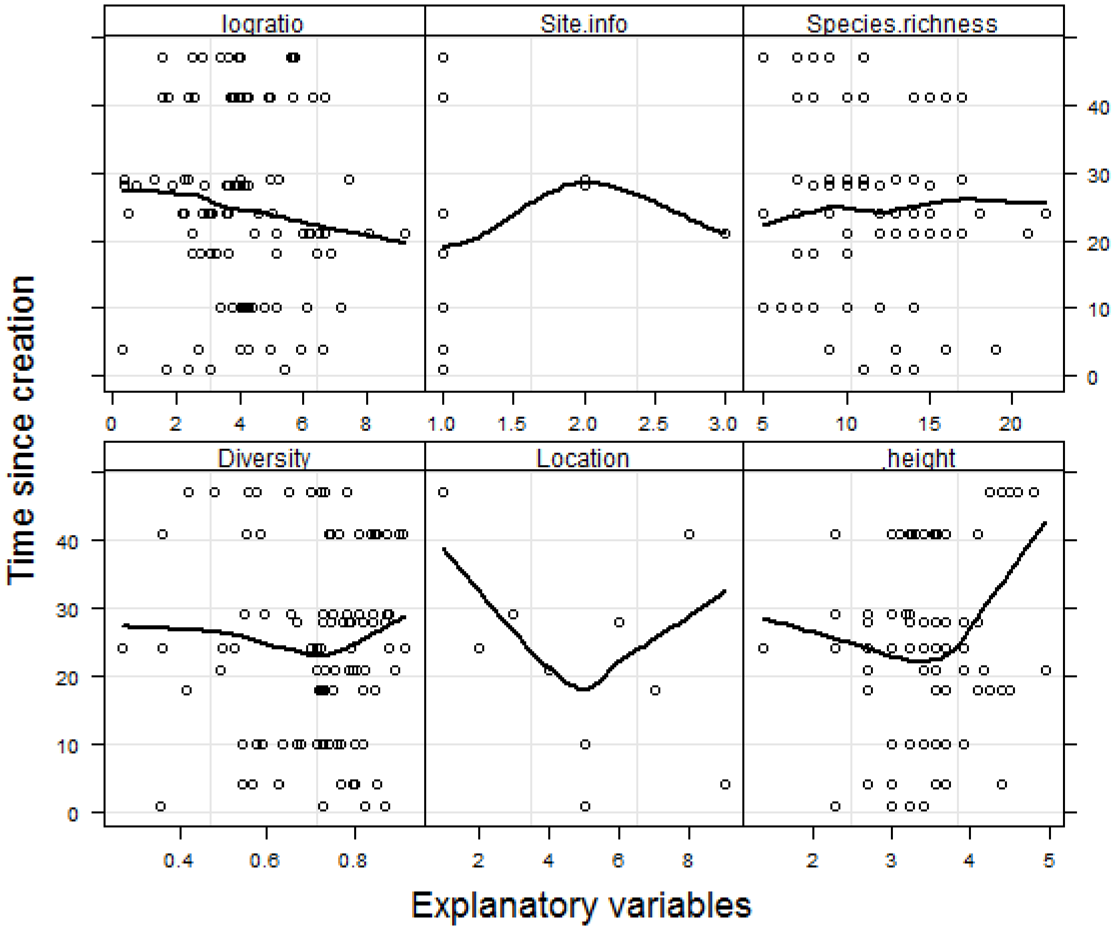


Figure 4.80: Y variable (Time since creation), plotted against explanatory community variables

To assess for spatial autocorrelation in the data, a variogram, as recommended in Zuur, Ieno, & Elphick (2010) and Dormann (2007) was made. Figure 4.81 shows the output of the initial variocloud and the subsequent variogram. No evidence of spatial autocorrelation was found.

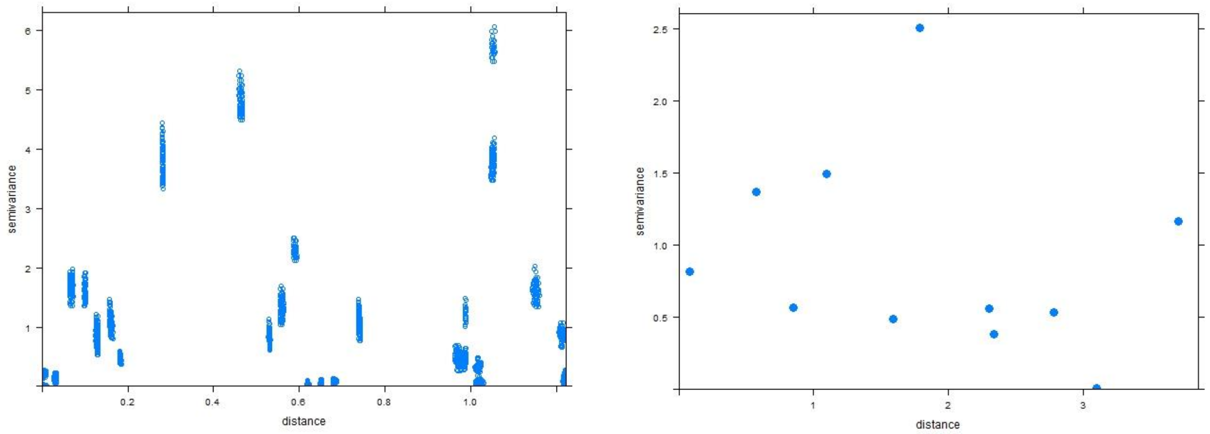


Figure 4.81: Variocloud and variogram showing no evidence of spatial autocorrelation.

4.8 TWINSPAN RESULTS

Two-Way Indicator Species Analysis (as discussed in Section 3.3.6) (TWINSPAN) was undertaken on the adjusted data comprising 62 species taken from 100 quadrats across 11 sites. A dendrogram and further output are presented in Figures 4.82 and 4.83.

The initial group, which involves all 100 quadrats (eigenvalue = 0.407), identified the following positive indicator species: Common Mouse-Ear *Cerastium fontanum*, Wild carrot *Daucus carota*, Rough hawkbit *Leontodon hispidus*, bare earth (ground devoid of vegetation) and Bird's-foot trefoil *Lotus corniculatus*. Bare earth's inclusion is surprising as this is normally a negative indicator. The negative indicator status is normally over 5%.

Overall negative indicator species identified were Common agrimony *Agrimonia eupatoria*, False oat-grass *Arrhenatherum elatius*, Yorkshire Fog *Holcus lanatus*, Cock's foot *Dactylis glomerata*, Meadow vetchling *Lathyrus pratensis* and White clover *Trofilium repens*. These are mostly in line with semi-natural grassland negative indicators. However, common agrimony *Agrimonia eupatoria* and Meadow vetchling *Lathyrus pratensis* were expected to be positive indicators. These indicators may not transfer satisfactorily to created grasslands from the literature.

The first division split the 100 quadrats in to two sections comprising a set of 63 quadrats and a set of 37 quadrats. The vast majority of the quadrats taken on calcareous soils were included in the second group. Many of the indicator species from the first division were replicated here. As such this first division appears to be separated mostly by soil type. The first group mostly comprising mesotrophic and PFA soils (n=63) included key negative indicator species also present in the overall grouping: Common agrimony *Agrimonia eupatoria*, False oat-grass *Arrhenatherum elatius*, Cock's foot *Dactylis glomerata*. Of this initial group's indicators, only Rough hawkbit *Leontodon hispidus* was also present in this group as a positive indicator. All other positive and negative indicator species are provided in Table 3.4 below.

The second group (n=37) included key positive indicator species Common rush *Juncus effusus*, Creeping bentgrass *Agrostis stolonifera*, Greater bird's-foot trefoil *Lotus pedunculatus*, and Meadow buttercup *Ranunculus acris*. It is interesting that Creeping bentgrass appears in both groups as a positive indicator. This makes it more likely for inclusion later to allow relevance across soil types. However, it is more advanced to identify which could make it troublesome fitting the objectives.

A dendrogram is presented in Figure 4.82 to the third level of division. This also highlights key indicator species identified from the TWINSPAN analysis. The ordered two-way output table is also presented below. As the table can be difficult to interpret, the site number has been placed under the quadrat numbers. Table 4.4 sums up this data and highlights TWINSPAN identified indicators in bold text.

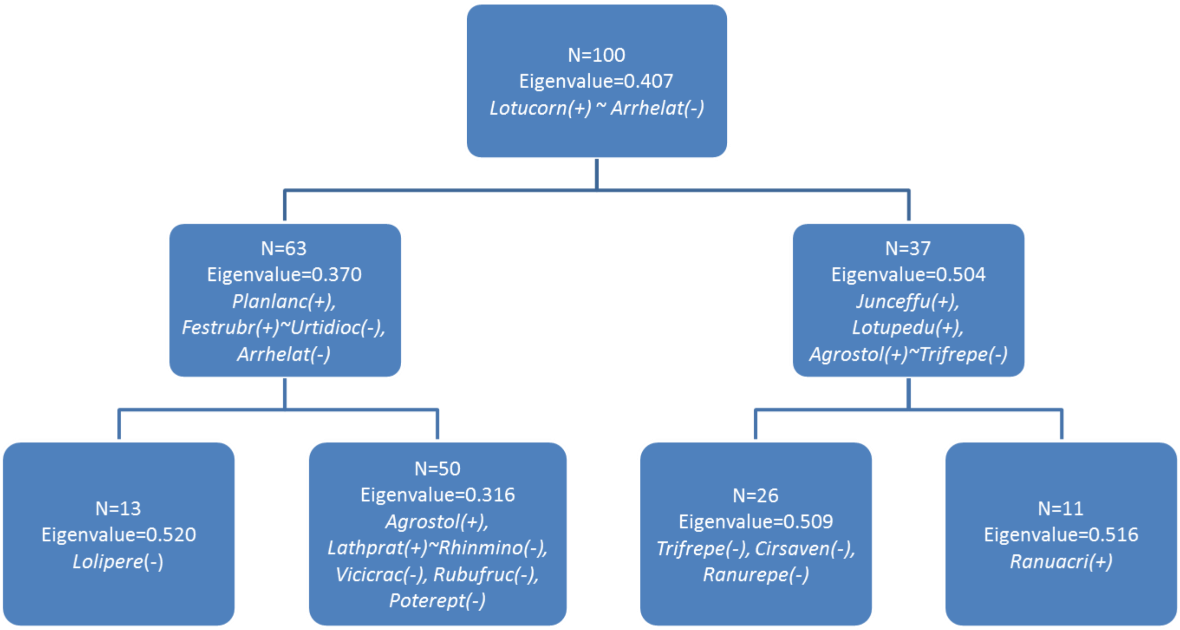


Figure 4.82: Dendrogram showing first 3 levels of TWINSPAN analysis and key indicator species for divisions.

```
                 1
             5990499929929 447122333446772445555679 31581445567788888 223333347888827679666 3 5662    26711151111
             4380357952436312618902307745158025683099293049136790128912445678685647725112342157010467869034685789
 Site code:  5877188737898811223329915644955555347212652555562444477899111115255573463766689836628442333288688820

 7 Anth sylv -1-1-1---1-1----------------------------------------------------------------------------------------  00000
24 Elyt repe -4---1-1-41-----------------------------------------------------------------------------------------  00000
30 Hera spho ----1--11-131-------------------------------1------------1------------------------------------------  00000
60 Urti dioi 4441-1-1---41--1-----1------------------------------------------------------------------------------  00000
 9 Arrh elat 444444---4444----1----1-43---1---------144--44444444-44---34433-3-44-113333441----------1-----------  00001
16 Cirs vulg --------1---------------1--------------1-----------------1----------41------------------------------  00001
29 Gali veru -------443-----1--------------------------4--------444444--4---------3----------1----4--------------  00001
47 Poap rat  -----------3---------------------------------------1----3-------------11----11-----------1----------  00001
 2 Agri eupa --------1--3------------------------------1-------------113114----3344------------------------------  000100
 4 Agro giga -----1-------------------------------------------41--1-4---------1----------------------------------  000100
46 Poaa nnu  ------11----------31---------1-------------1-11----------4------3---------11------------------------  000100
 1 Achi mill --------------14--31----------------------3-1---1------1------4-------434-----------------1---------  000101
19 Crep vesi ----------------------1-1--------------------11-----------------1-1---------------------------------  000101
35 Lath prat --------1--1--3---------------1------1--44-------3----4-114144--------------------------------------  000101
56 Sene jaco 1-----------------111----1--1---11--------1----11-------31--13-1--11341-44-4------------------------  000101
62 Vici crac -------------314-----------------------1------------------------------1-44-3341---------------------  000101
26 Equi sp   ----------------------4-----------------------------------------------------------------------------  00011
58 Trif repe --------3----44334443444---1-1414--44444---------1---------1-----------------1----------------------  00011
61 Vero cham -----------1------441-----------------------------------13------------------------------------------  00011
21 Dact glom -----4-43141-----4--3-1---------1--------3-11---11--144--13-----1-3---13-114-------------111---1----  00100
 6 Alop prat -----1-----4---1-1--1-----3-------------------------------1-------------------1---------------------  001010
13 Cham angu --44------3----------11--------------------------------------------------1---1-------------1--------  001010
28 Gali apar ---41-111-11--------------------------1----1--------------------------------------------1-----------  001010
39 Loli pere --134444------1-4------4--31-------------------------------344-11------------------------1-1-------1  001010
 3 Agro capi ----411---------3--------4-4------1-3---41------4-----------------------------------------11---1----  001011
 5 Agro stol -------------1-34-------4-444133414-44131--1431134344443---------1--------------------------1-1-14-1  001100
11 Cent nigr -------------1-431--------31------------4431---------1--4------------4--------1---1-----1-----------  001100
52 Ranu repe -------------34--331-11-4--4-1444---34------1-4---------141133--33-34---------41---------------1----  001100
59 Unid enti ----------------4----------1----------------------3---------------------1-1--------1----------------  001100
14 Cirs arve --------------13--1111314314111----14-13----11-111-----------------------1--1--3--------------1-----  001101
12 Cera font -------------113--11111-------1-------1-------1---------------------------1----1--------------------  00111
23 Desc cesp --------------41---------------------------4----------------------------------1-----------1---------  0100
45 Plan lanc 4------------1--111-3-1-111-44444443-1--433-444-334-43334-444444444--411-343-41-34-41-1-4114---4-1--  0100
57 Trif prat -------------34----------------------3----------1--------1341-34-------1----11-----1----3311--------  0100
17 Crat mono --------3---------1---------------------434---------------41---------1-----------4-1-------1--------  0101
23 Desc cesp --------------41---------------------------4----------------------------------1-----------1---------  0100
45 Plan lanc 4------------1--111-3-1-111-44444443-1--433-444-334-43334-444444444--411-343-41-34-41-1-4114---4-1--  0100
57 Trif prat -------------34----------------------3----------1--------1341-34-------1----11-----1----3311--------  0100
17 Crat mono --------3---------1---------------------434---------------41---------1-----------4-1-------1--------  0101
18 Crep capi ------------------------------------------------3------------------------1-1-1------1------1--------  0101
27 Fest rubr -------------1-1434441--------------4---4-44--------441344414434--34-434---434-4-4444---1-11---1----  0101
42 Medi lupu ------------------1-1----------------3----1---1-----3--1---------4---31-44-334-------1-1-4----------  0101
31 Holc lana --1-4-4-44-4411-1-43414-441-444444443444--4344414331---34433433144341114433---1----44---1111-4414-3-  0110
50 Prun vulg ---------------------1-----3----------34--------------------1133-1--41---------4---1--------13------  0110
43 Myos ramo ----------------1--11-1--------------------------------------------------------1--------------------  0111
44 Phle prat -----344----------------------------------13----------------------------------1----------------1----  0111
48 Poat riv  --------3----111------------------------------------------------------------------------1-----------  0111
55 Rubu frut -1--3---43334-----411144----1------1--34------------------------------1---3----4----3---1-3---------  0111
20 Cyno cris -------------31-----4----3----------------------1--------------------1--------4----------1----------  10
37 Leuc vulg 1------------4-11-1-1---------------1------1----------------------------------1--------4-4----------  10
49 Pote rept ------------------3--34-----------------1---------44----------------4-44-4-----4---------443--------  10
53 Rhin mino ---------------1------------------------------------------1-----------41344-11-----------443--------  10
54 Rosa cani ---------------------------------------11----------------------1--31-1-----------4--1--1------------  1100
15 Cirs palu ----------------------1-----------------13-------------------------------------1-------------1--11-1  11010
51 Ranu acri --------------------------11-----------111--------------414---------------------------------434--11-  11010
25 Equi arve ---------------------------------------------------------------------1--31---------------------3-44-  11011
33 Junc effu --------------------------------------------------------------------------------------------4444-4-4  11011
34 Junc infl -----------------------------------1----1-------------------------------------1-----------------4444  11011
41 Lotu pedu ----------------------------------------3---------------------------------------------------4344-4--  11011
 8 Anth vuln ----------------------------------------------------------------------1--------------4-44444--------  11100
22 Dauc caro 1-------------1------------------------------------------------------------------11--1-11-11--------  11100
32 Hypo radi -------------------------1------------------1---1---------------1--------------------1311-13--------  11100
38 Linu cath --------1-----------------------------------------------111---------1------------1--11434-----------  11100
10 Bare .Ear --------------3-----3-------------------------------------------4-------------444-431444-134443-3---  11101
36 Leon hisp --------------------1-------1-------------4-1------------------------1----------34441---1-----------  11101
40 Lotu corn -------------4-4-----413---34-44-44-3-44-----1---1-444-1--11-----------43-----31444444114-41----4444  1111

             0000000000000000000000000000000000000000000000000000000000000000000000000000001111111111111111111111
             0000000000000111111111111111111111111111111111111111111111111111111111111111110000000000000001111111
             0000111111111100000000000000000000000000111111111111111111111111111111111111110000000011111100001111
                 000011111000000000000000111111111111000000000000000000000000000001111111011111110000111
                     00011000011111110000111111111111000000000000000011111111111111000001111 011111
                              0000111    0000000000110001111111111111000000000001100111      00001
```

Figure 4.83: TWINSPAN output table highlighting sites

Variable name	Latin name	Common name	Division 1 (n=100)		Division 2 (n=63)		Division 3 (n=37)	
			(+)	(-)	(+)	(-)	(+)	(-)
Achimill	*Achillea millefolium*	Yarrow						
Agrieupa	***Agrimonia eupatoria***	**Common agrimony**		✓	✓			
Agrocapi	*Agrostis capillaris*	Common bent				✓		
Agrogiga	*Agrostis gigantea*	Black bent						
Agrostol	***Agrostis stolonifera***	**Creeping bent**			✓		✓	
Alopprat	*Alopecurus pratensis*	Meadow foxtail						
Anthsylv	*Anthriscus sylvestris*	Cow parsley				✓		
Anthvuln	*Anthyllis vulneraria*	Kidney vetch						✓
Arrhelat	***Arrhenatherum elatius***	**False oat-grass**		✓		✓		
Bare.Earth	***Bare Earth***	**Bare earth**						
Centnigr	*Centaurea nigra*	Common knapweed						✓
Cerafont	***Cerastium fontanum***	**Common mouse-ear**	✓					✓
Chamangu	*Chamerion angustifolium*	Rose-bay willow-herb				✓		
Cirsarve	*Cirsium arvense*	Creeping thistle			✓			✓
Cirspalu	*Cirsium palustre*	Marsh thistle					✓	
Cratmono	*Crataegus monogyna*	Hawthorn						
Crepcapi	*Crepis capillaris*	Smooth hawksbeard						
Cynocris	*Cynosurus cristatus*	Crested dog's-tail						
Dactglom	***Dactylis glomerata***	**Cock's-foot**		✓		✓		
Dauccaro	***Daucus carota***	**Wild carrot**	✓					✓
Desccesp	*Deschampsia cespitosa*	Tufted hair-grass						
Elytrepe	*Elytrigia repens*	Couch grass				✓		
Equiarve	*Equisetum arvense*	Common horsetail					✓	
Festrubr	*Festuca rubra*	Red fescue			✓			✓
Galiapar	*Galium aparine*	Cleavers				✓		
Galiveru	*Galium verum*	Lady's bedstraw						
Heraspho	*Heracleum sphondylium*	Common hogweed				✓		
Holclana	***Holcus lanatus***	**Yorkshire-fog**		✓			✓	
Hyporadi	*Hypochaeris radicata*	Cat's-ear						✓

Table 4.4: TWINSPAN results – Bold highlights potential indicators from literature review (continues)

Variable name	Latin name	Common name	Division 1 (n=100)		Division 2 (n=63)		Division 3 (n=37)	
			(+)	(-)	(+)	(-)	(+)	(-)
Junceffu	***Juncus effusus***	**Soft rush**					✓	
Juncinfl	*Juncus inflexus*	Hard rush					✓	
Lathprat	***Lathyrus pratensis***	**Meadow vetchling**		✓	✓			
Leonhisp	***Leontodon hispidus***	**Rough hawkbit**	✓					✓
Leucvulg	*Leucanthemum vulgare*	Ox-eye daisy						✓
Linucath	*Linum catharticum*	Fairy flax						✓
Lolipere	*Lolium perenne*	Perennial rye-grass				✓		
Lotucorn	***Lotus corniculatus***	**Bird's-foot trefoil**	✓		✓			
Lotupedu	***Lotus pedunculatus***	**Greater bird's-foot**					✓	
Medilupu	*Medicago lupulina*	Black medick			✓			
Myosramo	*Myosotis ramosissima*	Early forget-me-not						
Phleprat	*Phleum pratense*	Timothy				✓		
Planlanc	*Plantago lanceolata*	Ribwort plantain			✓			
Planmajo	*Plantago major*	Greater plantain					✓	
Poaannu	*Poa annua*	Annual meadow-grass						
Poatriv	*Poa trivialis*	Rough meadow-grass						
Poterept	*Potentilla reptans*	Creeping cinquefoil						
Prunvulg	*Prunella vulgaris*	Self-heal						
Ranuacri	***Ranunculus acris***	**Meadow buttercup**					✓	
Ranurepe	*Ranunculus repens*	Creeping buttercup			✓			✓
Rhinmino	*Rhinanthus minor*	Yellow rattle						
Rosacani	*Rosa canina*	Dog rose						
Rubufrutagg	*Rubus fruticosus agg*	Bramble				✓		✓
Senejaco	*Senecio jacobaea*	Ragwort						
Trifprat	*Trifolium pratense*	Red clover						✓
Trifrepe	***Trifolium repens***	**White clover**		✓				
Urtidioi	*Urtica dioica*	Nettle				✓		
Vicicrac	*Vicia cracca*	Tufted vetch						

Table 4.4: TWINSPAN results – Bold highlights potential indicators from literature review (continued)

4.9 *DETRENDED CORRESPONDENCE ANALYSIS (DCA) - DECORANA*

To further establish potential indicator species, a Detrended Correspondence Analysis (DCA) was ran in DECORANA, using the vegan package in R (Oksanen et al., 2015). This can help identify species responses to years since creation, and further environmental and management variables. Analysis was also run for plant family abundance. Plant families can be easier to identify than individual species as they often share traits. This would be desirable in the context of this study. Full code is presented in Appendix 7. Method used as recommended by Gauch (1982), with detailed method following Oksanen's R vignette (2015). DCA was run on individual site data, and Group A and B species.

The graphical outputs of DCA are a better way to understand the results and identify trends in the floral data. The writer of the tool himself sees "ordination primarily as a graphical tool, and (does) not show too much exact numerical results" (Oksanen, 2015). However, Table 4.5 shows the output of the DCA analysis by for the first 4 axes, for each separate data analysis. Eigenvalues do not indicate excessively high variance. Detailed DCA output for each quadrat, and each species per site, is provided in Appendix 3.

Dataset	Output	DCA 1	DCA2	DCA3	DCA4
Attenborough Nature Reserve	Eigenvalues	0.2087	0.12449	0.11216	0.11303
	DCA values	0.2096	0.08806	0.04629	0.01621
	Axis lengths	1.3224	1.02063	0.99836	1.03343
Brandon Marsh	Eigenvalues	0.4104	0.2300	0.19413	0.04187
	DCA values	0.4230	0.2371	0.07589	0.02436
	Axis lengths	2.4699	1.8165	1.67628	0.72927
Houghton Regis	Eigenvalues	0.3379	0.1805	0.10194	0.183098
	DCA values	0.3717	0.2043	0.03903	0.007211
	Axis lengths	1.8935	1.5910	1.05075	1.615138
King's Meadow	Eigenvalues	0.2987	0.1936	0.09478	0.12556
	DCA values	0.3199	0.1933	0.03961	0.01226
	Axis lengths	1.8752	1.7987	0.92604	1.24615
North Cave	Eigenvalues	0.3144	0.1806	0.11800	0.07268
	DCA values	0.3484	0.1559	0.06189	0.02232
	Axis lengths	2.1768	1.5511	1.31819	1.09530
Parc Slip	Eigenvalues	0.3303	0.1813	0.07539	0.07284
	DCA values	0.3794	0.1512	0.10657	0.03874
	Axis lengths	1.7987	1.5506	0.93569	0.98497
Ryton Meadow	Eigenvalues	0.1962	0.1793	0.11226	0.089364
	DCA values	0.2536	0.1621	0.05369	0.007479
	Axis lengths	1.4484	1.4011	1.11777	0.947470
Ufton Fields	Eigenvalues	0.3478	0.2269	0.15090	0.11451
	DCA values	0.3680	0.2772	0.08099	0.02092
	Axis lengths	2.1641	1.9732	1.34403	1.32215
Whittleford Park	Eigenvalues	0.4125	0.3357	0.2558	0
	DCA values	0.5129	0.3942	0.1055	0
	Axis lengths	2.5327	2.2307	1.9036	0

Table 4.5: DCA output for individual sites

Dataset	Output	DCA 1	DCA2	DCA3	DCA4
Group A	Eigenvalues	0.2612	0.2286	0.2082	0.1890
	DCA values	0.3501	0.2200	0.1889	0.1568
	Axis lengths	2.7470	2.1315	2.2078	1.9883
Group B	Eigenvalues	0.3223	0.2303	0.2648	0.2244
	DCA values	0.5022	0.3415	0.2792	0.1900
	Axis lengths	2.6858	2.1079	2.2909	2.0927

Table 4.6: DCA output for floral Groups

Dataset	Output	DCA 1	DCA2	DCA3	DCA4
Families	Eigenvalues	0.1754	0.2029	0.2009	0.1388
	DCA values	0.3373	0.2641	0.1857	0.1131
	Axis lengths	2.2207	2.1347	2.3712	1.6751

Table 4.7: DCA output for floral families

As no axis length in any set is longer than 4, the data is not heterogeneous enough to require unimodal analysis. As such, a linear analysis was undertaken in line with Šmilauer & Lepš (2014).

4.9.1 Graphical output of DCA

Configuration of the analysis allowed the ordination to assess the importance of further explanatory variables and the potential indicators relating to these. It would be beneficial to show indicator species signifying time since creation, especially if this can be linked to species richness. For species groups A and B and the family groups, further DCA analysis was ran to determine if community structure and species presence is affected by Time since creation and/or the soil type and management of the site. Table 4.8 shows the output of these analyses.

Group A species	DCA 1	DCA 2	R2	Pr (>r)	Significance
Time since creation	0.67837	0.73472	0.0539	0.092	.
Soil Type	0.93368	0.35812	0.0953	0.009	**
Management	0.00507	-0.9999	0.1717	0.002	**
Group B species	**DCA 1**	**DCA 2**	**R2**	**Pr (>r)**	**Significance**
Time since creation	0.77143	0.63632	0.1203	0.004	**
Soil Type	-0.50616	0.86244	0.0812	0.011	*
Management	-0.49967	-0.86622	0.0265	0.295	
Families	**DCA 1**	**DCA 2**	**R2**	**Pr (>r)**	**Significance**
Time since creation	-0.01908	0.99982	0.0122	0.557	
Soil Type	0.89309	0.44987	0.2401	0.001	***
Management	0.34748	-0.93769	0.1029	0.005	**
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Permutation: free Number of permutations: 999					

Table 4.8: DCA output with significance codes of explanatory variables

Group B species show a greater correlation to time since creation than Group A species, although both show some level of significance. Group B species show a stronger correlation with management and soil type, highlighting the continual importance of these factors on community structure. As an additional check, any resulting indicator species were checked for habitat inclusion across a broad range of grasslands. Time since creation does not seem to be indicated within the family groups. Both axes DCA 1 and DCA 2 show a positive relationship with time since creation.

The following plots visually displays the potential indicator species in relation to the Y variable time since creation and other site specific variables Site Info (soil type) and Management.

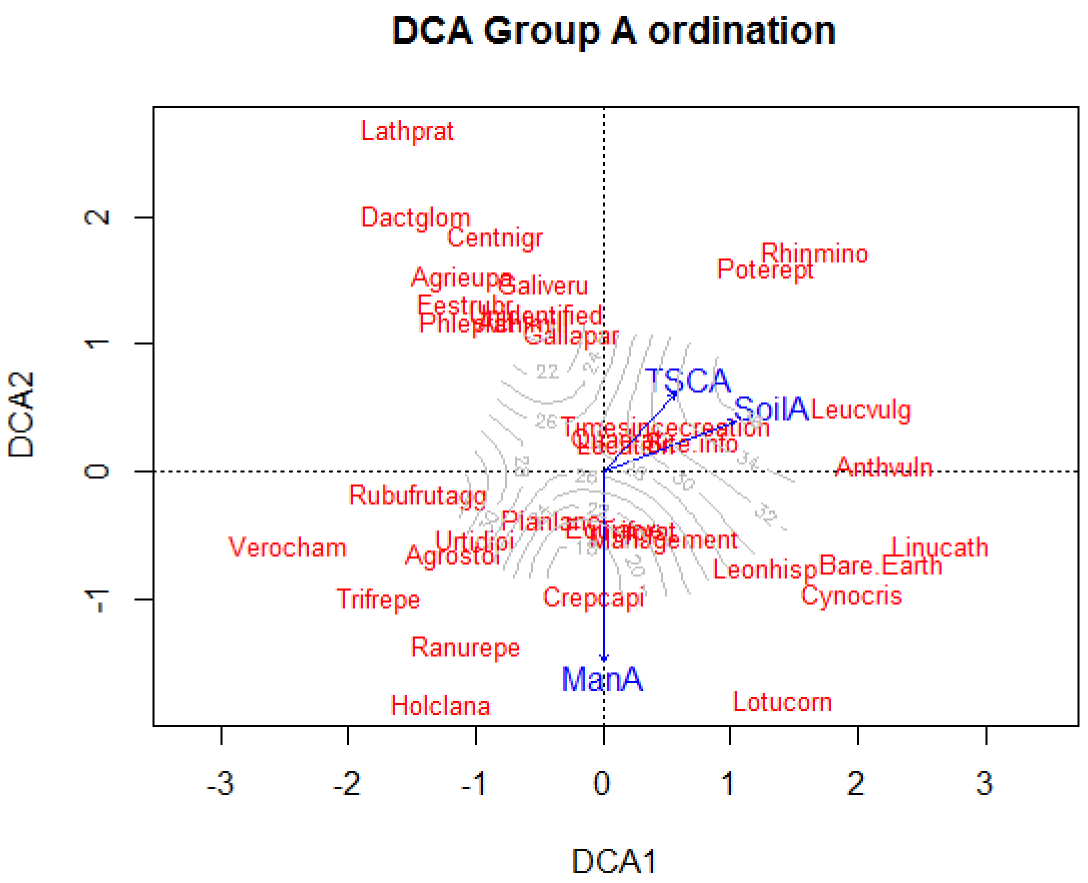


Figure 4.84: Indicator species for Group A associated with management, Site info (soil type) and Y variable time since creation (where ManA = Management, TSCA = Time since creation, Soil A = Soil Type)

From this ordination the main species associated with time from Group A species are Yellow rattle *Rhinanthus minor*, Creeping cinquefoil *Potentilla reptans*, and to a lesser extent Ox-eye daisy *Leucanthemum vulgare.* Yellow rattle *Rhinanthus minor* is frequently associated with a desirable reduction in grass species in relation to herbs, and an improvement of grassland quality. Creeping cinquefoil *Potentilla reptans*, often considered a weed on decorative lawns, can be a valuable contribution to grasslands, for example in providing food sources to butterfly larvae such as the Grizzled Skipper *Pyrgus malvae* (Butterfly Conservation, 2015). These three species are relatively easy to identify, especially Ox-eye daisy for which there are few if any others that look similar. This flower is commonly seen even in urban areas or on road sides.

Figure 4.85 shows the same ordination undertaken for Group B species, which showed a higher correlation with time since creation.

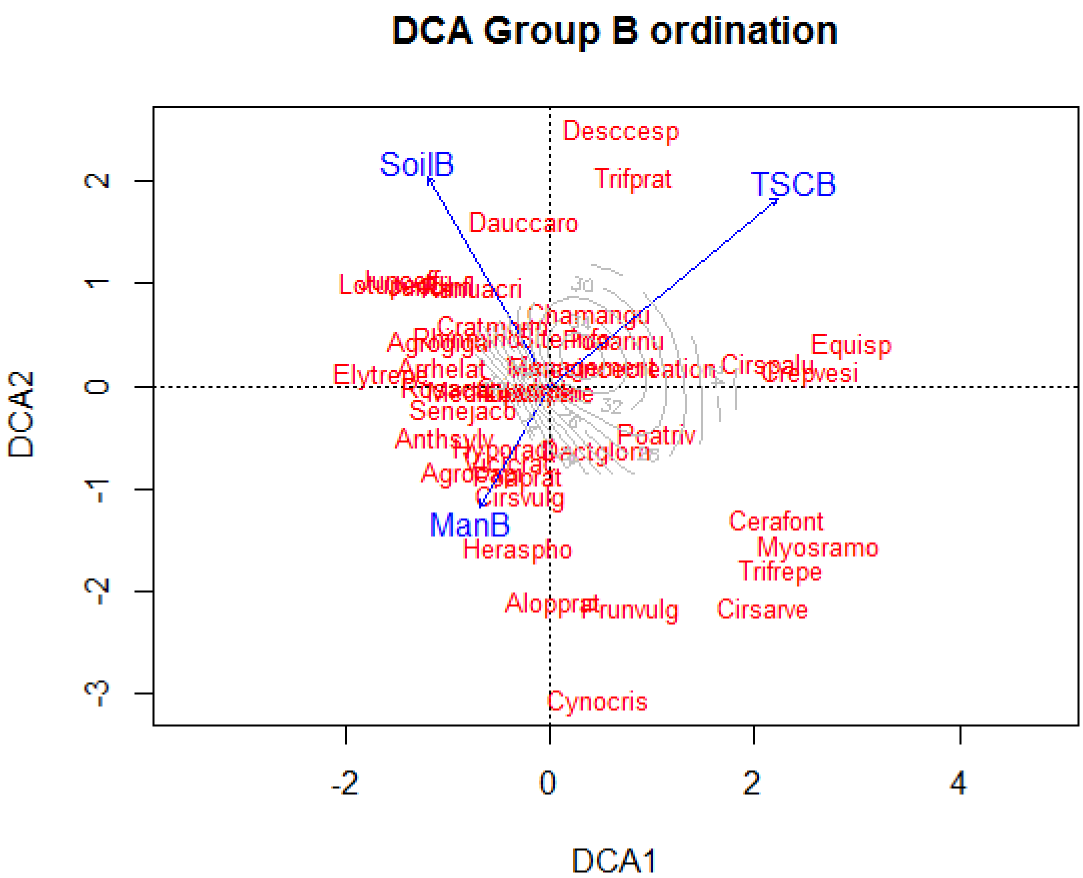


Figure 4.85: Indicator species for Group B associated with management, Site info (soil type) and Y variable Time since creation (where ManB = Management, TSCB = Time since creation, Soil B = Soil Type)

This plot identifies key species Red clover *Trifolium pratense,* Tufted hair-grass *Deschampsia cespitosa*, Marsh thistle *Cirsium palustre* , Horsetail sp. *Equisetum sp.*, Annual meadow-grass *Poa annua*, and Rose-bay willow-herb *Chamerion angustifolium*. With the exception of red clover, these species are more challenging to identify with other species bearing close resemblance (e.g. Common horsetail *Equisetum arvense*, Smooth meadow-grass *Poa pratensis*).

4.10 Desirable indicator levels

In the preceding sections, a number of potential indicators, both individual species and community, have been identified as indicators of created grasslands with a focus on time. The vast majority of indicator species identified by statistical analysis are established indicators located in the literature. The final stage of this analysis required us to establish the levels of effect of indicators, both negative and positive. Attempts can then be made to link these with Ecosystem Service provision. This can allow the appreciating value over time be properly represented in the second stage of the study.

Table 4.9 summarises all potential indicators, their means of identification and currently known optimal/non-optimal values extracted from the literature.

Indicator name		**Identification of indicator**	**Negative/ positive**	**Applicable grassland types**	**Optimum/Non-optimal levels (literature)**
Individual species	*Agrimonia eupatoria* (Common agrimony)	TWINSPAN Literature	Negative Positive	Most	Present (CG6, MG5)
	Arrhenatherum elatius (False oat-grass)	TWINSPAN Literature	Negative	Most	<10% of sward
	Bare Earth	Literature TWINSPAN	Negative	All	<5%
	Cerastium fontanum (Common Mouse-Ear)	TWINSPAN	Positive	Most	Presence
	Chamerion angustifolium (Rose-bay willow-herb)	DECORANA	Positive	Mostly calcareous	Presence
	Cirsium palustre (Marsh thistle)	DECORANA	Positive	Wet grasslands	Presence
	Dactylis glomerata (Cock's foot)	TWINSPAN Literature	Negative	All	<10% of sward
	Daucus carota (Wild carrot)	Literature TWINSPAN	Positive	Most (Pioneer)	Presence (newly created)
	Deschampsia cespitosa (Tufted hair-grass)	Literature DECORANA	Negative	Most	<10% of sward
	Equisetum sp. (Horsetail sp.)	Literature DECORANA	Negative	Most	No more than "rare" (<5%)

Table 4.9: Summary of indicator species identified in analysis of first hand data – greyed out rows indicate species which have conflicting outcomes on their indicative qualities (continues)

Indicator name		Identification of indicator	Negative/ positive	Applicable grassland types	Optimum/Non-optimal levels (literature)
Individual species	*Holcus lanatus* (Yorkshire Fog)	Literature TWINSPAN	Negative	Most	Individually <10%, collectively <20%
	Lathyrus pratensis (Meadow vetchling)	Literature TWINSPAN	Positive Negative	Most; damp	Presence
	Leontodon hispidus (Rough hawkbit)	Literature TWINSPAN	Positive	All	Presence
	Leucanthemum vulgare (Ox-eye daisy)	Literature DECORANA	Positive	All	Present in newly created grasslands
	Lotus corniculatus (Bird's-Foot trefoil)	Literature TWINSPAN	Positive	All (Pioneer)	Presence
	Poa annua (Annual meadow-grass)	DECORANA	Positive	All	Presence
	Potentilla reptans (Creeping cinquefoil)	Literature DECORANA	Positive	Most; disturbed	Presence
	Rhinanthus minor (Yellow rattle)	Literature DECORANA	Positive	All	Presence
	Trifolium pratense (Red clover)	DECORANA	Positive	All	Presence
	Trofilium repens (White clover)	Literature TWINSPAN	Negative	All	Individually <10%, collectively <20%
Community variables	Species richness	Literature	Positive on increase	All	Presence
	Species diversity	Literature	Positive on increase	All	Presence
	Herb:grass ratio	Literature	Positive (herb)	All	40-60% herb cover
	Quadrat mean height (cm)	Literature	Positive (with height)	All	Varied – no taller than 80cm except in hay meadows

Table 4.9: Summary of indicator species identified in analysis of first hand data – greyed out rows indicate species which have conflicting outcomes on their indicative qualities (continued)

It is interesting that the vast majority of potential indicators identified by TWINSPAN and DECORANA analyses were also identified in the literature search and are already often used as indicators for natural grasslands as was hypothesised. Many of the outputs of the cluster and correspondence analysis followed the expected results extracted from the literature. However, a small number of species diverged from expected output. *Lathyrus pratensis* (Meadow vetchling) and *Agrimonia eupatoria* (Common agrimony), positive indicators identified in the literature, were negative indicators in the TWINSPAN analysis. Due to uncertainty of these species as indicators, they were excluded in the context of this study. If these sites, and further sites could be re-sampled in future, these potential indicators may be understood further.

4.10.1 Community bioindicators variables

The literature review revealed that habitat quality is often associated with changes in community variables. Species richness in particular is of interest due to theoretical link to Ecosystem Service provision and therefore value. Our relevant variables comprise species richness, species diversity, quadrat mean height (with upper limit), and herb:grass ratio. The following Pearson correlation plot shows these variables against Time since creation. The size of the circle relates to the influence of the correlation.

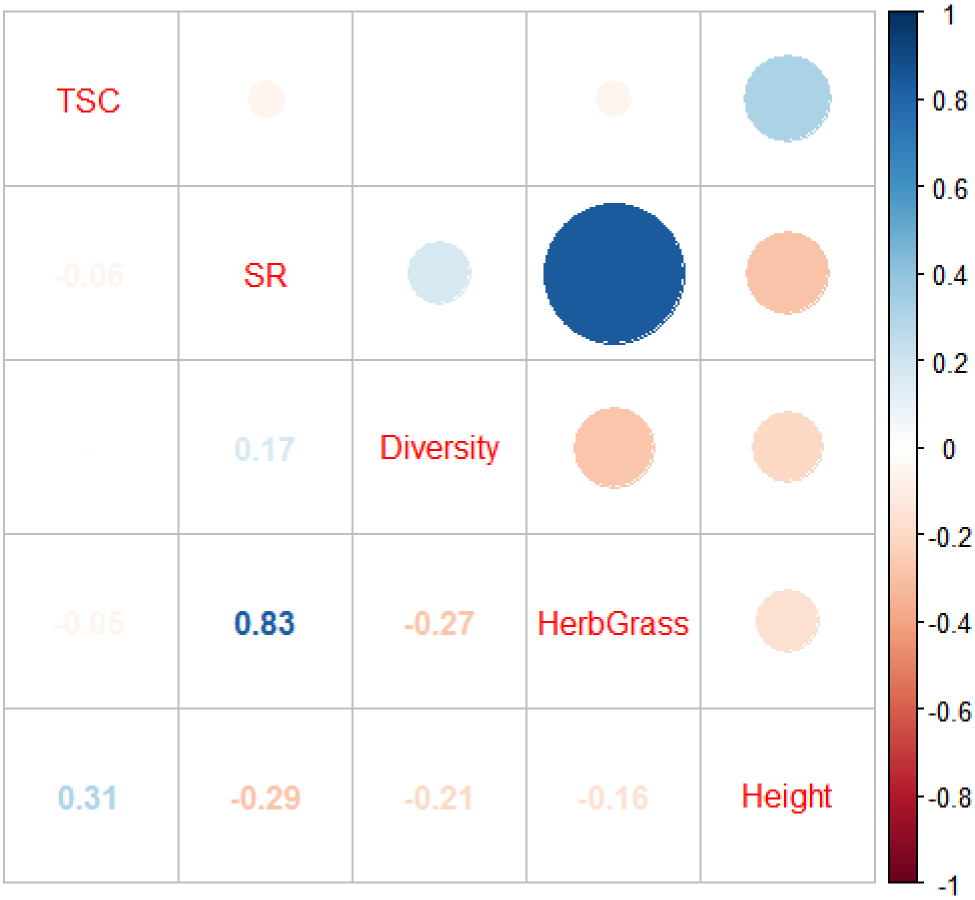
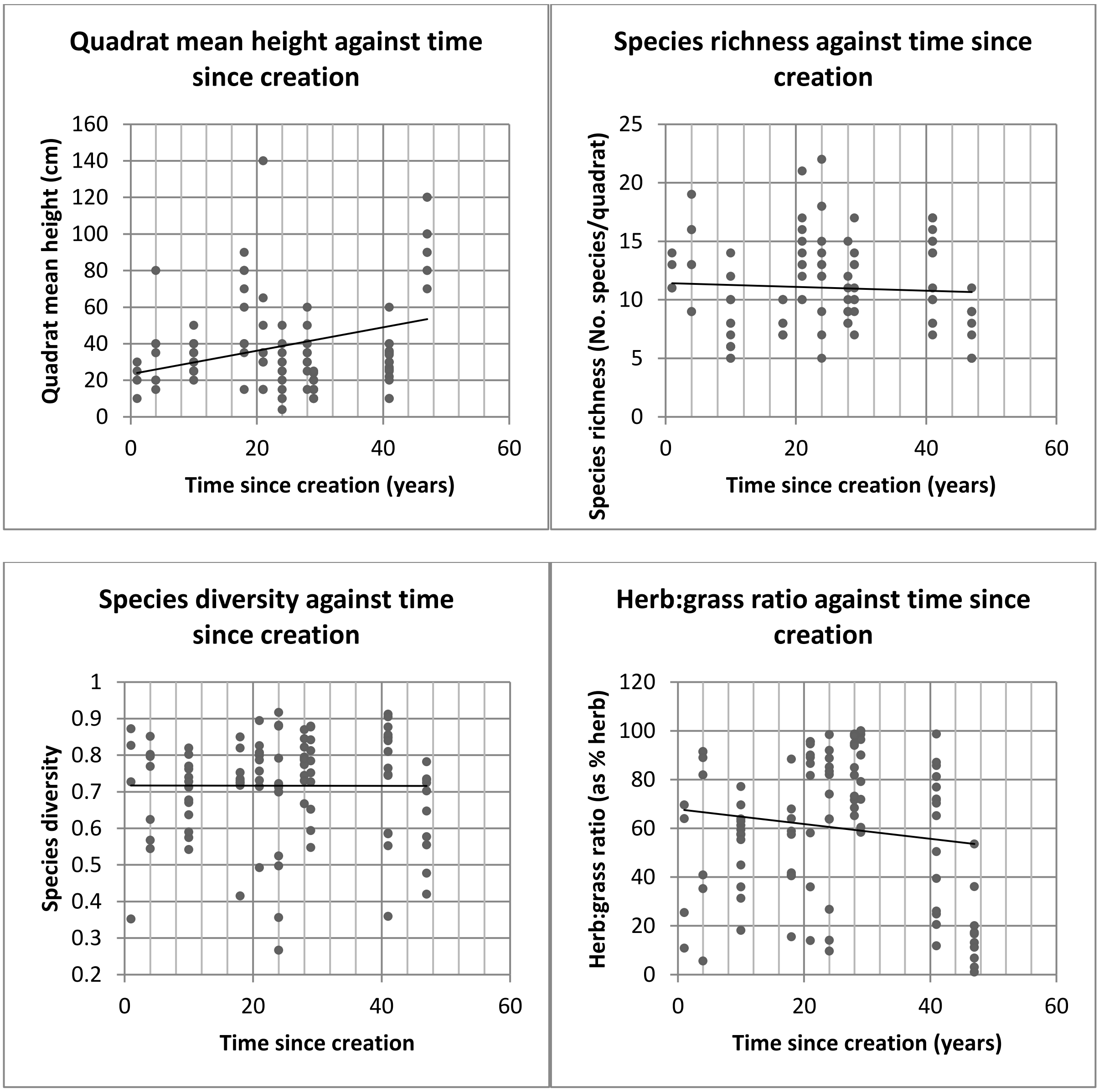


Figure 4.86: Correlation plot showing effect of time since creation on species richness (SR), species diversity (Diversity), quadrat height (Height) and herb:grass (HerbGrass) ratio

This plot shows there is no correlation between species diversity against time since creation. A weak correlation between species richness and herb:grass ratio and time since creation. A stronger positive correlation exists between quadrat height (cm) and time since creation. Herb:grass ratio shows a very strong positive correlation with species richness. To investigate this further, scatterplots were drawn including best-fit line. Figures 4.87 to 4.90 highlight the relationships between these community variables and time since creation.



Figures 4.87 to 4.90: the relationships between quadrat mean height, species richness, species diversity and herb:grass ratio against time since creation.

Examining these plots begins to explain the unexpected negative correlation. Although Species richness and herb:grass ratio appear to increase with time, it decreases sharply in line with the oldest set of quadrats, Attenborough Nature Reserve (47 years post creation). The excessive heights of the quadrats at Attenborough Nature Reserve also strongly influence the effect of height on time. As discussed in Section 4.4, this grassland contains an abundance of tall, undesirable grass species and invading woody species (e.g. hawthorn *Crataegus monogyna)*. It is therefore indicated that this site is, despite its age, is of lower biodiversity value. This is reinforced by the quadrat height generally exceeding upper limits of recommended quadrat height. To test this, the quadrats from Attenborough Nature Reserve were examined for known negative indicators (taken from Section 2.4).

Indicator name		**Optimum/Non-optimal levels (literature)**	**Presence at Attenborough Nature Reserve**	**Abundance**
Individual species	*Agrimonia eupatoria* (Common agrimony)	Present (CG6, MG5)	✗	-
	Arrhenatherum elatius (False oat-grass)	<10% of sward	✓(8/10 quadrats)	3-75%
	Bare Earth	<5%	✗	-
	Dactylis glomerata (Cock's foot)	<10% of sward	✓(4/10 quadrats)	1-25%
	Deschampsia cespitosa (Tufted hair-grass)	<10% of sward	✗	-
	Equisetum sp. (Horsetail sp.)	No more than "rare"	✗	-
	Holcus lanatus (Yorkshire Fog)	Individually <10%, collectively <20%	✓(5/10 quadrats)	1-65%
	Lathyrus pratensis (Meadow vetchling)	Present	✗	-
	Trofilium repens (White clover)	Individually <10%, collectively <20%	✗	-
Community variables	Quadrat mean height (cm)	No taller than 80cm	✓(9/10 quadrats)	

Table 4.10: Presence and levels of identified indicators at Attenborough Nature Reserve

From analysis so far, it has been shown Attenborough Nature Reserve contained a number of undesirable species. It also had a low proportion of indicators of stable communities.

Three negative indicators were present in the sward, often with high abundance of up to 75% of the quadrat. These high proportions of undesirable grasses, the low herb ratio, and excessive quadrat height, along with noted woody species outside of the quadrats (Hawthorn *Crataegus monogyna,* Dock *Rumex* sp.), would indicate that despite the age of this site, it remains a poor quality grassland. To test this further, the data from Attenborough Nature Reserve was removed from the dataset and the correlation analysis re-ran. These results are shown below.

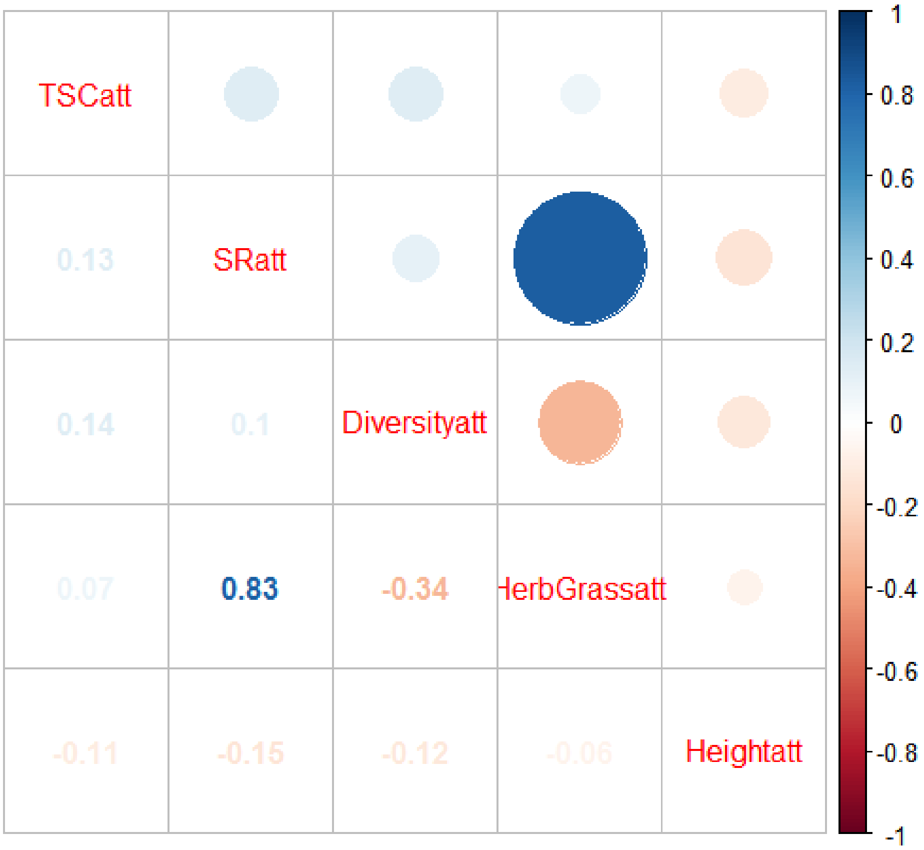
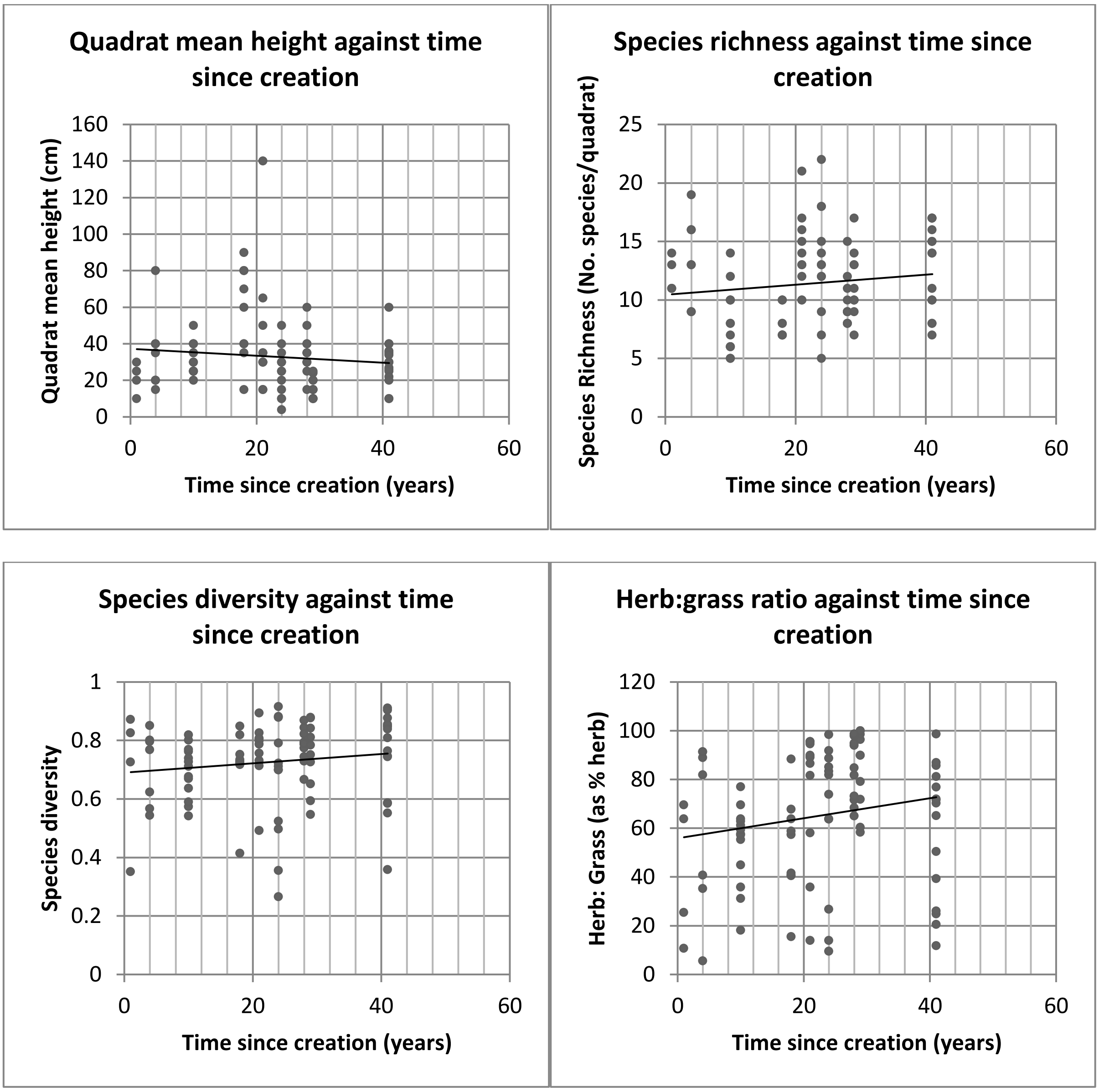


Figure 4.91: Correlation between Time since creation and community variables with Attenborough Nature Reserve data removed.



Figures 4.92 – 4.95: the relationships between quadrat mean height, species richness, species diversity and herb:grass ratio against time since creation on all sites except Attenborough Nature Reserve.

Once Attenborough Nature Reserve has been taken out of the dataset, the results act more in line with theory. The correlation between quadrat height and time since creation is reduced, while the correlations with species richness, diversity and herb:grass ratio increase and become positive. This has helped support the usefulness of the currently identified bioindicators of created grassland. This is an important output of the study. It also indicates that Time since creation does not automatically imply higher biodiversity value.

Now that reference to current knowledge, and statistical analysis has identified indicators of created grassland quality over time, how are these indicators represented specifically on our sites? Which of our sites fulfil the indicator criteria are noted in Table 4.11.

Species/community indicator		***Arrhenatherum elatius* (False oat-grass)**	**Bare Earth**	***Cerastium fontanum* (Common Mouse-Ear)**	***Chamerion angustifolium* (Rose-bay willow-herb)**	***Cirsium palustre* (Marsh thistle)**	***Dactylis glomerata* (Cock's foot)**	***Daucus carota* (Wild carrot)**	***Deschampsia cespitosa* (Tufted hair-grass)**	***Equisetum sp.* (Horsetail)**	***Holcus lanatus* (Yorkshire Fog)**	***Leontodon hispidus* (Rough hawkbit)**
Guideline cut offs for indicator	Number of quadrats	>10% of sward	>5%	Presence	Presence	Presence on wet grassland	>10% of sward	Presence (newly created[a])	>10% of sward	>5%	Individually >10% or collectively >20%	Present in newly created grasslands
Indicator met? Average across site (sub-site where applicable): Attenborough	10	✓ 17%	×	×	✓	NA	✓ 11%	NA	×	×	✓ 22% (C)	NA
Brandon (1)	9	×	×	✓	✓	✓	×	NA	×	×	✓ 25% (I)	NA
Brandon (2)	3	×	×	✓	×	×	×	NA	×	×	✓ 25% (I)	NA
Houghton Regis	10	×	✓ 6%	×	×	NA	×	NA	×	×	✓ 25% (I)	NA
King's Meadow	10	×	✓ 7%	×	✓	NA	×	NA	×	×	×	NA
North Cave(1)	7	×	×	✓	×	×	×	×	×	×	✓ 65% (I)	✓
North Cave(2)	6	✓ 11%	×	✓	×	×	×	✓	×	×	✓ 35% (I)	×
North Cave(3)	4	×	×	×	×	×	×	×	×	×	×	×
Parc Slip (1)	3	×	×	×	×	✓	×	NA	×	×	×	NA
Parc Slip(2)	3	×	✓ 7%	×	×	✓	×	×	×	×	✓ 10% (I)	NA
Parc Slip (3)	4	×	×	×	×	✓	×	×	×	×	×	NA
Ryton(1)	3	×	×	×	×	NA	×	NA	×	×	×	NA
Ryton(2)	3	✓ 12%	×	×	×	NA	×	NA	×	×	×	NA
Ryton(3)	3	✓ 23%	×	×	×	NA	×	NA	×	×	×	NA
Ufton Fields (1)	12	×	×	×	×	NA	×	NA	×	×	✓ 75% (I)	NA
Ufton Fields (2)	3	✓ 24%	×	×	×	NA	×	NA	×	×	×	NA
Whittleford	7	×	✓ 6%	✓	×	NA	×	✓	×	×	×	×

[a] Newly created is assumed to be less than or equal to 10 years old

Table 4.11: Levels of potential indicators at all created grassland sites with negative indicators in grey (continues)

Species/community indicator			*Leucanthemum vulgare* (Ox-eye daisy)	*Lotus corniculatus* (Bird's-Foot trefoil)	*Poa annua* (Annual meadow-grass)	*Potentilla reptans* (Creeping cinquefoil)	*Rhinanthus minor* (Yellow rattle)	*Trifolium pratense* (Red clover)	*Trofilium repens* (White clover)	Species richness	Species diversity	Herb:grass ratio (% herb cover)	Quadrat mean height (cm)
Guideline cut offs for indicator		Number of quadrats	Presence (newly created[a])	Presence	Presence	Presence	Presence	Presence	Individually >10%, collectively >20%			40-60% herb cover	Varied – < 80cm not hay meadows
Indicator met? Average across site (sub-site where applicable)	Attenborough	10	NA	×	✓	×	×	×	×	7.7	0.64	18%	95
	Brandon (1)	9	NA	✓	✓	✓	×	✓	✓ 25% (I)	14	0.61	62%	24
	Brandon (2)	3	NA	✓	×	×	×	×	✓ 35% (I)	10.7	0.83	74%	25
	Houghton Regis	10	NA	✓	×	×	×	✓	×	11	0.75	84%	16
	King's Meadow	10	NA	✓	✓	✓	✓	✓	×	14.1	0.76	74%	45
	North Cave(1)	7	×	✓	✓	×	×	×	×	9.7	0.7	51%	31
	North Cave(2)	6	✓	✓	✓	×	×	×	×	6.5	0.69	67%	34
	North Cave(3)	4	✓	✓	×	×	×	×	✓ 15% (I)	12.3	0.69	42%	21
	Parc Slip (1)	3	NA	×	×	✓	×	×	✓	12.7	0.77	83%	50
	Parc Slip(2)	3	NA	✓	×	×	×	×	×	8	0.79	79%	35
	Parc Slip (3)	4	NA	✓	×	×	×	×	×	9.3	0.79	86%	26
	Ryton(1)	3	NA	✓	×	✓	×	×	×	8.3	0.76	56%	45
	Ryton(2)	3	NA	✓	×	×	×	✓	×	8	0.73	54%	55
	Ryton(3)	3	NA	✓	×	✓	×	×	×	8	0.66	48%	70
	Ufton Fields (1)	12	NA	✓	✓	×	✓	✓	×	13.5	0.77	63%	30
	Ufton Fields (2)	3	NA	×	×	✓	×	×	×	9	0.68	44%	27
	Whittleford	7	✓	✓	✓	×	✓	✓	×	13.6	0.7	62%	36

[a] Newly created is assumed to be less than or equal to 10 years old

Table 4.11: Levels of potential indicators at all created grassland sites with negative indicators in grey (continued)

The total number of positive and negative indicator species was calculated per sub-site. This is presented in Table 4.12 below.

Site name	Time since creation (at time of fieldwork)	No. of negative species indicators	No. of positive species indicators (no. for new grasslands)	Mean site species richness	Herb percent	Mean quadrat height (cm)
North Cave(3)	1	1	5	12.3	42	21
Whittleford Park	4	1	6	13.6	62	36
North Cave(1)	10	1	3 (+1)	9.7	51	31
North Cave(2)	10	2	5	6.5	67	34
Ryton(1)	18	0	2	8.3	56	45
Ryton(2)	18	1	2	8	54	55
Ryton(3)	18	1	2	8	48	70
King’s Meadow	21	1	6	14.1	74	45
Brandon (1)	24	1	7	14	62	24
Brandon (2)	24	2	2	10.7	74	25
Parc Slip (1)	28	1	2	12.7	83	50
Parc Slip(2)	28	2	2	8	79	35
Parc Slip (3)	28	0	2	9.3	86	26
Houghton Regis	29	2	2	11	84	16
Ufton Fields (1)	41	1	4	13.5	63	30
Ufton Fields (2)	41	1	1	9	44	27
Attenborough	47	2	2	7.7	18	95

Table 4.12: Presence of indicator values by site – sorted by time since creation

Attenborough Nature Reserve’s data had already been discussed regarding its effect on indicator significance. Using the established indicator set it was clear that the grassland had some undesirable species and characteristics despite its age. Of particular note is its high mean quadrat vegetation height (95cm) and comparably low site species richness (7.7).

4.10.2 Species richness

Across the literature, species richness has long been used as a descriptor for plant and animal communities, for example responses to human impacts or general biodiversity of a site. On the whole higher species richness is desirable but in some contexts this is mitigated by other factors such as nutrient loading. In grasslands showing under disturbance, more species-rich swards were found to be more resilient (Tilman & Downing, 1994). As discussed in Section 2.2.7, species richness can be used as a proxy indicator of biodiversity (Costanza et al., 2007). Time since creation has been shown to have a mildly positive effect on species richness. To investigate further, the links between our positive and negative species indicators are now studied. This can strengthen the usefulness of the proposed indicators and their link to Ecosystem Service provision and value.

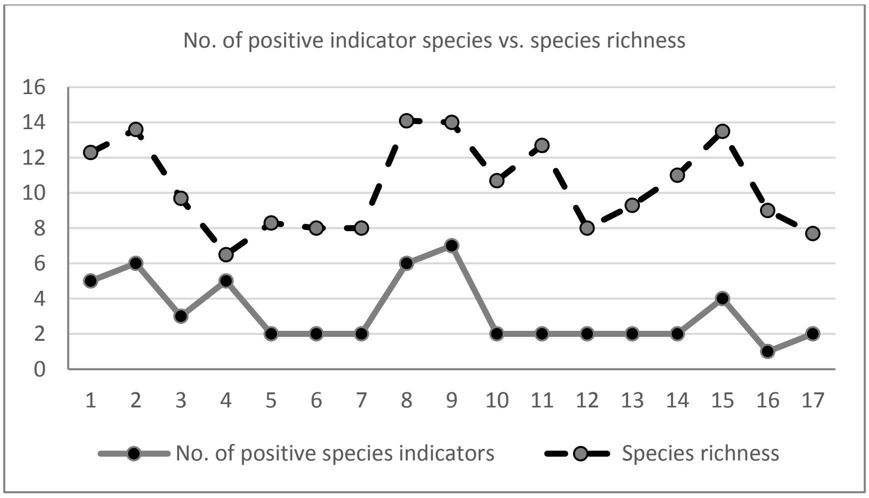


Figure 4.96: No. of positive indicator species per sub-site vs. species richness per sub-site

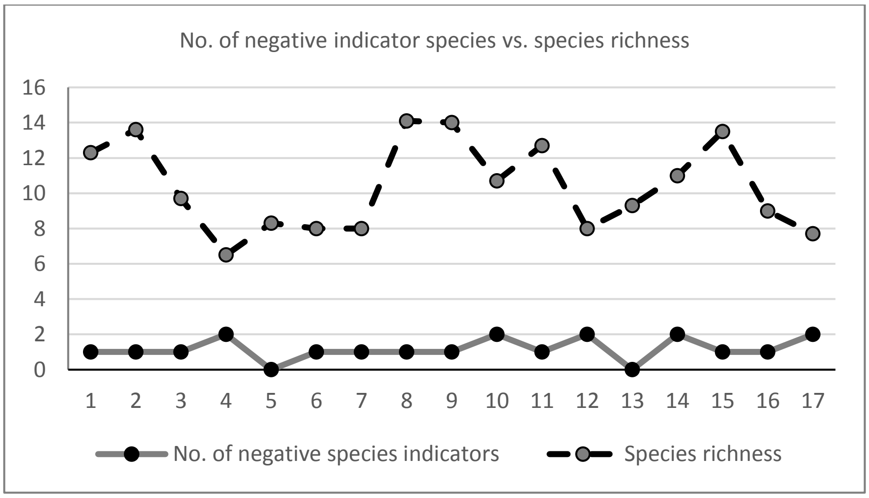


Figure 4.97: No. of negative indicator species per sub-site vs. species richness per sub-site

The number of positive indicator species on site appears to show a solid link to species richness. As these have a solid link to the literature, this is particularly encouraging for the use of these indicators on further created grasslands. As a challenge of this study is reliably linking biodiversity status to economic value, correlation with a variable with known links to Ecosystem Service provision (Section 2.2.7) is promising. Number of negative indicator species does not seem to show as obvious a correlation.

In Section 2.6.5, it was noted from results of a systematic review that a number of authors took the definition of species richness to be different. Whereas some used the above metric for site data, mean species richness, others claimed this was a different metric (Gotelli & Colwell, 2001). They, and others claim species richness is only relevant when it is not divided by any other unit, i.e. total number of species. To further test the effect this discrepancy could have on output, we now repeat the previous experiment with total species richness for our sub-sites.

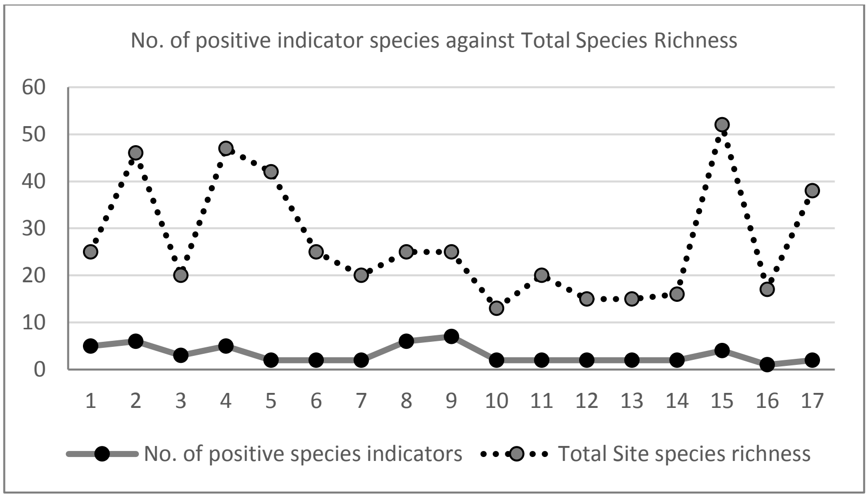


Figure 4.98: No. of positive indicator species per sub-site vs. total species richness per sub-site

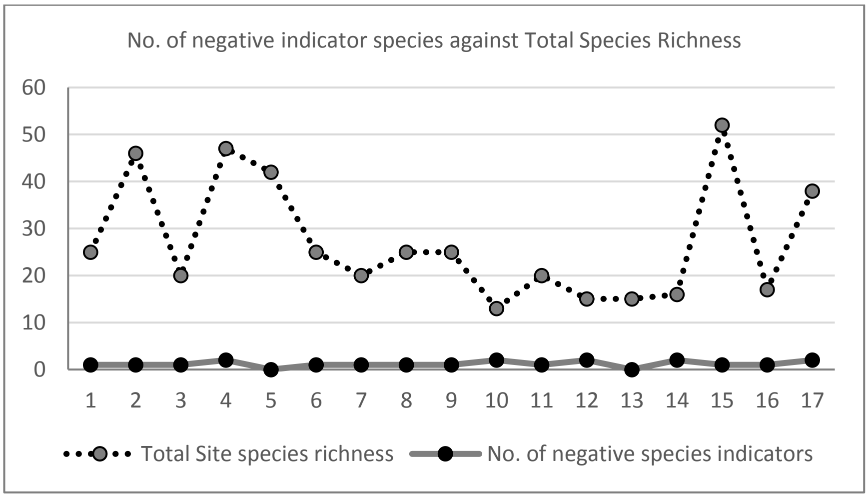


Figure 4.99: No. of negative indicator species per sub-site vs. total species richness per sub-site

To test the strength of these correlations, a correlation plot was made looking at No. of positive indicator species, no. of negative indicator species, mean species richness, total species richness, and quadrat mean height. This is presented in Figure 4.100.

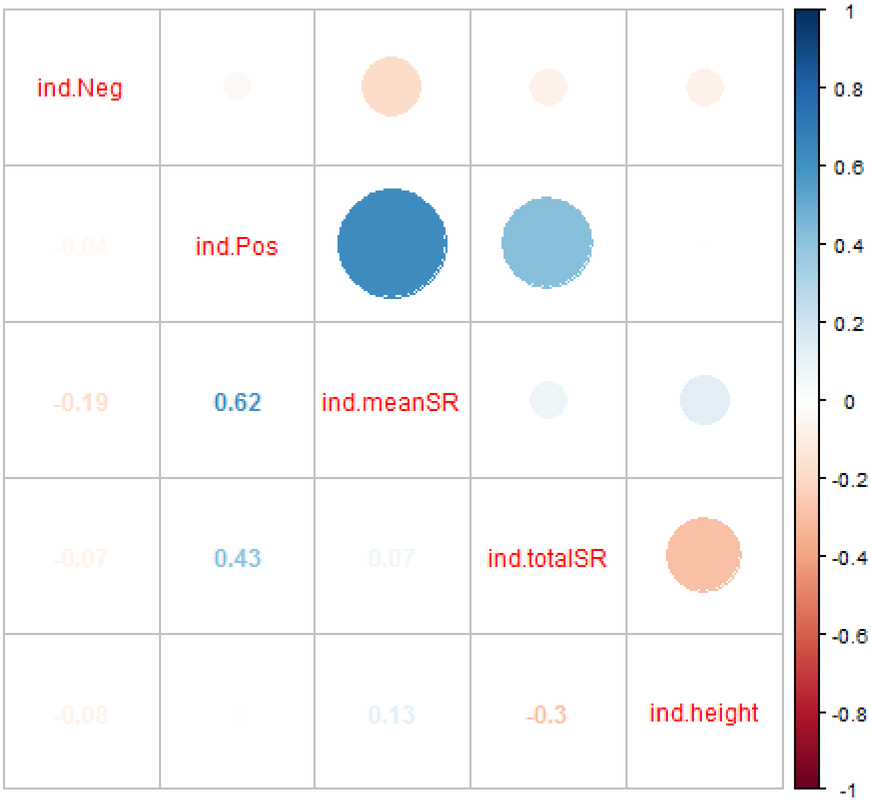


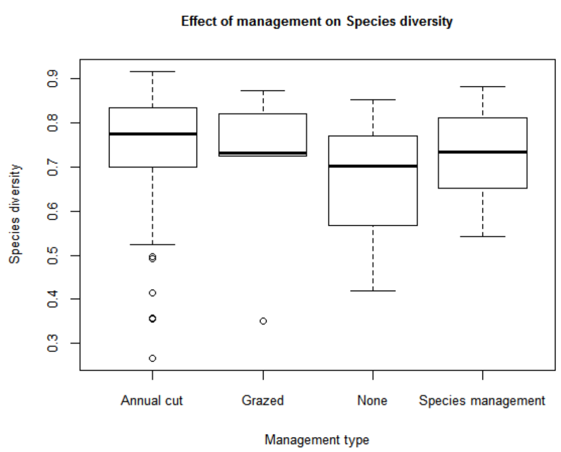
Figure 4.100: Correlation strength between no. of indicators, measures of species richness, and mean quadrat vegetative height

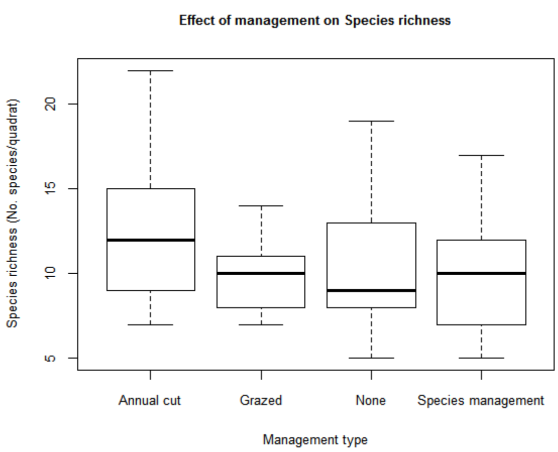
There is clearly a stronger relationship (0.62) between the no. of positive indicators on site and mean species richness, than with total species richness. However, this is still a significant correlation using Zuur, Ieno, & Elphick's cut off of 0.3 (2010). Using this cut off also shows a significant negative correlation between mean quadrat height and total species richness. In this case mean species richness was not significant. No. of negative indicators was not significantly correlated with either measure of species richness of mean quadrat height.

These findings are important as we know there is a link between species richness and NPP, or output of Ecosystem Services (Section 2.2.7). This provides us with a known means of estimating value in created grasslands using species richness, predicted by our indicator species. The value of Ecosystem Services provided by grasslands is investigated in Chapter 5. Linking the results of Chapter 4 (indicator species) and Chapter 7 (Econometric valuation) is discussed in Chapter 8.

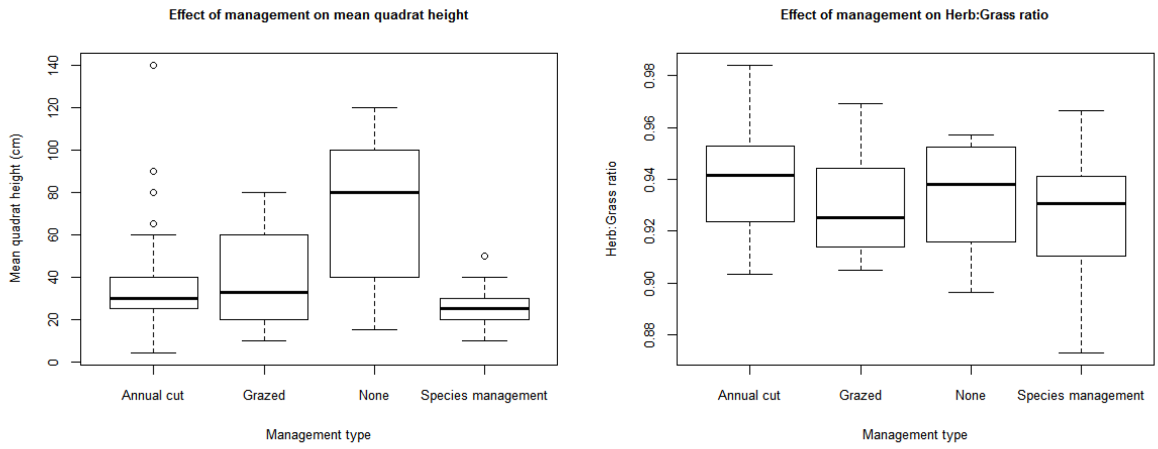
4.11 *Effect of Management*

So far this analysis has explored potential bioindicators for created grasslands. In this section, we explore the research question "Are there optimal management techniques that can be performed on created grasslands to help ensure a good quality sward?" (outlined in Section 2.3.8). We have established community bioindicators. The following plots show the effect of different management techniques on these community variables.



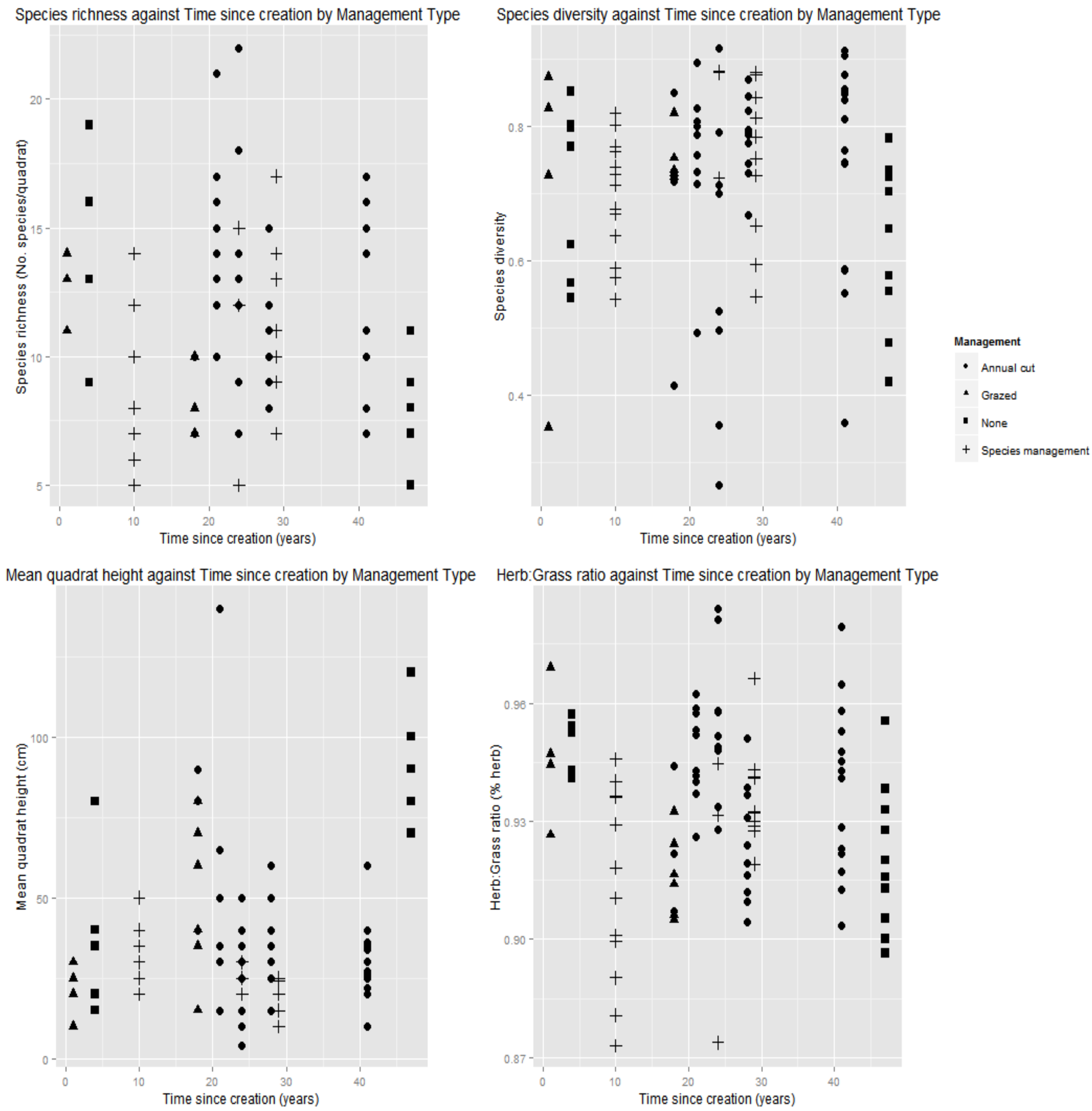


Figures 4.101 and 4.102: Effect of management on species richness and species diversity



Figures 4.103 and 4.104: Effect of management on mean quadrat height (cm) and herb:grass

These plots show the significant effect management can have on created grasslands. As discussed in Section 2.3, an annual cut can improve the long-term quality of the grassland, although it can have implications for other non-plant species. From this data, the annual cut seems to produce the highest levels of species richness, species diversity and herb:grass ratio. It also produces amongst the lowest mean quadrat height, although the main range of 20-40cm is more desirable than the 80 cm mean associated with no management. A lack of management regime also produces amongst the lowest richness, and diversity. Grazing, and species management (meaning here scrub and/or ragwort removal), produce similar means across all of the community variables. It is important to find out whether these same community gains are achieved over differing time periods. As such, the community variables were plotted against Time since creation taking management in to account.



Figures 4.105 – 4.108: Effect of management type on physiological factors against time

These results suggest a lack of management regime allows early peaks in positive indicators such as richness and diversity. In the longer term, grasslands with controlled management regimes show better results. Although species management shows poorer results in the short term, in the longer term sites with this management show comparable indicator levels as the other regimes.

4.12 EFFECT SIZES OF INDICATORS ON SPECIES RICHNESS

A suite of potential indicators have now been identified using common statistical methods. These include positive and negative indicator species, and community indicators such as mean quadrat height (cm) and herb:grass ratio. The desirable levels of these indicators are outlined in Table 3.9. Reference to the literature has identified a link between species richness as a proxy for biodiversity, and NPP, or Ecosystem Service provision (Costanza et al., 2007). A linear regression model was run to establish the significance of our identified indicator and species richness. This was based on per quadrat species richness as sample size was too small on a sub-site level (n=11). Analysis so far on species diversity may be useful for future floristic studies. However, due to its computational requirements, it is not deemed fit as a suitable indicator based on our research objectives. As such, this variable is no longer included in further study. The results of the initial regression are presented below in Table 4.13.

Indicator type	**Coefficient (Std. error)**	**Significance**
Intercept	11.35046 (8.086)	<0.0001 ***
No. positive indicators present	1.72103 (0.27892)	<0.0001 ***
No. negative indicators present	-0.68318 (0.50599)	0.1802
Quadrat mean height (cm)	-0.02978 (0.01330)	0.0275*
Herb:grass ratio (Herb %)	-0.01232 (0.01403)	0.3820
R^2	0.3482 (35%)	
p-value	<0.0001***	
***= 0.001 ** = 0.01 *=0.05 .=0.1 Marginal R^2 = Proportion of variance explained by fixed effects alone Conditional R^2 = Proportion of variance explained by fixed and random effects		

Table 4.13: Output of regression model studying indicators on species richness

All of the outputted coefficients with the exception of herb:grass ration are in line with expected results. As the number of positive indicator species increases, so does species richness. As the number of negative indicators increase, species richness reduces. The number of negative indicator species is not however a significant variable in this regression. Species richness, as expected, increases as vegetative height decreases. This variable was also significantly correlated with species richness. Herb:grass ratio, using herb percent as a proxy, decreased as species richness improved. As an increase in herb species is normally desirable, this is contrary to our hypotheses. There is however an upper limit of herb percent in a sward so perhaps this reflects this phenomena. Further fieldwork data may change these outcomes. Further study may increase the significance of the negative indicator presence and this could be included in the final model.

Insignificant results were then removed from the regression model and re-run. The results are shown below. These coefficients can be used as our link to Ecosystem Service output and therefore value in the following chapters.

Indicator type	**Coefficient (Std. error)**	**Significance**
Intercept	9.88453 (0.67840)	<0.0001 ***
No. positive indicators present	1.71463 (0.26366)	<0.0001 ***
Quadrat mean height (cm)	-0.02544 (0.01142)	0.0282*
R^2	0.3481 (35%)	
p-value	<0.0001***	
***= 0.001 ** = 0.01 *=0.05 .=0.1		

Table 4.14: Secondary output of regression model studying indicators on species richness

R^2 is reasonable for a cross-sectional regression with a small data set, especially with many unknown potential explanatory variables. The model shows a very high p-value. Not unexpectedly, there is a potential list of variables that would further explain species richness in created grasslands. These could include soil fertility or climate.

Examination of residual plots revealed no evident violations of model assumptions (shown below in Figure 4.109). Outliers refer to particularly tall vegetation. This is not anomalous in itself and was deemed unsuitable for removal.

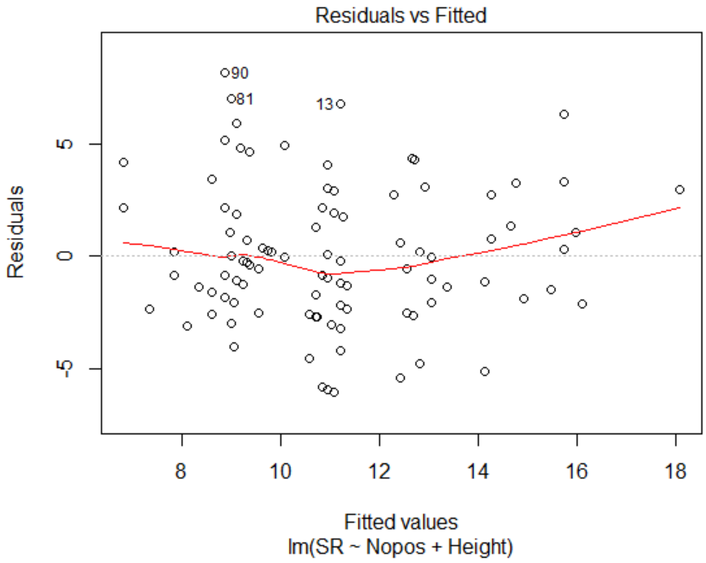


Figure 4.109: Residual plot for regression model showing effect of significant indicators on species richness

4.13 Significant Findings from Floral Community Analysis

- Potential positive and negative indicator species of grassland biodiversity sourced from an extensive literature review transferred to created grassland habitats in a number of cases (Table 2.9);
- Using common ecological statistical methods (TWINSPAN; DECORANA) on first-hand data collected from created grasslands, further indicator species were sourced (Table 4.9);
- Using these indicators, we were able to identify lower biodiversity grasslands from within the dataset;
- The number of negative indicators was not significantly correlated to species richness.
- Management of created grasslands has a strong effect on the community structure of the grassland, although further study on this would be beneficial. An annual cut appears to encourage the highest biodiversity in the long term.

- Most importantly, the number of identified positive indicators within a quadrat is significantly correlated to species richness (number of species per sample). This is also the case for mean quadrat height (cm). As species richness can be used as a proxy for biodiversity, this provides us with a link to Ecosystem Service provision (Costanza et al., 2007).

The coefficients from the final regression model provide us with the impact of number of positive indicator species per quadrat and mean vegetative height (cm) on species richness. These indicator species are one of the major contributions of the thesis. They allow quick establishment of biodiversity levels in created grassland, and crucially can predict species richness on site without the need for a full botanical survey. To emphasise the importance of this, the diagram initially presented in Figure 1.1 is altered in line with results. This is important as the link from species richness is used to inform estimated value in Chapter 7.

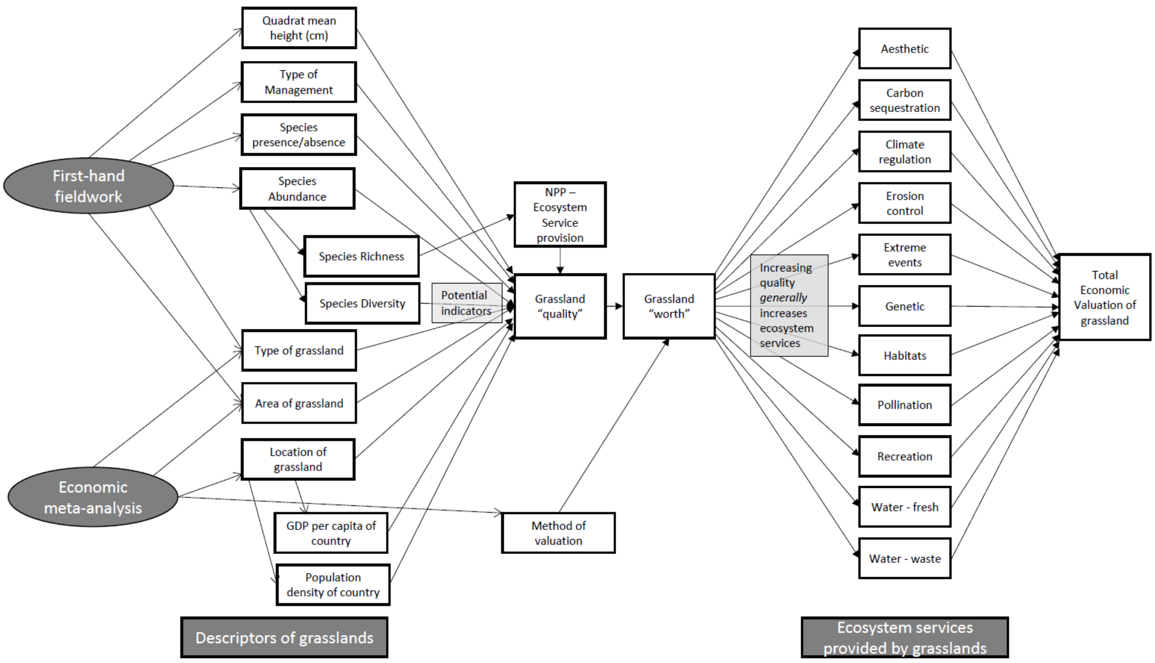


Figure 4.110: Altered diagram outlining main links and themes within the study

Theories and findings surrounding Ecosystem Service valuation is discussed and explored in the next chapter, to allow us to estimate a Value Transfer coefficient for created grasslands with different levels of biodiversity. In Chapter 7, our indicator suite is linked with transferred value to provide a model that can be used as a quick reference to Ecosystem Service provision in created grasslands.

CHAPTER 5: ECONOMIC VALUATION OF GRASSLAND HABITATS – LITERATURE REVIEW

5.1 INTRODUCTION

The previous chapter explored bioindicators of created grasslands. This identified a number of positive indicator species which are significantly correlated with species richness. Species richness, as a proxy to biodiversity, has been linked with NPP, or Ecosystem Service provision (Costanza et al., 2007). This was discussed in Section 2.2.7. In this chapter, economic application of value to Ecosystem Service provision is explored. This is to prepare for Value Transfer to UK created grasslands in Chapter 6. First, the background and importance of ecological economics is explored, along with discussion of theories of welfare economics. A systematic review of global grassland values is then undertaken. This provides us with estimates of value, along with temporal and spatial variables. Papers and their associated values are studied, and a mixed-effects model is run. A classical meta-analysis could not be performed due to heterogeneity of input data. Although variance of input data is high, and of predicted values, important inferences on the causes of the variance are made. Method of valuation has a significant effect holding other variables constant. Socio-economic aspects of the area valued are also highly significant. The importance of this is discussed, before transfer of value is undertaken in Chapter 7.

5.1.1 Background to ecological economics

Valuing the services provided to us by nature in an economic sense is a relatively recent idea spawned in the 20th century. Of course, land value has long varied according to its potential outputs. Benefits such as fertility and proximity to other services have historically generated a higher price for land.

By the 18th century this colloquial knowledge was being studied further. This became especially pertinent as more intensive agriculture began to take place and potential scarcity of land became an issue (see for example Marx, 1867-1883). The process took shape with the onset of the International Society for Ecological Economics in 1988 (first conference 1990) and the journal

Ecological Economics (first issue 1989). Since then research in the field has expanded widely. In 1997 Costanza published "The Value of the World's Ecosystems and Natural Capital". This attempt at valuing all known habitats has a citation count of 5968 on Web of Science (2015). Since then, more precise studies have been undertaken across a range of habitats. Reviews of these values and the impact of environmental and socio-economic variables have also increased (see for example Woodward & Wui, 2001; Brander, Florax & Vermaat, 2006; Brouwer et al., 1997).

5.1.2 Why economically value Ecosystem Services?

Until well in to the last century, the fields of economics and ecology were on the whole far removed from each other. Economics is a human-centric based study of a human-centric construct - the production, consumption, and transfer of wealth. Meanwhile, ecology has studied natural systems, organisms, and the interactions between these with little concern for human needs (Belovsky et al., 2004). However the ideals of "insatiable wants and infinite resources" (Daly & Farley, 2011, pg. xxi) are clearly no longer feasible, and factoring nature in to our desires is now unavoidable. To study ecosystems as an entity wholly separate to humans is futile considering our impact on them. This alone doesn't justify the inclusion of economics. Ecological anthropology, the study of "relationships between a population of humans and their biophysical environment" (Townsend, 2009, pg. 104), is already in existence. On top of this, the Ecosystem Services discussed previously expressly concern the services provided *to humans.*

Integrating Ecosystem Services alone into an established system of growth and development may however be unachievable. The Millennium Ecosystem Assessment (MA, 2000) was an ambitious attempt at this, breaking services down in to understandable pieces. It was an achievement in terms of structuring ecological processes and highlighting often unseen value to humans (Boyd & Banzhaf, 2007; Daily, 1997). However, any attempt at valuation from it has been deemed inadvisable due to prevalence for double counting (Fisher, Turner & Morling, 2009). This is mostly due to the lack of widely accepted/understood units still attached to services. Although some Ecosystem Services have a natural unit (e.g. tonnes or other weights of CO_2 sequestered), most rely on heavily qualitative measures (e.g. recreation). There are also concerns over potential overlaps between processes and final services. For example, fresh water can provide a quality fish supply delivering recreation services to anglers, but this fresh water supply is also a final Ecosystem Service for humans (Boyd & Banzhaf, 2007). In this instance, conceptually, should fresh water be counted as two services or one?

Economic accounting can play an important part in structuring Ecosystem Services and allowing them space in decision-making. Virtually all services we receive as humans come at a cost (e.g. food, clothing etc.), and as Costanza put so succinctly "The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite" (1997, pp.1). With this in mind, and an otherwise lack of measuring the benefits ecosystems provide us, an economic pricing system seems logical. Cowling discusses the general agreement amongst authors to pursue economic valuation as, "most societies have an intuitive notion of economic value" (2008, pg. 9485). After all, if we had to replace all of our Ecosystem Services artificially, how much would this cost us?

5.2 Non-market valuation

A vast quantity of research has highlighted the changeable nature of land rent values through time and space (see for example Cheshire & Sheppard, 1995). Values of land over time have been shown to fluctuate according to soil quality, accessibility, and proximity to features such as rivers or towns (Lüscher, 2004). Until relatively recently however, land value was based on output in terms of revenue, i.e. total biomass of crops obtained. Services provided by the land we do not place a value upon are called non-market values. These values are not generally included in land prices or land rents, but are increasingly being calculated and included in land use decisions. The UK Government's

"Biodiversity 2020" policy document stresses the importance of integrating valuation in to decision making in the coming years.

In this section, the issues surrounding non-market valuation are explored, along with recent efforts to incorporate it in to normal markets. A discussion of the various means of non-market valuation is made, and a systematic review undertaken to obtain data on grassland valuation.

5.2.1 Theories of value and price

Classical economics, on the whole, deals in *prices*, not necessarily *value*. Goods that can be wholly unimportant or made of poor quality materials can still hold a high price, for example some designer clothing (Heal, 2000). Ecological economics deal in goods and services which have an arguably infinite value, and yet no price. The price/value paradox has been debated throughout the history of economics, and becomes more pertinent within this field.

"Though he spends for instance much more on tea than on salt, yet salt is of greater real worth to him; and that this would be clearly seen if he were entirely deprived of it" (Marshall, 2013 (originally 1890)).

Costanza et al.'s seminal paper in *Nature* estimates the total economic value of Ecosystem Services to be between $16 and 54 trillion (1997). This figure is far higher that the aggregate Gross World Product (GWP), at $18 trillion in 1997. Does this mean then that Costanza's estimate was too high, or that we have not factored in an important part of global economics for too long? Ayres (1998), in response to the paper, estimated that a "few hundred billion" dollars should be enough to at least repair much of the damage we have already caused.

If this then is the *value* of our Ecosystem Services, how then to decide which are most important? How do we estimate a *price* on the services to include them in to the market? Under the current system, a landowner of an area of natural habitat has the choice whether to keep the area untouched, or convert the land in to, for instance, a quarry. The normal course of action would be to undertake a discounted net income stream, wherein the option with the highest net present value (NPV) (discussed in Section 2.2.7) would be chosen. Clearly this choice is skewed, the habitats are high in value, but have no monetary benefits for the landowner. Option demand implies that people hold an intrinsic Willingness to Pay (WTP) to retain the option to use a good such as a park or recreation facility. People may also hold a WTP for this good even without any intention of using it (Kula, 2012). There is currently little means to include this demand in to land use decisions.

5.2.2 Stock vs. flow

Much discussion has taken place over the differences and cross-overs between stationary services (natural capital, or stock) and processes and flows of services (natural income). How these are conceptualised depend on the method of assigning the services. Costanza prefers a conceptualisation where "natural capital and natural income are aggregates of natural resources in their separate stock and flow dimensions, and forming these aggregates requires some relative valuation of the different types of natural resource stocks and flow" (Costanza & Daly, 1992). This study will try, where possible to avoid overlap of service provision unless theoretically sound.

5.2.3 What methods are in place to attach "prices" to non-market goods?

Some Ecosystem Services already have an established value attached, while others are currently unaccounted for. Figure 5.1 outlines Ecosystem Services and their current status in the market.

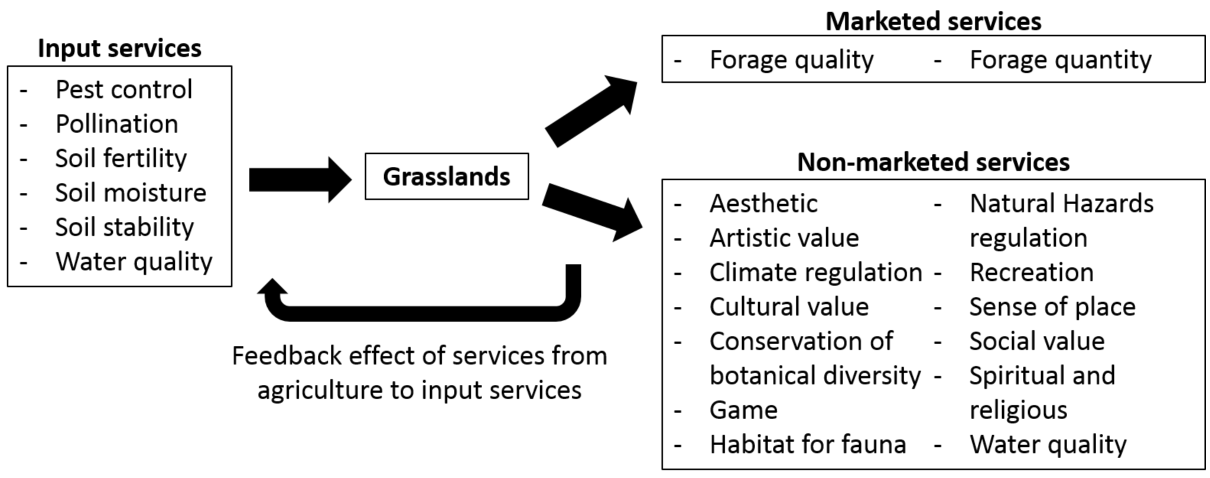


Figure 5.1: Market status of Ecosystem Services (reproduced from Lamarque et al., 2011)

Clearly, only a minority of established Ecosystem Services are currently marketed. The process of assigning values to the remainder seems a mammoth task. However, it is easy to forget that all other products were once economically un-valued, and weights, measures and prices were assigned to all of these eventually (Boyd & Banzhaf, 2007). A thriving field of welfare economics[30] in relation to ecology has emerged. The following discussed the theory and methods so far utilised in non-market valuation. These are important for the study ahead as it is likely a number of methods will be utilised in included papers from the systematic review.

5.2.4. Total Economic Valuation (TEV)

TEV is defined here in line with Pascual and Muradian "the sum of the values of all service flows that natural capital generates both now and in the future" (2010). This value cannot be elicited without the means of a method of valuation, these are discussed below.

[30] Welfare economics: the ability of policy-makers and markets to allocate resources (LSE, 2002)

a. Contingent Valuation Method (CVM)

Contingent valuation hinges upon the revealed preferences of a person's Willingness to Pay (WTP) for environmental goods. Based on consumer behaviour theory (Fishbein, 1967) a good, in the eyes of the consumer, is made up of a discrete set of parts. The consumer's perceived attributes towards the good are not necessarily representative of the true set of attributes. This is especially true in ecological goods where public knowledge of services provided by nature may be poor. This is by no means just ignorance on the part of the public, even experts are still often unaware of interactions between ecological functions. This ignorance of the true value of ecological functions ("functional transparency") is one of the most limiting factors in contingent valuation studies and this is discussed further below.

CVM, most often involving WTP, is a means of eliciting the public's perception of value of ecological resources via questioning (de Groot et al., 2012). WTP is intrinsically linked to welfare economics due to its attempt to quantify the worth of a commodity, through identifying what would have to be taken from, or given to a beneficiary if the commodity was improved, or reduced (Carson, Flores & Mead, 2001). WTP studies have been undertaken on a wide range of ecological resources, including green electricity (Roe et al., 2001; Wiser, 2007), rare and endangered species (Loomis & White, 1996), and freshwater systems (Wilson & Carpenter, 1999). WTP has also been utilised in numerous Governmental or empirical agency reports (e.g. DEFRA, 2008).

WTP is seen by many as the "conceptually correct" and now standard means of eliciting the worth of non-market goods (Just et al., 1982 in Loomis & White, 1996; Wilson & Carpenter, 1999). However, a major concern with the validity of WTP estimates is whether the public are best placed to make well-informed judgements on the worth of ecological resources (Christie, Hanley & Wright, 2006). This is especially pertinent considering definitions of biodiversity and its measurement are still somewhat contested even by experts, as discussed during the systematic review of floral studies in Section 3.2. There is also a potential concern that the public measurably favour "attractive" species over less charismatic species that play a larger role in overall biodiversity (Christie, Hanley & Wright, 2006). This is supported by a 2007 study that found WTP respondents favoured animals over plants, and vertebrate animals over invertebrates and micro-organisms, despite their crucial role in ecosystem functioning (Martín-López et al., 2007). Higher awareness amongst public become of ecological functioning, the higher WTP estimates are likely to become in future modelling. Observed variance between WTP and Willingness to Accept (WTA – the converse value to WTP), has also been high. This has led some to question whether this divergence goes beyond what economic theory can account for (Knetsch, 2005 is Spash & Vatn, 2006). The more study that is conducted in the field, the more these uncertainties can be accounted for.

A number of high profile CVM studies have taken place in the UK and further afield. Christie et al. conducted a study for DEFRA valuing Ecosystem Service benefits delivered by the Biodiversity Action Plan. This study is revisited in the economic systematic review conducted later in this chapter. Similarly, Meyerhoff et al. conducting a CVM survey valuing the benefits obtained from a national strategy on biological diversity. Both studies went to great lengths to mitigate some of the known problems of CVM. They imparted information to respondents by a variety of mediums to ensure adequate knowledge, and prior knowledge of ecological functions was established. With correct attention to assumptions and ensuring best knowledge by respondents, CVM can be used to good effect to establish public perceptions of value. CVM survey is beyond the scope of this study, and because of this, and fears grassland Ecosystem Services are not adequately understood by the public, this method will not be pursued.

5.2.5 Indirect market valuation

Indirect market valuation attempts to elicit an unstated WTP via other aspects of the economic market. A number of methods exist within this topic, these are discussed below.

a. Travel Cost Method (TCM)

The cost people will pay to access Ecosystem Services can be used as a proxy to their “payment” for those services (de Groot et al., 2012; Heal, 2000). This may also include the cost of the time a person invests in travelling to and from a site (Healy et al., 2013). This method is mostly used for recreational sites and may not capture the full value of Ecosystem Services delivered by the site. For example, Shrestha et al. estimated the value of recreational fishing in Brazil using the travel cost method (2002). They concluded the model worked acceptably to estimate recreational fishing. However, few papers attempt TCM beyond recreational ecosystem services and as such TCM will not be used as a stand-alone method of value in this study. Further methods such as survey could be used alongside (Randall, 1994).

b. Avoided Cost (AC)

A number of ecosystems provide services that would otherwise cost us money. For example, forests provide flood control, and the avoided cost of repairing property damage caused by flooding could be used as a proxy to this service (de Groot et al., 2012). The IPCC estimated the value of carbon is between $5,200 to $15,600/ha, using the avoided cost of carbon emitted in to the atmosphere (IPCC in Wilson, 2009). This is potentially a more direct means of valuing certain Ecosystem Services, but is inapplicable to a number of services without an obvious avoidance, such as cultural value or aesthetic appreciation.

c. Replacement Cost (RC)

Replacement cost is similar to avoided cost, where Ecosystem Services are replaced by man-made systems (de Groot et al., 2012). This could include waste treatment, or coastal defence (Costanza, 2006). Kaiser and Roumasset applied the replacement cost method to value groundwater recharge from trees. This found the payoff from natural tree services is high. In the context of this study, although this method provides a demonstrable “cost” of losing a particular service, there are a number of cited difficulties. Firstly, many aspects of biodiversity do not have a replacement, for example most species (Healy, 2013). Also, this method would likely only value one aspect of an ecosystem, such as the waste treatment services of a wetland. This would underestimate the total value which should include carbon sequestration, recreation etc. (Heal, 2000). As such, where applicable, further methods would have to be employed.

d. Hedonic pricing (HP)

Hedonic methods involve utilising other costs as a proxy for the service in question. This usually involves using house prices close to and distant from an ecological service to infer whether the difference is associated with that service (de Groot et al., 2012). It is rarely the case that two houses are identical except for an ecological service, and as such there is a lot of error involved with this method (Heal, 2000). However, there is also the argument that a well-defined statistical model could extract the “hidden” price from all other variables with some level of accuracy (Heal, 2000). Irwin (2002) highlighted studies using hedonic methods to value different types of open space presented high variation in outcome. In a hedonic pricing study of UK amenity values the authors highlighted the importance of including all possible environmental variables to the model for accuracy (Cheshire & Sheppard, 1993). Due to the variability in current results, a hedonic pricing method will not be pursued in this study. However, results from existing grassland hedonic studies will be included in analysis.

e. Net Present Value (NPV)

The essence behind NPV (sometimes known as marginal benefits) is that an amount of money today has the potential to be worth more at a future time due to interest and investment opportunities etc. As for an object which has a single purchase price to represent all benefits received in the future by it, NPV attempts to aggregate all future Ecosystem Services in to one present value. In addition, receiving monies at a future time means those monies are currently worth less than the future amount. In order to accurately calculate the future benefits, a discount rate is applied. This rate is a percentage figure which will estimate future receipts in to current figures. The basic equation for the discount rate is:

Equation 4.1: Discount rate $$1/(1+i)n$$

where i is the interest rate (decimal format) and n is the number of years to be discounted.

In environmental economics, a discount rate of 3.5% is widely used and endorsed by the UK Government (HM Treasury, 2013; Devon Wildlife Trust, 2015). However it is often deemed appropriate to use differing rates. Jacobsen, Vedel & Thorsen (2013) used a rate of 3% in valuing Natura 2000 forests in line with review papers (Brukas et al., 2000; Thorsen, 2010 in Jacobsen, Vedel & Thorsen, 2013). Similarly, a 3% rate was used in Gascoigne's study on land use planning options from recommendations from the social cost of carbon (SCC) working group (Gascoigne et al., 2011). Higher discount rates are frequently used, for example a 6% discount rate used in Woodward and Wui's review of wetland values (2001). This higher figure could allow for further unseen or acknowledged services provided by the policy site.

The advantage of NPV is its ability to take future benefits and convert these in to a single, current figure. This allows a comprehensive look at the true non-market benefits of natural resources, and a potential incentive to developers and land owners to develop high quality habitats. NPV has been used to value a wide range of non-market goods, such as forest management (Howard & Valerio, 1995); but most commonly in land-use planning (see for example Gascoigne et al., 2011; Costanza et al., 2006). Although Costanza et al. avoided the use of NPV and discounting for their estimation of the value of the world's Ecosystem Services, this was still employed for certain sections. This highlights that discounting can help aggregate future benefits but the variability in accuracy is acknowledged as being high.

f. Value transfer

As discussed above, all the currently available methods have a number of positive and negative features. There is a very real possibility of problems such as double counting, or failure to include Ecosystem Services provided leading to over- or under-estimation of grassland value. Conducting some of the types of methods above can also be prohibitively expensive or time-consuming (Costanza et al., 2006). As such, the value transfer method identifies previously conducted studies valuing sites (hereon called *study* sites) and their associated Ecosystem Services under similar circumstances. These are then applied to another site under scrutiny (hereon called *policy* sites) (Navrud & Ready, 2007). Value transfer is used widely in the literature. Brander and Schuyt (2010) used the value transfer process to estimate a value of the world's wetlands as $3.4 billion per year. Other examples include the recreation value of woodland (Forestry Commission, 2003), and Xie's alteration of Costanza's global values to be applicable to China (2010). The latter is included in the systematic review undertaken in Section 5.6. With the rise in interest in environmental valuation, value transfer is becoming common in land use decisions and policy evaluations (Navrud & Ready, 2007).

An obvious concern with value transfer methods is the possibility that values will be transferred where environmental and socio-economic variables of the study and policy sites are incompatible (Barton, 2002 in Spash & Vatn, 2006). Criticisms of value transfer studies cite a lack of focus on socio-economic variables of the study and policy sites. The surrounding population of a site could affect its direct and passive use value. Therefore care must be taken to match as much as possible between sites to ensure adequate transfer. From the literature, it would seem the variables that are most important to match to adequately capture Ecosystem Service provision and value are:

1. the environmental good or Ecosystem Service, its quantity/quality and the change in this quantity/quality;
2. the surrounding or using population, their use of the good or service and their socio-economic characteristics;
3. constructed market characteristics;
4. temporal aspect from primary study to transfer;
5. geographical location.

(Spash & Vatn, 2006; Boyd & Banzhaf, 2007; Seppelt et al., 2011)

A further concern is the validity of primary studies transfer values are being taken from (Green, 2004). This is especially pertinent as certain studies have valued Ecosystem Services as more than the global income (for example Costanza, 2007), and violate validity tests (Spash & Vatn, 2006). It is hoped that undertaking a systematic review to capture as many potential values as possible could be seen to alleviate some of the error of simply choosing an individual study site. This, in conjunction with extensive descriptive and qualitative analysis (Brouwer, 2000), can remove some of the error from potentially invalid primary studies.

The below diagram summarises the value transfer process as outlined in Spash and Vatn, 2006.

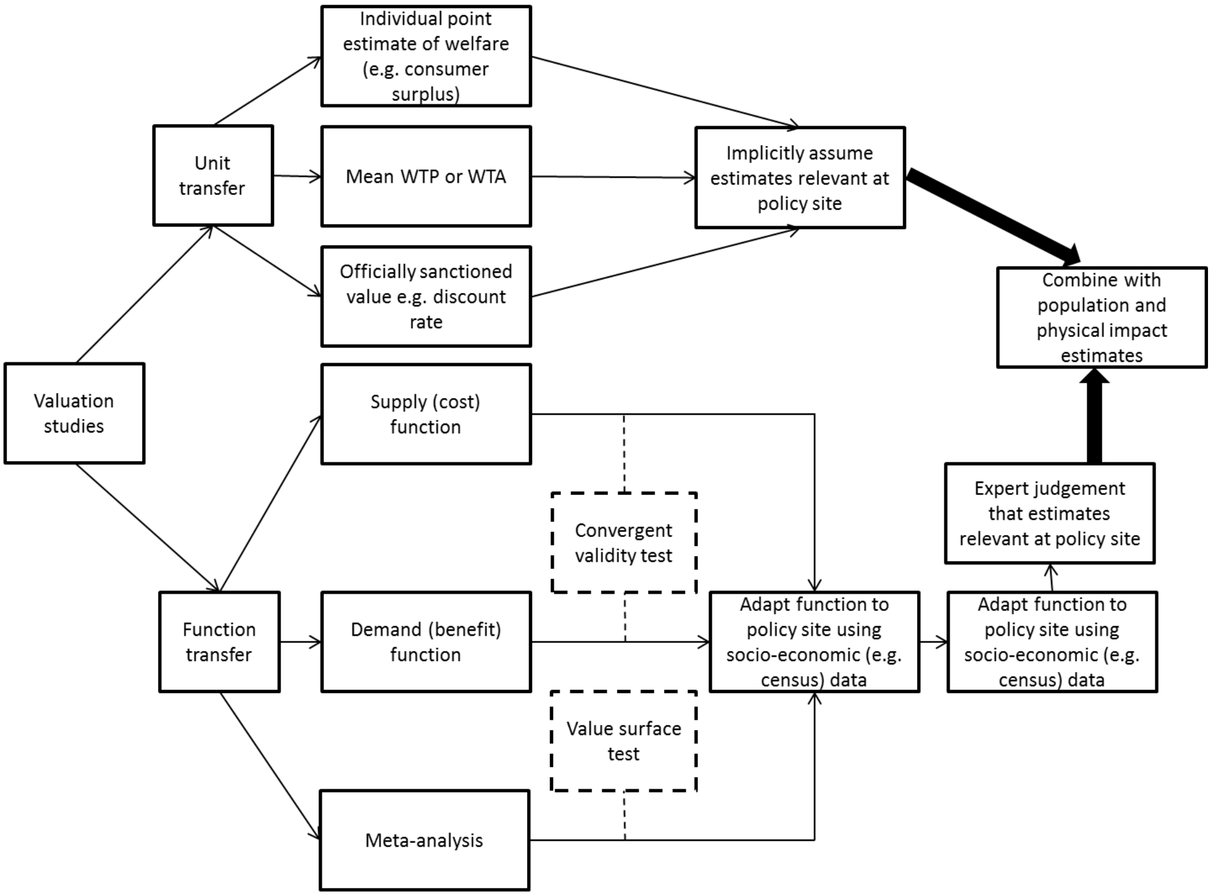


Figure 5.2: Diagram outlining value transfer process (adapted from Spash & Vatn, 2006)

Figure 5.2 shows how the value transfer process first requires locating relevant valuation studies according to the variables identified in Section 5.2.5f. "Function transfer" or "Unit transfer" refer to whether you are inferring service provision or economic value from the initial study. From here, relevant values from the study site can be inferred, and applied to judgements at the policy site. This must include socio-economic variables to ensure compatibility.

5.2.6 Choosing valuation methodology

While reviewing the available methodologies for environmental valuation, one is struck by the apparent uncertainty across the field. Every method has a number of advocates, and potentially a larger group of critics. Despite large-scale and high-profile reports such as the Millennium Ecosystem Assessment (2005), no operationally viable method has emerged (Seppelt et al., 2011).

Where uncertainty is high, utilising work already undertaken and building on this should help the field to grow. As Belovsky notes, “There is a lack of appreciation for past literature; this in part, leads to ecology’s fickleness towards central issues” (2004, pg. 246). The systematic review process, already used in Section 3.2, allows a comprehensive view of literature to be revealed. This process would allow research already undertaken in to grassland values to be utilised, and hopefully allow further understanding to be revealed. Individual models “explaining” the variation in past studies have been further called for in the literature (Loomis & White, 1996). These are especially pertinent if they include a range of physical, social, and economic factors where possible (Hancock, 2010; Spash & Vatn, 2006; Brouwer, 2000). These have already been undertaken across the field (see for example Bateman et al., 2011; Brouwer, 2000; Walsh, Johnson & McKean, 1992; Boyle, Poe & Bergstrom, 1994) in other habitats such as wetlands. No such study has been undertaken for grasslands to our knowledge. The more we attempt to observe the factors that alter valuation outcomes, and try to predict these, the stronger the field will emerge (Clark et al., 2001). Keeping in mind the usefulness of any model to policy-makers and those working within the field is paramount (Jakeman, Letcher & Norton, 2006). This study has been specifically designed with practitioners in mind to aid further growth of created grasslands.

5.3 Conclusions on initial literature review on valuation methods

This section has outlined available non-market valuation methods, and discussed their benefits. This discussion has highlighted the complex nature of the methods. Conducting surveys, or inferring value from other values such as house prices are time-consuming and still liable for high levels of error. To mitigate these effects, a full analysis of all currently available valuation studies of grasslands will be undertaken. This allows both important research on the variability of grassland non-market values, and allows an adequate value transfer based on variables suggested from the literature (Section 4.2.5f).

5.4 Identifying values of grassland habitats – Econometric review and analysis methods

5.4.1 Introduction and purpose of systematic review

As discussed in Section 5.2.3, a number of different methods exist to attempt to place value on ecological services. The number of different methods could mean a fragmentation of the paradigm, and lower confidence in results achieved. To alleviate this, this study will first undertake a systematic review of grassland valuation studies. This can synthesise and shed light on the drivers on current grassland values. As these studies can provide a number of explanatory variables, these can be tested to find the main sources of variation in assigned grassland values. This review will also provide a number of actual values of Ecosystem Service provision in grasslands. These results can be used for Value Transfer according to biodiversity output in Chapter 7.

5.4.2 Applying a systems approach to assess variation in value of grasslands

In this paper, we will attempt to address the main drivers of grassland valuation, and explain variation between attempts at valuation. There are a large variety of sources of variation in this work. Ecological systems are highly complex (Brouwer, 2000), and availability of discrete data in the field of environmental economics is limited. As such, in line with other papers in the field, a systems approach to eliciting grassland values is undertaken (Brouwer et al., 1997). This approach will involve both in-depth qualitative and quantitative analysis of the ecological benefits grassland provide and the connections between these. This systems approach acknowledges that within a system most of the components will affect the other components, and will provide us with a more comprehensive view of grassland values and the inherent difficulties in valuing them. It is highly likely unknown variables still exist that would contribute to the study further.

5.5 Systematic Review

An extensive search of the literature was conducted in order to identify published and unpublished studies valuing grassland ecosystems.

5.5.1 Search strategy

Searching was conducted in November 2014. All searching was conducted by a single reviewer (SLC) with 25% blind checked by second reviewer (GL).

Scientific electronic resources: Relevant articles were identified through electronic database searching completed using the following five databases: ISI Web of Knowledge (including ISI Web of Science), JSTOR, Science Direct, Scirus (all journal sources), and Scopus. All references retrieved via these searches were examined for relevance. All papers suitable for inclusion in the meta-analysis were published papers or official reports. Search terms comprised "Grassland"; "Savannah"; "Valuation"; "Valu*"; "Economic"; "Econometric", and various combinations of these.

Internet resources: Due to the high volume of irrelevant results on web and Google Scholar searches, these were capped at 100 hits. The Centre for Evidence-Based Conservation's (CEBC) systematic review guidelines recommend 50 hits for such searches, but this was doubled to maximise relevant paper's inclusion (CEBC, 2006). Web-engine searches were completed using Google Scholar. Due to the large number of results decreasing in relevance, the first 5 pages of search were included (CEBC 2006). Search terms used were identical to those above.

Bibliographies of located papers were also studied for further suitable papers. Any paper valuing non-market benefits derived from grassland ecosystems were checked for suitability.

5.5.2 Inclusion criteria and data preparation

Valuations of agricultural outputs were not included (hay biomass; food production etc.), as these marketable products have been extensively researched. This is not to say these values will not be taken in to account if agricultural outputs can be used from a created grassland. Water processes were included as these services go beyond drinking water and are non-market in most cases.

Despite some other valuation meta-analyses excluding values from benefit transfer, these were included as long as the original value was not repeated across the analysis. This allowed inclusion of values adjusted for grasslands from studies valuing specific Ecosystem Services from any ecosystem. A high number of papers were excluded from the final meta-analysis. This was mainly due to presence of marketable agricultural outputs; failure to specify source of benefit transfer value; and repeated benefit transfer values (especially from Costanza, 1997; and Xie, 2010). Some papers were rejected as grassland services were valued alongside another aspect of nature without the means to separate the two. If a high and low estimate of value was provided, both of these values were included to allow a sense of scale and quality (e.g. Asia Pacific Environmental Exchange, 2010). Although other studies of ecosystem valuation tend to only focus on contingent valuation or hedonic valuation alone, both are included in this study. Despite this, Willingness to Pay (WTP) estimates could only be included if study area and relevant population were specified.

The following variables were extracted from included papers where provided: Country of study; Within-country location; Latitude; Longitude; Gross Domestic Product (GDP); Population density; Grassland type; Area (ha); Ecosystem Service valued; Internal citation (Benefit Transfer only); Valuation method; and value provided. If any of these variables were omitted, research was undertaken to reliably locate this information elsewhere. Values for many of these variables were often omitted. GDP and population density (2012) were taken from World Bank data (2014). Population density was converted to people/ha. Longitude and latitude were located as close to study site as possible from iTouchMap (2014).

Grassland types were often not specified, or under generic biome types such as "Grassland/Rangeland". In numerous studies grassland types were highly spatially specific, such as "Upland Calcareous Grassland" for the UK (Christie et al., 2011). There is currently no accepted set of global grassland types, beyond "Temperate", "Tropical Savannah" and "Other" (see for example

Woodward, S, 2008). Recent work attempts classification of the world's grasslands further (Dixon et al., 2014). Where possible, grasslands were assigned to their closest Type (outlined in Table 6.3), but many had to be assigned as generic "Grassland".

Ecosystem Service descriptors varied widely across the included studies, although all encompassed the accepted Ecosystem Service type. All service descriptors were unified according to The Economics and Ecosystems of Biodiversity (TEEB) descriptors. Ecosystem Service types valued are presented in Figure 5.1 (TEEBWEB, 2014). Services were sometimes aggregated in such a way, or in a manner where establishing the definition of what was included, that assignment to any standard was a challenge. Some overlap between service assignments is likely. All Ecosystem Services and grassland types are broken down in Section 6.2.

Figure 5.3: Ecosystem Service types (reproduced from Millennium Ecosystem Assessment, 2005)

To allow comparison of results, values were standardised to US$2013/ha/year with method in line with de Groot et al. (2012). Values were first converted to the currency of the country of study (where appropriate). These were then adjusted to 2013 values using GDP deflators for the relevant country. Finally these were converted to US$ using Purchasing Parity Power (PPP) values relative to 2013. PPP values are "the number of units of a country's currency required to buy the same amounts of goods and services in the domestic market as U.S. dollar would buy in the United States" (World Bank, 2014). In one case (Brenner-Guillermo, J., 2007, in Van der Ploeg & de Groot, 2010), figures were given in 1991 pesetas, therefore a second phase of analysis took place inflating the value to 1999, converting to Euros, then continuing to inflate to 2013 prices. Gross Domestic Product (GDP) deflators, exchange rates and PPP factors were taken from World Bank indicator data (World Bank, 2014).

As GDP is a non-stationary variable, this can cause extreme collinearity with other trended variables. This can lead to misleadingly significant regression models, known as "spurious regression" (Granger & Newbold, 1974). This should not present a problem over the relatively short time period involved in this data. Nevertheless the Breusch-Godfrey test will be performed on any models where GDP is included for assurance. This econometric test is recommended to account for any auto-correlation (Hatekar, 2010).

Area values in km^2 or acres were converted to hectares, and WTP estimates per person or household could be converted to per hectare (ha) if area of study and relevant population were specified. This was often not the case and a number of studies were excluded accordingly. This was a problem encountered in other conceptually similar studies (Brouwer et al., 1997). Capitalised values were converted to annualised figures using a discount rate of 6% in line with Woodward and Wui (2001), as discount rates were not generally specified in each study.

Further potential explanatory variables were sourced to help explain variation in grassland values. All variables are presented in Table 6.1.

5.6 STUDY ASSESSMENT AND DESCRIPTIVE STATISTICS

As there is potentially a high source of variation from the data set, a number of aspects of interest were examined from study to study in line with other published valuation reviews (Brouwer et al., 1997). This involves:

- Publication details
- Methodological details and standardised method
- Research objective
- Ecosystem Services values and assigned Ecosystem Service

Mean and median were calculated for all numeric or integer values.

5.7 DATA EXPLORATION

Data exploration was undertaken following Zuur, Ieno, & Elphick (2010) for within-study consistency.

Step 1: Are there outliers in Y and X?

A boxplot and dot chart were made for all valuation outputs (Total Economic Value (TEV) and individual Ecosystem Service values ($/ha/year)), as well as all explanatory variables. As in the floral analysis, any identified outliers were then examined using a Cook's plot. Any data points over 1 will be considered for alteration to reduce risk of influential observations (Fox, 2002 in Zuur, Ieno & Elphick, 2014). Transformation of the data or removal of the outlier will be pursued if necessary. Removal of any data, however, will be avoided where possible as recommended by Zuur, Ieno, & Elphick (2010), although Gauch (1982) advises removal. This is due to concerns that a single 'outlier' in a relatively small dataset could be capturing an important, if rare, piece of information. Removal could impair full capture of ecosystem function and service value.

Step 2: Do we have homogeneity of variance?

Step 2 (examining the residuals vs. fitted values for the model) is performed after modelling took place. Model plots were examined for unusual distribution of residuals including over-dispersion.

Step 3: Are the data normally distributed?

Boxplots and scatterplots created as part of Step 1 (Outliers) were re-examined for evidence of non-normal distributions. Transformations were undertaken if necessary.

Step 4: Are there lots of zeros in the data?

As this data set is not species data, zeros are not deemed an issue in this analysis. Nevertheless the initial dataset was examined with this in mind.

Step 5: Is there collinearity among the covariates?

As well as examining the scatterplots created, a Pearson correlation coefficient was created for each variable. A highly conservative cut-off of 0.3/-0.3 was set according to Zuur, Ieno, & Elphick (2010). Although this is particularly caution, we believe it is prudent considering the small dataset, and potential for variance and spurious regression. Collinear variables were not included in any model.

5.*7.1 Kruskal-Wallis test*

A Kruskal-Wallis test was performed on explanatory variables to establish level of inequality across categorical variable levels. R code for these tests is provided in Appendix 7.

5.8 Multi-level mixed-effects model

A number of mixed-effect generalised linear models were pursued to capture potential grouping effects within the selected papers. Mixed-effects modelling was deemed appropriate considering the individual services being valued within a larger value set. This was dependent on group agreement indices calculated according to Bliese (2013).

The explanatory variables can be divided in to three main groups, the methodological characteristics (e.g. Valuation Method, Year of Study), geographical characteristics (e.g. Latitude, Longitude, Grassland Type, logArea), and socio-economic characteristics (GDP, Population density, Percent Agricultural Land, ANS). Socio-economic variables were, on the whole, inferred from outside the studies to further inform the model. These were sourced from the World Bank (2014).

Multilevel modelling methodology follows Bliese (2013). Grouping agreement indices (R_{wg}) were calculated according to James, Demaree & Wolf (1984). Further analysis was conducted on variables with in-group variance of more than 0.7 according to Bliese (2013). Intra-class correlation values were calculated according to Bliese (2000). The variability of $\tau 00$[31] was calculated using an unconditional means model.

Marginal and conditional R^2 values were calculated where marginal R^2 is the proportion of variance described by the fixed effects elements alone and conditional R^2 is the proportion of variance explained by both the fixed and random effect. An ANOVA was run to compare mixed-effects and purely fixed effect models to establish significance of using random effects. To assess forecasting ability of model outputs, Mean Absolute Percentage Error (MAPE) was used. This is calculated as in Equation 5.1:

[31] $\tau 00$: Between-group variance

Equation 5.1 $$\left|\frac{y_{obs}-y_{pred}}{y_{obs}}\right|$$

Where y_{obs} is a vector of values extracted from included studies and y_{pred} is a vector of values outputted by the relevant mixed-effects model.

A higher MAPE output indicates higher forecasting error.

5.9 Key assumptions relating to this study

1. Where uncertainty in method is high, unpacking all variables could lead to further understanding of the drivers of environmental value;
2. *Price* and *value* are inherently different concepts. This study is attempting to capture the value of grasslands in a way comprehensible to humans. Outputted values are not intended as a "price" of grasslands;
3. Applications of value are temporally and spatially contextual, and not in ways that are well understood.

5.10 Economic research objectives and hypotheses

1. Use the systematic review process to identify grassland valuation papers within the inclusion criteria

Hypothesis – there will be high variation within grassland values. Ecosystem Service value estimates will vary widely.

2. Using statistical analysis and modelling, attempt to identify the drivers of variation in grassland values

Hypothesis – Method of valuation will play a major part of explaining the variation in grassland value as discussed in Section 5.2.3. Ecosystem Service values will vary by grassland type due to differential delivery.

CHAPTER 6: ASSIGNING ECONOMIC VALUES TO GRASSLANDS – RESULTS AND ANALYSIS

6.1 INTRODUCTION

In Section 5.2.3, the varied methods of undertaking non-market valuations were discussed. This highlighted the wide range of methods available, and also the wide range of results that can be extracted. In this section, we outline the outputs of our investigation in to grassland valuations. In Chapter 7 we then transfer this information to our floral data. As there is still high uncertainty around habitat valuation, available data has been explored in a number of ways in an attempt to extract the most reliable estimate. As this process is still relatively in its infancy, we believe these results help to synthesise current research and draw more in-depth conclusions on the variations in grassland valuation. Further valuation studies would improve the model immeasurably.

6.2 SYSTEMATIC REVIEW – DESCRIPTION OF INCLUDED PAPERS

23 sources of data (reports and journal articles) with 145 associated values were extracted in the systematic review. This “vertical” sheet with one row per Ecosystem Service value or TEV was transposed in to a “horizontal” sheet with one row per grassland type per study (n=53). This meant, in some cases, aggregating two or more scores valuing the same grassland type. This occurred for example where a model gave more than one output for the same grassland but it was uncertain what variable(s) caused the change. The number of studies would have been considerably higher if more studies explicitly stated sources, method and detailed site information. Table 6.1 summarises the main features of our data set. A table with all extracted variables, and further variables (e.g. population density), is included in Appendix 10.

Variable grouping	Variable
Dependent	Total value
Geographical variables	Latitude
	Longitude
	Area (ha)/logArea (ha)
	Alpine and sub-Alpine
	Grassland (generic)
	Restored
	Temperate
	Tropical
	Wet and seasonally wet
Methodological variables - for further description see Section 4.2.3	Year0
	Avoided Cost
	CVM
	Damage Cost
	Direct Market Pricing
	Ecosystem Service Values
	Expert Survey
	Maintenance Cost
	Marginal Abatement Cost
	NPP
	Other hedonic
	Replacement
	Value transfer
Socio-economic variables	GDP
	Popdens
	Percagri (Percent agricultural land in country of study)
	Annual Net Saving (ANS)($2014) (True saving rate of economy taking in to account depletion of natural resources and pollution damage)

Table 6.1: Outline of extracted variables from included grassland valuation studies (continues)

Variable grouping	Variable
Ecosystem Services	MAServ (Ecosystem Service Group e.g. Regulating, Supporting…)
	MAServ2 (Ecosystem Service Type e.g. Carbon sequestration, Aesthetic…)
Individual Ecosystem Service values (2013$/ha/year) - For further description see section 2.2.6	Aesthetic
	Biological
	Carbon
	Climate
	Erosion
	Events
	Genetic
	Habitats
	Pollination
	Recreation
	Waste
	Water

Table 6.1: Outline of extracted variables from included grassland valuation studies (continued)

Studies were included from 15 countries, also with one from Europe as a whole, and two global studies. Figure 6.1 shows the locations of included studies. Clearly more studies take place in Europe and the USA. As the map shows, further studies in South America, Africa and northern Asia would be beneficial.

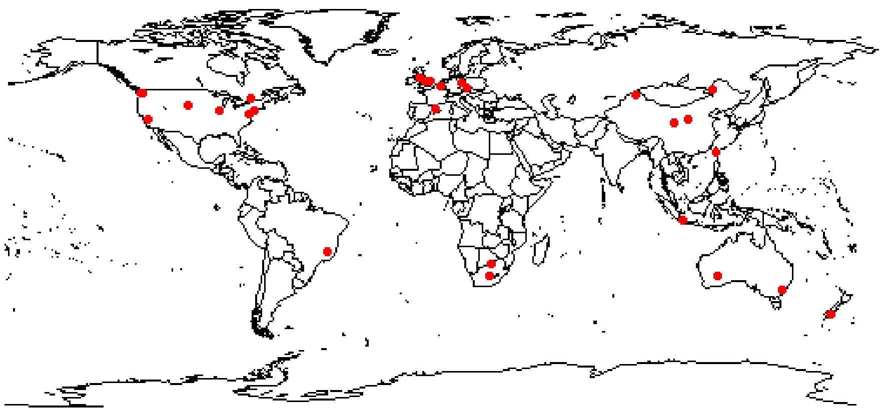


Figure 6.1: Map showing location of included valuation studies

6.2.1 Economic Systematic review results - Study characteristics: publication details

Table 6.2 outlines the publication details of all included studies. This shows the type of study undertaken and its year of publication.

No.	Authors	Type of publication	Year of publication
1	Agency for Nature Conservation and Landscape Protection of the Czech Republic	Government report	2010
2	Asia Pacific Environmental Exchange	Report	2005
3	Asia Pacific Environmental Exchange	Report	2010
4	Barnes, J.I.	Research Discussion	1998
5	Brander, L. & McEvoy, M.	Government report	2012
6	Christie, M. et al.	Government report	2011
7	Costanza, R. et al.	Report	2006
8	Dissanayake, S.T.M. & Ando, A.W.	Journal article (LE)	2014
9	Dodds, W.K. et al.	Journal article (BS)	2008
10	Dong, X. et al.,	Journal article (OA)	2007
11	Dong, X. et al.	Journal article (EC)	2012
12	Gaodi, X. et al.	Journal article (JRE)	2011
13	Glaves, P., Egan, D. & Harrison, K.	Report	2009
14	Heidenreich, B.	Report	2009
15	Kosonen, M., Otsamo, A. & Kuusipalo, J.	Journal article (FEM)	1997
16	Kroeger, K. et al.	Report	2009
17	Meyerhoff, J., Angeli, D. & Hartje, V.	Journal article (ESP)	2012
18	Resende, F.M., Fernandes, G.W. & Coelho, M.S.	Journal article (BJE)	2013
19	Sala, O.E. & Paruelo, J.M.	Book chapter	1997
20	Turpie, J.K.	Journal article (EE)	2003
21	Van der Ploeg, S. & de Groot, R.S.	Database*	2010/2012

Table 6.2: Publication details on included studies (continues)

No.	Authors	Type of publication	Year of publication
22	Wang, R.J. et al.	Journal article (AMM)	2011
23	Wen, L.	Journal article (PLoS 1)	2013
Where: JRE = Journal of Resources and Ecology FEM = Forest Ecology and Management EC = Ecological Modelling ESP = Environmental Science and Policy BJE = Brazilian Journal of Ecology EE = Ecological Economics OA = Outlook on Agriculture AMM = Applied Mechanics and Materials LE = Land Economics BS = BioScience *leading to publication in *Ecosystem Services*			

Table 6.2: Publication details on included studies (continued)

6.2.2 Economic Systematic review results - Study characteristics: grassland types

As the geographical spread covered between study to study varies widely between the very local and global, similarly there is a wide representation of grassland types under study. As discussed in Section 5.3, these are too heterogeneous to attempt to apply value adequately. As such, standardised grassland types were applied to the original types. As with Ecosystem Service assignment, this was a challenge due to potential overlaps and lack of definition of grassland types. Assigned grassland types and their original type if stated are provided in Table 6.3 below.

No.	Original grassland type (inferred if necessary)	Assigned grassland type
1	Alluvial meadows	Seasonally wet and wet
1	Seasonally wet and wet grasslands	Seasonally wet and wet
1	Mesic grasslands	Grassland

Table 6.3: Original grassland types and assigned grassland types of included papers (continues)

No.	Original grassland type (inferred if necessary)	Assigned grassland type
1	Alpine and subalpine grasslands	Alpine and sub-Alpine
1	Dry grasslands	Grassland
1	Heathlands	Grassland
1	Salt marshes	Seasonally wet and wet
1	Alpine and subalpine grasslands	Alpine and sub-Alpine
1	Forest fringe	Grassland
1	Pastures and managed grasslands	Grassland
2	Grassland/shrubland	Grassland
3	Grasslands/Rangelands	Grassland
4	Savannah	Savannah
5	Urban green space	Urban
6	Lowland dry acid grassland	Grassland
6	Lowland calcareous grassland	Grassland
6	Improved grassland	Grassland
6	Upland hay meadow	Grassland
6	Upland calcareous grassland	Grassland
6	Lowland hay meadow	Grassland
6	Purple moor grass	Grassland
7	Grassland/rangeland	Grassland
8	Prairie	Temperate
9	Restored grassland	Restored
9	Native grassland	Grassland
10	Grassland	Grassland
11	Temperate grassland	Temperate
12	Grassland	Grassland

Table 6.3: Original grassland types and assigned grassland types of included papers (continues)

No.	Original grassland type (inferred if necessary)	Assigned grassland type
13	Mixed	Grassland
14	Temperate grassland	Temperate
15	Imperata grassland	Restored
16	Perennial rangeland	Grassland
17	Grassland	Grassland
18	Rupestrian grassland	Grassland
19	Grasslands	Grassland
20	Grassland	Grassland
21	Grassland	Grassland
21	Tussock	Grassland
21	Temperate natural grasslands	Temperate
22	Temperate steppe	Temperate
22	Temperate meadow-steppe	Temperate
22	Marsh	Seasonally wet and wet
22	Alpine meadow	Alpine and sub-Alpine
22	Lowland meadow	Grassland
23	Alpine grassland	Alpine and sub-Alpine

Table 6.3: Original grassland types and assigned grassland types of included papers (continued)

6.2.3 Economic Systematic review results - Study characteristics: objectives

Although all of the studies were chosen for their economic valuations of grasslands and grassland services, the overall objectives of the study differ. Table 6.4 overleaf specifies the main objective or research question of each study.

No.	Research question/objective of study	Methods used	Grassland types valued	Number of assigned services values extracted
1	Ecosystem Services provided by various grassland types across different uses, and the economic value of these	Replacement	3	6
2	Value of Ecosystem Service Enhancement caused by salmon conservation	Value Transfer	1	8
3	Valuing nature's benefits in the region	Value Transfer	1	6
4	Value of non-use services as a complement to agriculture	Direct Market Pricing	1	1
5	Valuation of Ecosystem Services provided by grasslands	Value Transfer	1	1
6	Value of improvements to Ecosystem Services caused by UK Biodiversity Action Plan	CVM	1	NA (TEV)
7	Value of all Ecosystem Services and natural capital in the region	Value Transfer	1	2
8	Valuing benefits from restoration efforts	CVM	1	NA (TEV)
9	Comparing the economic benefits from restored and native grasslands	Value Transfer	2	6
10	Valuing Ecosystem Services alongside agriculture in the region	Replacement	1	3
11	The value of Ecosystem Services damaged by human impacts	Emergy (Other hedonic)	1	NA (TEV)
12	Altering Costanza's Ecosystem Service values for application in China	Value Transfer/CVM	1	5
13	Valuing Ecosystem Services provided by grassland in the region	Value Transfer	1	4
14	Total Economic Value of global Temperate Grasslands	Value Transfer	1	2

Table 6.4: Research objectives of included valuation papers (continues)

No.	Research question/objective of study	Methods used	Grassland types valued	Number of assigned services values extracted
15	Economic benefits of different land uses in *Imperata* grassland	Discounted cash flow (Other hedonic)	1	NA (TEV)
16	Valuing environmental benefits from conservation	Replacement	1	1
17	Valuing environmental benefits from conservation	CVM	1	NA (TEV)
18	Valuing plant diversity storage systems	Replacement	1	1
19	Valuing Ecosystem Services provided by grasslands	Replacement	1	2
20	Biodiversity existence values	CVM	2	NA (TEV)
21	Database of previously extracted valuation data	Value Transfer	2	13
22	Ecosystem Service values of habitats in the region	Replacement	1	NA (TEV)
23	Effect of degradation intensity on Ecosystem Service values	Direct use values	1	3

Table 6.4: Research objectives of included valuation papers (continued)

6.2.4 Economic Systematic review results - Study characteristics - Ecosystem Services valued

As discussed in Section 2.2.6, ecosystems and their functions provide a wide range of both tangible and intangible services to humans. For this systematic review, we have attempted to extract which services are valued, and the value attached to these. This was, in many cases, very challenging. These challenges were encountered in other similar studies (Brouwer et al., 1997). The services were often defined in a different way to other papers, or overlapped with other services. If it was impossible to distinguish which service(s) specifically the value related to, this paper had to be excluded. A challenge existed in that if assignment was too broad, the true value may not be captured. Likewise, if it was too narrow, there were too few values for comparison. Table 6.5 highlights the originally identified services valued in each study, and the TEEB service these were most closely matched to. As some of the papers valued multiple services, some papers are duplicated in this table.

No.	Ecosystem Service valued	TEEB service assignment
1	Invasion regulation	Biological control
1	Carbon sequestration	Carbon sequestration and storage
1	Erosion regulation	Erosion prevention and maintenance of soil fertility
1	Water regulation	Fresh water
1	Nitrogen removal	Local climate and air quality
1	Recreation	Recreation and mental and physical health
1	Wildlife viewing	Aesthetic appreciation and inspiration for culture, art and design
1	Aesthetic	Aesthetic appreciation and inspiration for culture, art and design
2	Science & Historic Info.	Aesthetic appreciation and inspiration for culture, art and design
2	Aesthetic Information	Aesthetic appreciation and inspiration for culture, art and design
2	Biological Control	Biological control
2	Soil formation	Erosion prevention and maintenance of soil fertility
2	Soil retention	Erosion prevention and maintenance of soil fertility
2	Nursery function	Habitats for species

Table 6.5: Ecosystem Services valued and assigned Service for included valuation studies (continues)

No.	Ecosystem Service valued	TEEB service assignment
2	Refugium function	Habitats for species
2	Climate regulation	Local climate and air quality
2	Gas regulation	Local climate and air quality
2	Genetic resources	Maintenance of genetic diversity
2	Pollination	Pollination
2	Recreation	Recreation and mental and physical health
3	Gas regulation	Local climate and air quality
3	Biological Control	Biological control
3	Pollination	Pollination
3	Soil retention	Erosion prevention and maintenance of soil fertility
3	Waste treatment	Waste-water treatment
3	Water regulation	Fresh water
3	Gas regulation	Local climate and air quality
3	Pollination	Pollination
4	Wildlife viewing	Aesthetic appreciation & inspiration for culture, art & design
5	Aesthetic	Aesthetic appreciation & inspiration for culture, art & design
6	NA (TEV)	NA (TEV)
7	Aesthetic & Recreation	Aesthetic appreciation & inspiration for culture, art & design
7	Soil formation	Erosion prevention and maintenance of soil fertility
8	NA (TEV)	NA (TEV)
9	Soil erosion control	Erosion prevention and maintenance of soil fertility
9	Water supply	Fresh water
9	Gas regulation	Local climate and air quality
9	Nutrient cycling	Local climate and air quality
9	Biodiversity	Maintenance of genetic diversity
9	Disturbance regulation	Moderation of extreme events

Table 6.5: Ecosystem Services valued and assigned Service for included valuation studies (continues)

No.	Ecosystem Service valued	TEEB service assignment
9	Recreation	Recreation and mental and physical health
10	Carbon sequestration	Carbon sequestration and storage
10	Soil preservation	Erosion prevention and maintenance of soil fertility
10	Oxygen release	Local climate and air quality
11	NA (TEV)	NA (TEV)
12	Soil formation & conservation	Erosion prevention and maintenance of soil fertility
12	Hydrological cycle	Fresh water
12	Gas regulation	Local climate and air quality
12	Biodiversity maintenance	Maintenance of genetic diversity
12	Waste treatment	Waste-water treatment
13	Aesthetic	Aesthetic appreciation & inspiration for culture, art & design
13	Carbon sequestration	Carbon sequestration and storage
13	Soil formation	Erosion prevention and maintenance of soil fertility
13	Biodiversity/Genetic	Maintenance of genetic diversity
14	Stored carbon	Carbon sequestration and storage
14	Pollination	Pollination
15	NA (TEV)	NA (TEV)
16	Carbon sequestration	Carbon sequestration and storage
17	NA (TEV)	NA (TEV)
18	Plant diversity storage service	Maintenance of genetic diversity
19	Carbon sequestration	Carbon sequestration and storage
19	Nitrous oxide emissions	Local climate and air quality
20	Methane uptake	Local climate and air quality
20	NA (TEV)	NA (TEV)
21	Erosion prevention	Erosion prevention and maintenance of soil fertility
21	Water purification	Waste-water treatment

Table 6.5: Ecosystem Services valued and assigned Service for included valuation studies (continues)

No.	Ecosystem Service valued	TEEB service assignment
21	Climate regulation	Local climate and air quality
21	Genetic resources	Maintenance of genetic diversity
21	Drinking water	Fresh water
21	Irrigation water	Fresh water
21	Hydro-electric	Fresh water
21	Ecotourism	Recreation and mental and physical health
21	Biological Control	Biological control
21	Soil formation	Erosion prevention and maintenance of soil fertility
21	Erosion prevention	Erosion prevention and maintenance of soil fertility
21	Water regulation	Fresh water
21	Climate regulation	Local climate and air quality
21	Pollination	Pollination
21	Water purification	Waste-water treatment
21	Erosion prevention	Erosion prevention and maintenance of soil fertility
22	NA (TEV)	NA (TEV)
23	Carbon sequestration	Carbon sequestration and storage
23	Nitrogen sequestration	Local climate and air quality
23	Biodiversity maintenance	Maintenance of genetic diversity

Table 6.5: Ecosystem Services valued and assigned Services for included valuation studies (continued)

There are, potentially, still some conceptual issues in Ecosystem Service assignment which could affect the outcomes of the valuation study. For example, in study 21, both “soil formation” and “erosion control” were assigned as the TEEB service “Erosion prevention and maintenance of soil fertility”. Although this is the correct assignment, as each are taken as individual service values, this could provide an underestimate in both cases for the value of the umbrella TEEB service. Where this could be a potential source of underestimation, overestimation is also feasible where a service which is valued as “Aesthetic” (for example high abundance of wildflowers), is also being valued for its pollination services. These overlaps or potential double counts could however be the truest representation of the actual functioning of ecosystems. A further example could be where fresh water is valued for its recreational potential (fishing), and as a drinking water source (Boyd and Banzhaf, 2007). This could be an interesting chance at further study once more valuation studies have taken place.

This study acknowledges the potential for underestimation and/or double counting. This is, unfortunately, relatively common across the field of ecological economics at present (see for example Boyd and Banzhaf, 2006; de Groot, Wilson & Boumans, 2002; Morse-Jones et al., 2010). Every effort has therefore been made to be explicit in assumptions and assignments while extracting information from papers to allow further extrapolation where required.

In 7 studies, a TEV of the grassland(s) was carried out. If stated, the Ecosystem Services included in this total value varied between studies. Table 6.6 investigates what is included within this total value in the studies this applies to. Although technically some of these TEVs did separate out value in to composite service parts, these could not be separated due to heterogeneous units e.g. $/bird/acre or $/% area of wildflower coverage.

Study no.	**Ecosystem Services included in TEV**
6	Wild food; non-food products; climate regulation; water regulation; sense of place; charismatic species; non-charismatic species
8	Bird species richness; bird species density; presence of endangered species; % area of wildflower; number of burnings per year; distance to grassland from home
11	CO2 fixation; O2 release; supply of organic matter; Soil conservation
15	Harvesting; carbon sequestration; Biodiversity
17	Biodiversity loss/gain
20	Biodiversity conservation
22	soil erosion control; water conservation; direct production; gas regulation

Table 6.6: Ecosystem Services included in any included TEV studies

The total values are clearly made up of vastly different services, and certainly not the full range of services provided by grasslands. As such, any outputs from statistical study will be investigated to judge the impact of this.

6.3 DATA EXPLORATION

Data exploration was undertaken to identify initial trends in the valuation data, and to establish suitability of the data for modelling. A boxplot and scatter graph was drawn for both the dependent and explanatory variables, these are displayed below.

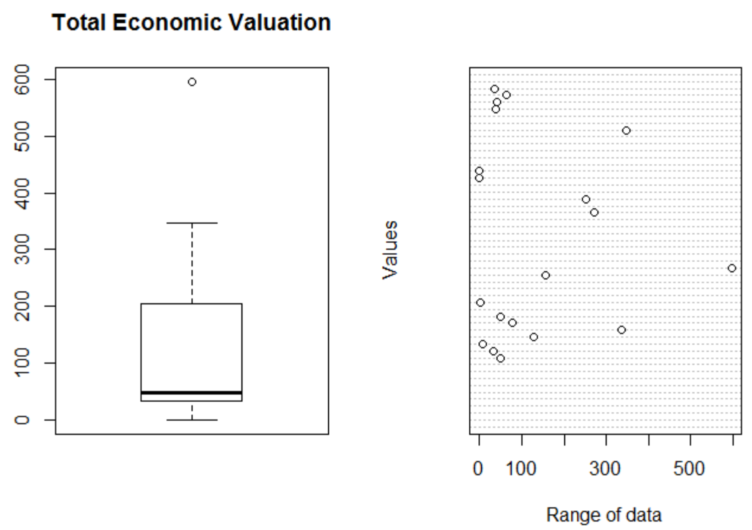


Figure 6.2: Box plot and scatter plot for TEV values extracted

These plots show the literature contains a wide variation in $/ha/year values of grasslands. This is likely because of differing numbers of services valued between studies. One data point (Dong et al., 2012), is somewhat higher than the other figures. This was a valuation of the Natural Capital Value of natural pastures in North Xinjiang, China. The figure is not so high to be considered an outlier considering our initial lack of understanding regarding variation in valuation.

Ecosystem Services

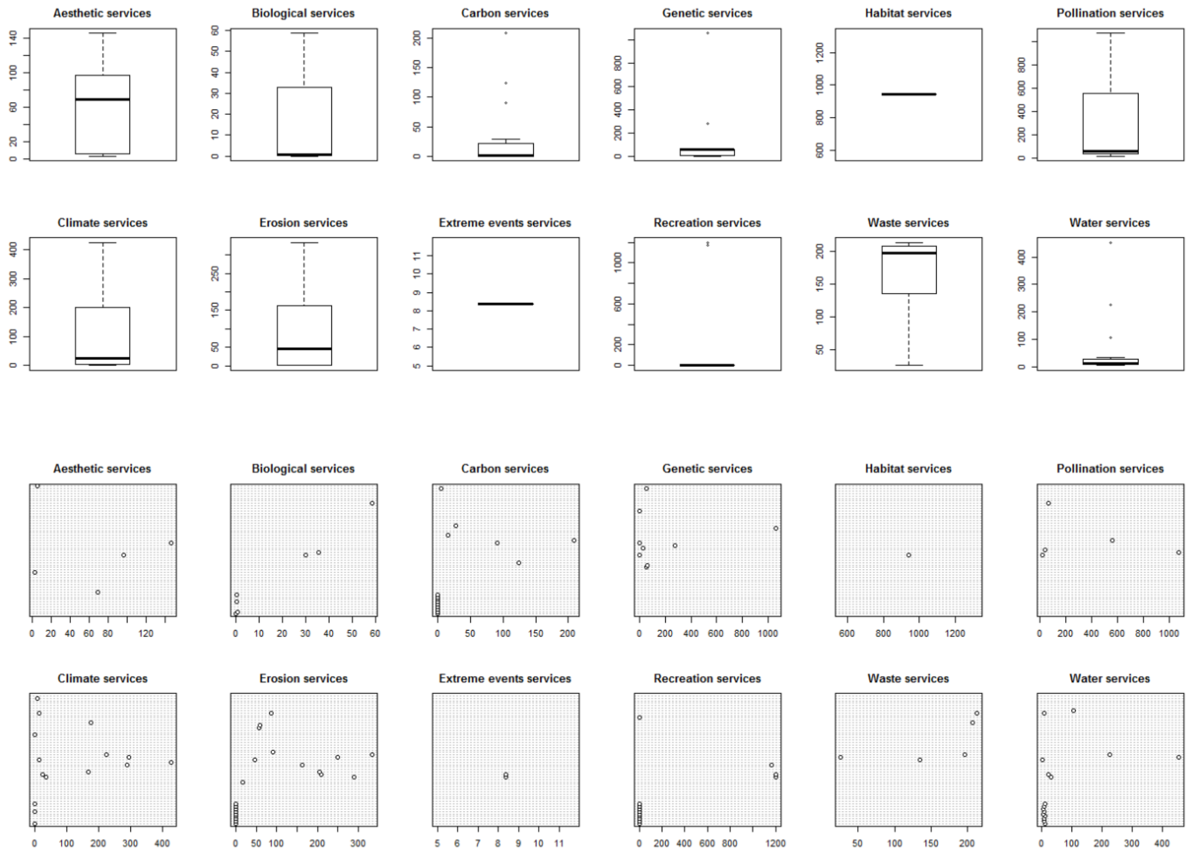


Figure 6.3: Plots showing distribution of Ecosystem Service values

These plots highlight the wide ranging and sometimes skewed nature of the valuation of individual Ecosystem Services. Some services only have a very small amount of points for comparison (Habitats, Extreme events), while others show widely varying values (especially Recreation Services, Carbon sequestration, Waste services and Pollination). To investigate this further, descriptive statistics for all individual Ecosystem Service values and Total Economic Valuations are shown below.

Variable	Min ($/ha/yr)	Max ($/ha/yr)	Median ($/ha/yr)	Mean ($/ha/yr)	Variance	Standard deviation	n*
Aesthetic	1.22	145.69	37.53	53.40	3011	54.87	6
Biological	0.04	58.67	0.72	17.94	481.48	21.94	7
Carbon	0.08	208.47	0.31	31.55	7544.74	59.54	15
Climate	0.01	425.07	13.69	88.01	14384.1	119.93	19
Erosion	1.21	333.38	17.73	78.88	10695.29	103.42	23
Events	8.37	8.37	8.37	8.37	NA	NA	2
Genetic	0.02	1055.2	55.02	171.17	104227.1	322.84	9
Habitats	116.39	825.70	471.05	471.05	NA	NA	2
Pollination	18.37	1076.09	62.58	350.83	172016.3	414.75	5
Recreation	0.25	1199.7	0.25	274.75	250863.9	500.86	13
Waste	26.44	213.2	162.27	129.71	6397.24	79.98	6
Water	4.63	453.7	13.23	52.64	11885.96	109.02	18
Total Economic Valuation (TEV) – summation of above means	**177.03**	**6003.24**	**842.75**	**1728.3**	**581507.1**	**1787.15**	**125**
Total Economic Valuation (TEV) from papers	**0.03**	**595.96**	**45.5**	**124.53**	**23774.36**	**154.19**	**20**

Table 6.7: Descriptive statistics for all Ecosystem Services and TEVs (from non-summed data sheet)

Initial descriptive statistics show us a number of skewed distributions with long tails of high values. One of the services only had two estimates (e.g. Habitats). It was initially hoped service values could individually be modelled against their explanatory variable to help explain their variation. Due to the low number of observations for most of the services, however, this would violate basic assumptions of any model. This would be an interesting further study once more valuation studies have taken place.

6.3.1 Exploration of TEV

The figures obtained for TEV are highly variable (variance=25624.6), with uncertainty caused by often unknown inclusion of services. In line with Brouwer's 1997 study of wetland service values, a Kruskal-Wallis test was performed for TEV values against explanatory variables. The Kruskal-Wallis test is appropriate for datasets that could violate normality assumptions as is the case in this study. This may help explain some of the variation in grassland TEV values.

TEV~Method

Hypothesis	x^2	p **value**
Equality of **TEV** figures across **Valuation Methods**	7.2629	0.03

Table 6.8: Results of Kruskal-Wallis test for Valuation Methods

x^2 relates to the chi-squared statistic and p value is the two-tailed probability value for the test. The significant p value indicates non-equality across the method groups. A boxplot relays this information further below:

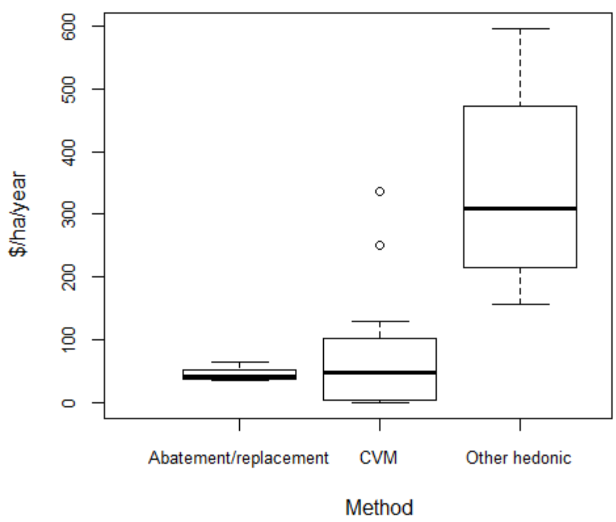


Figure 6.4: Exploration of TEV by Method

"Other hedonic" methods clearly show higher variance than contingent or Abatement/replacement methods. It also tended to show higher values as demonstrated in the box plot. "Other hedonic" involves some lesser used methods as "Emergy" or discounted cash-flow models (discussed in Section 5.2.3). As the study progresses, it would be beneficial to establish whether these values are over-estimations or the other methods are under-estimations. Value methods are disaggregated further in later models in order to attempt to infer more information on method influence.

TEV~Grassland Type

Hypothesis	x^2	p **value**
Equality of **TEV** figures across **Grassland Types**	4.8969	0.43

Table 6.9: Results of Kruskal-Wallis test for Grassland Types

x^2 relates to the chi-squared statistic and p value is the two-tailed probability value for the test.

The insignificant p value shows there is better equality across the Grassland Types in the dataset. This is even despite uncertainty assigning standardised grassland types. The below box plot shows TEV by Grassland Type.

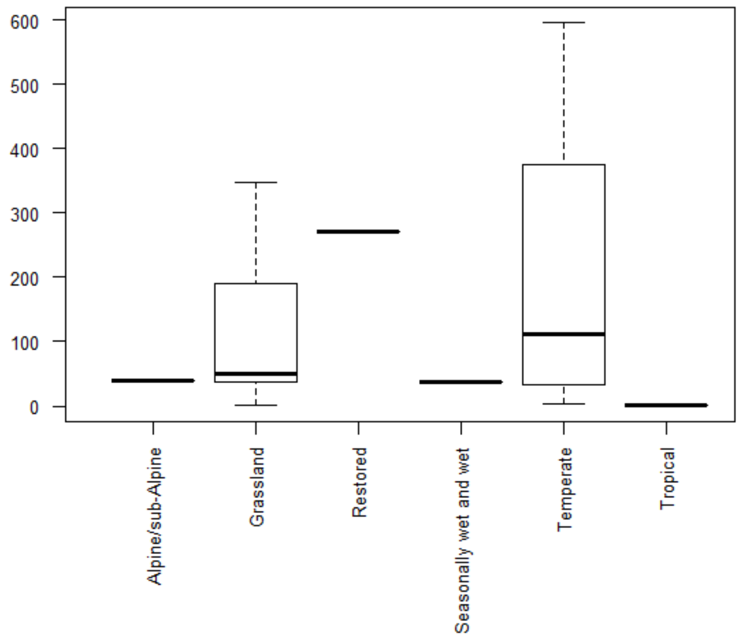


Figure 6.5: Boxplot showing distribution of values by Grassland Type

Interpretation is hindered by a lack of data points for a number of the Grassland Types. Despite this, it is clear that Temperate grasslands are valued higher across the literature than other types. Somewhat surprisingly, restored grasslands are also valued higher than a number of other grassland types. This reinforces the need for further research in to the benefits of created and restored grasslands.

6.4 Mixed-effects modelling

A linear mixed-effect model was run according to Section 5.6. The theoretical difficulty arose from attempting to model values where we had a range of total values for grasslands, "TEV", with no indication of how much each individual service contributed, and then a range of individual service values, where there is no indication of the total value of the grassland. This is highlighted by Figure 6.6 outlining the structure of the data extracted. It is hoped that the mixed-effect modelling structure will mitigate this difficulty.

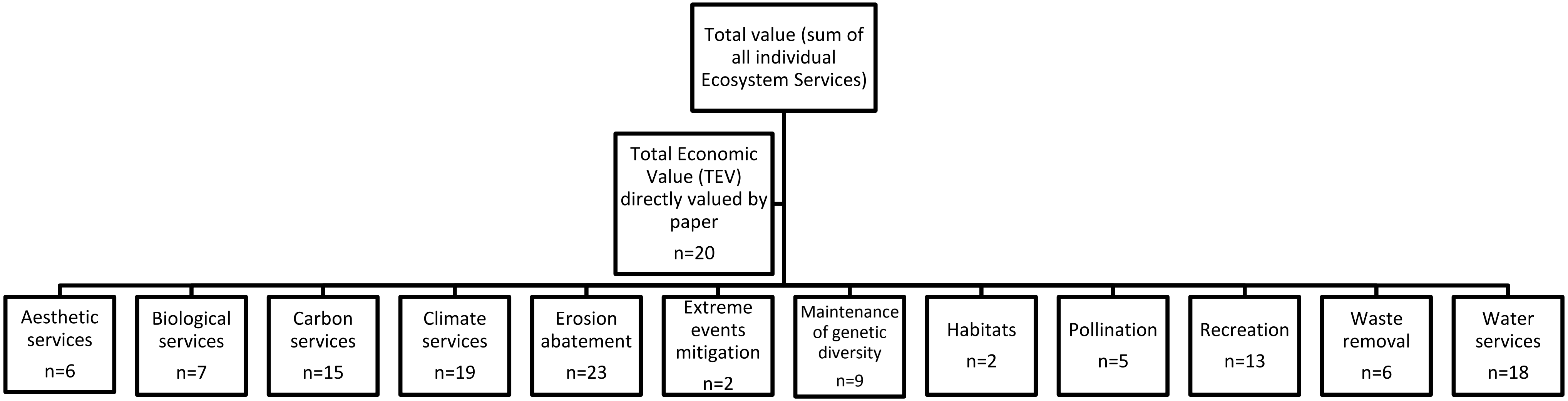


Figure 6.6: Diagram outlining structure of valuation data obtained from systematic review

Further variable description (full R code provided in Appendix 7)

Variable grouping	Variable	Mean	Median
Dependent	Total/logTotal (y) ($/ha/year)	113.43/2.84	18.37/2.69
Geographical variables	Latitude	40.72	47.57
	Longitude	-2.8865	15.750
	Area(ha)/logArea (ha)	2.92*10^7/11.69	3.70*10^4/10.52
	Alpine and sub-Alpine	N/A	N/A
	Grassland (generic)	N/A	N/A
	Restored	N/A	N/A
	Temperate	N/A	N/A
	Tropical	N/A	N/A
	Wet and seasonally wet	N/A	N/A
Methodological variables	Year0 (years since year of oldest)	16.19	17.00
	Avoided Cost	N/A	N/A
	CVM	N/A	N/A
	Damage Cost	N/A	N/A
	Direct Market Pricing	N/A	N/A
	Ecosystem Service Values	N/A	N/A
	Expert Survey	N/A	N/A
	Maintenance Cost	N/A	N/A
	Marginal Abatement Cost	N/A	N/A
	NPP	N/A	N/A
	Other hedonic	N/A	N/A
	Replacement	N/A	N/A
	Value transfer	N/A	N/A
Socio-economic variables	GDP (2013$)	6.76*10^12	2.68*10^12
	Popdens (per ha)	1.11	1.36
	Percagri (Percent agricultural land in country of study)	54.5	54.7
	Annual Net Saving[32] (ANS)($2014)	10.28	5.7

Table 6.10: Included variables and their initial descriptive statistics (continues)

[32] ANS: True saving rate of economy taking in to account depletion of natural resources and pollution damage

Variable grouping	Variable	Mean	Median
Ecosystem Service variables	Aesthetic ($/ha/year)	53.40	37.53
	Biological ($/ha/year)	17.94	0.72
	Carbon ($/ha/year)	31.56	0.31
	Climate ($/ha/year)	88.01	13.69
	Erosion ($/ha/year)	78.88	17.73
	Events ($/ha/year)	8.37	8.37
	Genetic ($/ha/year)	171.17	55.02
	Habitats ($/ha/year)	116.39	471.05
	Pollination ($/ha/year)	350.83	62.58
	Recreation ($/ha/year)	274.75	0.25
	Waste ($/ha/year)	129.71	162.27
	Water ($/ha/year)	52.64	13.23

Table 6.10: Included variables and their initial descriptive statistics (continued)

All analyses were undertaken in RStudio Version 0.98.1074 – © 2009-2014 RStudio, Inc. The values in 2013 US$ were the dependent variable *y*. Due to the skewed nature of the dependent variable, the model performed best with logged Total. As some studies were based on a local level, while some valued grasslands over whole countries, areas varied widely. Generalised linear mixed-effects models were ran using MAServ2 and Method as grouping variables. The explanatory variables can be divided in to three main groups, the methodological characteristics (e.g. Valuation Method, Year of Study), geographical characteristics (e.g. Latitude, Longitude, Grassland Type, logArea), and socio-economic characteristics (GDP, Population density, Percent Agricultural Land, ANS). Socio-economic variables were, on the whole, inferred from outside the studies to further inform the model. A model was run for each of these three groups, then a full model with all variables was run. The model performed optimally using the logged versions of GDP and Area. As such, the coefficients of these logged variables are elasticities. A percentage change in the dependent variable *y* should produce a small percentage change in the logged *x* variable. As some studies were based on a local level, while some valued grasslands over whole countries, areas varied widely. The new estimated model in matrix notation:

Equation 6.1: Estimated mixed-effects model

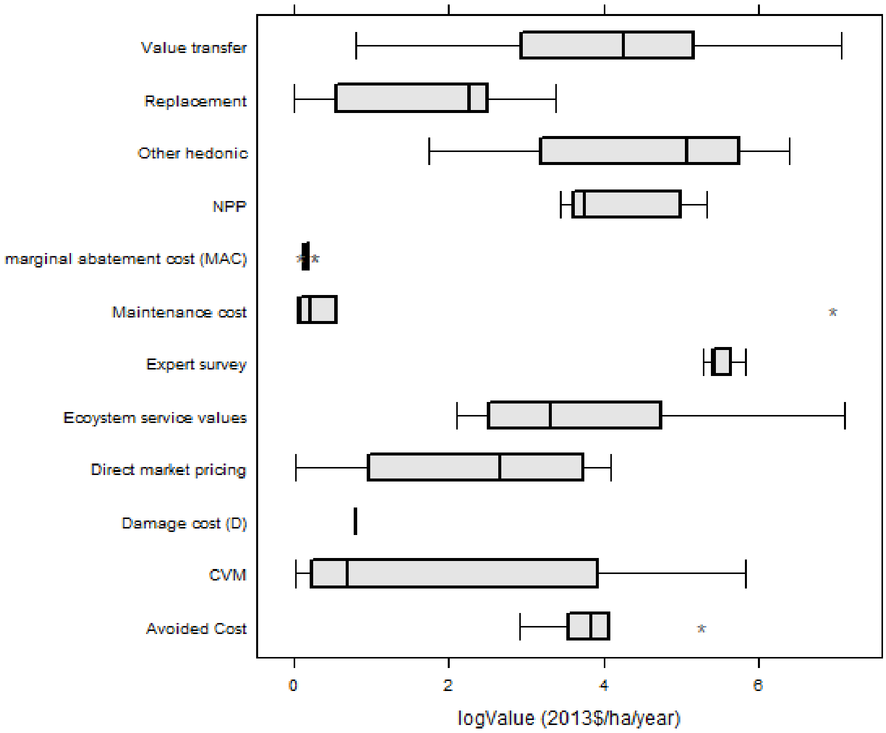
$$Y_{ij} = \mu + \alpha_k + \beta_k + (\alpha\beta)_{jk} + e_{ij}$$

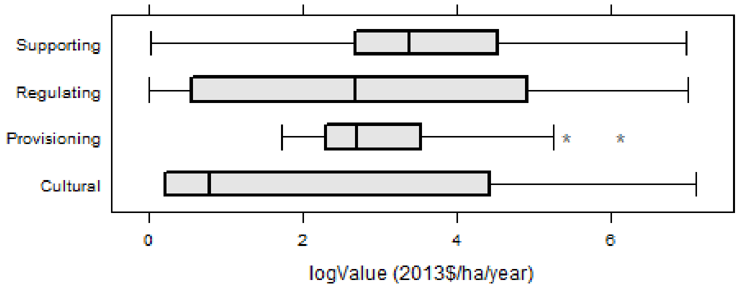
Where Yij is the vector of responses for individual studies i in group j, of which i is equal to the grand mean μ, β is the effect of the kth level of the random effects, α is the effect of the kth level of fixed effects, $\alpha\beta$ is the interaction between random and fixed effects, and e_{ij} is the error term.

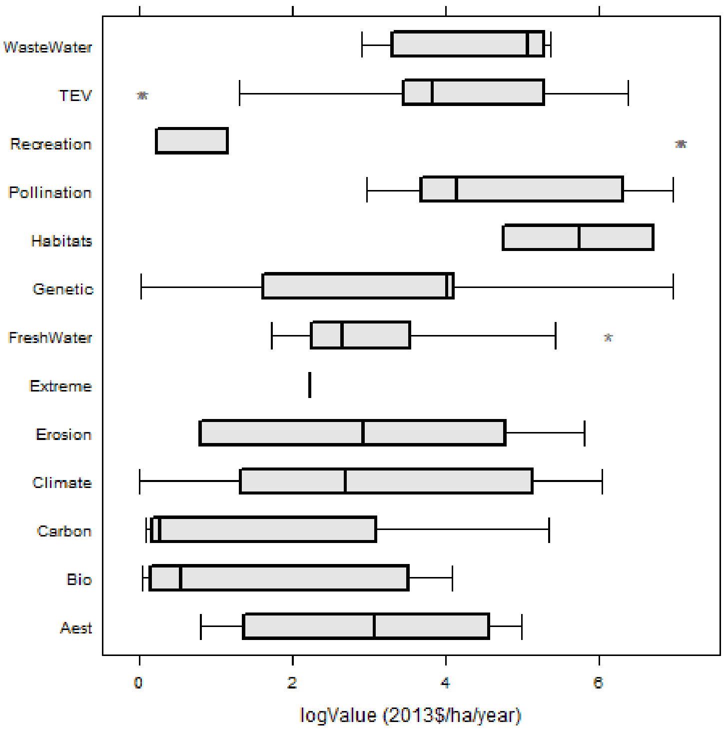
All variables are stated in Table 6.10 on the previous page.

6.4.1 Group-mean reliability

The first stage of multi-level modelling requires extensive testing that potential groupings exist in the data. Boxplots showing the impact of potential grouping factors are displayed below in Figures 6.7-6.9.

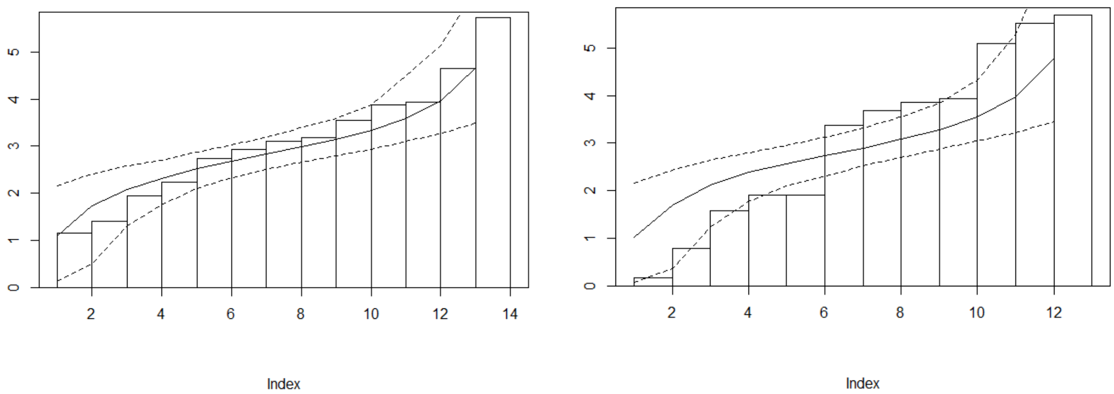






Figures 6.7-6.9: Effects of potential grouping factors of logValue (2013$/ha/year)

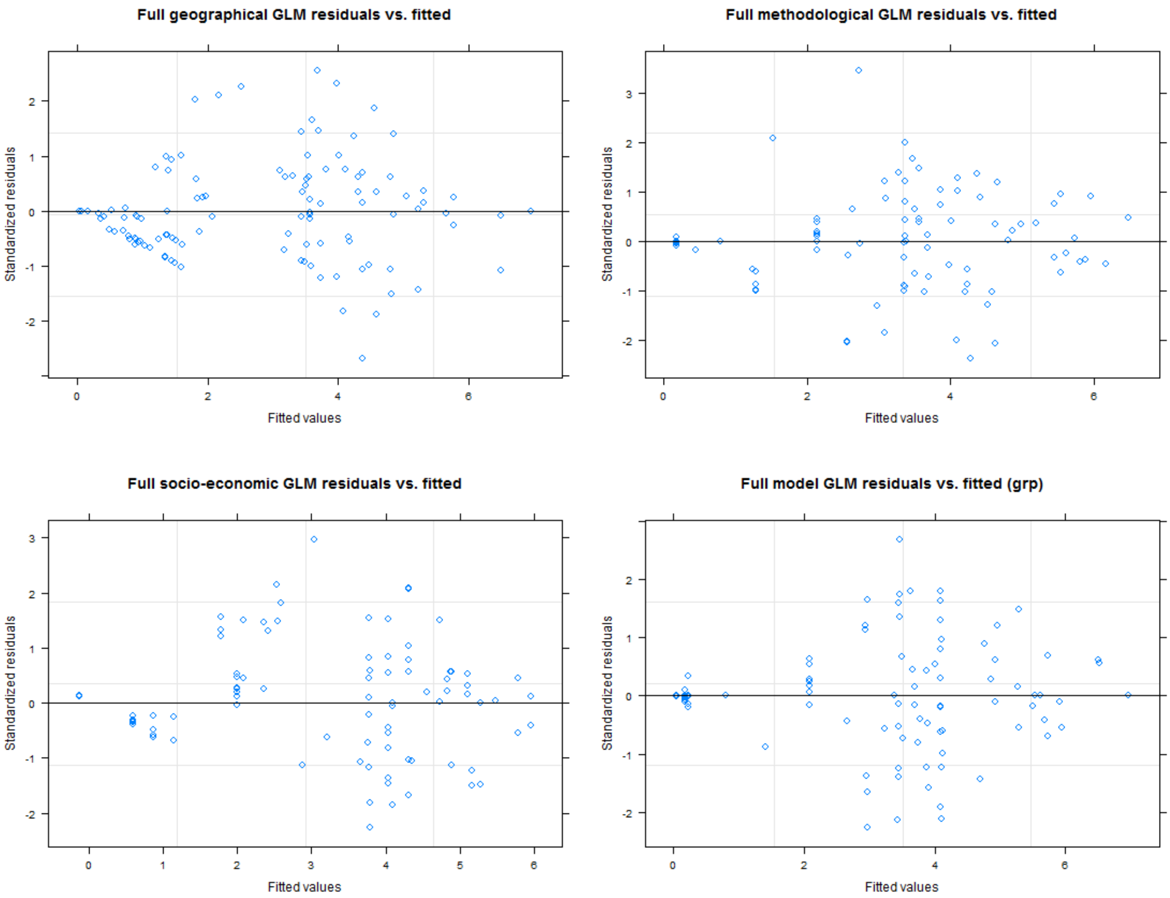
As differing Ecosystem Service provision is valued across the included studies, service as a grouping factor is most theoretically sound. However, reference to the literature implies method could have a significant effect on value outcome. As such, method was also tested as a grouping factor. Agreement indices (R_{wg}) analysis showed poor in-group variance for MAServ (6%), but good in-group variance for MAServ2 (76%) and even better for Method once standardised (86%). ICC(1) calculations showed 13% of the variance in individual logValue estimates can be attributed to MAServ2 (standardised Ecosystem Service) and 48% for Method2. Group-mean reliability estimates were 56% and 90% respectively. Plots indicating good in-group reliability are presented in Figures 6.10 and 6.11. This is indicated by the solid black line mirroring the gradient of the bars. Although both show within-group agreement, clearly Method2 shows a particularly strong association by group to value (Bliese, 2000). The variability of $\tau 00$ was significant to 0.1 for MAServ2 and <0.001 for Method2.



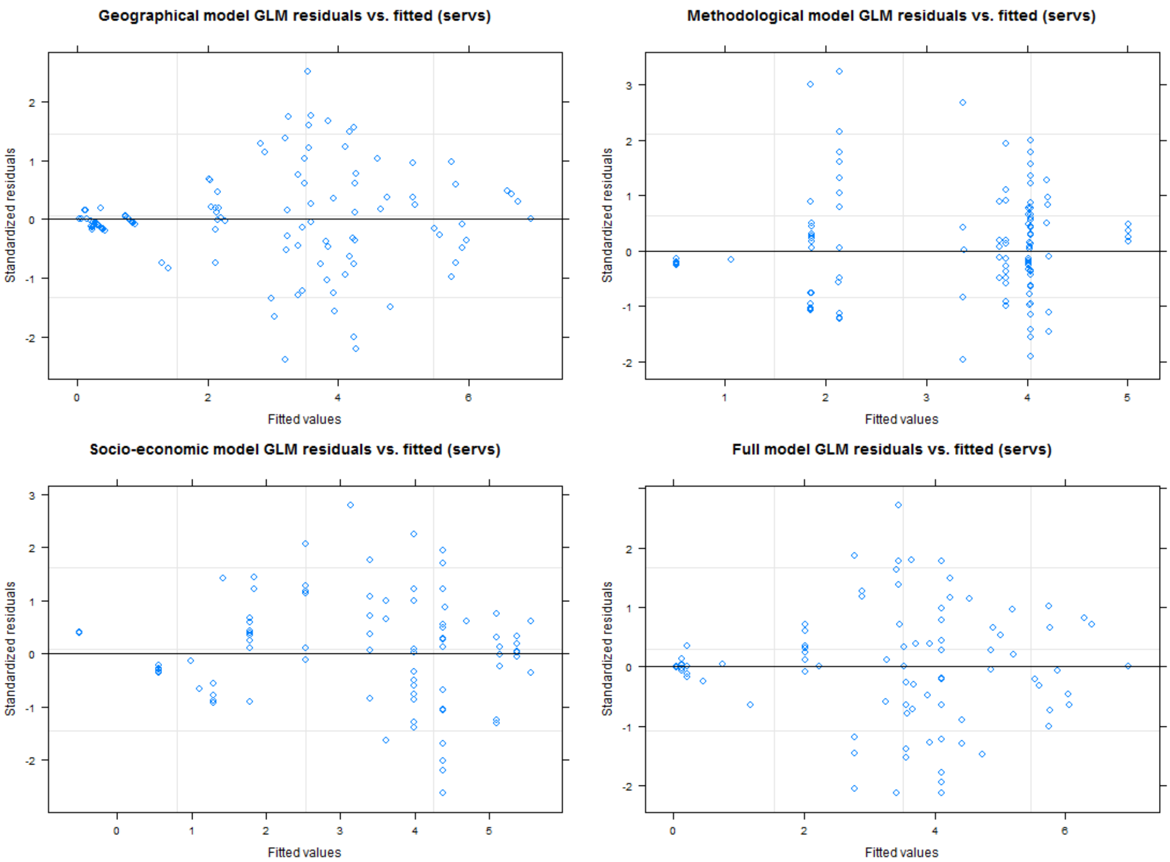
Figures 6.10 and 6.11: Plot to show group mean reliability by Ecosystem Service and Method

6.5 *Full model*

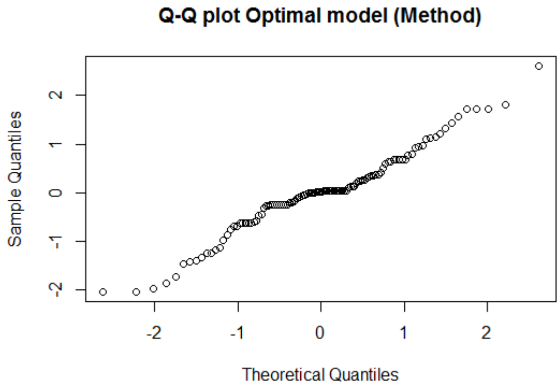
Due to over-parameterisation of the full model, ANS and Type could not be included in the initial model. Model outputs are summarised in Tables 6.11 and 6.12 below. Residual vs. fitted plots from all models are presented in Figures 6.12-6.19 to assess any homogeneity of variance or other violations.

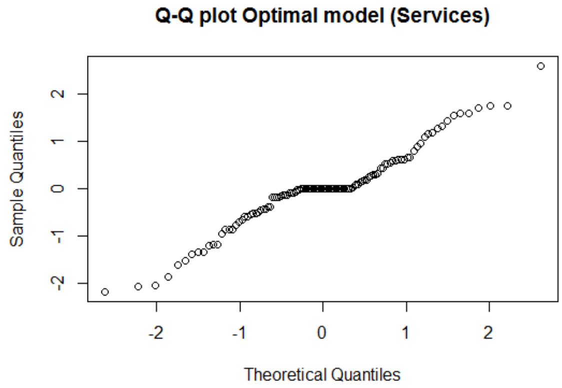


Figures 6.12-6.15: Fitted vs. residual plots for all models with Ecosystem Services as random



Figures 6.16-6.19: Fitted vs. residual plots for all models with Valuation Method as random





Figures 6.20 and 6.21: Q-Q plots for both models

Residual plots look acceptable. There is possibly a little over-dispersion in the Geographical model (signified by a slightly cone-shaped residual pattern), but nothing of concern. Outputs of models are presented in Tables 6.11 and 6.12 showing variable coefficients, significance and robust standard errors. Descriptions of variables and their shortened names are outlined in Table 6.10.

Included variables		Full geographical model	Full methodological model	Full socio-economic model	Optimised model
		Coeff. (Std. error)	Coeff. (Std. error)	Coeff. (Std. error)	Coeff. (Std. error)
Intercept		-2.77 (1.99)	2.02 (1.33)	-16.94 *** (2.88)	-68.41*** (19.8)
1Geographical variables	Continent: Asia	17.98***(4.6)			-44.65*** (10.98)
	Continent: Australia	14.11***(2.82)			7.19 (4.4)
	Continent: Europe	8.99* (3.87)			16.55*** (4.83)
	Continent: N America	1.10 (3.23)			24.89***(6.47)
	Continent: S America	4.16. (2.27)			45.92 ***(9.82)
	logArea	0.03 (0.05)			-
	Latitude	-0.09. (0.05)			-
	Longitude	-0.08*** (0.02)			-
	Type: Grassland	0.52 (0.65)			-
	Type: Restored	0.85 (0.88)			-
	Type: Temperate	0.73 (0.89)			-
	Type: Tropical	0.49 (2.0)			-
	Type: Wet	-0.06 (0.69)			-
	Type: Urban	-			-
Methodological variables	Year0		0.1* (0.05)		-
	Method: CVM		-5.46*** (1.24)		-12.57***(2.57)
	Method: Damage cost		-3.26** (1.16)		-9.59*** (2.43)
	Method: Direct Market		-0.3 (1.51)		-0.30 (1.18)
	Method: ES values		0.65 (1.02)		-12.27***(3.23)
	Method: Expert survey		1.99. (0.97)		-11.26***(3.19)
	Method: Maintenance		-0.79. (1.3)		-9.95*** (2.49)
	Method: MAC		-3.07* (1.28)		-9.63*** (2.43)
	Method: NPP		1.86 (1.24)		-11.67***(3.23)
	Method: Other hedonic		-1.24 (1.59)		-11.27***(3.23)
	Method: Replacement		-2.06* (0.97)		-8.34*** (2.38)
	Method: Value transfer		1.07 (1.02)		-12.25*** (3.2)
Socio-economic variables	Population density			0.80* (0.32)	-4.87*** (1.8)
	logGDP			0.77*** (0.09)	-
	Percagri			-0.06* (0.02)	1.09*** (0.29)
	ANS			0.03* (0.01)	2.23*** (0.54)
Marginal R^2 (%)		**57**	**51**	**56**	**69**
Conditional R^2 (%)		**65**	**85**	**64**	**88**

***= 0.001 ** = 0.01 *=0.05 .=0.1
Marginal R2 = Proportion of variance explained by fixed effects alone
Conditional R2 = Proportion of variance explained by fixed and random effects

Table 6.11: Fixed-effects output for hierarchical model with Ecosystem Service valued as grouping factor

Included variables		Full geographical model	Full methodological model	Full socio-economic model	Full model
		Coeff. (Std. error)	Coeff. (Std. error)	Coeff. (Std. error)	Coeff. (Std. error)
Intercept		-2.47 (2.96)	2.62*** (0.98)	-17.78*** (3.5)	-55.53*** (9.95)
Geographical variables	MAServ2: Biological	0.64 (0.9)			1.13 (0.8)
	MAServ3: Carbon	0.26 (0.89)			0.68 (0.75)
	MAServ4: Fresh water	1.1 (0.71)			1.52** (0.67)
	MAServ5:Waste water	0.75 (0.87)			1.06 (0.82)
	MAServ6: Habitats	2.56*** (0.91)			2.97*** (0.85)
	MAServ7:Climate	0.37 (0.65)			0.67 (0.61)
	MAServ8: Genetic	-0.21 (0.71)			-0.01 (0.66)
	MAServ9: Extreme events	-0.82 (0.97)			-0.66 (0.92)
	MAServ10: Pollination	0.54 (0.92)			0.88 (0.87)
	MAServ11: Recreation	3.58*** (0.82)			3.51*** (0.74)
	MAServ12: TEV	7.06*** (1.05)			2.23* (1.06)
	Continent: Asia	7.76 (7.25)			-2.19 (1.71)
	Continent: Australia	7.2** (2.81)			3.01** (1.27
	Continent: Europe	4.65 (7.3)			0.51 (1.21)
	Continent: N America	1.6 (5.58)			-4.7** (1.87)
	Continent: S America	9.77*** (2.21)			3.09 (2.07)
	logArea	-0.004 (0.05)			
	Latitude	-0.01 (0.09)			
	Longitude	-0.02 (0.02)			
	Type: Grassland	-0.03 (0.5)			
	Type: Restored	-0.1 (0.72)			
	Type: Temperate	-0.51 (1.32)			
	Type: Tropical	-0.06 (1.5)			
	Type: Wet	-0.13 (0.52)			
	Type: Urban	-			
Methodological variables	Year0		0.03 (0.05)		
Socio-economic variables	Population density			0.84** (0.33)	-0.32 (0.46)
	logGDP			0.78*** (0.12)	2.09*** (0.39)
	Percagri			-0.04* (0.03)	
	ANS			0.02 (0.02)	
Marginal R^2 (%)		**41**	**<1**	**52**	**72**
Conditional R^2 (%)		**92**	**45**	**62**	**87**

***= 0.001 ** = 0.01 *=0.05 .=0.1
Marginal R^2 = Proportion of variance explained by fixed effects alone
Conditional R^2 = Proportion of variance explained by fixed and random effects

Table 6.12: Fixed-effects output for hierarchical model with Valuation Method as grouping factor

Valuation Method Random effects groups	Estimated coefficient	**Ecosystem Service valued** Random effects groups	Estimated coefficient
Avoided Cost	0.4	MAServ1: Aesthetic	-0.96
CVM	-2.03	MAServ2: Biological	-0.04
Damage Cost	0.44	MAServ3: Carbon	-0.4
Direct Market Pricing	-0.14	MAServ4: Fresh water	0.2
Ecosystem Service Values	-0.36	MAServ5: Waste water	-0.06
Expert Survey	0.38	MAServ6: Habitats for species	1.35
Maintenance Cost	0.1	MAServ7: Local climate/air quality	-0.46
Marginal Abatement Cost	0.48	MAServ8: Genetic resources	-0.97
NPP	-0.03	MAServ9: Moderation of extreme events	-1.25
Other hedonic	-0.62	MAServ10: Pollination	-0.19
Replacement	1.53	MAServ11: Recreation	2.58
Value transfer	-0.48	MAServ12: TEV	3.8*10^15
-	-	MAServ13: Waste water	-0.06

Table 6.13: Estimated coefficients of random effects groups in both models.

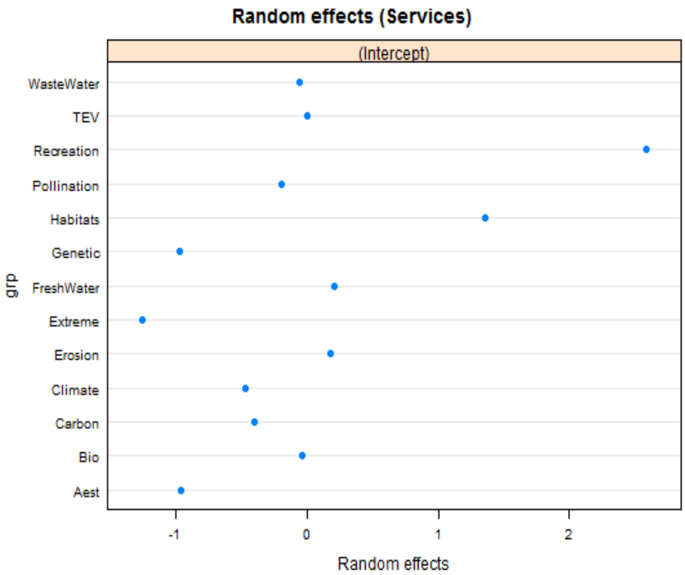


Figure 6.22: Random effect levels of Ecosystem Services on the full Services model

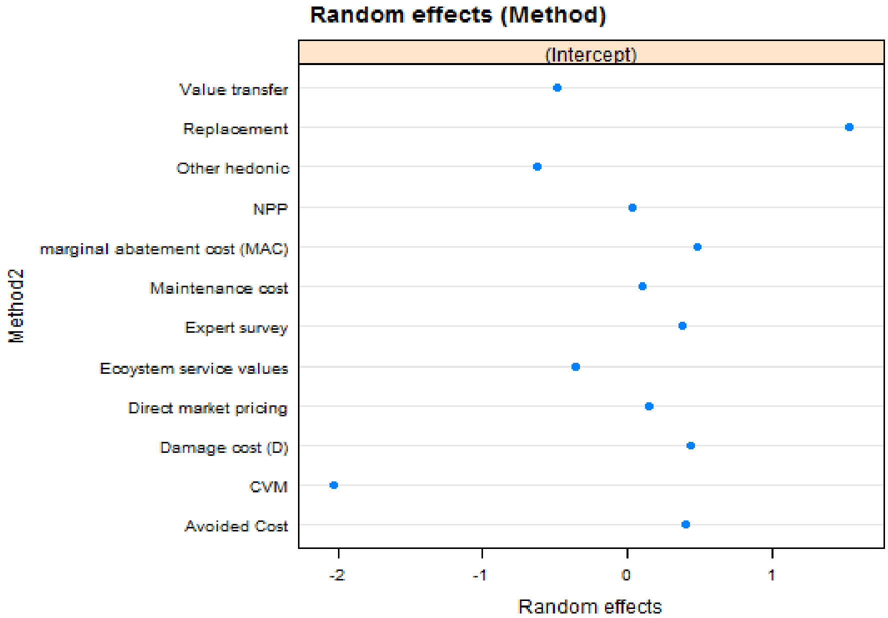


Figure 6.23: Random effect levels of Method of valuation on the full Method model

ANOVAs ran on purely fixed effect models against the full mixed-effect models showed there was a significant difference between them (Method p-value = 0.0002; Service p-value = 0.002). This shows the inclusion of random effects improves the overall models in both the cases of Method and Services as a grouping factor.

The model that presumed grassland value was a function solely of methodological variables performed most poorly based on Marginal R^2. This effect was mitigated by the presence of service under value as a random effect (Conditional R^2 = 85%). The models looking purely at socio-economic or geographical factors performed considerably better based on variance explained. When all variables were included, the full model using MAServ2 as a grouping factor explained 88% of variation in grassland values using conditional R^2 calculations. This figure is high considering uncertainties in unexplained variables and the number of inferred figures. Despite MAServ2's grounds as the most theoretically accurate grouping factor, the model with Method2 as random effects shows a marginally higher conditional R^2 of 89% of variance explained.

Methods of valuing public good assets such as ecological function still show distinct variation of outcome holding all other factors constant. All but Direct Market Pricing show significance in the full Services model of >99%. Despite showing a significant negative effect on value in the model using services as a grouping factor, as a random effect, replacement method shows a larger positive effect on total value obtained (-8.34 as fixed effect, 1.53 as random effect). CVM has a significant negative coefficient as both a fixed and random effect, in line with initial box plots. This could support the hypothesis that the public do not have a sound understanding of ecological values which can underestimate the true value of Ecosystem Services.

Year was mildly significant in the methodological model with services as random effects. At no other point was it significant to the model. The significant positive coefficient implied values were estimated lower in the older studies. This could reflect increased understanding of grassland services and concern over recent increased land use changes, or could simply be the effect of inflation.

Area studied (logged) was never significant in any model. This is most likely due to inconsistency of what constitutes a "site" in included studies. Where many wetlands are valued over one specific site (for example the Snoqualmie Basin in Earth Economics, 2010), grasslands were often valued on a more generic basis, i.e. all grasslands in Germany (Meyerhoff, Angeli & Hartje, 2012). This means small, fragmented areas of grassland were often also valued alongside specific nature reserves, alongside all grasslands in a region or country. Where method of valuation was taken as the random effects, area also did not prove significant.

Latitude was never significant and Longitude only was where Services rather than Method were the random effects. The lack of significance for Latitude is a surprise considering evidence is already in place that Latitude has a strong effect on NPP and as such, value (Imhoff et al., 2004 in Costanza et al., 2007).

The higher significance of Longitude could be indicative of the effects of socio-economic factors on perceived grassland value. The result from this is difficult to interpret however as countries and continents with higher GDP etc. have both low and high longitudes (e.g. Europe is in the region of 0-30 degrees longitude while the USA is in the region of 100 degrees longitude). As such Continent is a more decipherable variable. Continental factor variables were strongly significant where services were used as a random effect. This could imply that services are valued differently according to location of study. Asia and North America showed more consistent low coefficients amongst the continents. The proxy variable "Percent Agriculture" is not especially low for Asia, but perhaps due to the large quantities of grasslands still remaining, the value is perceived as less. It could also be due to a lower proportion of studies using the methods that had higher value estimates such as Replacement value. For North America, the population density is relatively low, as is percent agriculture. This could imply due to a relative lack of grassland scarcity, and less people living closely together, perceived grassland value is still relatively low.

South America showed the highest values across all models. This should be treated with some caution however as only one study was undertaken there, valuing Genetic Diversity very highly. This value could still reflect true value. A recent study cited in National Geographic showed South America to be amongst the highest risk areas for biodiversity loss due to climate change (Urban, 2015 in National Geographic, 2015). This is due to their naturally small populations of species. The same study states Australasia is likely to suffer biodiversity loss. Our values for Australasia are not very high, but genetic information and habitat Ecosystem Service values do not exist for Australasia in our dataset. It would be interesting to see if this follows the evidence for South America. North America shows high values overall despite the above study stating they are unlikely to suffer biodiversity loss as highly as other continents. However, the few studies in the USA valuing genetic information and habitats are much lower than the South American estimates which do then support the hypothesis. The higher values throughout other services for North America may reflect a higher public and Governmental awareness of sustainability measures.

No aspect of grassland type was significant in any of the models. It was thought that this could have a high impact on value, especially since different grassland types show higher aesthetic value. There were difficulties in aggregating grassland type as it often was not specified. The broader type could be inferred to an extent from country in study in some cases. It would have been preferable to classify all of the grasslands to their finer scales to evaluate their values, however in many cases only one instance of certain grasslands were extracted in the systematic review. Interestingly, urban grasslands show the highest value. This could be explained by scarcity of urban grasslands and increased value placed upon them by city dwellers with limited access to ecological amenities. As this variable was insignificant however, caution should be taken on this interpretation.

Socio-economic factors provided some of the most interesting findings. In order to better inform the model, logGDP, Population density, Percent agriculture in the country of study, and ANS were modelled. Population density was significant in all models except in the full Methodological random effects model. This insignificance in this model could mean population density works as a relative proxy for other variables, and its impact is mitigated by variables such as Continent. From Pigouvian theory we would expect environmental taxes to increase with population density. This is due to more people being exposed to effects of environmental degradation (Backhaus and Wagner, 2006). As such it would make sense for values of remaining environmental resources to increase with population density. Strangely, population density, where significant, shows a negative coefficient contrary to this estimate. It is unclear whether this is due to mis-assignment of values. As ANS is an indicator of a country's sustainability, we would expect grassland values to increase in countries that value sustainability. This hypothesis holds in its strongly significant positive coefficient in the Services random-effect model. Although ANS is a relatively new statistic, this may give support to its use as a sustainability and Ecosystem Service value indicator.

It was expected that as percent of agriculture increases, so does value of grasslands as agricultural progress often relies upon destruction of semi-natural grasslands. Despite this, percagri shows a mildly negative coefficient in socio-economic models, switching to a strong positive coefficient in the full model. The significance of this positive in a more substantive model may mitigate its negative values without the temperance of other explanatory variables. Due to these somewhat unclear results, percent agriculture may not be a reliable indicator of grassland value.

GDP (logged) is strongly significant showing a very positive effect on value across all models. This could suggest as countries improve standard of living, perceived values in public good benefits such as grassland increase. This could perhaps be explained by increased free time and a desire to spend this in nature.

Theoretically, MAServ should have been the ideal grouping factor, as each included paper was studying one or more of these services from grasslands. Model fit was good with a grouping factor of MAServ2 (88% conditional R^2). Despite the significance of "Habitats for Species", this was based on only 2 estimates and should be interpreted with caution. Recreation showed a significant positive effect on value as both fixed and random effect, highlighting the potential importance again on people's growing importance on leisure in ecological assets. Studies valuing total economic value (TEV), taking in to account all services, showed a strong positive effect on value in all models. This is most likely as it should theoretically be valuing a higher number of services, and as such, the positive coefficient should be much higher.

6.6 *Reliability of mixed-effects model*

It was highly desirable to create a grouped multi-level model which could use available socio-economic, geographical and methodological variables to help predict individual Ecosystem Service values, which could be summed to provide a total value for any grassland.

Despite this, a number of potential biases exist due to uncertainties in the input data. There is little indication of level of Ecosystem Service provision in the data set. Further variables were inferred where possible to improve model fit (e.g. percentage agriculture). This increases the value transfer opportunities, but further service provision data would have been desirable.

Another difficulty is that not all Ecosystem Services may be included in valuation. Unlike in similar models of other habitats (see for example Woodward & Wui, 2001), the individual services valued are on the whole always present to some degree in grasslands. Therefore outputs may seriously underestimate grassland value. This concern is supported by a look at predicted values from each model. For the model with Method as its random effects, predicted values do not exceed $10/ha/year. For the model with Services as random effects, predicted values do not exceed $7/ha/year. To investigate the in-sample forecasting ability of the model further, Mean Absolute Percentage Error (MAPE) was calculated (Brander, Florax & Vermaat, 2006).

This is calculated as in Equation 6.2:

Equation 6.2 $$|\frac{y_{obs}-y_{pred}}{y_{obs}}|$$

Where y_{obs} is a vector of values extracted from included studies and y_{pred} is a vector of values outputted by the relevant mixed-effects model.

For the Method random-effects model, the MAPE was 79%. For the Ecosystem Service random-effects model, the MAPE was 73%. This is a high level of forecast error. As such, the model can be used to inform the drivers of Ecosystem Service values, but full value transfer from fitted output would be inadvisable.

Poor predictive capacity is likely due to the massive variation in input data. This was also experienced in Brander, Florax and Vermaat's meta-analysis of wetland valuations, hindering prediction ability (2006). The variation in individual service values and overall grassland values is extremely large. For example, one overall grassland value was $36.68/ha/year (Wang & Yang, 2011), whereas another single Climate Ecosystem Service value in the same country (China), was $223.58/ha/year. This sort of discrepancy makes any model output highly uncertain. The usefulness of model outputs will be discussed further in Chapter 7.

6.7 Conclusions from mixed-effects model

This analysis has highlighted the sometimes considerable limitations in the value of natural habitats. Values obtained showed a huge diversity in size, as well as the method of estimation. Further testing was undertaken to identify if the influence of valuation method formed unintentional groups within the dataset. Method proved to have very high within and between group variance, and proved a significant random effect in the overall model. This shows that despite valuing the same services across a similar vector of geographical and socio-economic criteria, the methods of valuation are still potentially not well-aligned. As transformation of the data was required (GDP, Area, Total Value), interpretation of the random effects should be with caution (Gurka et al., 2006).

Socio-economic variables proved a significant source of variation in grassland valuations. This would suggest scarcity of habitat and high populations are forcing people to begin to understand the consequences of grassland loss.

A recommendation to ensure explicit descriptions of methods used and sites studied are given. This follows advice in other notable meta-analyses of natural habitat valuations (David, 1993 in Woodward & Wui, 2001). As Value Transfer methods are clearly used often, and with such uncertainty, rigorous explanation of site details allow better transfer. This review and meta-analysis begins to shed light on some of the most important factors in the value of grasslands. Due to the highly skewed nature of the data, model output should be treated with some caution. The model would benefit from further studies of grassland value across the globe, allowing a more comprehensive analysis of important variables.

6.8 Summary of important findings from economic review

- After a systematic review of the literature, we extracted 145 individual valuation figures of both Ecosystem Service and TEVs of grasslands globally;
- Variation is extremely high amongst the revealed dataset;
- Interrogation of this data revealed method of valuation is highly significant in outcome value;
- Socio-economic data also has a significant effect on assigned value;
- Reliable modelling of the values is still somewhat unachievable due to variation of input data.

Chapters 5 and 6 have presented an overview and analysis of current knowledge of grassland valuations. Examination of residual plots and indication of variance explained (R^2) seemed to show effective modelling took place. However, due to the number of services valued in each paper varying, forecasting of total value of different grasslands from the model is inadvisable. This is confirmed by high MAPE figures as in Brander (2010). Addition to the dataset by further studies could allow more robust forecasts being possible from the model. Despite this, the analysis has provided a number of suitable value transfer estimates. Chapter 7 takes both indicator data from Chapter 3 and valuation estimates from Section 5 in an attempt to apply relevant values to UK created grasslands according to identified biodiversity. Using the significant links between presence or abundance of identified indicator species, species richness, NPP and value (see Sections 4.12 and 4.13), this can allow a final model valuing sites according to present indicator species to be developed in Chapter 7. This link is one of the main contributions of the thesis and is explored in Figure 4.110. It is hoped this model will be empirically useful in addition to its contribution to academic knowledge. This is discussed further in Chapter 8.

CHAPTER 7: APPLICATION OF VALUE TO CREATED GRASSLANDS

7.1 INTRODUCTION

Chapters 2 to 4 investigated the floral structure of created grasslands and the potential presence of indicator species of grassland quality over time. A number of positive indicator species were identified across the included sites. The number of positive indicator species on site, and mean vegetative height (cm) was significantly correlated to species richness. This can be used as a proxy for biodiversity and has been linked to Ecosystem Service provision (through NPP) (Costanza et al., 2007. This indicator species predictor of species richness, and its subsequent link to Ecosystem Service provision, is the crucial link between site variables and value.

Chapters 5 and 6 used the systematic review process and statistical methods to provide an analysis of current grassland values in the literature. This chapter investigates means of transferring the econometric analysis information to the earlier floral analysis. An initial diagram presented relates variables involved in the floral and econometric analyses and the observed links between them.

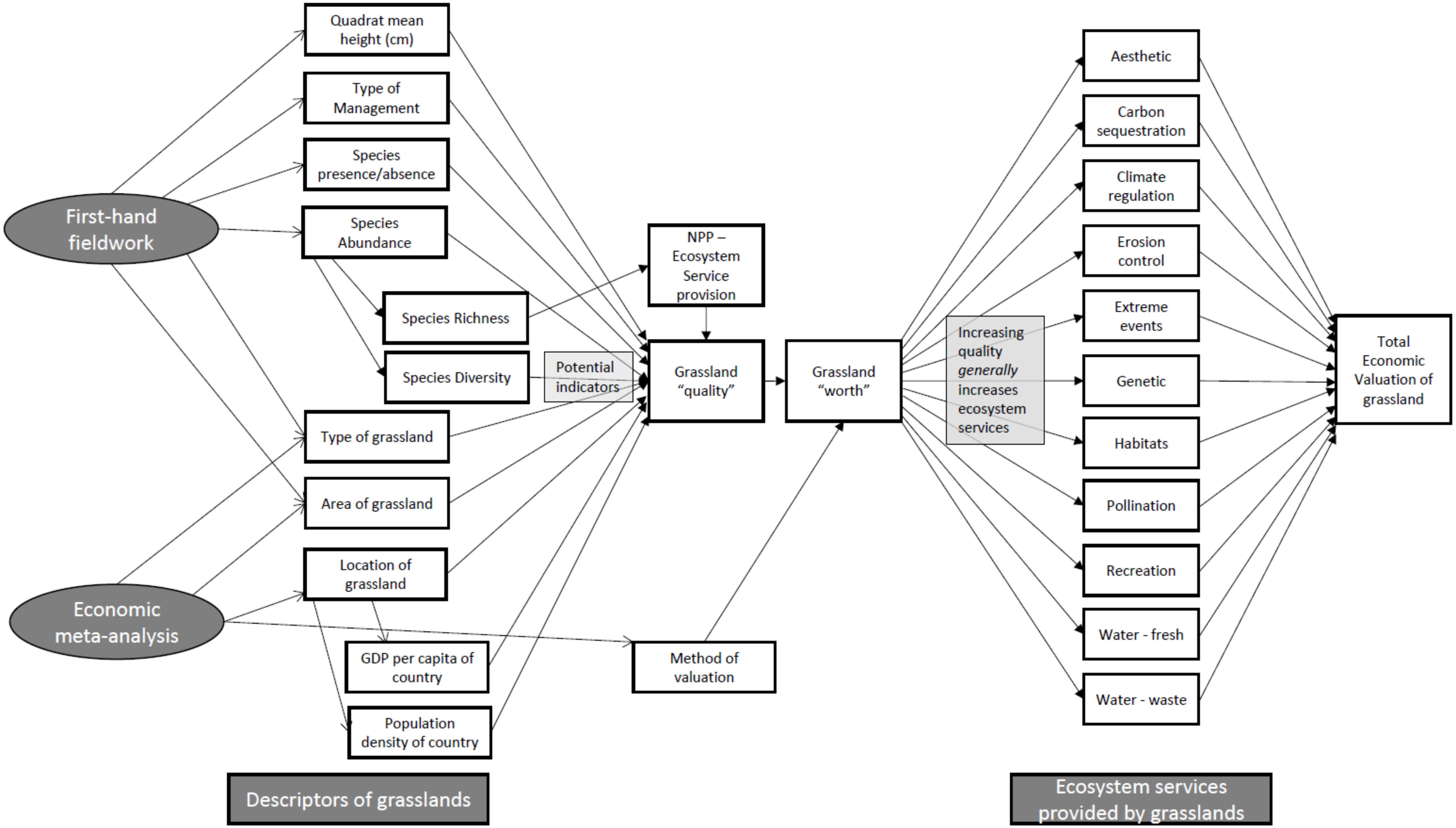


Figure 7.1: Graphical representation of variables identified across the study and observed links between them

Figure 7.1 is presented as a means of structuring the variables so far encountered in this study. The two main branches of study, ecological and economic, are represented on the left. The most important variables studied within each branch are then outlined. The first-hand fieldwork provides variables that convey quality of grassland, such as quadrat mean height, and presence of indicator species. The economic analysis presents valuation information by type, area, and location extracted from studies within the systematic review. As this information is also provided from first hand fieldwork data, these variables are linked. These variables lead to estimates of innate grassland quality, prior to any economic value being applied. Methods of value link directly to the economic value applied, which can be inferred from grassland quality. The link between grassland quality and floral data, and perceived economic value via NPP, is explored firstly in Chapter 3, then further below in Section 7.2. Grassland values extracted in the systematic review are generally disaggregated by Ecosystem Service, presented towards the right of the diagram. These values, guided by benchmarks decided in Section 7.3 can then be applied to study sites according to identified indicators of grassland quality.

7.2 Perceived links between floral data and Ecosystem Service delivery and value

One of the objectives of this study was to devise a tentative means of quantifying the Ecosystem Service delivery of grasslands post-creation. From Chapter 3, we now have a suite of indicator species, both positive and negative, along with indicative community variables. These have attached guidelines of desirable limits sourced from an extensive literature review. From a simple linear regression performed, it was found that number of positive indicator species present (within a quadrat) had a significant positive effect on species richness of the quadrat. Quadrat mean height (cm) was found to have a significant negative relationship with species richness. Although this trend seemed to follow at a sub-site level, there were too few points for regression (n=11). If and when further data from created grassland is produced, and the regression re-ran, other indicators could become significantly linked to species richness. This is especially the case for herb:grass ratio which showed a strong correlation in initial data exploration.

Although this will no doubt fail to fully capture the complexity involved in habitat interactions, it has presented a fairly quick means of establishing biodiversity. Crucially, this provides a quick tool for predicting site species richness, which would otherwise require a full botanical survey. As Section 4.12 showed, species richness is significantly linked to our suite of indicator species. This in practice means we can reliably estimate species richness from the presence of selected indicators. Reference to the literature revealed significant links between species richness, and NPP, a unit showing the delivery of Ecosystem Services. A tentative estimate of a 1% increase in species richness leading to a 1-2% rise in NPP was provided (Costanza et al., 2007). This is, in turn, linked to value of the grassland. As such, an improvement in species richness on created grasslands reasonably links to a rise in economic value.

We have a number of identified indicator species and community variables which it would be desirable to add to the model. We have already shown that the number of positive indicators on site, and mean vegetative height (cm) are significantly linked to species richness.

7.3 Methods of value application

As such, the extensive data exploration and analysis is revisited here in an attempt to establish a suitable Value Transfer for UK grasslands. Many reports looking at this research question apply a basic Value Transfer method, where a value associated with temporally and spatially similar grasslands are applied to the grassland of study.

In Section 5.2.3, a number of desirable features of Value Transfer were discussed from the literature. These are revisited here in order to inform the valuation decision.

a. the environmental good or Ecosystem Service, its quantity/quality and the change in this quantity/quality – As we have specific individual Ecosystem Service values, summation method of all of these should mean that the full range of Ecosystem Services present in grasslands are represented. There would also potentially be a minimum/maximum figure available as a proxy for changes in quality over time or with management.

Individual values for all Ecosystem Service values were not available for any studies conducted in the UK, however TEVs were which could be used instead as a proxy. However, as Table 7.1 (below) shows, these total values potentially underestimate value as they do not value all possible Ecosystem Services.

As mentioned previously, little research has been conducted specifically in to created grasslands, especially on land reclaimed from industry. As such, no values from such grasslands are represented in our data set. There is no way to judge our hypothesis that despite perhaps lower "quality" than natural and semi-natural grasslands, value is higher due to the mitigation of pollution and lack of services from its previous use.

b. the surrounding or using population, their use of the good or service and their socio-economic characteristics – Aside from our values from the UK mentioned above, that obviously reflect the correct socio-economic aspects of the country (not fully accounting for variation between areas in the UK), we have a number of figures from areas with similar socio-economic characteristics. For example, the study undertaken in Germany (Meyerhoff et al., 2012) shows similar characteristics. Summation of all services may obscure socio-economic characteristics without a higher number of individual service values to infer this from better.

c. constructed market characteristics – This follows the above summary.

d. temporal aspect from primary study to transfer – As all values were inflated to 2013$ using econometric techniques in line with de Groot et al. (2012), some of the temporal aspect has been eliminated. In addition, Year of study was never significant across any modelling scenario. This could indicate that temporal elements of the study are not as relevant as other factors. If socio-economic aspects of the location of study have changed dramatically since it was undertaken, this could however be obscured. This could, for example, be the case in Gaodi et al., 2003, as China's economy has altered in the last 13 years.

e. geographical location - Beyond the socio-economic aspects that come with geographical location, and discussed above, geographical region has an influence on the type of soil and grassland that is likely to occur on it. Despite temperate grasslands showing an initial larger value than others, grassland type was not significant across any of the models. Despite this, we do have a study available undertaken in the UK. This had broken down grassland valuations by the more specific UK types discussed in Section 2.2 (Spash & Vatn, 2006; Boyd & Banzhaf, 2007; Seppelt, 2011).

Previous experiments have shown a correlation between latitude and NPP, a proxy for ecosystem service provision and therefore value (Lieth, 1978; Imhoff et al., 2004 in Costanza et al., 2007). This was not evidenced in our study, but due to high variability of values, this is not to say the correlation does not exist. As such, a study from a similar latitude, representing NPP provision, would be an adequate value transfer.

Using the in-depth analysis of obtained figures from the current literature, a number of options exist. These are discussed below:

a. Using Value Transfer from relevant grassland valuation studies. A large number of studies, especially in land use decisions, use this method (see for example Costanza, 2006; Dodds et al., 2008). The advantages and disadvantages of this method are discussed in Section 4.2.3. Two studies from the UK were extracted (Christie et al., 2011; Glaves, Egan & Harrison, 2009), with 8 separate study site valuations. The grassland types, before aggregation, are highly specific to the UK. This would allow more robust Value Transfer to be undertaken. Valuations from restored grasslands were also acquired which should be more relevant to an improving created grassland.

b. Using aggregate Total Economic Valuation (TEV) estimates from extracted studies and using the estimates from sites as temporally or spatially similar to the UK as possible. These include some values from the UK and restored grasslands as discussed above. As discussed in Section 6.5, these TEVs appear to underestimate grassland value in comparison to other means. Establishing particularly low values of ecosystems could be troublesome for future project appraisal.

c. Using a summation of Ecosystem Service values extracted from some, or all, of the existing literature. This method ensures all Ecosystem Services provided by grasslands are captured in valuation. Although theoretically the type of grassland would severely alter grassland value, "Type" of grassland had no significant effect on value across any modelling option pursued.

Table 7.1 examines potential values sourced from the systematic review from the range of options discussed above.

Option		Study name	Specific grassland type[a]	Ecosystem Service/Total[b]	Minimum value ($/ha/yr)	Maximum value ($/ha/yr)	Median value ($/ha/yr)	Mean value ($/ha/yr)	Value ($/ha/yr)
1	Policy site – study site Total Value Transfer from most relevant studies	Christie et al., 2011	Lowland dry acid grassland	Total					**8.36**
		Christie et al., 2011	Lowland calcareous	Total					**31.89**
		Christie et al., 2011	Improved grassland	Total					**48.59**
		Christie et al., 2011	Upland hay meadow	Total					**49.04**
		Christie et al., 2011	Upland calcareous grassland	Total					**78.12**
		Christie et al., 2011	Lowland hay meadow	Total					**128.91**
		Christie et al., 2011	Purple moor grass	Total					**335.76**
		Glaves, Egan & Harrison, 2009	Mixed UK	Aesthetic					**145.69**
		Glaves, Egan & Harrison, 2009	Mixed UK	Carbon sequestration					**90.73**
		Glaves, Egan & Harrison, 2009	Mixed UK	Soil formation					**90.73**
		Glaves, Egan & Harrison, 2009	Mixed UK	Biodiversity/Genetic					**2.95**
		Dodds et al., 2008	Restored USA	Sum of ES valuations[c]	1507.06	1517.82	-	1512.44	**1512.44**
		Kosonen et al., 1997	Restored Indonesia	Total	-	-	-	-	**271.98**
2	Aggregate TEV values from included studies	Christie et al., 2011; Meyerhoff et al., 2012; Dong et al., 2012; Dissanayake & Ando, 2013; Kosonen et al., 1997; Turpie, 2003; Wang & Yang, 2011.	Various	Total	**0.03**	**595.96**	**45.5**	**124.53**	**124.53 (mean)**
3	Summation of all ES values	All	Various	Total (summation of 12 Ecosystem Services)	**177.03**	**6003.24**	**842.75**	**1728.3**	**1728.3 (mean)**

[a] Before standardisation of Grassland Type

[b] Before standardisation to TEEB Ecosystem Service types

[c] Ecosystem Services included: Climate, Erosion, Extreme events; Fresh water; Genetic information; Recreation. Min and max figures indicating two figures provided for Climate value.

Table 7.1: Comparative table of options available for valuation of created grassland habitats.

The evidence so far points to a theme of underestimation in total values of grasslands. When Ecosystem Services are taken in to consideration separately, they tend to be valued much higher. An aim of this study is to value the benefits of creating grasslands in the UK in favour of other, less ecologically beneficial, options. As such, underestimation of the value of these systems could be destructive to this aim and overall efforts to improve the UK's habitats.

The figures for summation of all Ecosystem Service values, and Dodd's estimate of restored grassland value are relatively similar. After consideration of the various issues surrounding valuation, using a Value Transfer from Dodd's study of restored grasslands will be utilised. The reasoning for using this figure for a benchmark are as follows. This is a value for already restored grasslands, so it should represent the end product of a restoration and/or creation project, corresponding to highest species richness. Comparative to other potential values, it is relatively high. As there is a theme of under-representation of benefits from ecology, a higher value may help encourage further creation or discourage destruction of habitat. As such a higher figure could be beneficial for conservation.

Now that the code, and structure of study exists, it is hoped that this figure can be updated as more valuation studies are undertaken. This would be an interesting path for further study.

7.4 Final model and conclusions

The overall goal of this study was to attempt to identify "quick and easy" indicators of biodiversity success in created grasslands. These indicators were to be used as a link with economic valuations of natural habitats. After an exhaustive search of the current literature across both paradigms, and extensive statistical analysis, we now have a model which can be used to provide quick assessment of created grassland habitats. The following assumptions, taken from the literature and analysis in this study, are considered in development of the final model:

a. The regression analysis in Section 4.12 allows us to estimate (per quadrat) species richness from presence of identified indicator species and mean quadrat height.

b. The reference species richness is the maximum species richness (per quadrat) recorded within our dataset (22 species per quadrat). This makes it a realistic benchmark for created grassland quality. This could be altered as appropriate with further data retrieval and the model easily adjusted.

c. The reference Value Transfer estimate discussed above ($1512.44/ha/year, Dodds et al., 2008) is relevant to the reference species richness identified above. This figure is deemed to be a benchmark for maximum value of created or restored grasslands. Therefore an estimated quadrat species richness of 22 is worth $1512.44/ha/year. This figure could also be altered according to future research.

d. A 1% increase in species richness leads to a 1-2% rise in NPP (Costanza et al., 2007). As NPP is a proxy for Ecosystem Service provision, this is in turn used as a proxy for value. As such, a 1% increase in species richness leads to a 1-2% rise in value. This also works conversely, where a 1% decrease in species richness leads to a 1-2% decrease in NPP. The resulting model will use the mean of this range (1.5%) as a range cannot be used.

This final model in notation form, is presented below.

Equation 7.1: Final model estimating 2013$/ha/year based on indicator levels

$$V = V_{ref}\left[1 + NPP_C\left(\frac{\beta + 1.71NOP - 0.03MQH}{SR_{ref}}\right)\right]$$

Where V is the value of the policy site (2013$/ha/year), V_{ref} is the reference value (2013$1512.44/ha/year),$NPP_C$ is the change in NPP output relevant to 1% species richness change,

β is the intercept term, NOP is the number of positive indicator species present, MQH is the mean quadrat height (cm) and SR_{ref} is the reference species richness (per quadrat)

7.5 Model output

Figures 7.2 and 7.3 show screenshots from the attached Excel spreadsheet. This sheet uses input indicator data to estimate site value based on Equation 7.1. The model was tested using differing indicator inputs. The results are shown in Table 7.2.

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Figures 7.2 and 7.3: Screenshots from Excel spreadsheet calculating site value (£/year)

NPP (Ecosystem Service) change estimate[a]	Example no. positive indicator species[b]	Example mean quadrat height (cm)[c]	Estimated value (£/ha/year)
1.5	Low	Low	154.12
1.5	High	High	579.82
1.5	Low	High	224.42
1.5	High	Low	509.51

[a] per 1% species richness change

[b] where "low" is estimated at 1 present indicator and "high" at 4 present indicators

[c] where "low" is estimated 80cm and "high" at 40cm (based on literature reference levels)

Table 7.2: Model outputs (£/ha/year) based on upper and low indicator levels

Outputted values are in line with expected results. The Excel spreadsheet quickly calculates an estimated value based on research undertaken. This Excel spreadsheet using its internal model (Equation 7.1) was utilised to establish overall Ecosystem Service value of the sites. This is provided per year, but also over the site's lifetime using years since creation. Table 7.3, updated from Table 4.1 outlines the main input variables, and the outputted value of each site.

Sub-site	*Time since creation (years)*	*Site Area*	Indicator species present	Species richness	Quadrat mean height (cm)	Value (£/hectare/year)	Value (£/sub-site/year)	Value (total £ over lifetime)
Attenborough	47	3.54	2	7.7	95	246.22	871.61	40,965.52
Brandon (1)	24	4.31	7	14	24	963.34	4,151.99	99,647.80
Brandon (2)	24	3.24	2	10.7	25	369.25	1,196.38	28,713.18
Houghton Regis	29	44	2	11	16	385.07	16,943.12	491,353.12
King's Meadow	21	1.05	6	14.1	45	807.96	848.36	17,815.57
North Cave(1)	10	3.26	4	9.7	31	595.64	1,941.78	19,417.83
North Cave(2)	10	3.06	4	6.5	34	590.37	1,806.52	18,065.20
North Cave(3)	1	4	2	12.3	21	397.28	1,505.14	1,505.14
Parc Slip (1)	28	0.23	2	12.7	50	325.31	74.82	2,095.01
Parc Slip(2)	28	1.59	2	8	35	351.68	559.17	15,656.67
Parc Slip (3)	28	1.53	2	9.3	26	367.50	562.27	15,743.54
Ryton(1)	18	0.4	2	8.3	45	334.10	133.64	2,405.52
Ryton(2)	18	3.3	2	8	55	316.52	1,044.53	18,801.50
Ryton(3)	18	1.9	2	8	70	290.16	551.30	9,923.42
Ufton Fields (1)	41	3	4	13.5	30	597.40	1,792.19	73,479.78
Ufton Fields (2)	41	0.4	1	9	27	247.27	98.91	4,055.28
Whittleford	4	43	7	13.6	36	942.25	40,516.62	162,066.49

Table 7.3: Calculated values of fieldwork sites and input data

Table 7.3 above highlights how improving the biodiversity of a site significantly improves the value of ecological services output by created grasslands. Despite being one of the newest sites, targeting seeding and management mean a high proportion of indicator species (and high species richness) were present on site. This, coupled with a good vegetative height, push per hectare per year values to £942.25. Over the 4 years since creation this totals £162,066.49 of ecological services provided, which is an impressive figure even noting the large site area.

In contrast, sites with lower quantities of indicator species and tall vegetation (e.g. Attenborough and Ryton (3) only reach values of around £250/ha/year, which impacts on total site value considerably. Outputting the values of the fieldwork sites helps to highlight the ease of communication over more traditional ecological metrics. Stating a site has a yearly ecosystem service value of £1,941.78 for example is far more interesting than stating it has a species richness of 9.7. We are confident the model helps to communicate services provided to humans by created grasslands.

In the concluding section (overleaf), the main findings of the research are outlined, along with theoretical implications and potential further study.

CHAPTER 8 - CONCLUSIONS

This thesis aims to find a quick means of establishing biodiversity on created grassland sites, and to establish the monetary value of the services they provide. To our knowledge, no such indicator species analysis has been undertaken on created grasslands. No analysis of grassland valuations has been undertaken despite similar studies on wetland habitats (e.g. Woodward & Wui, 2001). As such, the results are novel to both the fields of ecology and economics. This study is as a direct result of queries from clients of Middlemarch Environmental Ltd. These mostly pertained to increasing habitat provision on new developments and how to judge their success. The majority of these queries came from non-ecologists who wish to know how beneficial their sites are without in-depth ecological knowledge. Ecological services are complex and, understandably, are not fully perceived by those with power in land use decisions, who could underestimate the value of these services. Those in charge of land use decisions often do not have the time or resources to fully study the implications of these decisions. This is especially relevant for the long-term survival of natural resources that have no tangible benefits. Despite these clients showing great interest in the Ecosystem Service concept alone, using money as a unit to describe the services provided to humans stresses their importance. The process has become more utilised by Governments, policy-makers and ecological economists as a means to include life-giving services in a well-established economic climate (see for example DEFRA, 2007; UNEP, 2007).

The consequences of our intense habitat destruction of the last century are helping this push for more structured conservation. Recent flooding in the U.K. arguably caused by over-urbanisation and habitat destruction is estimated to have cost over £5 billion (The Guardian, 2016). It could be argued that the natural resources that normally prevent flooding, for example trees, wetlands and grasslands, are therefore worth at least £5 billion just for this one service. Biodiversity 2020 was an important policy document outlining the Government's strategic plan to maintain and improve Britain's natural resources (DEFRA, 2011). This was largely based on the Convention on Biological Diversity (CBD) Strategic Plan 2011-2020, one of the largest biodiversity summits ever to have taken place. This concluded that England's natural areas do not "represent a coherent and resilient ecological network that would be capable of responding to the challenges of climate change and other pressures." (DEFRA, 2011, pg. 13). Their evidence highlighted the quantifiable benefits nature has on human physical and mental health. As such, the beginning of this study as this report came out was timely and its objectives in line with rationale presented in the document.

The next part of this chapter will synthesise the main findings from this study. These are summarised in reference to the research objectives outlined in Chapter 1. The theoretical and policy implications of these findings are discussed, followed by the main limitations encountered. Implications for further study borne from these limitations will be outlined. Finally, the main outputs of the thesis will be reiterated.

The initial systematic review of floral indicator species studies resulted in interesting findings (discussed further below). This was conducted in order to inform the first-hand fieldwork undertaken. The systematic review process, despite being time consuming, ensures the greatest capture of relevant literature. It also helps to eliminate the chances of selection bias (CEBC, 2006). This systematic review was of great use for ensuring appropriate methods were chosen for this study. However, potentially the most important finding from this review was the highlighting of discrepancies in definitions and methods (Section 3.2.5). Terms that are assumed to be universal were sometimes found to be used according to different definitions. Explicit definitions were frequently not given, and the reader is forced to make inferences which could skew comparative strength. This informed this study, as accepted definitions for any ambiguous terms were outlined. The systematic review process also highlighted the widespread use of NVC classifications, but ambiguous survey methods. Considering this use of the NVC classifications, and the NVC's inception by a large number of ecologists, this method was adopted, and is recommended for further surveying.

The first-hand data generated from conducting surveys on 9 created grasslands (with 16 sub-sites) generated a suite of bioindicators. These were outlined in Table 3.9 of Section 3.10. Confidence in identified indicators was built through intensive reference to the literature. This allowed established indicators of biodiversity to be scrutinised in the context of this data, as well as providing theoretical background to further indicators detected by statistical analysis. On the whole, the indicators identified were in line with bioindicators of semi-natural grasslands, as hypothesised in Section 2.5. However, there were a few surprises that deviated from the literature. This included identified positive indicators Bare Earth, normally deemed undesirable over 5%. As confirmation of the suitability of the identified bioindicators, the number or level of present indicators on site correlated significantly with species richness. This measure has long been used as a biodiversity indicator, reinforcing the robustness of the identified indicators, and providing a theoretical link with Ecosystem Service provision.

The indicator selection was conducted with research objectives in mind. This included disregarding any indicator species that are too easily misidentified as another to allow accessibility by developers and other non-ecologists. This mainly involved grass species such as creeping bentgrass *Agrostis stolonifera* or Tufted hair-grass *Deschampsia cespitosa*. Another objective was ensuring methodologies did not exclude any potential important indicators; species removal was avoided (Zuur, Ieno, & Elphick, 2010). Instead, species that would otherwise have been disregarded due to statistical violations were relegated to a Group B. This was in line with the earlier stated research objective to ensure no missed indicators arise from species removal. A number of species were however removed, as they were present in less than 5% of quadrats (Bachand et al., 2014). This is in line with other indicator species studies, as rare indicator species would violate our research objectives regarding their properties.

The data allowed inferences to be made on best practice for management of created grasslands. Due to interference from other environmental variables, any results on management effects are encouraged across the literature (Rahman, 2013; Smart, 2005). The analysis found biodiversity to be highest where at least minimal management has been undertaken, but especially an annual cut. These results seem to be broadly in line with current theory (Cooper & Huffaker, 1997; Rahman, 2013). This minimal management particularly appears to help reduce competitive weeds and grasses, as were found in the unmanaged Attenborough Nature Reserve. The managed Whittleford Park, by contrast, at only a year old, showed little signs of early colonisers such as nettle Urtica dioica or cleavers Galium aparine. Undesirable species can be forced out of a community in this way, but this study does not have the scope to research the potential consequences of this in the long term. Although, environmental conditions can often be out of the control of the land use manager, in creation attempts this can, to an extent, be directed. Soil type has long been known to have an effect on species composition. To stay in line with research objectives, indicator species were chosen for their cross-soil-type relevance. However, this study indicates good biodiversity can be achieved on unusual or previously poor soil. For example, King's Meadow, created on pulverised fuel ash (PFA) soil, showed the highest mean species richness across all sites. This management information could be of great use to land-use managers to achieve the optimum biodiversity.

Development of a "quick" biodiversity valuation model for created grasslands was the most important output of the study. As part of building this, a multi-level model of past valuations was built, which is widely called for in the literature (Loomis & White, 1996; Hancock, 2010; Spash & Vatn, 2006; Brouwer, 2000; Clark et al., 2001). The variance of the input data led to an unacceptably high prediction error (MAPE). As such, this model could not be used as a predictive tool, however the values within it helped inform a rigorous value transfer. The multi-level model is discussed further later in the conclusions.

A final equation was built based upon identified bioindicators and Value Transfer from the systematic review of grassland valuations (Equation, 7.1, Section 7.4). This equation informed an Excel spreadsheet so a non-botanist can undertake a quick appraisal of the species on site, and translate this in to a monetary value. As an example, a site with a high (4) number of indicator species present, and good (40cm) vegetation height, is estimated at £579.82/ha/year. As the processes involved in establishing these figures were particularly time consuming (e.g. intensive fieldwork; systematic reviews and analysis), this research can reduce times and costs for land managers. It is hoped it will encourage further habitat creation as the benefits are better understood.

The choice of statistical analysis had the potential to provide wildly different outcomes. This study highlighted the importance of avoiding the removal of variables that violate statistical rules. Although EDA recommended certain species were not analysed together, instead of complete removal, a subset "Group B" was established. This allowed identification of species of interest in a group that would otherwise have been removed. Interestingly, this B group ended up with the best correlation with explanatory variables Time since creation, management and soil type. This could suggest this method is used further to ensure thorough analysis of species data where removal is currently the norm.

This study dealt with a number of theoretical decisions, and consequences. Prior to valuing any aspect of nature, accepting a method of structuring the benefits received from grasslands was required. It is only relatively recently that the human benefits, rather than ecology in its own right, are being considered so fully. This is perhaps in line with the consequences of natural capital reduction being felt. As the valuation of ecological benefits is so anthropocentric, it was deemed theoretically sound to keep this theme in mind throughout the study.

Although the ecosystem service approach is widely accepted (see for example TEEB, 2014; MA, 2001; Costanza et al., 1997), the finer points of this are still under discussion. Separating what constitutes an ecosystem process from a final service is important to avoid double counting (Boyd & Banzhaf, 2007). As Boyd and Banzhaf point out, the final price of a car includes any intermediary processes and parts such as making the tyres (2007). To avoid these problems, mostly highlighted from the MA

(2000), the TEEB approach to Ecosystem Service assignment was taken (2014). This avoids processes such as “Water purification” and only includes final services such as “Fresh water”. Assignment to this structure was kept consistent throughout the thesis. During the economic systematic review and analysis Ecosystem Service assignment was often a challenge (Section 6.2.4), as other authors have taken a different approach. In light of this, all assumptions are stated so the research can be disaggregated if needed for further analysis. This study was conducted in line with the most widely accepted theories in the field at present (e.g. Fisher, Turner & Morling, 2009; Costanza et al., 1997).

Another finding that could, and should, have theoretical and methodological implications is that the method of valuation of grassland appeared to have the strongest effect on final value. There are concerns surrounding the accuracy of most accepted non-market valuation methods. Contingent methods could underestimate value due to ignorance by the surveyed public of the full range of benefits received by habitats (Christie, Hanley & Wright, 2006). The travel cost method could also underestimate value by only taking in to account the recreational benefits of the site (Randall, 1994). A Kruskal-Wallis test across extracted data from the systematic review showed inequality across the values according to valuation methodology (Section 5.7.1). Although variance was very high within the multi-level models, they revealed interesting results. In line with theory, contingent methods showed a significant negative coefficient, indicating these values could underestimate total Ecosystem Service delivery.

This finding was particularly surprising considering that grassland type remains insignificant to overall assigned value. This appears to suggest that all grassland types offer the same Ecosystem Services. This is contrary to theory, as many Ecosystem Service’s delivery depends upon soil type or other environmental variables. However, the strong significance of socio-economic variables was an interesting finding, with mixed comparability to known theory. Despite Pigouvian theory stating perceived value of nature increasing with population density, the contrary was found in the analysis. ANS, an indicator of a country’s sustainability, was expected to increase in line with perceived value, and this hypothesis held within the context of this model. This could show support of the relatively new indicator ANS being integrated further in to non-market valuation studies. Socio-economic variables such as GDP etc. were rarely, if ever, stated in included papers. Considering these findings, perhaps more emphasis on socio-economic variables would be useful in further study.

A number of limitations were encountered during this study. These are first summarised here, followed by recommendations for further study stemming from this thesis.

The unknown seeding information for most of the sites was unfortunate. Mostly the case for grasslands created a long time ago, little information on initial creation was kept. For the purposes of this study this was not too limiting, as the bioindicators were meant to be relevant without in-depth site or soil information. For the purposes of further successional research however, this may cause difficulty. It is recommended that ecologists and land use planners keep historic seeding information to allow further study in future.

Highlighting the frequent mis-definition or lack of definition in ecological surveys meant this study was particularly sensitive to repeating this mistake. Species richness was used more in the sense of density (by an area), which has been criticised as improper use. However site species richness in its purest form is problematic as full site surveys are impractical, one of the points of conducting this in the first place. The quadrat system is a proxy for this sort of time-consuming survey method and therefore needs the area.

A further conceptual difficulty is whether there are truly “created” natural habitats. Although all of the grasslands surveyed were previously non-natural (e.g. industry etc.) some will or may have been grasslands prior to quarrying or building. Although it is possible some seed banks remain, the extreme disruption to the landscape is taken in this study to have gone beyond disturbance prior to restoration. As such, and with the support of land-use managers spoken to, all grasslands surveyed were deemed to be created rather than restored.

Modelling the economic data was very challenging. These challenges have been experienced in other similar valuation studies (e.g. Brouwer, 2000; Brander, Florax & Vermaat, 2006). The structure of the data, and especially the dependent variable, was complex, and multi-level modelling seemed the most sound. This was reinforced by a wide variety of statistical tests to ensure model fit. At least in the context of this dataset, multi-level modelling seemed to capture a surprising amount of information regarding variation in valuation figures. It was hoped that from previous economic valuation studies that we could prepare a model that could predict, based on location and other explanatory variables, its Ecosystem Service value. This model provided us with a number of interesting findings in terms of explaining variation in included values. However, calculation of MAPE showed the model's forecasting error to be very high. As such it was deemed inappropriate to extract prediction values from this. This issue was compounded by the need to log the dependent variable, made necessary by its skewed nature. Any outputs from the model would have been classified as elasticities making interpretation more challenging.

This thesis was based to a large extent within the field of economics. The main research objective was to apply an economic valuation to grasslands based on their biodiversity. However, to avoid placing a spurious application of value to a relatively under-studied habitat, an indicator species analysis was undertaken to provide estimates of biodiversity in created habitats. This process threw up a number of threads outside the remit of the study that would benefit from further investigation. This is especially pertinent within the complex field of succession and its pathways. In accordance, the data has been collected and arranged with the intention that further study could be undertaken on it (see for example further community variable data in Table A9.2 (Appendix 9).

Community and environmental variables that could be used in further successional studies were calculated. These included CSR, Ellenberg, and NVC classifications. A second set of fieldwork on the same sites, presenting more time data points, would be very interesting. This would allow a number of questions to be addressed. Firstly, early successional species could be tracked to see if these do decrease with age within the same site. These would include ox-eye daisy *Leucanthemum vulgare* and the less desirable barren brome *Anisantha sterilis*. It would also allow the mapping of any new species and the effect these may have on the plant community. This could delve deeper in to threads of research such as facilitation, invasion, and inhibition of certain species.

The systematic review of grassland valuation studies has provided a range of values and their associated explanatory variables. As and when further studies are undertaken, these could be added to the database to further inform re-runs of the model. This could help alleviate some of the variation and error within outputs. If variation of input data is reduced, it is possible the model could be used for finer predictive modelling.

It would have been very desirable to complete these further threads within this study. However, time and costs as always mean a ring must be drawn around research. Hopefully these threads will be picked up in future. For the foreseeable future, the designed Excel spreadsheet will be used within Middlemarch Environmental Ltd. to estimate value of created grasslands, and hopefully encourage further creation of biodiversity-rich swards.

There are a number of key implications in terms of empirical usefulness. The "green" credentials of major businesses are now an important facet of business. This model is likely to find most use either for mitigation, or marketing practices. Mitigation and compensation schemes to offset environmentally damaging practices are common. For example, the Chartered Institute of Ecology and Environmental Management (CIEEM) outline mitigation strategies possible within Ecological Impact Assessments (EcIA) where environmental or habitat damage will take place (CIEEM, 2010).

These could include further habitat creation, or smaller measures such as timing construction work outside of breeding times. These types of works are often undertaken by the industrial partner Middlemarch Environmental. This model could allow a company to express the ecological services saved or enhanced by a mitigation or compensation scheme without the need for further trained ecologists.

Outputs from the final model could also be used as marketing for companies looking to showcase their green credentials. The carbon footprint or weight of carbon saved has worked its way in to the public consciousness, with huge companies such as Google (2016) or Innocent Drinks (2016) showcasing how their green practices such as recycled packaging etc. have saved a certain amount of carbon. In a similar vein, Barrett Homes, who created Whittleford Park on a site of ex-industry could claim they are generating £40,516.62 a year in Ecosystem Services. This gives weight to the project and can reflect the company in a better public light. It is also easier for the public to comprehend than many other means of conveying ecological benefits. It is hoped this model encourages further creation of habitat and a culture of Ecosystem Service generation.

Final Conclusions

This study attempted to identify bio-indicators of created grassland quality and apply an economic value depending of biodiversity levels. These indicators and valuation estimates are deeply embedded in the literature, informed by two systematic reviews.

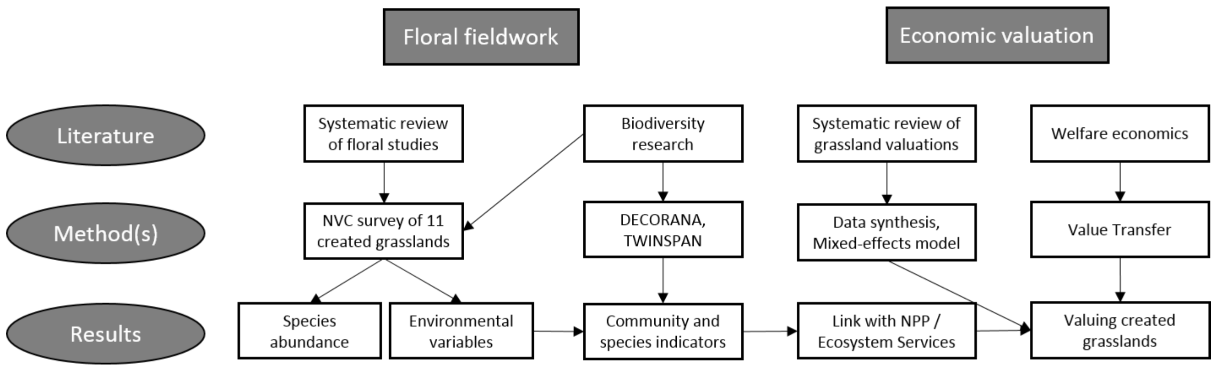

Figure 8.1: Structure of thesis and main findings

Figure 8.1 outlines the main structure and findings from the study. The "Results" line presents the crucial link between the community and species bio-indicators identified, and economic values, via species richness and NPP. This link between ecological data and economic value, embedded in theory (discussed in Chapters 4, 5 and 6) is potentially the most important contribution to knowledge.

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Referenced marked with [a] denote papers included in the floral survey systematic review

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Glossary

Agronomic: Matters relating to agricultural aspects of ecology

Alluvial meadows: Grasslands located on riverbanks

Biocapacity: the capacity of an area's natural resources to support life within it

Biodiversity: "Biodiversity comprises all the millions of different species that live on our planet, as well as the genetic differences within species. It also refers to the multitude of different ecosystems in which species form unique communities, interacting with one another and the air, water and soil." (Swingland, 2001)

Biofuel: fuel derived from living matter

Bioindicator: a variable that describes the biodiversity and health of the study site

Biological invasion: "…a species' acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population." (Valéry et al., 2008)

Chronosequence: "…a series of sites of different ages with similar climate, parent materia, topography, and potential to be colonizesd by the same organisms" (Chapin et al., 2006)

Chronosequencing: establishing successional traits through surveying sites with similar attributes that are of different ages

Community: "…all the plants occupying an area which an ecologist has circumscribed for the purposes of study" (Crawley, 2009)

Connectivity: "the extent to which a landscape facilitates the movements of organisms and their genes" (Rudnick et al., 2012)

Created grassland: Areas of grassland artificially created on areas previously not grassland.

Disturbance: where environmental or landscape conditions are changed, altering the ecosystem

Ecosystem Service: "The direct and indirect contributions of ecosystems to human wellbeing" (TEEB, 2014)

Ecosystem: a community of connected organisms and their environment

Fodder: food for livestock

Forage: food for livestock

Fragmentation: "the discontinuity, resulting from a given set of mechanisms, in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, or survival in a particular species" (Franklin et al., 2002)

Genetic diversity: "any measure that quantifies the magnitude of genetic variability within a population" (Hughes et al., 2008)

Glossary

Grassland: (also known as Steppes, Prairies, Pampas, Llannos, Cerrados, Velds, Savanna, Rangeland) "land covered with herbaceous plants with less than 10 percent tree and shrub cover,"

Greenhouse gases (GHGs): any gas that contributes to climate change through absorption of radiation

Habitat: the natural environment of an organism

Herbaceous: a plant with seeds and leaves without the presence of woody tissue

Herbivory: The eating of plants by animals

Improved grasslands: High species diversity with few agricultural species. Never been subject to agricultural involvement (The Grassland Trust, 2014)

Indicator species: a species that describes the biodiversity and health of the study site

Management (Ecology): Human measures taken to maintain or improve biodiversity and contextual ecosystem functioning (e.g. grazing, annual cut)

Natural Grasslands: Grasslands not modified by human activity (The Grassland Trust, 2014)

Net Primary Productivity (NPP): a measure of solar energy driving a system

Pioneer plants/Early colonisers/ruderals: the first plants to arrive in a successional pathway, either primary or secondary

PM10: Particulate Matter up to 10 micrometers in size

Restoration: the process of renewing damaged or destroyed habitats or ecosystems

Restored grassland: Areas of degraded grassland where diversity and richness are restored through management.

Semi-improved grasslands: Modified by agricultural activities, e.g. fertiliser and over-grazing. Has lower diversity than Improved Grasslands (The Grassland Trust, 2014)

Semi-natural grasslands: Grasslands that have been altered by human activity (e.g. farming, burning etc.) (The Grassland Trust, 2014) These can be further disaggregated by soil type (Limestone/Calcareous; Marshy; Acid; Lowland Meadow and Pasture; Upland hay meadow)

Sequestration: Storage of a chemical or compound

Species accumulation curve: "The number of species found in 20-30 quadrats within a particular vegetation type is recorded and the results plotted against the number of samples. Where the curve levels off indicates the number of samples needed to describe most of the species in that vegetation type." (Kent, 2012)

Species diversity: "measures the probability of 'any two individuals drawn at random from an infinitely large community belonging to a different species' (Simpson, 1949)" (Rawlinson, 2009)

Species richness: Number of different species present

Succession: "…community change where one group of organisms at a given site is replaced by others as time advances" (Wali, 1999).

Temperate grasslands: Grasslands (see above) that occur within regions of the world with hot and cold seasons

Tropical grasslands: Grasslands occurring in regions of the world without a cold season

Unimproved grasslands: Low species diversity, with instances of rye grass and clover. Has been subject to fertiliser and heavy grazing. (The Grassland Trust, 2014)

Appendix 1: Further site information obtained

Houghton Regis

Site name: **Houghton Regis Chalk Pit CWS**

Status(es):	County Wildlife Site Site of Special Scientific Interest (subsite of the CWS) Roadside Nature Reserve (subsite of the CWS)
Gridref:	TL009234
Area:	52.7 hectares
Council(s):	Central Bedfordshire
History:	
1988	SSSI notified under 1981 Act
1990	CWS recognized
CWS recognized for:	Calcareous scrub and grassland
Main habitats present:	
UK BAP Priority	Lowland calcareous grassland Standing Open Water and Canals (Broad habitat)
Other habitat(s)	Marshy grassland Hedges

Site Description:

Phase 1 Survey 1990

A CWS containing a good diversity of chalk habitats.

The site is composed of:
Houghton Regis Chalk Pit
A large area of colonising calcareous grassland in the northern part extending from TL00302366 to TL01462350.

Houghton Regis Marl Lakes SSSI
Flooded chalk pit at TL013233, surrounded by calcareous grassland and scattered scrub, with steep sides, which are well colonised by trees and scrubland, and a reedbed in the southwestern corner.

Houghton Regis Cutting RNR
The cutting is on the eastern side of the A5 at Puddlehill, extending from TL003235 southeast to TL007231. Unimproved calcareous grassland and dense and scattered scrub that has developed on the steep sided chalk cutting.

SSSI Description from Natural England's website, © Natural England

Houghton Regis Marl Lakes have developed in a large disused quarry within the Lower Chalk north of Dunstable. The Lakes are an example of habitat type which is the rarest form of standing water in Britain confined to chalk or limestone areas with very few examples in southern England. A mosaic of wetland communities have developed associated both with the open water and water-logged areas surrounding the lakes including examples of base rich fen. This extensive area supports a range of other species associated with wetland habitats including an outstanding assemblage of dragonfly, as well as being an important ornithological site in the county.

The two marl lakes are different in character, one is deep and steep sided while the other is a large shallow lagoon. Characteristically for marl lakes they support an abundant Charophyte flora covering the lake bed. This includes both shallow water species such as *Chara hispida* (var. *hispida,)* and deep water species such as *Chara aspera.* The clear waters support other aquatic species including curly waterweed *Lagarosiphon major,* horned pondweed *Zannichellia pal ustris* and spiked water-milfoil *Myriophyllum spicatum.* The rich mollusc fauna associated with the lakes includes the species *Potamopyrgus jenkinsi,* a recent maritime colonist of freshwater typically found associated with beds of *Chara* in marl lakes. Emergent vegetation has developed around the lake margins, particularly on the shallow lagoon including species such as common spike-rush *Eleocharis palustris,* common club-rush *Schoenoplectus lacustris* and various rush species *Juncus* spp.

Fen communities are associated with the waterlogged area between the lakes and where a feeder stream enters the shallow lagoon. Common reed *Phragmites australis* is locally dominant but elsewhere there is a mosaic of other characteristic species including water horsetail *Equisetumfiuviatile,* marsh horsetail *Equisetum palustre,* lesser bulrush *Typha angustifolia,* lesser pond-sedge *Carex acutiformis,* hard rush *Jancus inflexus* and jointed rush *Juncus articulatus.*

Appendix 2: Included paper description and Further extracted values from economic systematic review

Authors	Year	Publication	Area of research
Angold, P.G.	1997	Journal of Applied Ecology	Impact of road
Barkham, J.P.	1992	Biological Conservation	Effects of management
Bennie, J. et al.	2006	Journal of Ecology	Influence of slope and aspect
Britton, A.J. & Fisher, J.M.	2007	Journal of Applied Ecology	Effects of nitrogen deposition
BSBI Recorder	2011	BSBI publication	Axiophyte identification
Cantarello, E. & Newton, A.	2008	Forest Ecology Management	Conservation status
Cherrill, A.J. & Rushton, S.P.	1993	Ecological Entomology	Status of moorland
Croxton, P.J. et al.	2005	Biological Conservation	Green lanes
Cullen, W. et al.	1998	Biological Conservation	Reclaimed quarries
Fraser, E.D.G. et al.	2006	Journal Environmental Management	Sustainability indicators
Hall, S.J.G. & Bunce, R.G.H.	1984	Transactions of the Natural History Society of Northumbria	Vegetation survey
Harmer, R. et al.	2001	Biological Conservation	Vegetative change
Hughes, J.C. & Huntley, B.	1986	Nordic Journal of Botany	Phytosociological study
Jones, M. et al.	2004	Plant Biology	Nitrogen deposition
Jump, A. & Woodward, F.	2003	New Phytologist	Cirsium species
Kennedy, F. & Pitman, R.	2004	Forest Ecology Management	Soil nitrogen status
Kirby, K.J. & Thomas, R.C.	2000	Journal of Vegetative Science	Vegetative change
Large, A.	2001	Applied Vegetation Science	Succession
Ling, K.A.	2003	Science of the Total Environment	Atmospheric pollution
Marshall, E.J.P. & Arnold, G.M.	1995	Landscape Urban Planning	Field margins
Marsland, A.	1989	Rutland Record	Hedgerows
Mazzoleni, S. et al.	1991	Coenoses	Succession
Morecroft, M.D. et al.	2002	Global Ecology and Biogeography	Effects of drought
Natural England	2000	Natural England publication	Countryside Monitoring Scheme
Pakeman, R.J. et al.	2009	Journal of Vegetation Science	Environmental Interactions
Peterken, G.F.	1976	Journal of Ecology	Forest vegetation changes
Pitcairn, C.E.R. et al.	1998	Environmental Pollution	Forest vegetation changes
Pitcairn, C.E.R. et al.	2002	Environmental Pollution	Effect of ammonia emissions
Rahman, M. et al.	2013	Journal of Nature Conservation	Capped landfill sites
Ratcliffe, D.A. et al.	1993	Biological Conservation	Fern conservation
Rawlinson, H.	2009	Earth and Environment	Impact of paths
Sage, R.B. et al.	2009	Biological Conservation	Impact of pheasants

Southall, E.J. et al.	2003a	Applied Vegetation Science	Willow carr development
Southall, E.J. et al.	2003b	Journal of Biogeography	Vegetation mosaics
Stevens, C.J. et al.	2009	Biological Conservation	Nitrogen deposition
Stevens. C.J. et al.	2011	Environmental Pollution	Nitrogen deposition
Tanner, R.A. & Gange, A.C.	2005	Landscape Urban Planning	Effect of golf courses
Trivedi, M.R. et al.	2008	Biological Conservation	Climate change
Tzoulas, K. & James, P.	2010	Urban Ecosystems	Urban biodiversity
Willi, J.C. et al.	2005	Biodiversity Conservation	Arable edges
Wilson, S.M. et al.	2001	Forest Ecology Management	Ground vegetation

Study authors	Ecosystem Service valued	Valuation figure
Dissanayake and Ando, 2014	Bird species richness ($/additional species) – no grassland near	0.812 (MMNL); 0.627 (MMNL with ASC); 0.795 (Nested Logit)
	Bird species density ($/birds per acre) – no grassland near	1.423 (MMNL); 1.100 (MMNL with ASC); 1.169 (Nested Logit)
	Endangered ($ per additional species) – no grassland near	6.306 (MMNL); 5.658 (MMNL with ASC); 7.173 (Nested Logit)
	Wildflowers (S/% area covered) – no grassland near	0.383 (MMNL); 0.338 (MMNL with ASC); 0.416 (Nested Logit)
	Burning ($/number per year) – no grassland near	-1.456 (MMNL); -1.605 (MMNL with ASC); -1.624 (Nested Logit)
	Bird species richness ($/additional species) – grassland near	1.105 (MMNL); 0.855 (MMNL with ASC); 0.305 (Nested Logit)
	Bird species density ($/birds per acre) – grassland near	1.936 (MMNL); 1.501 (MMNL with ASC); 1.667 (Nested Logit)
	Endangered ($ per additional species) – grassland near	8.582 (MMNL); 7.716 (MMNL with ASC); 10.226 (Nested Logit)
	Wildflowers (S/% area covered) – grassland near	-0.981 (MMNL); -2.189 (MMNL with ASC); -2.316 (Nested Logit)
	Burning ($/number per year) – grassland near	-0.401 (MMNL); -0.416 (MMNL with ASC); -0.343 (Nested Logit)

APPENDIX 3: INDIVIDUAL QUADRAT DCA OUTPUT

Species	DCA 1	DCA2	DCA3	DCA4	Totals
Achimill	-0.61140	1.24676	1.57744	-1.43791	81
Agrieupa	-1.10077	1.54966	1.28022	-0.77597	61
Agrostol	-1.17820	-0.70943	-1.38875	-1.32226	403
Anthvuln	2.20626	-0.00451	-0.39266	-0.07776	141
Bare.earth	2.18823	-0.71924	0.17576	1.04521	242
Centnigr	-0.84690	1.83859	0.71134	-2.13385	108
Crepcapi	-0.05165	-0.98545	-0.33364	1.69722	10
Cynocris	1.96462	-0.96198	0.13383	1.30477	49
Dactglom	-1.45062	1.94570	-2.41200	1.25605	213
Equiarve	0.09720	-0.43726	0.29528	-0.10239	32
Festrubr	-1.06836	1.33516	1.15541	-1.09013	464
Galiapar	-0.23654	1.07024	-2.38083	3.09876	29
Galiveru	-0.46748	1.43725	-1.84636	0.61335	232
Holclana	-1.25588	-1.77987	0.75931	1.47208	1163
Lathprat	-1.52318	2.69970	1.40748	-1.23491	157
Leonhisp	1.27134	-0.79879	-0.22481	-0.92974	61
Leucvulg	2.02815	0.55736	0.53061	-1.91755	68
Linucath	2.65753	-0.58809	0.32541	-0.40899	83
Lotucorn	1.41208	-1.81558	-1.01010	-1.31112	750
Phleprat	-1.06911	1.08716	-2.56222	2.20227	33
Planlanc	-0.41495	-0.28840	1.75749	-0.10915	867
Poterept	1.29871	1.65119	-0.07061	-0.90547	296
Ranurepe	-1.06825	-1.36606	1.26054	-1.52659	250
Rhinmino	1.66734	1.81603	2.12221	1.60311	135
Rubufrucagg	-1.42366	-0.14510	-1.91713	-0.29050	168
Trifprat	0.30075	-0.37891	2.52929	-2.34422	109
Trifrepe	-1.75031	-1.03208	-1.29594	-1.92145	411
Unidentified	-0.52444	1.26384	0.97594	-1.39848	19
Urtidioc	-1.00084	-0.40535	-0.88049	3.39314	61
Verocham	-2.45256	-0.52652	1.13867	0.04906	93

Table A3.1: Detailed DCA output for Group A species

Species	DCA 1	DCA2	DCA3	DCA4	Totals
Agrocapi	-0.73603	-0.42980	-2.27744	-1.53108	142
Agrogiga	-1.07848	0.44194	-1.22456	-1.20183	49
Alopprat	0.04743	-2.50926	0.34673	1.99733	26
Anthsylv	-1.00778	-0.78456	-1.71522	1.90257	5
Arrhelat	-1.02542	0.10259	-1.45929	1.46530	933
Cerafont	2.23130	-1.37217	1.68400	0.29412	17
Chamangu	0.39108	0.53844	-2.57080	1.80388	50
Cirsarve	2.09151	-1.91698	-0.81887	0.77141	90
Cirspalu	2.14443	0.37526	-1.06207	-1.00978	12
Cirsvulg	-0.26428	-1.04417	-0.81310	1.49778	15
Cratmono	-0.53708	0.67143	-0.98794	1.68977	80
Crepvesi	2.55271	0.14392	-1.09080	1.12208	6
Cynocris	0.48903	-3.38361	0.74437	-1.64513	49
Dactglom	0.47933	-0.72678	-1.26079	-1.36883	213

Table A3.2: Detailed DCA output for Group B species (continues)

Species	DCA 1	DCA2	DCA3	DCA4	Totals
Dauccaro	-0.23173	1.62294	0.97815	1.03759	9
Desccesp	0.70670	2.57150	0.25497	1.21345	78
Elytrepe	-1.64453	-0.13642	-1.02817	2.34679	38
Equisp	2.94971	0.41478	0.23594	0.09871	70
Heraspho	-0.29606	-1.88275	-1.03061	1.61349	12
Hyporadi	-0.43153	-0.74587	0.62721	-1.28051	18
Junceffu	-1.37831	1.24807	0.66173	-2.25100	130
Juncinfl	-1.13328	1.16573	-0.82815	-1.79459	108
Lolipere	0.01839	-0.07894	-2.08684	-1.95747	203
Lotupedu	-1.51052	1.21311	1.24293	-2.42869	85
Medilupu	-0.68210	-0.29242	2.10065	0.96537	158
Myosramo	2.63616	-1.57711	0.51930	-0.33714	5
Poaannu	0.63963	0.40083	1.16475	-1.52934	39
Poaprat	-0.29432	-1.13851	1.73498	2.05845	16
Poatriv	1.05634	-0.57997	0.78716	0.54016	9
Prunvulg	0.80438	-1.98564	-0.16399	1.54934	77
Ranuacri	-0.74506	1.14403	1.36835	1.13931	78
Rhinmino	-0.80815	0.17171	2.48214	-1.38152	135
Rosacani	-0.91631	-0.00274	-1.10746	1.45684	22
Senejaco	-0.84663	-0.33681	1.72815	1.32815	112
Trifprat	0.84971	2.05618	1.03989	2.64415	109
Trifrepe	2.26770	-1.89814	-0.17166	-0.69214	411
Vicicrac	-0.37883	-0.88139	2.00486	0.97509	104

Table A3.2: Detailed DCA output for Group B species (continued)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
1	-0.286620	0.491785	0.555528	-0.195171	131
2	1.010089	-0.390701	0.120510	0.437355	140
3	0.514618	-0.373186	-0.141313	-0.815653	156
4	1.000564	-0.118381	-0.287589	0.200249	128
5	1.047296	-0.647800	-0.271203	-0.156062	154
6	1.586048	-0.270029	0.146606	0.130009	156
7	1.337682	0.074398	-0.106034	-0.006708	141
8	0.942447	-0.588642	-0.212414	-0.474621	171
9	-0.058417	-0.572917	-0.241710	0.054150	129
10	-0.023952	0.348671	-0.068506	0.235324	93
11	-0.757993	0.615555	-1.013712	0.105050	171
12	-0.285318	0.786631	0.469449	-0.317985	170
13	0.412146	0.165197	-0.133922	0.262794	110
14	0.137161	-0.261122	0.068905	0.550036	145
15	0.347093	-0.551484	-0.219070	0.048330	172
16	-0.021400	-0.223788	0.044902	0.494604	138
17	0.280883	-0.218342	-0.375135	-0.217004	154
18	0.263509	-0.031876	-0.155605	0.106114	129
19	0.329580	0.074991	-0.245994	0.053165	116
20	0.135763	-0.336688	-0.127198	-0.025442	191
21	0.085339	-0.477128	-0.107295	-0.056124	204
22	-0.670523	-0.742087	0.649471	0.536724	162
23	-0.568496	-0.588098	0.291813	0.976906	137
24	-0.315698	0.550282	0.832944	-0.257100	148

Table A3.3: Detailed DCA output by quadrat for Group A species (continues)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
25	-0.521463	0.209999	-0.814459	0.249427	149
26	1.094387	0.612602	0.446512	-0.235906	132
27	0.640545	1.020303	0.368200	-0.279711	142
28	-0.755588	-0.205987	0.180455	-0.214454	170
29	-1.160927	-0.192116	0.438746	-0.169563	162
30	-0.020801	-0.052476	0.239502	0.303144	129
31	0.443924	0.755000	0.038824	-0.357698	122
32	0.477215	-0.986842	-0.735218	-0.964550	161
33	-0.073750	0.170700	-0.336653	-0.392421	116
34	-0.081092	0.252837	0.221874	-0.032602	99
35	-0.503924	0.502313	0.813657	-0.286419	116
36	-0.518950	0.681183	0.827134	-0.375728	120
37	-0.161176	0.217163	0.952805	-0.277728	112
38	-0.033606	0.023940	1.175336	-0.496171	124
39	-0.197279	-0.588562	-0.570796	-0.424862	114
40	-0.675101	-0.303643	-0.917851	-0.601795	119
41	-0.186520	-0.283687	0.699838	-1.011401	138
42	0.035235	0.265047	-0.007743	-0.796548	121
43	-0.355235	-0.466124	0.037572	0.621300	105
44	-0.302205	-0.214930	-0.097065	-0.087449	119
45	-0.355539	-0.426166	0.694975	0.333906	159
46	0.096225	-0.348011	0.445313	0.371842	143
47	-0.525515	-0.622713	0.168609	-0.205146	149
48	-0.286683	-0.555226	0.319866	-0.222198	175
49	-0.497780	-0.710780	0.353551	0.634719	156
50	-0.087420	-0.820820	0.105031	-0.038721	182
51	-0.279902	-0.322824	0.660257	0.134385	153
52	-0.508648	-0.410209	0.167043	-0.277831	174
53	0.166914	0.171091	-0.191265	0.178805	76
54	-0.074199	0.005624	0.379321	0.327178	126
55	0.106912	-0.729110	0.031266	0.053990	172
56	-0.392057	-0.613885	0.021001	0.135376	162
57	0.367747	-0.199684	-0.094711	-0.330926	124
58	-0.082241	0.024943	0.379307	0.084686	114
59	-0.523390	1.144697	0.322055	-0.409158	130
60	0.303071	0.109917	-0.036984	-0.191271	159
61	0.386534	-0.326064	-0.095585	-0.204300	186
62	-0.191334	0.579320	-0.304529	-0.196327	141
63	0.162878	0.295418	-0.084357	0.110831	110
64	-0.019291	0.267906	0.248048	-0.006852	143
65	0.103685	0.170291	0.129529	0.077803	146
66	-0.222044	-0.328067	0.070885	0.471428	165
67	-0.045736	-0.231591	0.029379	0.486077	143
68	-0.601759	-0.340237	-0.502996	-0.523443	194
69	0.821650	0.417189	0.043750	0.033845	242
70	0.593181	0.156757	0.040624	0.172589	218
71	0.358774	0.410034	0.131143	0.289715	171
72	0.210642	0.213653	-0.064059	-0.087799	207
73	-0.124670	-0.001793	-0.223144	-0.225887	191
74	-0.299194	-0.056961	-0.559797	-0.402653	223

Table A3.3: Detailed DCA output by quadrat for Group A species (continues)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
75	-0.061482	-0.130202	0.028631	-0.280159	190
76	-0.247141	0.435742	0.060380	-0.374987	226
77	-0.042676	0.145419	-0.190126	-0.011721	177
78	-0.070652	-0.039166	0.533395	0.101400	231
79	0.248763	0.368785	-0.020350	-0.020892	191
80	0.284128	0.355995	-0.382025	-0.213432	228
81	0.111854	0.146180	-0.294897	-0.179161	249
82	-0.108272	0.486899	-0.573028	0.144405	230
83	-0.025251	0.317035	-0.131711	0.120577	222
84	0.099513	0.426972	-0.000162	-0.169073	156
85	-0.093400	0.278466	-0.073865	0.149517	140
86	-0.205863	0.036667	0.048273	0.164758	151
87	-0.179562	0.580967	0.1107769	-0.285791	176
88	-0.401077	0.676648	-0.269814	-0.149783	189
89	-0.132229	0.466877	-0.575851	0.209211	181
90	-0.517604	-0.300015	-0.405788	-0.507850	207
91	0.485740	0.603538	0.990816	0.637357	165
92	-0.371241	-0.402857	0.011259	0.669028	115
93	0.026200	0.129418	-0.287618	0.813932	81
94	-0.038942	0.448273	-0.543697	0.361778	82
95	-0.106005	0.584330	-0.666961	0.555016	88
96	-0.541549	-0.695099	0.139988	0.777130	144
97	-0.420966	-0.456535	0.003793	0.881508	130
98	-0.023813	0.088612	-0.292793	0.937832	91
99	-0.292611	0.812494	-1.032494	0.693180	123
100	0.146159	0.424160	-0.633754	0.877963	93

Table A3.3: Detailed DCA output by quadrat for Group A species (continued)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
1	0.106950	0.295809	1.123779	0.678738	81
2	0.276181	-0.867944	0.487720	-0.403369	89
3	0.676509	-0.448291	0.416325	-0.005877	98
4	0.173164	0.117554	0.404908	0.046297	65
5	0.195958	0.112480	0.355712	0.031933	63
6	0.143942	0.049083	0.367286	-0.067622	69
7	0.138729	0.111999	0.356552	0.052765	69
8	0.202593	0.238086	0.372441	0.215596	75
9	0.504099	-0.297535	0.237213	0.033359	84
10	0.419905	1.240000	0.281510	0.542652	130
11	0.662262	-0.594361	-0.377136	-0.615345	161
12	-0.259102	0.178521	-0.298871	0.130821	152
13	-0.445770	0.506584	0.523294	-0.436755	165
14	-0.267931	0.292284	0.295888	-0.459312	141
15	-0.155621	0.258175	-0.031357	-0.376677	122
16	-0.331552	0.379569	0.384830	-0.471042	143
17	-0.389816	0.429179	0.229270	-0.719877	150
18	-0.217760	0.293726	-0.047272	-0.412337	130
19	-0.485969	0.536878	-0.082561	-0.874315	182
20	-0.006162	0.074337	0.109123	-0.083848	107
21	0.011433	0.052596	0.123759	-0.078937	109

Table A3.4: Detailed DCA output by quadrat for Group B species (continues)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
22	0.525423	0.201446	0.903426	-0.112171	78
23	0.174828	-0.496825	0.412123	0.869051	90
24	0.109575	0.378590	0.337490	0.732085	101
25	0.571654	-0.091143	0.461311	0.235249	77
26	-0.026644	0.051305	1.394902	0.323963	115
27	0.231581	0.096982	1.024582	0.071454	73
28	0.963729	-0.430435	0.539352	-0.070630	93
29	0.944398	-0.405587	0.542410	-0.003071	84
30	0.593847	-0.537672	0.585541	-0.104121	86
31	0.688314	-0.776432	0.189898	0.633424	73
32	1.146153	-0.753735	0.182571	-0.158913	75
33	1.971231	-0.110062	0.168452	0.021150	144
34	0.170947	0.359664	0.064544	0.516878	70
35	0.034364	0.066884	-0.322066	-0.077580	72
36	0.043794	0.013086	-0.143983	-0.148154	71
37	0.235644	0.102130	0.266248	0.506754	62
38	0.428778	0.574741	0.530029	0.957131	81
39	0.803154	-0.702917	0.110607	0.164232	89
40	0.838977	-0.590326	-0.362827	-0.637855	110
41	0.795916	0.562246	0.464285	0.778510	127
42	0.448561	-0.400636	0.659905	0.241629	85
43	-0.393432	-0.031763	0.895965	-0.109445	125
44	-0.330895	0.020760	-0.477111	0.347096	99
45	-0.001736	0.01829	-0.035151	-0.137026	70
46	-0.045193	0.066902	-0.082253	-0.168977	81
47	0.081394	-0.221558	-0.428138	0.317521	105
48	0.273306	-0.221002	-0.032548	-0.201090	81
49	-0.121543	0.048831	-0.208746	0.051923	83
50	-0.043134	0.035153	-0.032818	-0.162150	72
51	-0.262604	0.058456	-0.346713	0.259672	101
52	0.411599	-0.363552	-0.058561	-0.267540	95
53	-0.395796	0.054904	-0.519508	0.421582	116
54	-0.357356	0.083296	-0.411927	0.320015	107
55	-0.097383	0.055088	-0.019206	-0.143248	77
56	-0.199270	0.037228	-0.212008	-0.253804	68
57	-0.324692	0.155939	-0.396360	0.265424	94
58	-0.714581	0.522475	0.284618	-1.132715	121
59	-0.153436	0.065884	-0.461903	-0.059133	97
60	-0.070985	0.075055	0.033304	-0.134345	99
61	-0.058181	0.064503	0.019645	-0.085584	102
62	-0.276690	-0.098315	-0.059815	0.201272	181
63	-0.162341	0.004406	0.090852	0.105760	127
64	-0.211324	-0.126924	0.657089	0.244185	160
65	-0.316302	-0.169539	0.770785	0.324191	185
66	-0.261454	-0.081216	-0.583996	-0.346031	157
67	-0.204403	-0.237064	-0.635773	-0.485263	169
68	0.841786	-0.706896	-0.075074	-0.365915	180
69	-0.089828	0.114094	0.523375	-0.265901	162
70	-0.008089	0.071509	0.211739	-0.137718	149
71	-0.228609	-0.093064	0.802214	0.209920	221

Table A3.4: Detailed DCA output by quadrat for Group B species (continues)

Site	DCA 1	DCA2	DCA3	DCA4	Totals
72	0.008605	0.053744	0.098085	-0.042684	147
73	0.435188	-0.337137	-0.044462	-0.074070	175
71	-0.228609	-0.093064	0.802214	0.209920	221
72	0.008605	0.053744	0.098085	-0.042684	147
73	0.435188	-0.337137	-0.044462	-0.074070	175
74	0.036569	-0.024872	0.095976	-0.057555	148
75	0.111286	-0.155038	-0.128871	-0.117170	170
76	0.086187	-0.024872	-0.066952	-0.265449	159
77	-0.210679	0.090605	-0.221811	-0.000788	187
78	-0.028823	0.037127	0.270795	-0.011365	152
79	-0.239381	0.081283	-0.243598	0.281993	187
80	-0.085273	0.066908	0.006217	0.074424	158
81	-0.006606	0.053772	0.202523	-0.061047	149
82	-0.015056	-0.032205	-0.183262	-0.142013	185
83	-0.034803	0.104113	0.092207	0.038771	157
84	-0.156961	-0.208678	-0.131792	0.082697	134
85	-0.479077	0.036778	-0.656635	0.384112	187
86	-0.497111	0.057198	-0.600421	0.370648	173
87	-0.331038	-0.077132	0.221487	0.116139	148
88	-0.343796	0.002924	-0.512821	0.066241	158
89	-0.365166	0.106606	-0.328994	-0.403476	140
90	0.410978	-0.381261	-0.054015	-0.226177	165
91	-0.324393	0.115873	1.141918	-0.589280	126
92	-0.430340	0.063840	-0.463635	0.648865	111
93	-0.654346	0.055374	-0.677553	0.959948	151
94	-0.427304	0.047662	-0.788003	0.666933	158
95	-0.146037	-0.050566	-0.890466	-0.353165	157
96	-0.272583	0.077633	-0.330835	0.416252	99
97	0.042303	0.040824	-0.513511	-0.657654	101
98	-0.356706	0.141806	-0.798328	0.740444	146
99	0.109193	-0.119183	-0.701539	-0.787240	134
100	-0.203534	0.160809	-0.863966	0.631889	143

Table A3.4: Detailed DCA output by quadrat for Group B species (continued)

APPENDIX 4: GRASSLAND BIOINDICATOR SPECIES IDENTIFIED FROM THE LITERATURE

Common agrimony *Agrimonia eupatoria* is an indicator of best grassland quality (English Nature, 1996). Useful for ease of identification, with few other grassland species which it could be confused with. "Indicator of weakly acid to weakly basic conditions; never found on very acid soils" (Hill, 1999). Used widely as a traditional herbal medicine (EMA, 2014)

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Figure A4.1: Common agrimony *Agrimonia eupatoria*

Cow parsley *Anthriscus sylvestris* is a negative indicator (agricultural weed) of Neutral grassland MG3,4,5,8 and Lowland meadows and Upland hay meadows. As a rough estimate, good quality grassland should not hold more than 5% of this species (JNCC, 2014). This is also a moist-site indicator, mainly on fresh soils of average dampness (Hill, 1999). Cow parsley can be confused in identification with the less common hemlock *Conium maculatum*.

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Figure A4.2: Cow parsley *Anthriscus sylvestris*

Kidney vetch *Anthyllis vulneraria* is a common positive indicator of calcareous grasslands (JNCC, 2014; Leicestershire Council, Unknown date). One of only two species that showed >5% abundance across any of the restored quarry sites studied by Cullen et al. (1997). Kidney vetch is the only larval foodstuff of the Small Blue butterfly *Cupido minimus*, priority species in the UK (Butterfly Conservation, 2014). Kidney vetch is highly tolerant of boron, particularly useful for planting on ex-industrial land and pulverised fuel ash (PFA) (Shaw, 1991).

Figure A4.3: Kidney vetch *Anthyllis vulneraria*

False oat-grass *Arrhenatherum elatius* is associated with a wide variety of other habitats and soil conditions, and abandoned and latrine areas (English Nature 1996). “It is the characteristic grass of MG1 community, typical of neutral grasslands and found on road verges, along hedges and river banks, often in association with cocksfoot. It is a coloniser and stabiliser of limestone scree, bare calcareous cliffs and maritime shingle and is also found in coastal dunes” (BSBI, 2014). As a common coloniser of abandoned areas, this grass could be useful in indicating Time since creation. This grass is relatively easy to identify in comparison to other grass species.

Figure A4.4: False oat-grass *Arrhenatherum elatius* (BSBI, 2014)

Common knapweed *Centaurea nigra* (Asteraceae) is a common positive indicator of neutral grassland (MG3 - MG5), and some calcareous grasslands (CG2, CG6) (JNCC, 2004). Found on moderately fertile or infertile soils (Sheffield Ecology Unit, 2012). This species is moderately easy to confuse with other thistle-like plants.

Figure A4.5: Common knapweed *Centaurea nigra* (Royal Horticultural Society, 2014)

Creeping thistle *Cirsium arvense* is characteristic of fertile soils with moderate disturbance, and abandoned and latrine areas (English Nature, 1996; Barkham, J.P, 1991). Creeping thistle is also commonly used as an improved grassland species (Smart, S.M. et al, 2005). Classified as a negative indicator and undesirable in grasslands (English Nature, 2001; Whyte, 2010; Natural England, 2013), this species could be useful to show the improving quality of grasslands over time. These are strong competitors for power (Büchs, W, 2003).

Figure A4.6: Creeping thistle *Cirsium arvense* (RHS, 2014)

Spear thistle *Cirsium vulgare* is a negative indicator of various grassland types (JNCC, 2014), and a species of nitrogen-rich soil (Smith, 2012).

Figure A4.7: Spear thistle *Cirsium arvense* (PFAF, 2014)

Cock's-foot *Dactylis glomerata* is a meadow and neutral grassland indicator (English Nature, 1996; Doncaster Council, 2007) and a coarse competitive grass (Natural England, 1999). Productive disturbed sites should begin to acquire cock's-foot after a while (Econet, 2014).

Figure A4.8: Cock's-foot *Dactylis glomerata* (Plant Systematics, 2014)

Wild carrot *Daucus carota* is a meadow indicator, and indicator of best grassland quality (English Nature 1996). Wild carrot occurs frequently in newly-created grasslands, but is scarce in long-established grasslands (Sheffield Ecology Unit, 2012).

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Figure A4.9: Wild carrot *Daucus carota* (PFAF, 2014)

Tufted hair-grass *Deschampsia cespitosa* is considered a negative indicator of neutral and marshy grasslands (JNCC, 2012). It is also indicative of W15 woodland with Fagus sylvatica (Wilson, 1999).

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Figure A4.10: Tufted hair-grass *Deschampsia cespitosa*

Common horsetail *Equisetum arvense* is considered a negative indicator of neutral grasslands and lowland meadows (JNCC, 2012). Horsetail species are an accumulator of heavy metals, for example zinc and lead, which could be used to study effects of planting on ex-industrial land (Ray & White, 1979).

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Figure A4.11: Common horsetail *Equisetum arvense*

Cleavers *Galium aparine* is a very common species, noticeable by its stickiness. It is considered a negative indicator of most grassland types (JNCC, 2012). Found to be able to colonise crops from adjacent hedgerows (Marshall, 1995).

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Figure A4.12: Cleavers *Galium aparine*

Lady's bedstraw *Galium verum* is a common meadow indicator (English Nature 1996). It is generally a good indicator of relatively interesting and possibly undisturbed sites (Econet, 2014)

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Figure A4.13: Lady's bedstraw *Galium verum*

Common hogweed *Heracleum sphondylium* is a meadow indicator, and indicator of best quality grassland (English Nature, 1996). Typical of infrequently grazed or undisturbed grasslands (Smith, 2012; Smart, 2005).

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Figure A4.14: Common hogweed *Heracleum sphondilium*

Holcus lanatus *Yorkshire-fog* is a common negative indicator species of various grassland types (JNCC, 2012). Found to be abundant on landfill sites restored as grassland studied by Rahman (2013). Can be a driver of species-poor grasslands as it strives on nutrient-rich soils and can out-compete other species (SNH, 2010).

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Figure A4.15: Yorkshire Fog *Holcus lanatus* (Naturespot, 2015)

Soft rush *Juncus effuses* is a common but undesirable species for lowland grasslands, which often thrives where bare ground is available. *Juncus effuses* may however dominate in good quality M23 grassland stands (JNCC, 2012). Indicator of poorly-drained soils, and showed to potentially have high stress tolerator indicator qualities (Spratt, Cooper & McCann, 2011).

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Figure A4.16: Common rush *Juncus effuses*

Meadow vetchling *Lathyrus pratensis* is a species-rich meadow indicator (English Nature, 1996; Natural England, 2015), and positive indicator species of MG3 and lowland calcareous grasslands (JNCC, 2012; Sheffield Ecology Unit, 2012). Typically grows on soils of moderate fertility (Sheffield Ecology Unit, 2012).

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Figure A4.17: Meadow vetchling *Lathyrus pratensis*

Rough hawkbit *Leontodon hispidus* is a positive indicator species of CG2, MG3 and 4 and U4 grasslands (JNCC, 2012). Commonly grows in unproductive grasslands (Sheffield Ecology Unit, 2012). Rough hawkbit can potentially be easily confused with dandelion.

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Figure A4.18: Rough hawkbit *Leontodon hispidus*

Oxeye daisy *Leucanthemum vulgare* is a positive indictor associated with a wide variety of other habitats and soil conditions (Leicestershire Council, 2014). Oxeye daisy tends to be an early starter in newly created grasslands (Natural England, 1999). Easily identifiable, it is often seen on roadsides and scrubland as well as grassland.

Aston University

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Figure A4.19: Oxeye daisy *Leucanthemum vulgare* (RHS, 2014)

Perennial rye-grass *Lolium perenne* is common in easily available seed mixes (Rahman et al., 2013) and agricultural seed mixes characteristic of fertile soils with moderate disturbance (English Nature, 1996). It is an indicator of non-species rich grassland and improved grassland (Smart et al., 2005; Bennie et al., 2006). In the early stages of creation or restoration it is desirable to see a reduction in Lolium Perenne over 5 years (Cornish & Hooley, 2012). “The principal characteristics that make neutral grassland distinct from agriculturally improved grassland are the less lush sward, greater range of taller grasses and herbs and in general a Perennial Rye-grass (*Lolium perenne*) cover of less than 25%” (Harris, Brearley & Doicl, 2014). Seen by interviewees as a good indicator of high fertility, along with other larger leaved plants (Lamarque et al., 2011).

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Figure A4.20: Perennial rye-grass *Lolium perenne* (BSBI, 2014)

Bird's-foot trefoil *Lotus corniculatus* is an indicator of a large range of grassland types, including MG3-8 neutral grasslands, acid, rush and moor grass, and calcareous stands (JNCC, 2004). Common on low to moderate fertility soils, it is also a relatively easy to identify species (Sheffield Ecology Unit, 2012).

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Figure A4.21: Bird's-foot trefoil *Lotus corniculatus*

Greater bird's-foot trefoil *Lotus pedunculatus* is common on damp soils (Sheffield Ecology Unit, 2012), and a positive indicator of some lowland meadow and upland hay meadow communities (JNCC, 2004; 2012).

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Figure A4.22: Great bird's-foot trefoil *Lotus pedunculatus*

Timothy *Phleum pratense* is a grass typical of semi-improved grasslands (Sheffield Ecology Unit, 2012), and a negative indicator in high abundance across all grassland types (agriculturally favoured species) (JNCC, 2004).

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Figure A4.23: Timothy *Phleum pratense*

Rough meadow-grass *Poa trivialis* is a species of disturbance or improvement (English Nature 1996). Found across numerous habitats and extensively in part due to its inclusion in many seed mixes (BSBI, 2014). "Early restoration (WoW) sites saw a reduction in rough meadow grass Poa trivialis, Yorkshire fog Holcus lanatus and perennial rye grass Lolium perenne after 5 years" (Cornish & Hooley, 2012, pg 176). "Occurs in a wide range of grasslands on fertile soils, typical of upland hay meadows, also found in damper habitats" (Sheffield Ecology Unit, 2012)

Figure A4.24: Rough meadow-grass *Poa trivialis* (BSBI, 2014)

Cowslip *Primula veris* is predominantly a species of moist calcareous soils (Sheffield Ecology Unit, 2012), but is also a positive indicator of MG4 and MG5 grasslands (JNCC, 2004; 2012). Cowslip is designated an indicator of best grassland quality (English Nature, 1996).

Figure A4.25: Cowslip *Primula veris*

Meadow buttercup *Ranunculus acris* is a meadow indicator (English Nature, 1996), particularly plentiful in over-grazed, moderately fertile pastures (Sheffield Ecology Unit, 2012).

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Figure A4.26: Meadow buttercup *Ranunculus acris*

Creeping buttercup *Ranunculus repens* is a competitive ruderal* species of disturbance or improvement (English Nature 1996; Spratt, Cooper & McCann, 2011), and invasive plant of disturbed habitats (Sage et al 2009). Creeping buttercup is considered a negative indicator across all grassland types (JNCC, 2004).

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Illustration removed for copyright restrictions

Figure A4.27: Creeping buttercup *Ranunculu repens* (RHS, 2014)

Yellow rattle *Rhinanthus minor* is a positive MG3/4 grassland and meadow indicator (English Nature, 1996; JNCC, 2012) which inhibits surrounding grass species (Natural England, 1999). As such, this species can encourage a higher herb to grass ratio which is preferential for optimum ecological value. A 2009 study concluded the sowing of *Rhinanthus minor* increase forb over grass productivity at a higher sowing density, but did not alter long-term species richness or diversity in newly established grasslands. This was found to decrease across all treatments (Westbury & Dunnett, 2007).

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Figure A4.28: Yellow rattle *Rhinanthus minor*

Bramble *Rubus fruticosus agg.* is an easily identifiable plant of multiple habitats but commonly field or woodland margins (Spratt, Cooper & McCann, 2011). Bramble is considered a negative indicator (JNCC, 2012).

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Figure A4.29: Bramble Rubus frucitosus agg.

Ragwort *Senecio jacobaea* is a species of disturbance or improvement (English Nature 1996) and a negative indicator (English Nature, 2000). Manual clearance of this species was being undertaken by volunteers at Houghton Regis Quarry during fieldwork.

Figure A4.30: Ragwort *Senecio jacobaea* (RHS, 2014)

White clover *Trifolium repens* is showed to potentially have high stress tolerator indicator qualities (Spratt, Cooper & McCann, 2011). White clover can skew the indicator qualities of herb to grass ratio by responding favourably to nutrient treatments (JNCC, 2004).

Figure A4.31: White clover *Trifolium repens*

Nettle *Urtica dioica* is a common, easily identifiable plant known for its stinging leaves. A competitive tall-herb (Spratt, Cooper & McCann, 2011), it is known as a negative indicator (agricultural weed) (JNCC, 2004; 2012).

Figure A4.32: Nettle *Urtica dioica*

Appendix 5: Family types revealed in fieldwork study

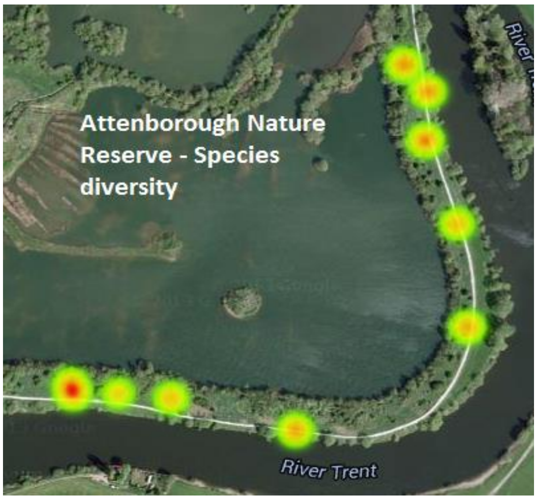
Family types used are shown in Table A5.1

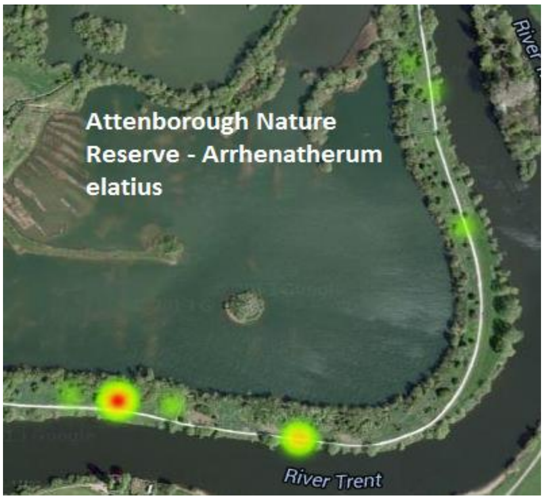
Family name (common)	Family name (Latin)
Carrot	Apiaceae
Daisy	Asteraceae
Birch	Betulaceae
Borage	Boraginaceae
Pink	Caryophyllaceae
Bindweed	Convolvulaceae
Sedge	Cyperaceae
Teasel	Dipsacaceae
Horsetail	Equisetaceae
Pea	Fabaceae
Beech	Fagaceae
Gentian	Gentianaceae
Geranium	Geraniaceae
Rush	Juncaceae
Mint	Lamiaceae
Flax	Linaceae
Willowherb	Onagraceae
Orchid	Orchidaceae
Broomrape	Orobanchaceae
Plantain	Plantaginaceae
Grass	Poaceae
Dock	Polygonaceae
Primrose	Primulaceae
Buttercup	Ranunculaceae
Rose	Rosaceae
Bedstraw	Rubiaceae
Nettle	Urticaceae

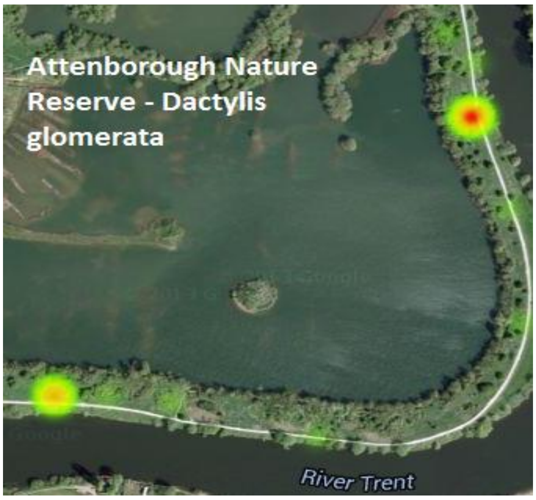
Table A5.1: Family types identified during field study

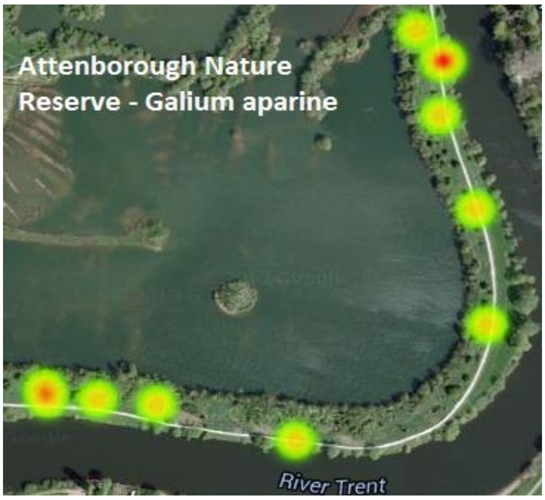
APPENDIX 6: FURTHER SPECIES HEAT MAPS FOR FIELDWORK SITES

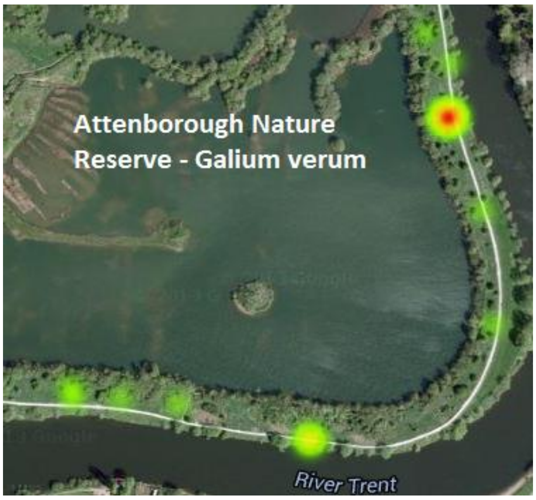
Site 1 – Attenborough Nature Reserve











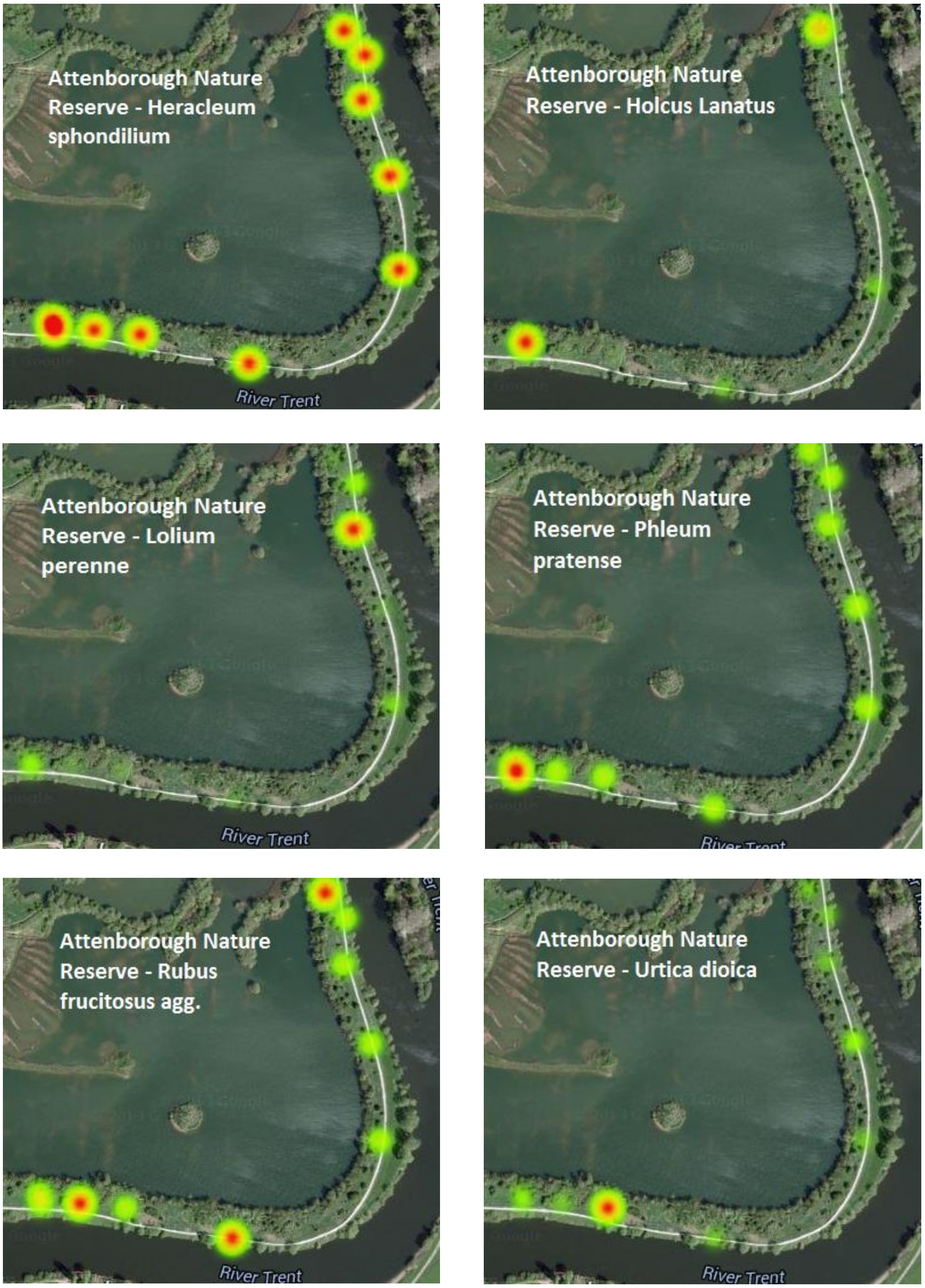
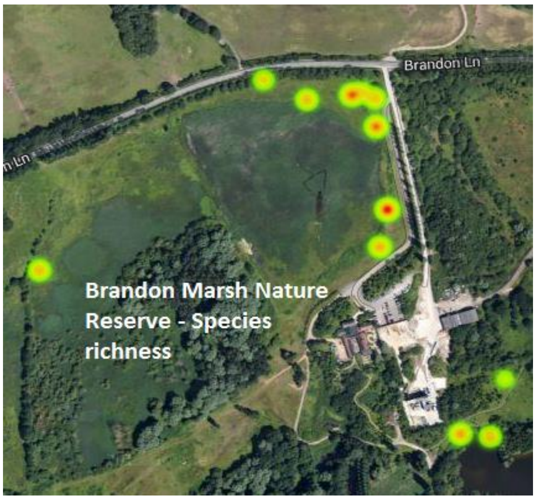
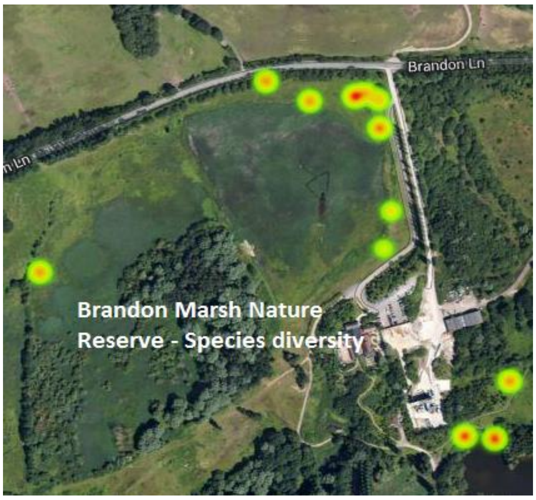
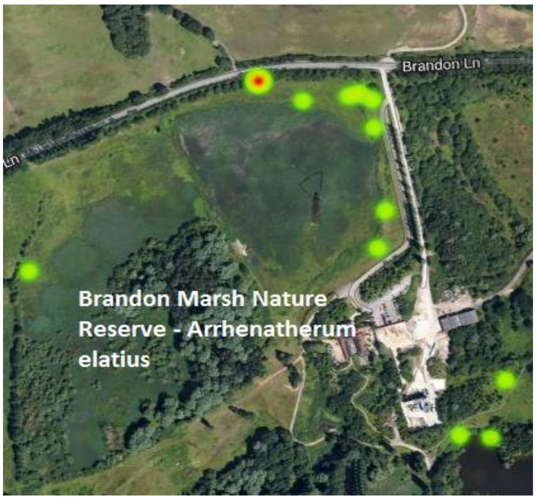


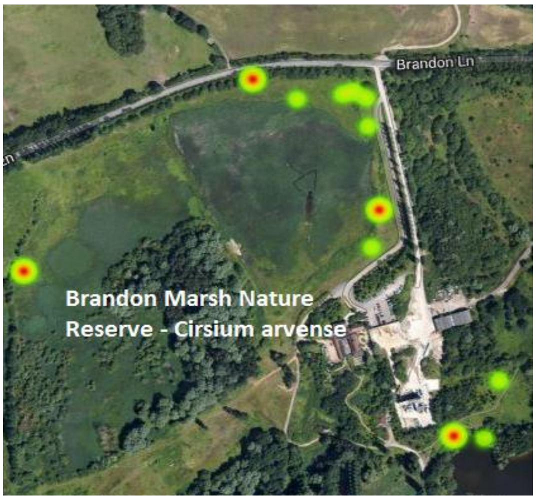
Figure A6.1: Additional species maps for Attenborough Nature Reserve

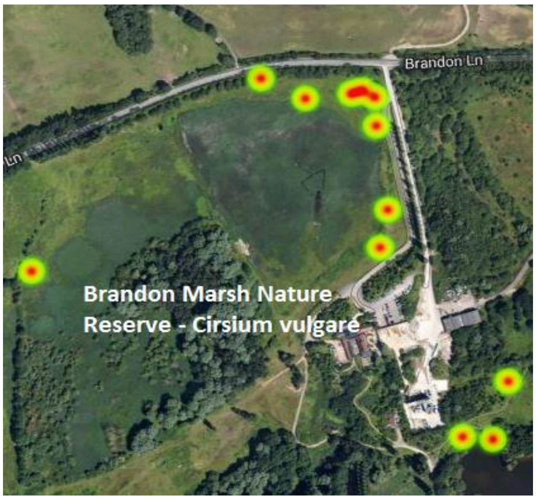
Site 2 – Brandon Marsh Nature Reserve

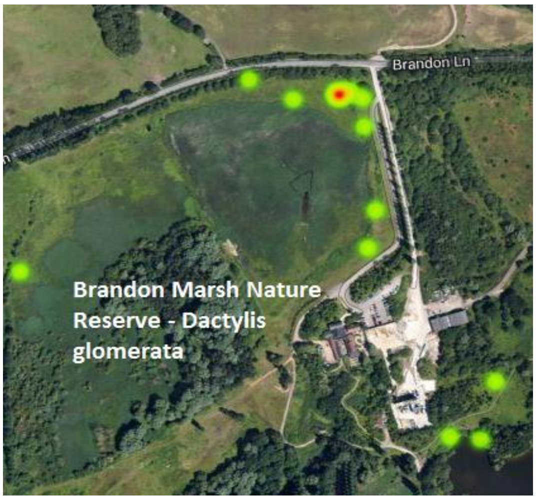


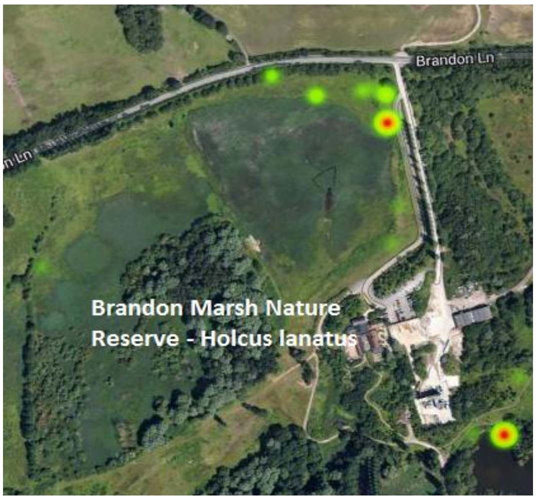


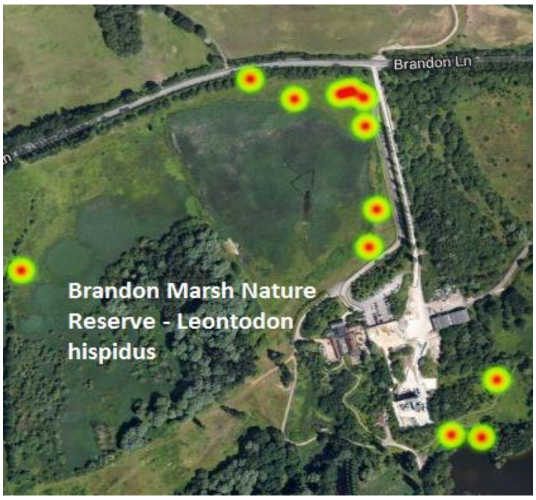


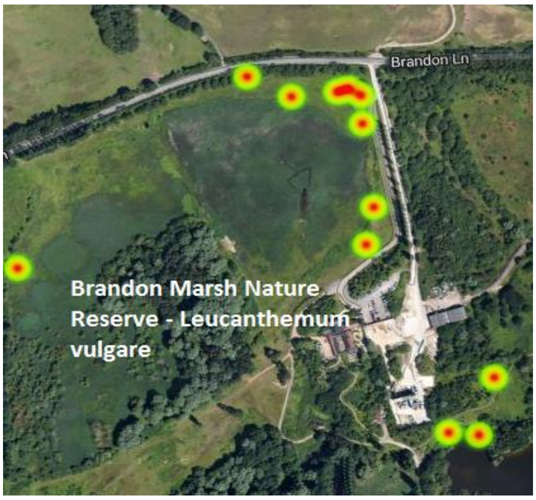




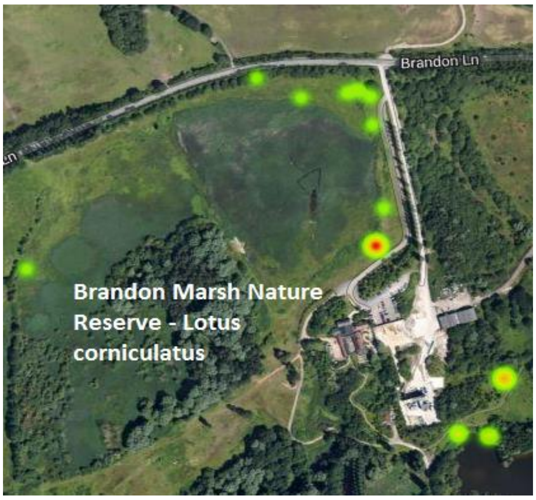


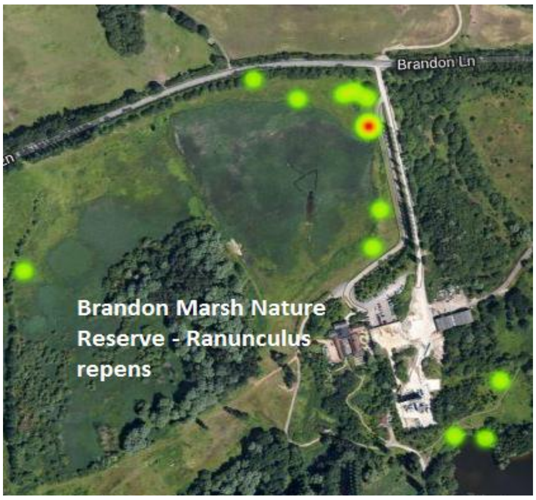

Brandon Ln
Brandon Marsh Nature
Reserve - Holcus lanatus


Brandon Ln
Brandon Marsh Nature
Reserve - Leontodon
hispidus


Brandon Ln
Brandon Marsh Nature
Reserve - Leucanthemum
vulgare


Brandon Ln
Brandon Marsh Nature
Reserve - Lolium perenne


Brandon Ln
Brandon Marsh Nature
Reserve - Lotus
corniculatus


Brandon Ln
Brandon Marsh Nature
Reserve - Ranunculus
repens

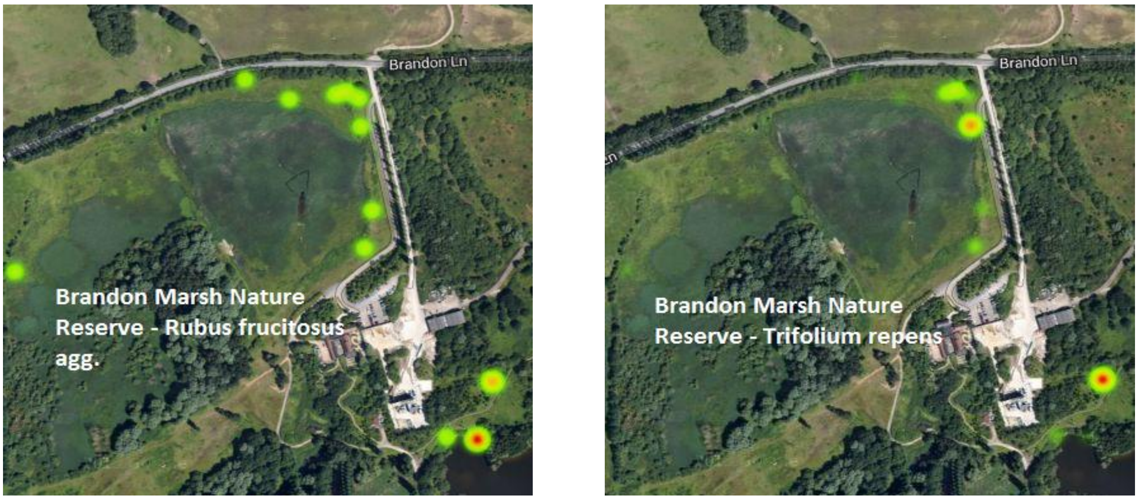


Figure A6.2: Additional species maps for Brandon Marsh

In contrast to Attenborough Nature Reserve, Brandon Marsh shows only low instances of undesirable species such as Perennial Rye-grass *Lolium perenne,* and bramble *Rubus frucitosus agg.*.

Site 3 – Houghton Regis

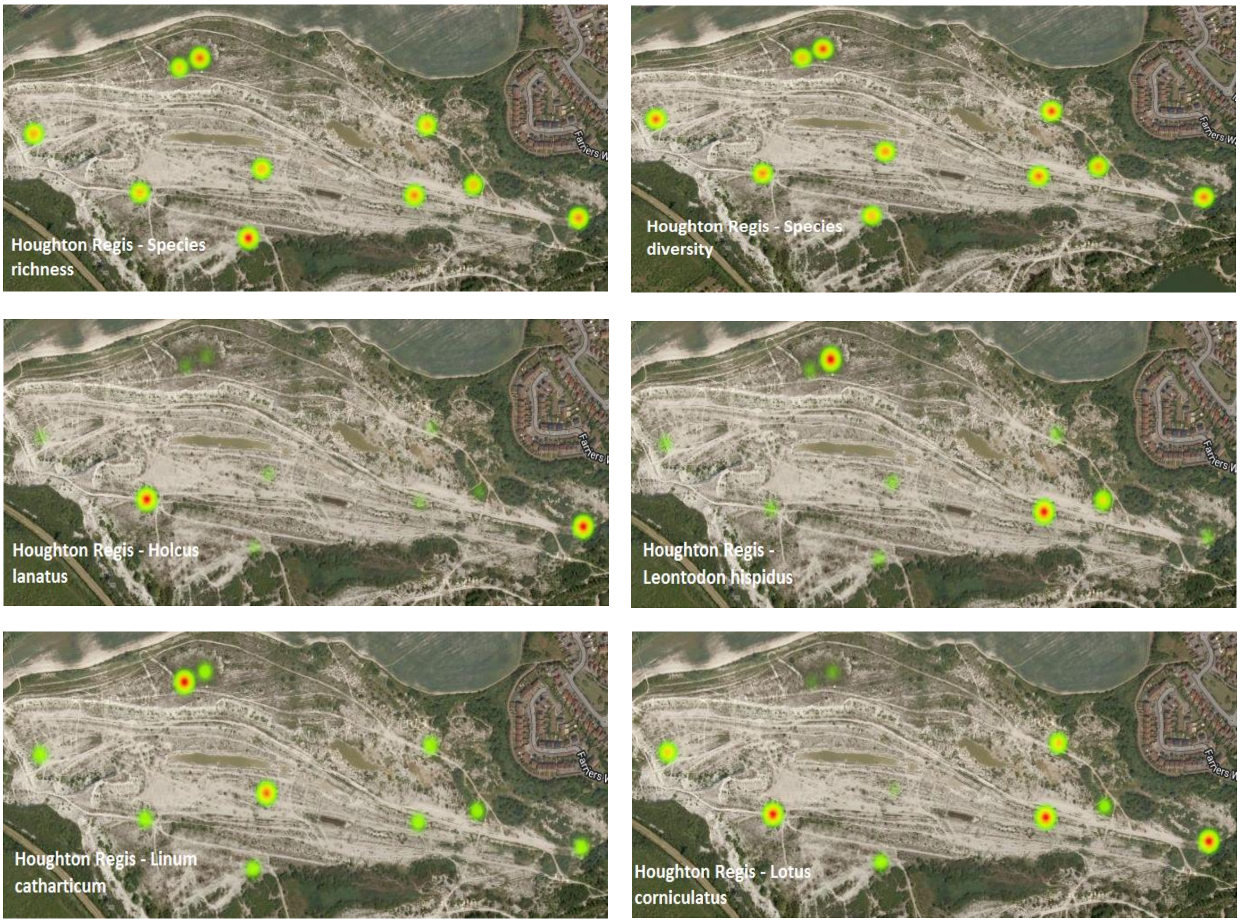


Figure A6.3: Additional species maps for Houghton Regis

Site 4 – King's Meadow

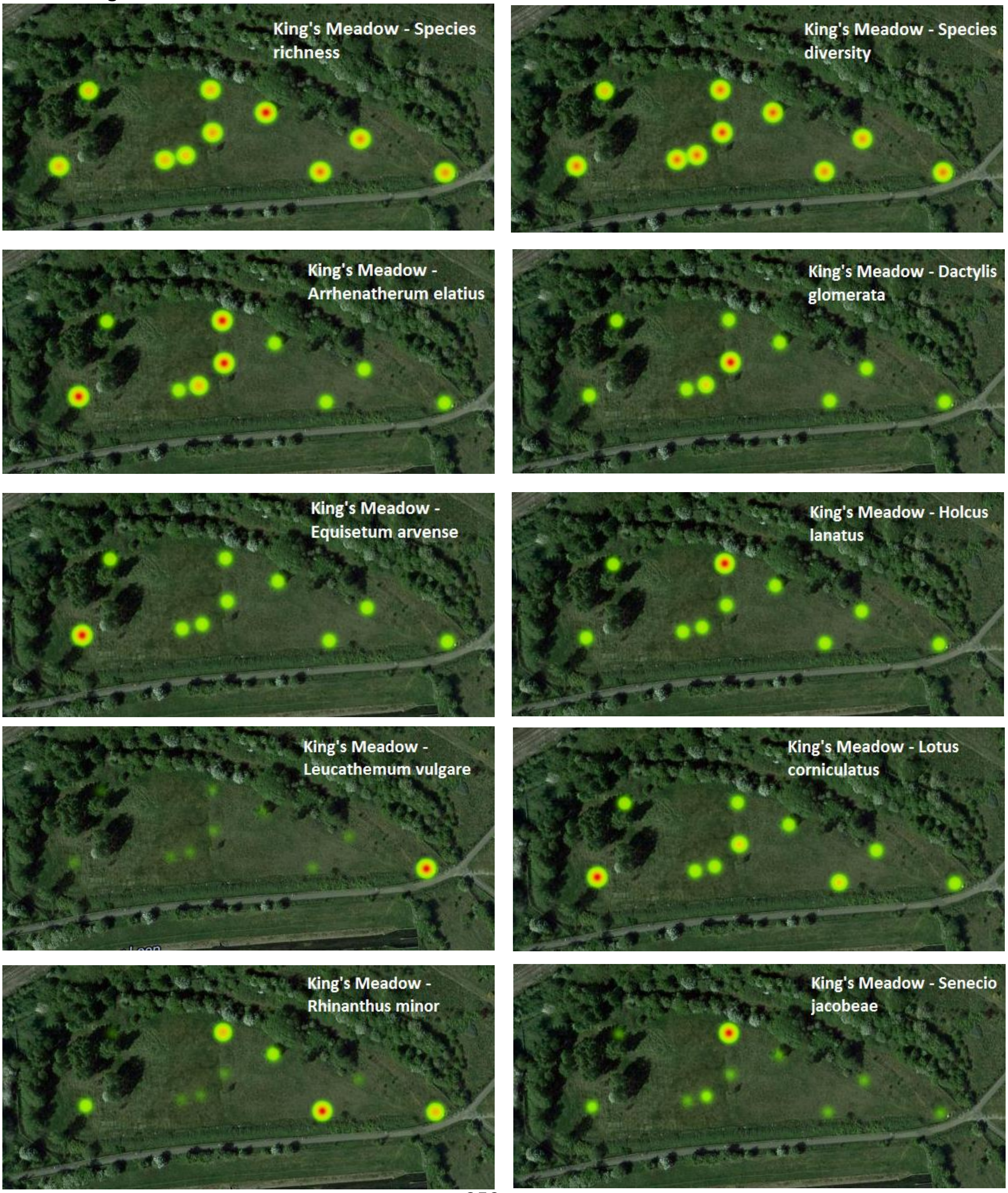
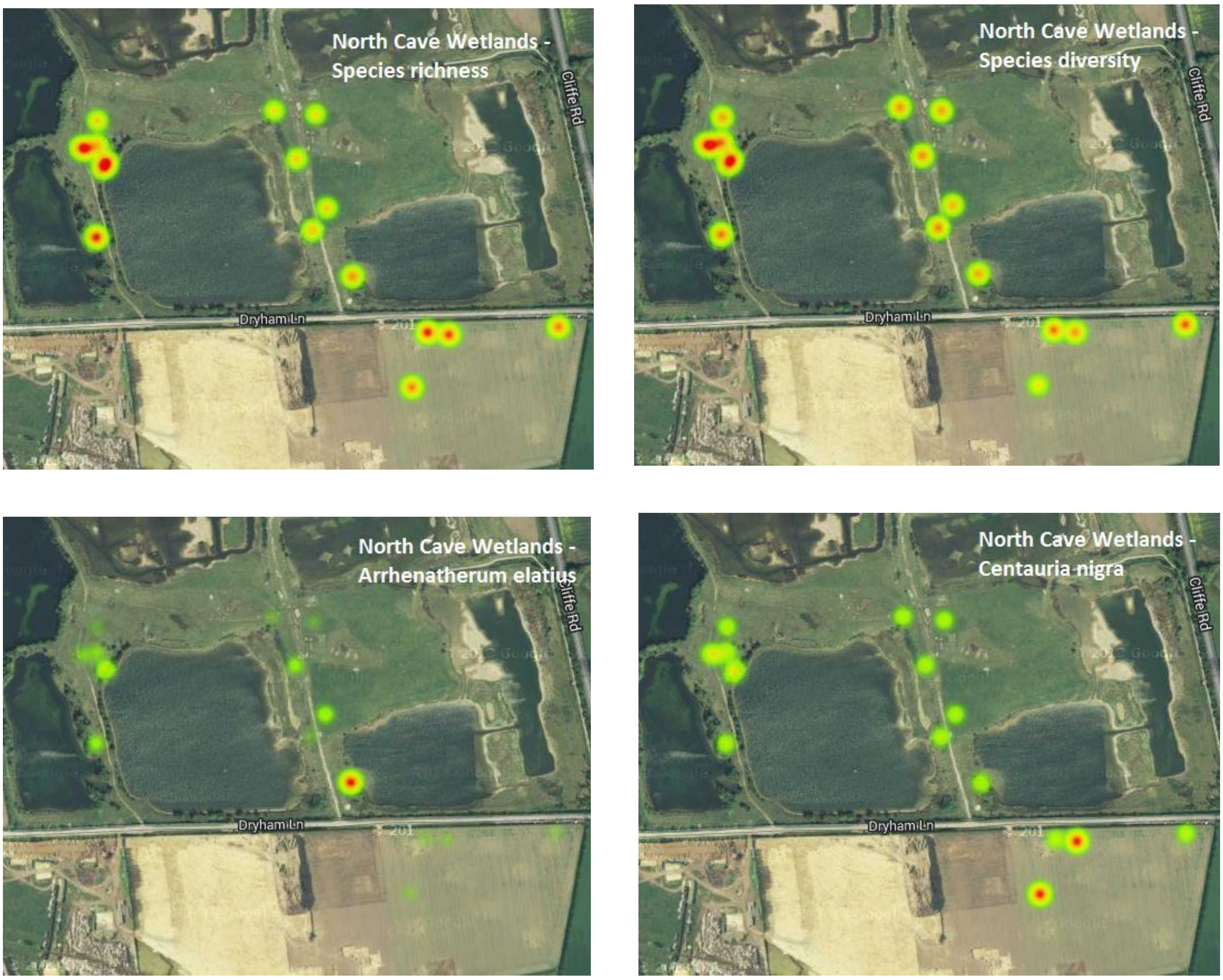


Figure A6.4: Additional species maps for King's Meadow

Site 5 – North Cave wetlands



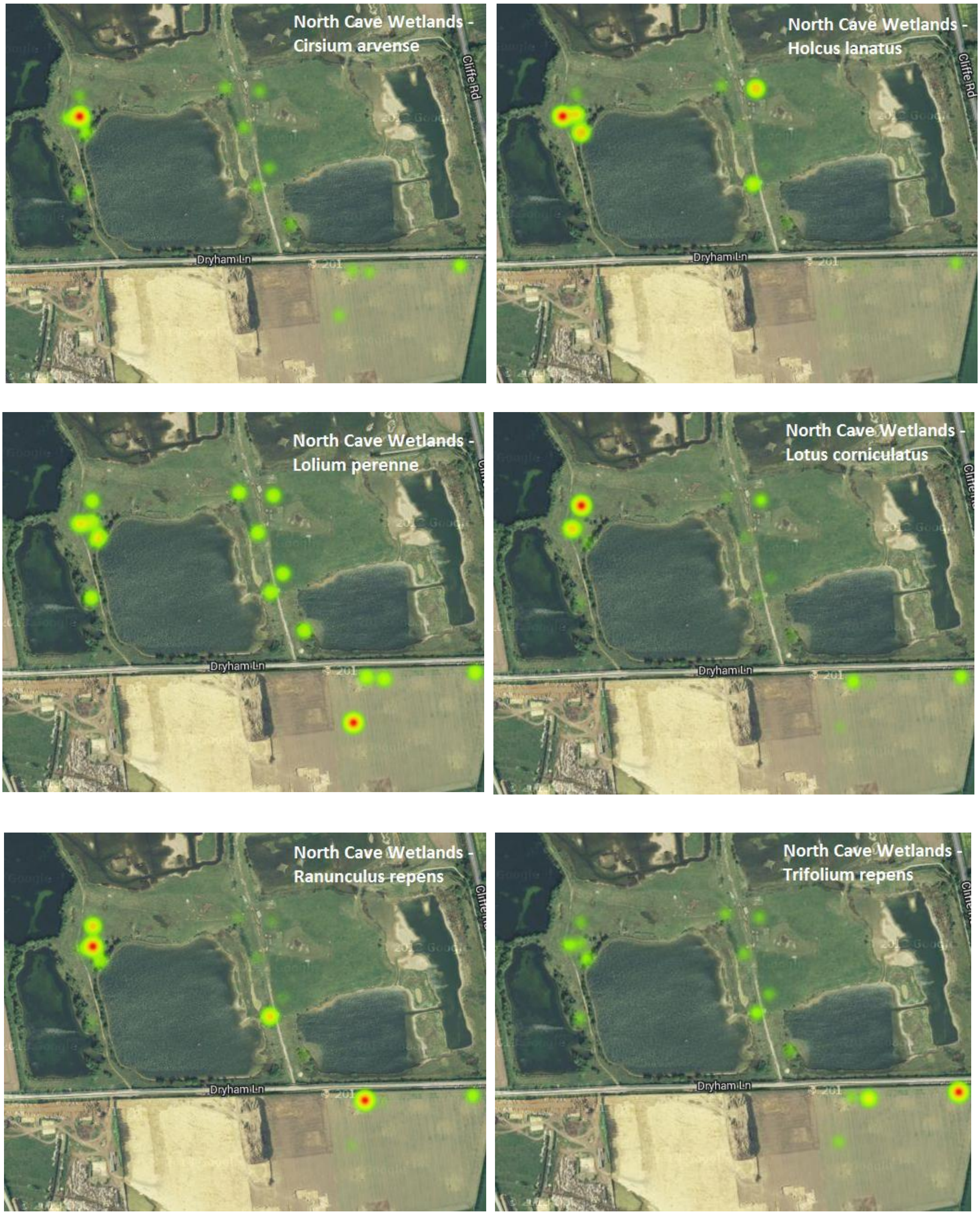


Figure A6.5: Additional species maps for North Cave Wetlands

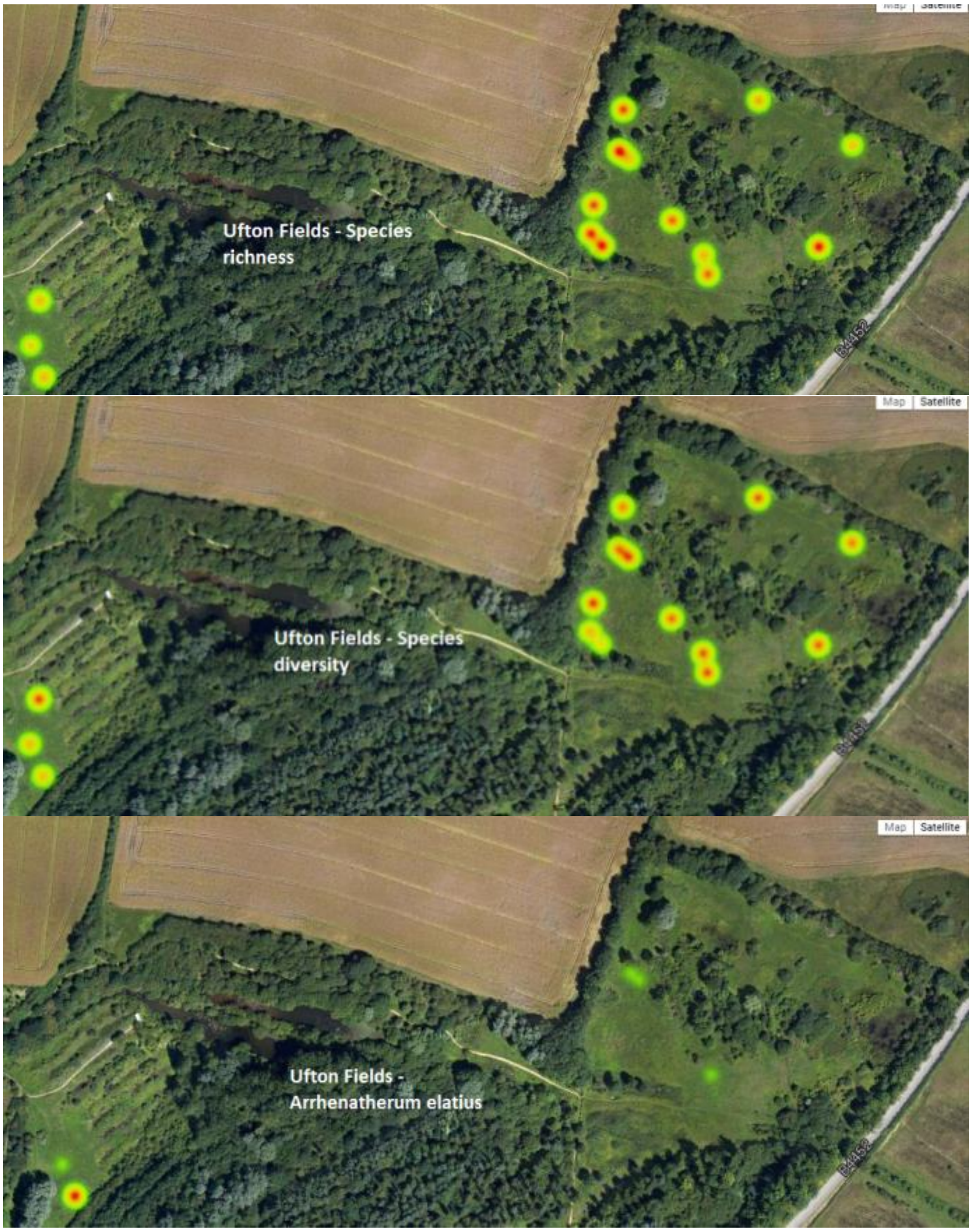
Site 6 – Parc Slip

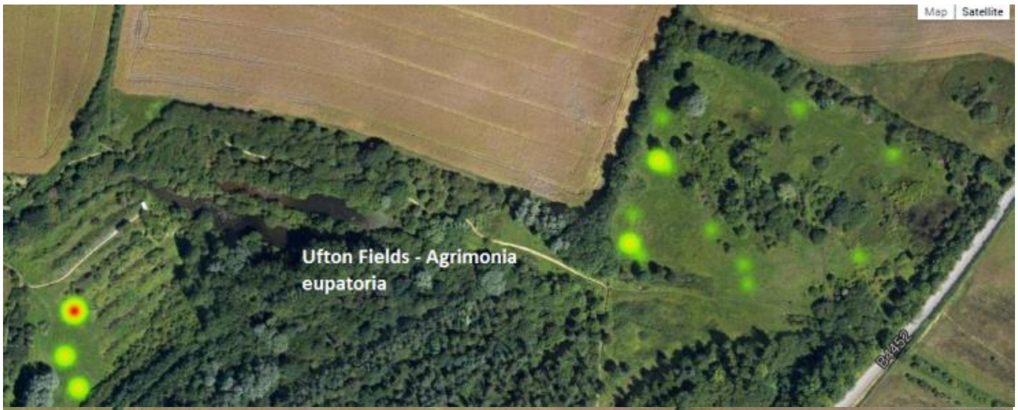
Figure A6.6: Additional species maps for Parc Slip Nature Reserve

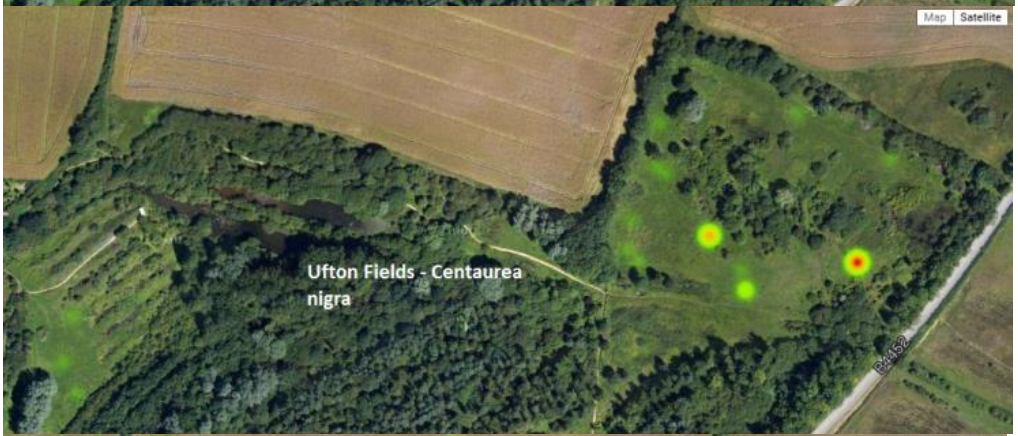
Site 7 – Ryton Meadows

Figure A6.7: Additional species maps for Ryton Meadows

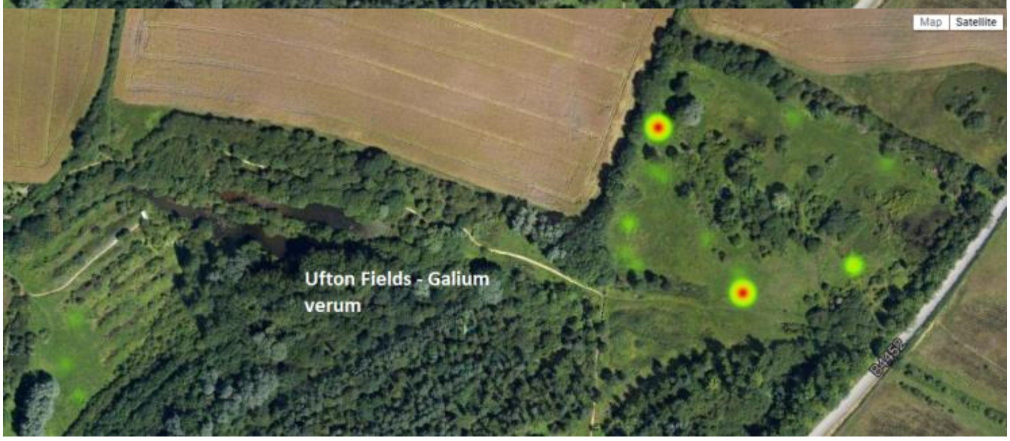
Site 8 – Ufton Fields

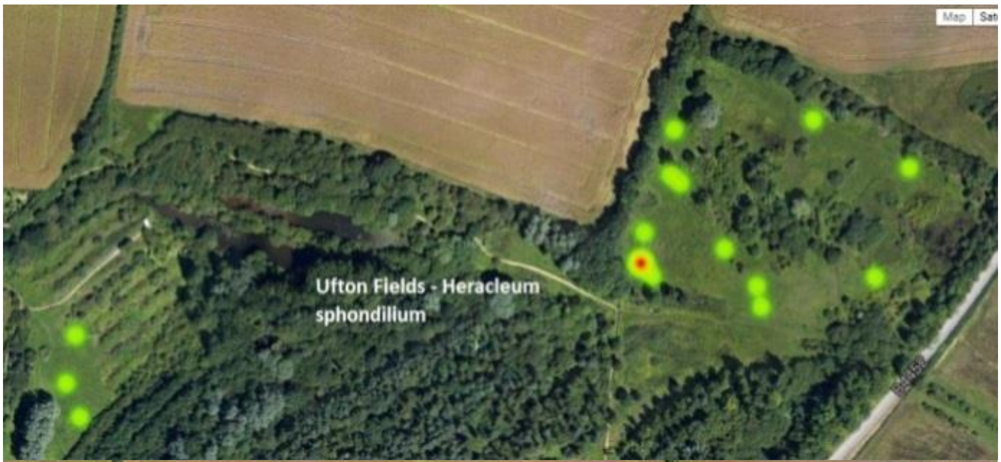


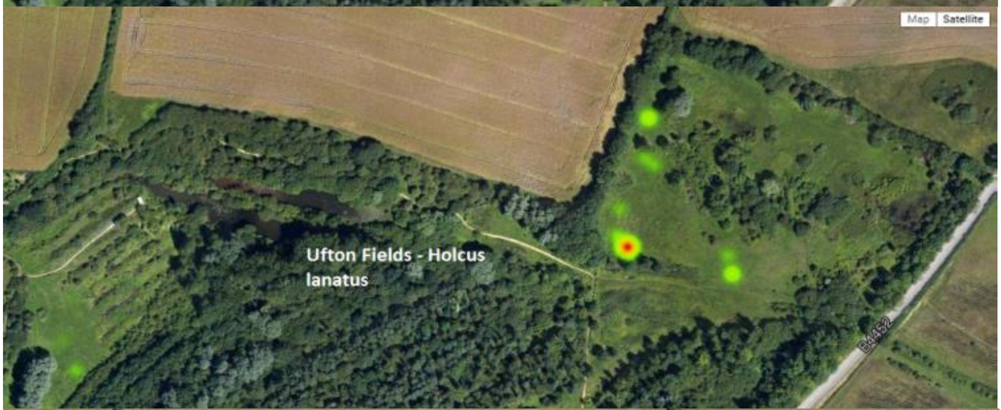

Map
Satellite
Ufton Fields - Agrimonia eupatoria


Map
Satellite
Ufton Fields - Centaurea nigra


Map
Ufton Fields - Dactylis glomerata

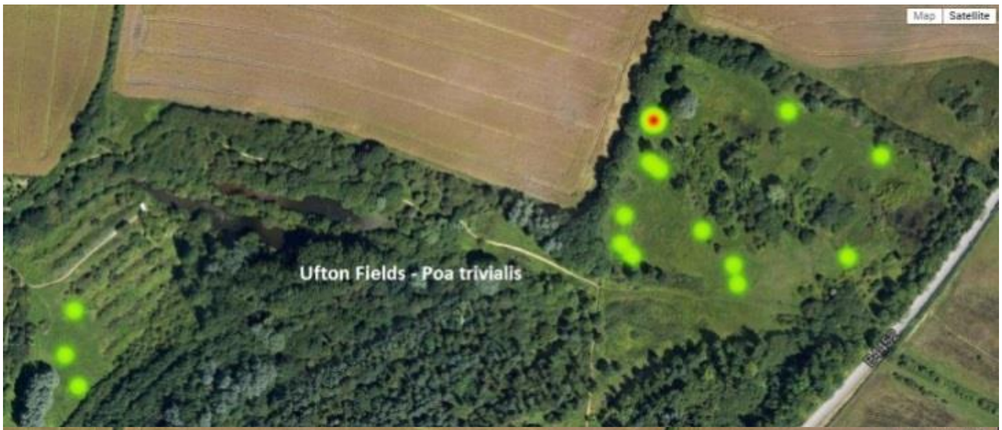

Map
Satellite
Ufton Fields - Galium verum

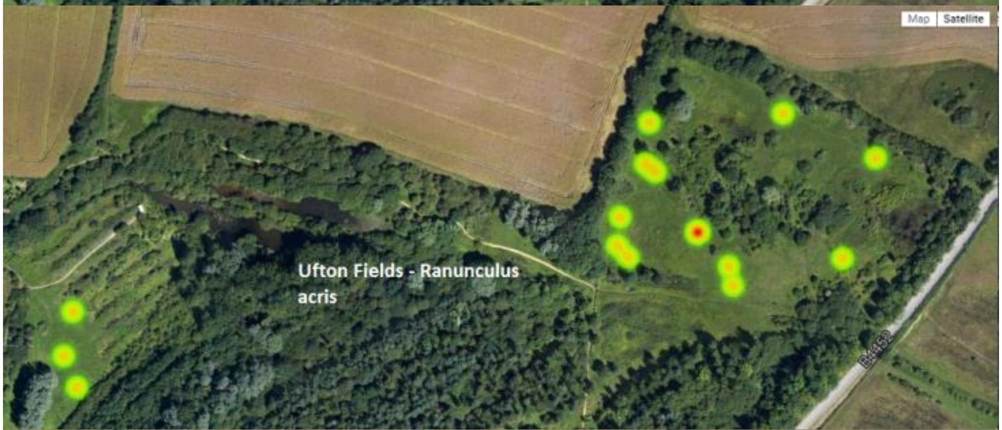

Map
Ufton Fields - Heracleum
sphondilium

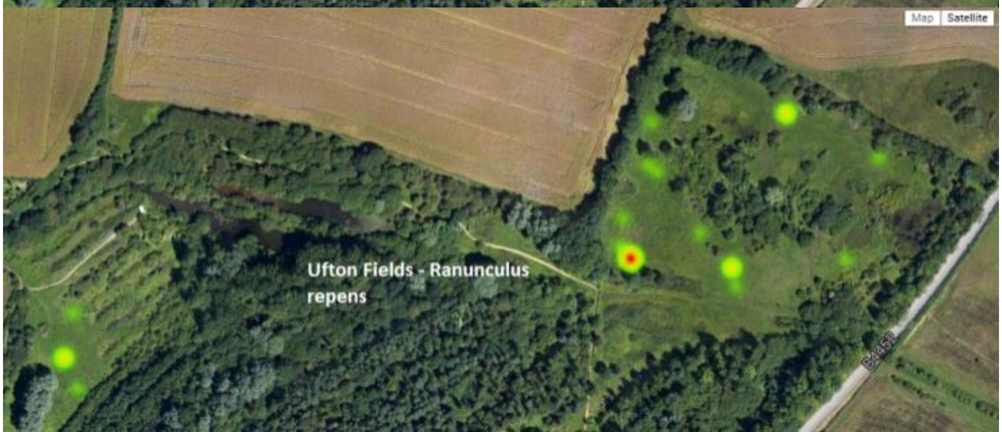

Map
Satellite
Ufton Fields - Holcus
lanatus


Map
Satellite
Ufton Fields - Lathyrus
pratensis


Map
Satellite
Ufton Fields - Lolium
perenne


Map
Satellite
Ufton Fields - Poa trivialis


Map
Satellite
Ufton Fields - Ranunculus
acris


Map
Satellite
Ufton Fields - Ranunculus
repens

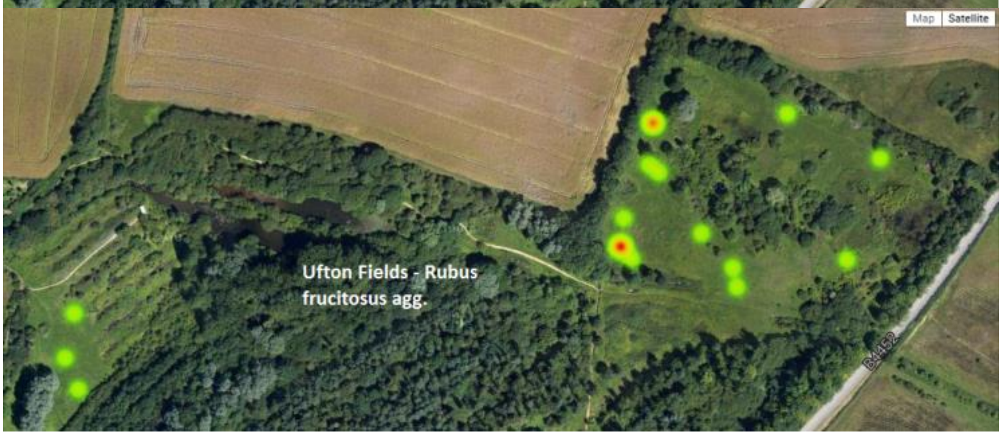

Map
Satellite
Ufton Fields - Rubus
frucitosus agg.

Figure A6.8: Additional species maps for Ufton Fields

Site 9 – Whittleford Park


Whittleford Park -
Centaurea nigra
Gorsy Way
Queen Elizabeth Rd
Queen Elizabeth Rd
Bar Pool Brook
Bar Pool Brook


Whittleford Park -
Dactylis glomerata
Gorsy Way
Queen Elizabeth Rd
Queen Elizabeth Rd
Bar Pool Brook
Bar Pool Brook


Whittleford Park -
Deschampsia
flexuosa
Gorsy Way
Queen Elizabeth Rd
Queen Elizabeth Rd
Bar Pool Brook
Bar Pool Brook


Whittleford Park -
Holcus lanatus
Gorsy Way
Queen Elizabeth Rd
Queen Elizabeth Rd
Bar Pool Brook
Bar Pool Brook


Whittleford Park -
Leucanthemum
vulgare
Gorsy Way
Queen Elizabeth Rd
Queen Elizabeth Rd
Bar Pool Brook
Bar Pool Brook

Figure A6.9: Additional species maps for Whittleford Park

APPENDIX 7: R CODE FOR DATA ANALYSIS

Relevant page references are provided in the following code to results/methods in main body of text

###Quadrat data exploration – Section 3.7

```
setwd("C:/Users/Laptop/Documents/Rworkspace)
quadrats <- read.csv("C:/Users/Laptop/Documents/Rworkspace/quadratsind1.csv", header=TRUE)
str(quadrats)
library(lattice)
source("C:/Users/Laptop/Documents/Rworkspace/HighstatLibV6.R")
```

###Outliers in Y - Time since creation

```
par(mfrow = c(1, 2))
boxplot(quadrats$Time.since.creation,
      main = "Time since creation")
dotchart(quadrats$Time.since.creation,
     xlab = "Range of data",
           ylab = "Values")
```

#Outliers in X

```
par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
dotchart(quadrats$Location, main = "Site")
dotchart(quadrats$Site.info, main = "Soil type")
dotchart(quadrats$Quadrat.mean.height.cm, main = "Quadrat mean height-cm")
dotchart(quadrats$Species.richness, main = "Species richness")
dotchart(quadrats$Diversity, main = "Species diversity")
dotchart(quadrats$HG, main = "Herb:Grass ratio")
```

#Try Log transformation of Herb:Grass ratio and mean height

```
logratio  <- log(quadrats$HG)
quadrats$logheight  <- log(quadrats$Quadrat.mean.height.cm)

par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
dotchart(quadrats$Location, main = "Site")
dotchart(quadrats$Site.info, main = "Soil type")
dotchart(quadrats$logheight, main = "Quadrat mean height-cm")
dotchart(quadrats$Species.richness, main = "Species richness")
dotchart(quadrats$Diversity, main = "Species diversity")
dotchart(quadrats$logratio, main = "Herb:Grass ratio")
```

#Assess collinearity

```
MyVar <- c("Location","Site.info",
        "logheight","Species.richness","Diversity",
        "logratio")
pairs(quadrats[, MyVar])

MyVar <- c("Location","Site.info",
        "logheight","Species.richness","Diversity",
        "logratio")
Mypairs(quadrats[,MyVar])
```

#Every covariate against X

```
MyX  <- c("Location", "Site.info", "logheight", "Species.richness"
        , "Diversity","logratio")
Myxyplot(quadrats, MyX, "Time.since.creation",
MyYlab = "Time since creation")
```

###Individual species exploration
#Lolium perenne exploration

```
xyplot(Time.since.creation~Lolium.perenne, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Lolium perenne (% per site)", main="Lolium perenne (Perennial Rye Grass)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

#Interaction of soil type
xyplot(Time.since.creation~Lolium.perenne|Site.info, data=comdata,
      xlab="Lolium perenne", strip=strip.custom(bg="white"),
      ylab="Time since creation", main="Lolium perenne (Perennial Rye Grass) by soil type"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

#ggplot Lolium perenne
Lolper.labels <- data.frame(
  time = c(45), #these relate to axis length/labels
  value = c(10), #these relate to axis length/labels
  label = c("p=0.001671"),
  type = c("NA*", "MVH")
)

g<-ggplot(comdata, aes(Time.since.creation, Lolium.perenne))+
        geom_point(color="firebrick", size=3)+
  geom_text(data = Lolper.labels, aes(x = time, y = value, label = label))
g<-g+ggtitle('Lolium perenne over time')
g<-g+labs(x="Time since creation (years)", y=expression(paste("Abundance (%)")))
g
g1<-g+theme(plot.title = element_text(size=15, face="bold", vjust=2))
g2<-g1 + theme(axis.text.y=element_text(angle=50, size=10, vjust=0.5),
        axis.text.x=element_text(angle=50, size=10, vjust=0.5))
g3<-g2 + ylim(c(0,40))
g4<-g3 + geom_smooth(method="lm", size=1.5, se=FALSE, fullrange=T)
g4

Lolper <- lm(Time.since.creation~Lolium.perenne, data=comdata)
summary(Lolper)

RMA1 <- resid(Lolper)
FMA1 <- fitted(Lolper)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Lolper",
    ylab = "Residuals Lolper",
```

```
    main = "Lolium perenne model")
abline(h = 0, v = 0, lty = 2)
```

#Cirsium arvense exploration

```
xyplot(Time.since.creation~Cirsium.arvense, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Cirsium arvense (% per site)", main="Cirsium arvense (Creeping thistle)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

qplot(x=Location.2, y=Cirsium.arvense, group=Location.2,
     data=comdata, geom="bar", stat="identity",
     position="dodge")
#needs some work
#ggplot

data2.labels <- data.frame(
  time = c(45), #these relate to axis length/labels
  value = c(4), #these relate to axis length/labels
  label = c("p=0.001371"),
  type = c("NA*", "MVH"))

g<-ggplot(comdata, aes(Time.since.creation, Cirsium.arvense))+
  geom_point(color="firebrick", size=3)+
  geom_text(data = data2.labels, aes(x = time, y = value, label = label))
g<-g+ggtitle('Cirsium arvense over time')
g<-g+labs(x="Time since creation (years)", y=expression(paste("Abundance (%)")))
g
g1<-g+theme(plot.title = element_text(size=15, face="bold", vjust=2))
g2<-g1 + theme(axis.text.y=element_text(angle=50, size=10, vjust=0.5),
             axis.text.x=element_text(angle=50, size=10, vjust=0.5))
g3<-g2 + ylim(c(0,40))
g4<-g3 + geom_smooth(method="lm", size=1.5, se=FALSE)
g4

Cirarv <- lm(Time.since.creation~Cirsium.arvense, data=comdata)
summary(Cirarv)

RMA1 <- resid(Cirarv)
FMA1 <- fitted(Cirarv)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Cirarv",
    ylab = "Residuals Cirarv",
    main = "Cirsium arvense model")
abline(h = 0, v = 0, lty = 2)
```

#Arrhenatherum elatius exploration

```
xyplot(Time.since.creation~Arrhenatherum.elatius, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
```

```
      ylab="Arrhenatherum elatius (% per site)", main="Arrhenatherum elatius (False oat grass)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

#ggplot Arrhenatherum elatius
Arrela.labels <- data.frame(
  time = c(45), #these relate to axis length/labels
  value = c(10), #these relate to axis length/labels
  label = c("p=0.001118"),
  type = c("NA*", "MVH"))

g<-ggplot(comdata, aes(Time.since.creation, Arrhenatherum.elatius))+
  geom_point(color="firebrick", size=3)+
  geom_text(data = Arrela.labels, aes(x = time, y = value, label = label))
g<-g+ggtitle('Arrhenatherum elatius over time')
g<-g+labs(x="Time since creation (years)", y=expression(paste("Abundance (%)")))
g
g1<-g+theme(plot.title = element_text(size=15, face="bold", vjust=2))
g2<-g1 + theme(axis.text.y=element_text(angle=50, size=10, vjust=0.5),
               axis.text.x=element_text(angle=50, size=10, vjust=0.5))
g3<-g2 + ylim(c(0,50))
g4<-g3 + geom_smooth(method="lm", size=1.5, se=FALSE, fullrange=T)
g4

Arrela <- lm(Time.since.creation~Arrhenatherum.elatius, data=comdata)
summary(Arrela)

RMA1 <- resid(Arrela)
FMA1 <- fitted(Arrela)

plot(x = RMA1,
     y = FMA1,
     xlab = "Fitted values Arrela",
     ylab = "Residuals Arrela",
     main = "Arrhenatherum elatius model")
abline(h = 0, v = 0, lty = 2)
```

#Leucanthemum vulgare exploration

```
xyplot(Time.since.creation~Leucanthemum.vulgare, data=comdata,
      xlab="Time since creation", strip=strip.custom(bg="white"),
      ylab="Leucanthemum vulgare ", main="Leucanthemum vulgare  (Oxeye daisy)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

qplot(x=Location.2, y=Leucanthemum.vulgare, group=Location.2,
     data=comdata, geom="bar", stat="identity",
     position="dodge")
#needs some work

Leuvul <- lm(Time.since.creation~Leucanthemum.vulgare, data=comdata)
summary(Leuvul)

RMA1 <- resid(Leuvul)
```

```
FMA1 <- fitted(Leuvul)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Leuvul",
    ylab = "Residuals Leuvul",
    main = "Leucanthemum vulgare  model")
abline(h = 0, v = 0, lty = 2)
```

#Poa trivialis exploration

```
xyplot(Time.since.creation~Poa.trivialis, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Poa trivialis (% by site)", main="Poa trivialis  (Rough meadowgrass)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Poatri <- lm(Time.since.creation~Poa.trivialis, data=comdata)
summary(Poatri)

RMA1 <- resid(Poatri)
FMA1 <- fitted(Poatri)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Poatri",
    ylab = "Residuals Poatri",
    main = "Poa trivialis  model")
abline(h = 0, v = 0, lty = 2)
```

#Ranunculus repens exploration

```
xyplot(Time.since.creation~Ranunculus.repens, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Ranunculus repens (% per site)", main="Ranunculus repens  (Creeping buttercup)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Ranrep <- lm(Time.since.creation~Ranunculus.repens, data=comdata)
summary(Ranrep)

RMA1 <- resid(Ranrep)
FMA1 <- fitted(Ranrep)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Ranrep",
    ylab = "Residuals Ranrep",
    main = "Ranunculus repens  model")
abline(h = 0, v = 0, lty = 2)
```

#Senecio jacobaea exploration

```
xyplot(Time.since.creation~Senecio.jacobaea, data=comdata,
```

```
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Senecio jacobaea (% per site)", main="Senecio jacobaea  (Ragwort)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Senjac <- lm(Time.since.creation~Senecio.jacobaea, data=comdata)
summary(Senjac)

RMA1 <- resid(Senjac)
FMA1 <- fitted(Senjac)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Senjac",
    ylab = "Residuals Senjac",
    main = "Senecio jacobaea model")
abline(h = 0, v = 0, lty = 2)
```

#Dactylis glomerata exploration

```
xyplot(Time.since.creation~Dactylis.glomerata, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Dactylis glomerata (% per site)", main="Dactylis glomerata (Cock's-foot)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Dacglo <- lm(Time.since.creation~Dactylis.glomerata, data=comdata)
summary(Dacglo)

RMA1 <- resid(Dacglo)
FMA1 <- fitted(Dacglo)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Dacglo",
    ylab = "Residuals Dacglo",
    main = "Dactylis glomerata model")
abline(h = 0, v = 0, lty = 2)
```

#Daucus carota exploration

```
xyplot(Time.since.creation~Daucus.carota, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Daucus carota (% per site)", main="Daucus carota (Wild carrot)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Daucar <- lm(Time.since.creation~Daucus.carota, data=comdata)
summary(Daucar)

RMA1 <- resid(Daucar)
FMA1 <- fitted(Daucar)

plot(x = RMA1,
```

```
    y = FMA1,
    xlab = "Fitted values Daucar",
    ylab = "Residuals Daucar",
    main = "Daucus carota model")
abline(h = 0, v = 0, lty = 2)
```

#Galium verum exploration

```
xyplot(Time.since.creation~Galium.verum, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Galium verum (% per site)", main="Galium verum (Ladies' bedstraw)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))

Galver <- lm(Time.since.creation~Galium.verum, data=comdata)
summary(Galver)

RMA1 <- resid(Galver)
FMA1 <- fitted(Galver)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Galver",
    ylab = "Residuals Galver",
    main = "Galium verum model")
abline(h = 0, v = 0, lty = 2)
```

#Heracleum sphondilium exploration

```
xyplot(Heracleum.sphondylium~Time.since.creation, data=comdata,
      xlab="Time since creation (years)", strip=strip.custom(bg="white"),
      ylab="Heracleum sphondylium (% per quadrat)", main="Heracleum sphondylium (Common
hogweed)"
      , lwd=3, cex=1.3,pch=20,
      type=c("p","r"))


Hersph <- lm(Time.since.creation~Heracleum.sphondylium, data=comdata)
summary(Hersph)

RMA1 <- resid(Hersph)
FMA1 <- fitted(Hersph)

plot(x = RMA1,
    y = FMA1,
    xlab = "Fitted values Hersph",
    ylab = "Residuals Hersph",
    main = "Heracleum sphondylium model")
abline(h = 0, v = 0, lty = 2)
setwd("C:/Users/Laptop/Documents/Rworkspace)

flor <- read.csv("C:/Users/Laptop/Documents/Rworkspace/regressionquadrats.csv", header=TRUE)
regflor <- flor[1:100,]
```

```
str(regflor)

library(corrplot)
library(lattice)


#Assign easy variable names
TSC <- regflor$Time.since.creation
Agrieupa <- regflor$Agrimonia.eupatoria
Anthsylv <- regflor$Anthriscus.sylvestris
Arrhelat <- regflor$Arrhenatherum.elatius
Cerafont <- regflor$Cerastium.fontanum
Chamangu <- regflor$Chamerion.angustifolium
Cirspalu <- regflor$Cirsium.palustre
Dactglom <- regflor$Dactylis.glomerata
Dauccaro <- regflor$Daucus.carota
Desccesp <- regflor$Deschampsia.cespitosa
Equisp <- regflor$Equisetum.sp
Holclana <- regflor$Holcus.lanatus
Lathprat <- regflor$Lathyrus.pratensis
Leonhisp <- regflor$Leontodon.hispidus
Leucvulg <- regflor$Leucanthemum.vulgare
Lotucorn <- regflor$Lotus.corniculatus
Poaannu <- regflor$Poa.annua
Poterept <- regflor$Potentilla.reptans
Rhinmino <- regflor$Rhinanthus.minor
Trifprat <- regflor$Trifolium.pratense
SR <- regflor$weight
str(rich)
Diversity <- regflor$Diversity
str(Diversity)
HerbGrass <- regflor$Herb
str(HerbGrass)
Height <- regflor$Height
str(Height)
Management <- regflor$Management
str(Management)

###DCA - DECORANA###
#Section 3.9
#Load packages
library(vegan)
library(MASS)

#Load files
DCA1 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location1.csv",
                 header=TRUE)
DCA2 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location2.csv",
          header=TRUE)
DCA3 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location3.csv",
          header=TRUE)
DCA4 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location4.csv",
          header=TRUE)
DCA5 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location5.csv",
```

```
            header=TRUE)
DCA6 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location6.csv",
            header=TRUE)
DCA7 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location7.csv",
            header=TRUE)
DCA8 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location8.csv",
            header=TRUE)
DCA9 <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/Location9.csv",
            header=TRUE)

DCAA <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/decorana data GroupA.csv",
            header=TRUE)
DCAB <- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/decorana data GroupB.csv",
            header=TRUE)
DCAFAM<- read.csv("C:/Users/Laptop/Documents/Rworkspace/DCAdata/quadfam.csv",
             header=TRUE)
summary(DCAA)
```

#Specify further explanatory variables

```
TSCA <- DCAA$Timesincecreation
TSCB <- DCAB$Timesincecreation
TSCFAM <- DCAFAM$Time.since.creation

ManA <- DCAA$Management
ManB <- DCAB$Management
ManFAM <- DCAFAM$Management

SoilA <- DCAA$Site.info
SoilB <- DCAB$Site.info
SoilFAM <- DCAFAM$Site.info
```

#Perform DCA on each site

```
ord1 <- decorana(DCA1)
ord1

ord2 <- decorana(DCA2)
ord2

ord3 <- decorana(DCA3)
ord3

ord4 <- decorana(DCA4)
ord4

ord5 <- decorana(DCA5)
ord5

ord6 <- decorana(DCA6)
ord6

ord7 <- decorana(DCA7)
ord7

ord8 <- decorana(DCA8)
```

ord8

ord9 <- decorana(DCA9)
ord9

orda <- decorana(DCAA)
orda

ordb <- decorana(DCAB)
ordb

ordfam <- decorana(DCAFAM)
ordfam

#more detail
summary(ord1)
summary(ord2)
summary(ord3)
summary(ord4)
summary(ord5)
summary(ord6)
summary(ord7)
summary(ord8)
summary(ord9)

summary(orda)
summary(ordb)
summary(ordfam)

#orda, ordb and ordfam of most interest

#########ORDA full analysis

View items in the list produced by decorana. The most useful elements will be
rproj and cproj.

names(orda)

#sample scores for the first 4 axes
orda$rproj

#taxon scores for the first 4 axes
orda$cproj

# extracts axis 1 & 2 scores for taxa
orda.taxonscores <- scores(orda,display=c("species"), choices=c(1,2))

###AXIS LENGTH UNDER 3 - LINEAR ORDINATION ADVISED
#Ordination plot
ordiplot (orda, display = 'sites', type = 'p')
ordiplot (orda, display = 'species', type = 't')

plot(orda)

```
text(orda, display=c("sites"), choices=1:2,cex=0.5)

nestedchecker(DCAA)
# plot samples as green crosses for axis 1 and 2
points(orda, display=c("sites"),choices=1:2,pch=3, col=("green"))

# plot labels for taxa for axis 1 and 2, using cex to shrink
# size of labels. Larger plots may also be used to alleviate
# congestion of labels.
text(orda, display=c("species"), choices=1:2,cex=0.7)

#Assessing significane of other variables - Group A
ord.fitA <- envfit(orda ~ TSCA + SoilA + ManA,
            data=DCAA, perm=999)
ord.fitA


#Plot this part of ordination - Group A
plot(orda, dis="species")
plot(ord.fitA)

ordisurf(orda, TSCA, add=TRUE, col=24,
       main="DCA Group A ordination")

#########ordb full analysis

#### View items in the list produced by decorana. The most useful elements will be
#### rproj and cproj.

names(ordb)

#sample scores for the first 4 axes
ordb$rproj

#taxon scores for the first 4 axes
ordb$cproj

# extracts axis 1 & 2 scores for taxa
ordb.taxonscores <- scores(ordb,display=c("species"), choices=c(1,2))


###AXIS LENGTH UNDER 3 - LINEAR ORDINATION ADVISED
#Ordination plot
ordiplot (ordb, display = 'sites', type = 'p')
ordiplot (ordb, display = 'species', type = 't')

plot(ordb)
text(ordb, display=c("sites"), choices=1:2,cex=0.5)

nestedchecker(DCAA)
# plot samples as green crosses for axis 1 and 2
points(ordb, display=c("sites"),choices=1:2,pch=3, col=("green"))

# plot labels for taxa for axis 1 and 2, using cex to shrink
```

```
# size of labels. Larger plots may also be used to alleviate
# congestion of labels.
text(ordb, display=c("species"), choices=1:2,cex=0.7)
#Assessing significance of other variables - Group B
ord.fitB <- envfit(ordb ~ TSCB + SoilB + ManB,
             data=DCAB, perm=999)
ord.fitB

#Plot this part of ordination - Group B
plot(ordb, dis="species")
plot(ord.fitB)

ordisurf(ordb, TSCB, add=TRUE, col=24, cex=0.5,
     main="DCA Group B ordination")
```

#########ordfam full analysis

```
#### View items in the list produced by decorana. The most useful elements will be
#### rproj and cproj.

names(ordfam)

#sample scores for the first 4 axes
ordfam$rproj

#taxon scores for the first 4 axes
ordfam$cproj

# extracts axis 1 & 2 scores for taxa
ordfam.taxonscores <- scores(ordfam,display=c("species"), choices=c(1,2))


###AXIS LENGTH UNDER 3 - LINEAR ORDINATION ADVISED
#Ordination plot
ordiplot (ordfam, display = 'sites', type = 'p')
ordiplot (ordfam, display = 'species', type = 't')

plot(ordfam)
text(ordfam, display=c("sites"), choices=1:2,cex=0.5)

nestedchecker(DCAA)
# plot samples as green crosses for axis 1 and 2
points(ordfam, display=c("sites"),choices=1:2,pch=3, col=("green"))

# plot labels for taxa for axis 1 and 2, using cex to shrink
# size of labels. Larger plots may also be used to alleviate
# congestion of labels.
text(ordfam, display=c("species"), choices=1:2,cex=0.7)
#Assessing significance of other variables - Group B
ord.fitFAM <- envfit(ordfam ~ TSCFAM + SoilFAM + ManFAM,
             data=DCAB, perm=999)
ord.fitFAM

#Plot this part of ordination - Group B
```

```
plot(ordfam, dis="species")
plot(ord.fitFAM)

ordisurf(ordfam, TSCB, add=TRUE, col=24, cex=0.5,
        main="DCA Group B ordination")
```

###Community variables

```
dotchart(rich, main = "Species richness")
dotchart(Diversity, main = "Species diversity")
dotchart(HerbGrass, main = "Herb:Grass ratio")
dotchart(Height, main = "Quadrat mean height (cm)")

regframe <- data.frame(TSC, SR, Diversity, HerbGrass, Height)
regframe
M <- cor(regframe)
corrplot.mixed(M)

plot(TSC, HerbGrass, xlab="Time Since Creation",ylab="Herb:Grass ratio",
    main="Herb:Grass ratio against Time Since Creation",
   pch=1, col="black", xlim=c(0,50), ylim=c(0.85,1), frame.plot=FALSE)
lines(lowess(TSC, HerbGrass), col="black")

plot(TSC, SR, xlab="Time Since Creation",ylab="Species Richness",
    main="Species Richness against Time Since Creation",
   pch=2, col="red", xlim=c(0,50), frame.plot=FALSE)
lines(lowess(TSC,SR), col="blue")

pairs(~TSC+HerbGrass+SR+Diversity,data=regflor,
  main="Community indicators")
lines(lowess(TSC, HerbGrass, SR, Diversity), col="blue")
```

##Effect of community variables on Time Since Creation

```
comreg <- lm(TSC ~ HerbGrass+SR+Diversity+Height)densityplot(Diversity ~ TSC |
factor(Management), regflor,
plot.points = FALSE, auto.key = TRUE, xlab = "Time since creation (years)",
ylab = "Species diversity",
main="Species diversity against Time since creation by Management type",
col="black")
summary(comreg)

boxplot(SR~Management, data=regflor, xlab = "Management type",
      ylab="Species richness (No. species/quadrat)",
        main="Effect of management on Species richness", cex.axis=0.8,
       cex.lab=0.8, cex.main=0.8)

boxplot(Diversity~Management, data=regflor, xlab = "Management type",
      ylab="Species diversity",
        main="Effect of management on Species diversity", cex.axis=0.8,
       cex.lab=0.8, cex.main=0.8)

boxplot(Height~Management, data=regflor, xlab = "Management type",
      ylab="Mean quadrat height (cm)",
        main="Effect of management on mean quadrat height", cex.axis=0.8,
```

```
       cex.lab=0.8, cex.main=0.8)

boxplot(HerbGrass~Management, data=regflor, xlab = "Management type",
      ylab="Herb:Grass ratio",
        main="Effect of management on Herb:Grass ratio", cex.axis=0.8,
       cex.lab=0.8, cex.main=0.8)

data<-iris
plot(TSC, SR, col=Management)
legend('topright', legend = levels(Management), col = 1:3, cex = 0.8, pch = 1)

library(ggplot2)

qplot(TSC, SR, data = regflor, shape = Management,
xlab="Time since creation (years)",ylab="Species richness (No. species/quadrat)",
     main="Species richness against Time since creation by Management Type",
     size=1)

qplot(TSC, Diversity, data = regflor, shape = Management,
xlab="Time since creation (years)",ylab="Species diversity",
     main="Species diversity against Time since creation by Management Type",
     size=1)

qplot(TSC, Height, data = regflor, shape = Management,
xlab="Time since creation (years)",ylab="Mean quadrat height (cm)",
     main="Mean quadrat height against Time since creation by Management Type",
     size=1)

qplot(TSC, HerbGrass, data = regflor, shape = Management,
xlab="Time since creation (years)",ylab="Herb:Grass ratio (% herb)",
     main="Herb:Grass ratio against Time since creation by Management Type",
     size=1)

SRreg <- lm(TSCatt~SRatt+Diversityatt+HerbGrassatt+Heightatt, data=regfloratt)
summary(SRreg)

regdataframe <- data.frame(SRatt=7, Diversityatt=0.9, HerbGrassatt=0.93, Heightatt=60)
predict(SRreg, regdataframe)
```

###Removing Attenborough

```
regfloratt <- read.csv("C:/Users/Laptop/Documents/Rworkspace/regressionquadratsatt.csv",
header=TRUE)

str(regfloratt)

TSCatt <- regfloratt$Time.since.creation
SRatt <- regfloratt$weight
Heightatt <- regfloratt$Height
str(SRatt)
Diversityatt <- regfloratt$Diversity
str(Diversityatt)
HerbGrassatt <- regfloratt$Herb
str(HerbGrassatt)
```

```
Manatt <- regfloratt$Management
str(Manatt)
Heightatt <- regfloratt$Height
str(Height)

##Community minus Attenborough

dotchart(SRatt, main = "Species richness")
dotchart(Diversityatt, main = "Species diversity")
dotchart(HerbGrassatt, main = "Herb:Grass ratio")
dotchart(Heightatt, main = "Quadrat mean height (cm)")

regframeatt <- data.frame(TSCatt, SRatt, Diversityatt, HerbGrassatt, Heightatt)
regframeatt
M <- cor(regframeatt)
corrplot.mixed(M)

lm1 <- lm(TSC~HerbGrassatt, SRatt, Diversityatt, Heightatt)
summary(lm1)
    plot(TSCatt, HerbGrassatt, xlab="Time Since Creation",ylab="Herb:Grass ratio",
    main="Herb:Grass ratio against Time Since Creation",
    pch=2, col="red", xlim=c(0,50), frame.plot=FALSE)
    abline(lm(TSCatt~HerbGrassatt), col="blue")


    plot(TSC, SR, xlab="Time Since Creation",ylab="Species Richness",
    main="Species Richness against Time Since Creation",
    pch=2, col="red", xlim=c(0,50), frame.plot=FALSE)
    lines(lowess(TSC,SR), col="blue")

    pairs(~TSC+HerbGrass+SR+Diversity,data=regflor,
    main="Community indicators")
    lines(lowess(TSC, HerbGrass, SR, Diversity), col="blue")

regframeatt <- data.frame(TSCatt, SRatt, Diversityatt, HerbGrassatt, Heightatt, Manatt)
regframeatt
M <- cor(regframeatt)
corrplot.mixed(M)
```

###Economic data analysis
#Chapters 4-6

```
#Valuesexploration.R
setwd("C:/Users/Laptop/Documents/Rworkspace)

horizontalvalues <- read.csv("C:/Users/Laptop/Documents/Rworkspace/Horizontal values - final.csv",
header=TRUE)
verticalvalues <- read.csv("C:/Users/Laptop/Documents/Rworkspace/vertical values - final.csv",
              header=TRUE)
str(horizontalvalues)

values <- horizontalvalues[1:52,]
str(values)
values$Key

library(lattice)
library(pastecs)

source("C:/Users/Laptop/Documents/Rworkspace/HighstatLibV6.R")
```

#Outliers in Y - TEV values

```
#Pages 215;

par(mfrow = c(1, 2))
boxplot(values$TEV,
     main = "Total Economic Valuation")
dotchart(values$TEV,
    xlab = "Range of data",
            ylab = "Values")


par(mfrow = c(1, 2))
boxplot(logTEV,
     main = "Total Economic Valuation")
dotchart(logTEV,
    xlab = "Range of data",
    ylab = "Values")

#Outliers in Individual service values

par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
dotchart(values$Aesthetic, main = "Aesthetic services")
dotchart(values$Biological, main = "Biological services")
dotchart(values$Carbon, main = "Carbon services")
dotchart(values$Climate, main = "Climate services")
dotchart(values$Erosion, main = "Erosion services")
dotchart(values$Events, main = "Extreme events services")

par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
dotchart(values$Genetic, main = "Genetic services")
dotchart(values$Habitat, main = "Habitat services")
dotchart(values$Pollination, main = "Pollination services")
dotchart(values$Recreation, main = "Recreation services")
dotchart(values$Waste, main = "Waste services")
```

```
dotchart(values$Water, main = "Water services")

par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
boxplot(values$Aesthetic, main = "Aesthetic services")
boxplot(values$Biological, main = "Biological services")
boxplot(values$Carbon, main = "Carbon services")
boxplot(values$Climate, main = "Climate services")
boxplot(values$Erosion, main = "Erosion services")
boxplot(values$Events, main = "Extreme events services")

par(mfrow = c(2, 3), mar = c(4, 3, 3, 2))
boxplot(values$Genetic, main = "Genetic services")
boxplot(values$Habitat, main = "Habitat services")
boxplot(values$Pollination, main = "Pollination services")
boxplot(values$Recreation, main = "Recreation services")
boxplot(values$Waste, main = "Waste services")
boxplot(values$Water, main = "Water services")
```

#Descriptive statistics for service values and TEV

```
stat.desc(verticalvalues, basic=F)
stat.desc(verticalvalues, desc=F)
setwd("C:/Users/Laptop/Documents/Rworkspace)

metavalues <- read.csv("C:/Users/Laptop/Documents/Rworkspace/Horizontal values - final.csv",
        header=TRUE)
meta1 <- metavalues[1:52,]
str(meta1)

metavert <- read.csv("C:/Users/Laptop/Documents/Rworkspace/vertical values - final.csv",
        header=TRUE)
metavert <- metavert[1:145,]
str(metavert)

library(VGAM)
library(maps)
library(mapdata)
library(ggplot2)
library(lattice)
library(MASS)
library(car)
library(mgcv)
library(HH)
library(lmtest)
library(plyr)
library(reshape2)
source("C:/Users/Laptop/Documents/Rworkspace/HighstatLibV6.R")

Total <- (meta1$Total)
Continent <- (meta1$Continent)
Country <- (meta1$Country)
GDP <- (meta1$GDPpercapita)
Popdens <- (meta1$Popdensha)
Year <- (meta1$Year0)
```

```
Type <- (meta1$Type)
Method <- (meta1$Valuation_method)
Servs <- (meta1$No_servs)
Area <- (meta1$Area_ha)
logArea <- log(Area)
Latitude <- (meta1$Latitude)
Longitude <- (meta1$Longitude)
Standard <- (meta1$Standardised)
meantotal <- (meta1$MeanTotal)

#This map works with lat and long - show study points

map('worldHires')
Lat <- (meta1$Latitude)
Long <- (meta1$Longitude)
points(Long,Lat,col=2,pch=20)

#creating graph to show continent

qplot(x=Continent, data=meta1, xlab="Continent",
    ylab="Frequency", main= "Continents")

levels(meta1$Continent)
print(meta1$Continent)
conts <- table(meta1$Continent)
barplot(conts, space=0.1, names.arg=c("Africa", "Asia", "Australasia",
                          "Europe","Global","North America","South America"),
        cex.names = 0.7, ylim=c(0,25),xlim=c(0,10), col="grey")
par(las=2)
title(adj=0.2,main = "Number of studies by continent",
    cex=1.1,col="black", font=4)

#Or maybe better

continent <- ggplot(meta1, aes(x=factor(Continent)))
continent + geom_bar(width=0.5) + coord_flip() + xlab("Continent")

#Grassland type graph

grasstype <- ggplot(meta1, aes(factor(Type)))
grasstype + geom_bar(width = 0.5) + coord_flip() + xlab("Grassland type")

#Studies by GDP per capita

plot(meta1$GDPpercapita)

###Graphical respresentation of data###
#Lattice type graph for x*y|z#

xyplot(Total~Type|Valuation_method, data=metavalues,
xlab="Grassland type", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))
```

```
#Graph to show values by number of services valued#

xyplot(Total~No_servs, data=metavalues,
xlab="Number of services", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))

#Graph to show value by area#

xyplot(Total~Area_ha, data=metavalues,
xlab="Area", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))

#Graph to show value by GDP per capita#

xyplot(Total~GDPpercapita, data=metavalues,
xlab="GDP per capita", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))

#Graph to show value by valuation method#

boxplot(Total~Valuation_method, data=metavalues,
xlab="Valuation method", ylab="Valuation ($/ha/year)",
    main="Valuation by method")

#Graph to show value by Population Density#

xyplot(Total~Popdensha, data=metavalues,
xlab="Population density", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))

#Boxplot showing value by continent#

bwplot(Total~Continent, data=metavalues,
xlab="Continent", strip=strip.custom(bg="white"),
ylab="Valuation ($/ha/year)", lwd=3, cex=1.3,pch=20,
type=c("p","r"))

sapply(meta1, is.nan)
#All FALSE

is.na(meta1$Total)
is.na(meta1$Latitude)
is.na(meta1$Longitude)
#No NAs

filled.contour(x = fld$x,
        y = fld$y,
        z = fld$z,
        color.palette =
          colorRampPalette(c("white", "black")),
```

```
       xlab = "Latitude",
       ylab = "Longitude",
       main = "Total value by Latitude and Longitude",
       key.title = title(main = "Value (2013$/ha/year)", cex.main = 1))
```

####Exploratory stats###
#Section 6.3

```
#Distributions

dotchart(metavalues$GDPpercapita, main = "GDP per capita distribution")
hist(metavalues$GDPpercapita, main= "GDP per capita distribution")

logGDP <- log(metavalues$GDPpercapita)

dotchart(logGDP, main = "GDP per capita distribution")
hist(logGDP, main= "GDP per capita distribution")

#OK now area

dotchart(metavalues$Area_ha, main = "Area distribution")
hist(metavalues$Area_ha, main= "Area distribution")

#Heavily skewed - need transformation

##logArea1 <- log(metavalues$Area_ha)##done further down

dotchart(logArea, main = "Area distribution")
hist(logArea, main= "Area distribution")

#Much better try this in later model - now Valuation method

dotchart(metavalues$Valuation_method, main = "Valuation method")
hist(metavalues$Valuation_method, main= "Valuation_method")

#OK now Type

dotchart(metavalues$Type, main = "Grassland Type")
hist(metavalues$Type, main= "Grassland Type")

#OK now No. servs

dotchart(metavalues$No_servs, main = "Number of services")
hist(metavalues$No_servs, main= "Number of services")

#OK now Year0

dotchart(metavalues$Year0, main = "Year0")
hist(metavalues$Year0, main= "Year0")

#OK

#OK now each service
```

```
dotchart(metavalues$Aesthetic, main = "Aesthetic")
hist(metavalues$Aesthetic, main= "Aesthetic")

dotchart(metavalues$Biological, main = "Biological")
hist(metavalues$Biological, main= "Biological")

dotchart(metavalues$Carbon, main = "Carbon")
hist(metavalues$Carbon, main= "Carbon")

dotchart(metavalues$Climate, main = "Climate")
hist(metavalues$Climate, main= "Climate")

dotchart(metavalues$Erosion, main = "Erosion")
hist(metavalues$Erosion, main= "Erosion")

dotchart(metavalues$Events, main = "Events")
hist(metavalues$Events, main= "Events")

dotchart(metavalues$Genetic, main = "Genetic")
hist(metavalues$Genetic, main= "Genetic")

dotchart(metavalues$Habitats, main = "Habitats")
hist(metavalues$Habitats, main= "Habitats")

dotchart(metavalues$Pollination, main = "Pollination")
hist(metavalues$Pollination, main= "Pollination")

dotchart(metavalues$Recreation, main = "Recreation")
hist(metavalues$Recreation, main= "Recreation")

dotchart(metavalues$Waste, main = "Waste")
hist(metavalues$Waste, main= "Waste")

dotchart(metavalues$Water, main = "Water")
hist(metavalues$Water, main= "Water")

#Does y need transformation?
dotchart(meta1$Total, main = "Total value")
hist(meta1$Total, main= "Total value")

#Heavily skewed with long right tail - normal for monetary amounts - try log10

logTotal <- log(meta1$Total+1)
dotchart(logTotal, main = "Total value")
```

#####Assigning easier names to variables#####

```
Total <- (meta1$Total)
Continent <- (meta1$Continent)
GDP <- (meta1$GDPpercapita)
Popdens <- (meta1$Popdensha)
logArea <- log(logArea)
#Area already logArea
```

```
Year <- (meta1$Year0)
Type <- (meta1$Type)
Method <- (meta1$Valuation_method)
Servs <- (meta1$No_servs)
Aest <- (meta1$Aesthetic)
Biological <- (meta1$Biological)
Carbon <- (meta1$Carbon)
Climate <- (meta1$Climate)
Erosion <- (meta1$Erosion)
Events <- (meta1$Events)
Genetic <- (meta1$Genetic)
Habitats <- (meta1$Habitats)
Pollination <- (meta1$Pollination)
Recreation <- (meta1$Recreation)
Waste <- (meta1$Waste)
TEV <- (meta1$TEV)
```

###Kruskal-Wallis – Method
#Section 5.5.1

```
kruskal.test(TEV ~ Method, data = meta1)
boxplot(TEV~Method, data=meta1, cex.axis=0.8, ylab="$/ha/year",
       xlab="Method")


###Kruskal-Wallis - Grassland Type

kruskal.test(TEV ~ Type, data = meta1)
par(mar = c(9, 3, 0.5, 2), mgp = c(5, 1, 0))
boxplot(TEV~Type, data=meta1, cex.axis=0.8, ylab="$/ha/year",
       las=2)

###############Basic linear regression on TEV

TEVreg <- lm(TEV ~ Area + GDP + Popdens, data=meta1)
summary(MC)
#p value 0.1041
#Adjusted R-squared 0.2256

RMC <- resid(MC)
FMC <- fitted(MC)

plot(x = FMC,
    y = RMC,
    xlab = "Fitted values MC",
    ylab = "Residuals MC",
     main = "MC Homogeneity")
     abline(h = 0, v = 0, lty = 2)


MC <- lm(Total~Servs + Year + logArea + Type + GDP + Popdens + Method,
        data=meta1)
summary(MC)
#p value 0.1041
```

```
#Adjusted R-squared 0.2256

RMC <- resid(MC)
FMC <- fitted(MC)

plot(x = FMC,
    y = RMC,
    xlab = "Fitted values MC",
    ylab = "Residuals MC",
     main = "MC Homogeneity")
     abline(h = 0, v = 0, lty = 2)

###Weight adjusted
logTotal1 <- log(Total+1)

Weightmod <- lm(logTotal1~Continent + Year + logArea1 + Type + GDP + Popdens + Method,
        data=metavalues, weights=Servs)
summary(Weightmod)
#p value 0.00204
#Adjusted R-squared 0.6127

RMC <- resid(Weightmod)
FMC <- fitted(Weightmod)

plot(x = FMC,
    y = RMC,
    xlab = "Fitted values MC",
    ylab = "Residuals MC",
     main = "MC Homogeneity")
     abline(h = 0, v = 0, lty = 2)

Weightmod1 <- lm(logTotal1~Continent + Year + logArea1 + Popdens + GDP + Method,
        data=metavalues, weights=Servs)
summary(Weightmod1)
#p value 5.597e-05 Adjusted R squared 0.664
#Better without Type

Weightmod2 <- lm(logTotal1~Continent + logArea1 + Popdens + GDP + Method,
        data=metavalues, weights=Servs)
summary(Weightmod2)
#p value 1.993e-05 Adjusted Rsquared 0.6777
#Better without Year
```

######################MULTILEVEL MODEL
#Section 6.4

```
Weightmodnest <- lm(logTotal1~Continent + Year + logArea1 + Type + GDP + Popdens + (1|Method),
        data=metavalues, weights=Servs)
summary(Weightmodnest)
values <- read.csv("C:/Users/Laptop/Documents/Rworkspace/Groupvalue.csv",
                 header=TRUE)
values1 <- na.omit(values)
str(values)
```

```
Percagri1 <- values$Percagri
ANS1 <- values$ANS
Cont1 <- values$Continent
Coun1 <- values$Country
Lat1 <- values$Latitude
Long1 <- values$Longitude
GDP1 <- values$GDP
Popdens1 <- values$Popdensha
Area1 <- values$Area_ha
Serv1 <- values$TEEBservice
MAserv1 <- values$MA_Code
Cit1 <- values$Citation
Method1 <- values$Valuation_method
Method21 <- values$Method2
Year1 <- values$Valuation_year
Year01 <- values$Year0
Value1 <- values$Finalvalue
Type1 <- values$Grassland_assigned
grp1 <- as.factor(values$Servcode)
as.factor(values$Servcode)
str(values$Servcode)
logValue1 <- log(Value1+1)
logArea1 <- log(Area1+1)
loggdp1 <- log(GDP1+1)

#values minus NA
Percagri <- values1$Percagri
ANS <- values1$ANS
Continent <- values1$Continent
Coun <- values1$Country
Lat <- values1$Latitude
Long <- values1$Longitude
GDP <- values1$GDP
Popdens <- values1$Popdensha
Area <- values1$Area_ha
Serv <- values1$TEEBservice
MAserv <- values1$MA_Code
Cit <- values1$Citation
Method <- values1$Valuation_method
Method2 <- values1$Method2
Year <- values1$Valuation_year
Year0 <- values1$Year0
Value <- values1$Finalvalue
Type <- values1$Grassland_assigned
grp <- as.factor(values1$Servcode)
as.factor(values1$Servcode)
str(values1$Servcode)
logValue <- log(Value+1)
logArea <- log(Area+1)
loggdp <- log(GDP+1)
```

```
library(multilevel)
library(ggplot2)
library(lme4)
library(lattice)
library(MuMIn)

###Possible groups by service - MAserv and grp (also Method)

###
str(values)

summary(values)
summary(logValue)
summary(logArea)

###Plots of potential grouping factors
qplot(logValue, grp, data=values, geom="boxplot", main="Logged value by Ecosystem
    Service type", xlab="Logged value ($/ha/year)", ylab=" ")

qplot(logValue, Method2, data=values, geom="boxplot", main="Logged value by Method of
Valuation",
    xlab="Logged value ($/ha/year)", ylab=" ")

grp1 <- lm(logValue~grp, data=values)
grp1
summary(grp1)
#p value 0.01

grp2 <- lm(logValue~MAserv, data=values)
grp2
summary(grp2)
#p value 0.02
```

###Multilevel modelling (following Bliese)
#Section 6.4

```
#ranvar=(A^2-1)/12 where A is the number of response options
#James et al., (1984) agreement index for multi-item scales
#grp=MAServ2 in paper

(13^2-1)/12
RWG.value.grp<-rwg(logValue,grp,ranvar=14)
RWG.value.grp[1:13,]
summary(RWG.value.grp)
#rwg mean = 0.76 good in-group variance

(5^2-1)/12
RWG.value.MAserv<-rwg(logValue,MAserv,ranvar=2)
RWG.value.MAserv[1:13,]
summary(RWG.value.MAserv)
#rwg mean = 0.07 very poor in-group variance

(4^2-1)/12
RWG.value.Method <- rwg(logValue, Method, ranvar=2)
```

```
RWG.value.Method[1:4,]
summary(RWG.value.Method)
#rwg mean = 0.57 reasonable in-group variance

(13^2-1)/12
RWG.value.Method2 <- rwg(logValue, Method2, ranvar=14)
RWG.value.Method2[1:4,]
summary(RWG.value.Method2)
#rwg mean = 0.86 very good in-group variance


###ICC test

#grp
grpmod<-aov(logValue~grp,data=values1)
summary(grpmod)

ICC1(grpmod)
ICC2(grpmod)
#> ICC1(grpmod)
#[1] 0.1295829
#> ICC2(grpmod)
#[1] 0.5619052

grpmod2<-aov(logValue~MAserv,data=values1)
summary(grpmod2)

ICC1(grpmod2)
ICC2(grpmod2)
#> ICC1(grpmod)
#[1] 0.07510371
#> ICC2(grpmod)
#[1] 0.6452557

methodmod<-aov(logValue~Method2,data=values1)
summary(methodmod)

ICC1(methodmod)
ICC2(methodmod)
#> ICC1(methodmod)
#[1] 0.4796125
#> ICC2(methodmod)
#[1] 0.8958553

graph.ran.mean(logValue, grp, nreps=1000, bootci=TRUE)
graph.ran.mean(logValue, Method2, nreps=1000, bootci=TRUE)
#both suggest good group levels

########FURTHER TESTS FOR GRP
#unconditional means model
Null.Model<-lme(logValue~1,random=~1|grp,data=values1,
            control=list(opt="optim"))

VarCorr(Null.Model)
```

```
#grp = pdLogChol(1)
#Variance  StdDev
#(Intercept) 0.6642318 0.8150041
#Residual    4.0895605 2.0222662

#Calculate ICC
0.6642318/(0.6642318+4.0895605)
#[1] 0.1397267

tmod<-aov(logValue~as.factor(grp),data=values)
ICC1(tmod)
#[1] 0.1295829 # similar to above good
```

#Estimating group-mean reliability

```
Null.Model<-lme(logValue~1,random=~1|grp,data=values,
            control=list(opt="optim"))
GREL.DAT<-GmeanRel(Null.Model)
names(GREL.DAT)
GREL.DAT$ICC
#[1] 0.1397267

GREL.DAT$MeanRel
#Some quite low
mean(GREL.DAT$MeanRel) #Average group-mean reliability
#[1] 0.5116187 quite similar to ICC

#Determining whether 00 is significant.

Null.Model.2<-gls(logValue~1,data=values,
              control=list(opt="optim"))

logLik(Null.Model.2)*-2
#'log Lik.' 489.9071 (df=2)
logLik(Null.Model)*-2
#'log Lik.' 485.3998 (df=3)
489.9071-485.3998
#[1] 4.5073

anova(Null.Model,Null.Model.2)
#Significant to 0.03
```

#####FURTHER TESTS FOR METHOD

```
#unconditional means model
Null.Model<-lme(logValue~1,random=~1|Method2,data=values1,
            control=list(opt="optim"))

VarCorr(Null.Model)
#grp = pdLogChol(1)
#Variance  StdDev
#(Intercept) 3.005016 1.733498
#Residual    2.494093 1.579270

#Calculate ICC
3.005016/(3.005016+2.494093)
```

```
#[1] 0.5464551

tmod<-aov(logValue~as.factor(Method2),data=values1)
ICC1(tmod)
#[1] 0.4796125 # similar to above good

#Estimating group-mean reliability
Null.Model<-lme(logValue~1,random=~1|Method2,data=values1,
        control=list(opt="optim"))
GREL.DAT<-GmeanRel(Null.Model)
names(GREL.DAT)
GREL.DAT$ICC
#0.5464551

GREL.DAT$MeanRel
#All very high >0.7 except 4
mean(GREL.DAT$MeanRel) #Average group-mean reliability
#[1] 0.8482809 very good
```

#Determining whether 00 is significant.

```
Null.Model.2<-gls(logValue~1,data=values1,
         control=list(opt="optim"))

logLik(Null.Model.2)*-2
#'log Lik.' 489.9071 (df=2)
logLik(Null.Model)*-2
#'log Lik.' 444.9439 (df=3)
489.9071-444.9439
#[1] 44.9632

anova(Null.Model,Null.Model.2)
#Significant to <.0001
#Much better in-group variance by Method rather than Service but not so theoretically sound

########################################################################################
#
###lme model with grp
#Geographical

Geog.Model.grp <- lme(logValue ~ Continent + logArea + Lat + Long + Type,
           random=~1|grp,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Geog.Model.grp)
plot(Geog.Model.grp, main="Full geographical GLM residuals vs. fitted")

r.squaredGLMM(Geog.Model.grp)

#Method/grp

#Method

Method.Model.grp <- lme(logValue ~ Method2 + Year0,
```

```
                random=~1|grp,data=values1,
                control=list(opt="optim"), na.action=na.omit)


summary(Method.Model.grp)
plot(Method.Model.grp, main="Full methodological GLM residuals vs. fitted")

r.squaredGLMM(Method.Model.grp)

#Socio economic/grp

Socio.Model.grp <- lme(logValue ~ Popdens + loggdp + Percagri + ANS,
                 random=~1|grp,data=values1,
                 control=list(opt="optim"), na.action=na.omit)


summary(Socio.Model.grp)
plot(Socio.Model.grp, , main="Full socio-economic GLM residuals vs. fitted")

r.squaredGLMM(Socio.Model.grp)
```

#Inclusive full model

```
Model.grp<-lme(logValue ~ Continent + Method2 + Popdens
          + loggdp + Percagri + Latitude + Longitude + Year0 + logArea,
          random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp)
r.squaredGLMM(Model.grp)
#AIC = 362.338/R2 = 0.71/0.89
#Remove Continent
Model.grp.1<-lme(logValue ~ Method2 + Popdens
          + loggdp + Percagri + Latitude + Longitude + Year0 + logArea,
          random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.1)
r.squaredGLMM(Model.grp.1)
#AIC = 398.69/R2 = 0.68/0.85 - keep continent
#Remove Latitude and Longitude
Model.grp.2<-lme(logValue ~ Continent + Method2 + Popdens
           + loggdp + Percagri +  Year0 + logArea,
           random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.2)
r.squaredGLMM(Model.grp.2)
#AIC = 359.2621/R2 = 0.68/0.88 - remove latitude and longitude (although R2 down slightly)
#Remove Method2
Model.grp.3<-lme(logValue ~ Continent +  Popdens
           + loggdp + Percagri +  Year0 + logArea,
           random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.3)
r.squaredGLMM(Model.grp.3)
#AIC = 389.75/R2 = 0.68/0.75 - keep Method2
#Remove Popdens
```

```
Model.grp.4<-lme(logValue ~ Continent + Method2
            + loggdp + Percagri +  Year0 + logArea,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.4)
r.squaredGLMM(Model.grp.4)
#AIC = 365.22/R2 = 0.68/0.87 - remove Popdens
#Remove loggdp
Model.grp.5 <-lme(logValue ~ Continent + Method2 + Percagri +  Year0 + logArea,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.5)
r.squaredGLMM(Model.grp.5)
#AIC = 376.3384/R2 = 0.56/0.93 - remove loggdp
#Remove Percagri
Model.grp.6 <-lme(logValue ~ Continent + Method2 + Year0 + logArea,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.6)
r.squaredGLMM(Model.grp.6)
#AIC = 371.2788/R2 = 0.57/0.93 - keep Percagri
#Remove Year0
Model.grp.7 <-lme(logValue ~ Continent + Method2 + Percagri + logArea,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.7)
r.squaredGLMM(Model.grp.7)
#AIC = 375.8194/R2 = 0.57/0.93 - remove Year0
#Remove logArea
Model.grp.8 <-lme(logValue ~ Continent + Method2 + Percagri,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.8)
r.squaredGLMM(Model.grp.8)
#AIC = 369.91/R2 = 0.57/0.92 - remove logArea
#Now try adding in previous variables to optimise model
#ANS - previously overparameterised
Model.grp.9 <-lme(logValue ~ Continent + Method2 + Percagri + ANS,
            random=~1|grp, data=values1, control=list(opt="optim"),na.action=na.exclude)

summary(Model.grp.9)
r.squaredGLMM(Model.grp.9)
#AIC = 362.8025/R2 = 0.63/0.88 - keep ANS
#Readd significant Popdens
Model.grp.10 <-lme(logValue ~ Continent + Method2 + Popdens + Percagri + ANS,
            random=~1|grp, data=values1, control=list(opt="optim"),
            na.action=na.exclude)


summary(Model.grp.10)
r.squaredGLMM(Model.grp.10)
#AIC=354.8942/R2=0.69/0.88
```

```
plot(Model.grp.10, main = "Full model GLM residuals vs. fitted (grp)")
r.squaredGLMM(Model.grp)

#random effects coefficients
ranef(Model.grp.10)
```

###lme model with Method2

```
Geog.Model.Method <- lme(logValue ~ Continent + Latitude + Longitude + logArea
                + Type + grp, random=~1|Method2,data=values1,
                control=list(opt="optim"), na.action=na.omit)

summary(Geog.Model.Method)
r.squaredGLMM(Geog.Model.Method)

plot(Geog.Model.Method, main="Geographical model GLM residuals vs. fitted (servs)")

#Method/Method
Method.Model.Method<-lme(logValue ~ Year0, random=~1|Method2,data=values1,
            control=list(opt="optim"), na.action=na.omit)


summary(Method.Model.Method)

plot(Method.Model.Method, main="Methodological model GLM residuals vs. fitted (servs)")
r.squaredGLMM(Method.Model.Method)

#Socio/Method
Socio.Model.Method<-lme(logValue ~ loggdp + Popdens + Percagri + ANS,
                random=~1|Method2,data=values1,
            control=list(opt="optim"), na.action=na.omit)


summary(Socio.Model.Method)

plot(Socio.Model.Method, main="Socio-economic model GLM residuals vs. fitted (servs)")
r.squaredGLMM(Socio.Model.Method)

#Full model/Method
Model.Method<-lme(logValue ~ grp + Continent + logArea + Popdens +
            loggdp + Percagri + ANS, random=~1|Method2,data=values1,
          control=list(opt="optim"), na.action=na.omit)

summary(Model.Method)
r.squaredGLMM(Model.Method)
#AIC = 361.4259/R2 = 0.71/0.87
#Remove grp
Model.Method.1<-lme(logValue ~ Continent + logArea + Popdens +
             loggdp + Percagri + ANS, random=~1|Method2,data=values1,
            control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.1)
r.squaredGLMM(Model.Method.1)
```

```
#AIC = 387.4368/R2 = 0.68/0.73
#Keep grp
#Remove Continent
Model.Method.2<-lme(logValue ~ grp + logArea + Popdens +
            loggdp + Percagri + ANS, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.2)
r.squaredGLMM(Model.Method.2)
#AIC = 405.8148/R2 = 0.46/0.85
#Keep Continent
#Remove logArea
Model.Method.3<-lme(logValue ~ grp + Continent + Popdens +
            loggdp + Percagri + ANS, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.3)
r.squaredGLMM(Model.Method.3)
#AIC = 355.5785/R2 = 0.70/0.87
#Remove logArea
#Remove Popdens
Model.Method.4<-lme(logValue ~ grp + Continent +
            loggdp + Percagri + ANS, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.4)
r.squaredGLMM(Model.Method.4)
#AIC = 356.7925/R2 = 0.71/0.88
#AIC only marginally different - keep Popdens?
#Remove loggdp
Model.Method.5<-lme(logValue ~ grp + Continent +
            Popdens + Percagri + ANS, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.5)
r.squaredGLMM(Model.Method.5)
#AIC = 367.3476/R2 = 0.54/0.87
#keep loggdp
#Remove percagri
Model.Method.6<-lme(logValue ~ grp + Continent +
            Popdens + loggdp + ANS, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.6)
r.squaredGLMM(Model.Method.6)
#AIC = 353.9225/R2 = 0.71/0.87
#Remove percagri
#Remove ANS
Model.Method.7<-lme(logValue ~ grp + Continent +
            Popdens + loggdp, random=~1|Method2,data=values1,
           control=list(opt="optim"), na.action=na.omit)

summary(Model.Method.7)
r.squaredGLMM(Model.Method.7)
```

```
#AIC = 348.4375/R2 = 0.72/0.87

#Optimal AIC/R2

plot(Model.Method.7, main="Full model GLM residuals vs. fitted (servs)")

#random effects coefficients
ranef(Model.Method.7)

#QQ-plots of both models
qqnorm(resid(Model.Method.7), main="Q-Q plot Optimal model (Method)")
#Fine
qqnorm(resid(Model.grp.10), main="Q-Q plot Optimal model (Services)")
#Fine

###Plot the random effects
plot(ranef(Model.grp.10), main="Random effects (Services)")
plot(ranef(Model.Method.7), main="Random effects (Method)")
```

#ANOVAs ran to show significance of random effects

```
Model.Method.lm<-lm(logValue ~ grp + Continent +
                 Popdens + loggdp,data=values1,
              na.action=na.omit)
anova(Model.Method.7, Model.Method.lm)
#p value = 0.0002

Model.grp.lm <-lm(logValue ~ Continent + Method2 + Popdens + Percagri + ANS,data=values1,
            na.action=na.omit)
anova(Model.grp.10, Model.grp.lm)
#p value = <0.0001

#Predicted fitted values from each model

fitted(Model.Method.7)

fitted(Model.grp.10)
```

APPENDIX 8: PERMISSIONS TO SURVEY AND METHOD STATEMENTS (WHERE APPLICABLE)

Method statement:

Method Statement & Risk Assessment
Name: Miss Samantha Cruickshank MSc.
Address: 35 Stoke Green Crescent
Coventry
CV3 1FY
Tel: 07806786581

Project/Contract	**PhD Ecological Economics - fieldwork**
Site Address	
Project Start Date	**June 2013**
Expected Duration	**2-3 months**
Projected Completion Date	**End August 2013**

Emergency Contact Details		
Contact **Tel**	**Middlemarch Environmental** **01676 525880**	**Barbara Cruickshank** **02476 271616**

The following method statement has been developed to provide a safe system of work and must be adhered to at all times, any significant deviation from this system must first be authorised by your manager or safety representative.

The main hazards to personal safety and health are;

a. Injury from slips trips and falls.
b. Exposure to sun for long periods of time.

Preventative Measures taken;

a. You must be "competent" to carry out the task.
b. Wear suitable protective clothing from weather conditions.

The main hazards to wildlife are;

a. Disturbance of ground nesting birds.
b. Interference of flora

Preventative Measures taken;

a. Be watchful for signs of disturbance of birds (warning calls etc.)
b. Try and keep a distance from ground nesting birds while surveying
c. Do not remove flora/fauna from site.

Task Methodology

a. 2x2m quadrats distributed at randomised coordinates on grassland habitats
b. Gradient/weather conditions/habitat type recorded
c. Each flora species within quadrat recorded
d. Percentage of quadrat cover of each flora species recorded
e. DOMIN scale cover of each flora species recorded
f. Any fauna seen during survey recorded

Staff & Training
The projects will be carried out by Sam Cruickshank MSc. under the training of Middlemarch Environmental Ltd. Sam Cruickshank has completed the Plant ID course ran by the University of Leicester.
First Aid
It is the responsibility of Sam Cruickshank to ensure adequate first aid provision.

Permits to survey:

Nottinghamshire
Wildlife Trust

PERMIT FOR STUDY OR RESEARCH ON TRUST RESERVES

This permit is issued to…Samantha Cruickshank

For the purpose of …Botanical survey

Subject to the enclosed rules governing ….Plants (Appendix 4)

The permit is issued on the condition that a copy of any species list or any other research documentation is sent to the Trust Office on completion of the project.

Issued on ….21st March 2013 and valid until ….31/10/2013

For study on ….King's Meadow Nature Reserve

This permit will be carried at all times whilst undertaking any visits to the reserve and will be shown to any Warden on request.

Please see reverse for any special conditions applicable to this particular study project.

Authorised by…. M G Walker.

On behalf of the Sites Committee of Nottinghamshire Wildife Trust

On ….21st March 2013

If a renewal of this permit is required for ongoing study or research please allow up 28 days to process.

Please address all correspondence to:-
Nottinghamshire Wildlife Trust, The Old Ragged School, Brook Street, Nottingham, NG1 1EA Tel. 0115 958 8242

Email. mwalker@nottswt.co.uk

Nottinghamshire
Wildlife Trust

PERMIT FOR STUDY OR RESEARCH ON TRUST RESERVES

This permit is issued to…Samantha Cruickshank

For the purpose of …Botanical survey

Subject to the enclosed rules governing ….Plants (Appendix 4)

The permit is issued on the condition that a copy of any species list or any other research documentation is sent to the Trust Office on completion of the project.

Issued on ….10th May 2013 and valid until ….31/10/2013

For study on ….Attenborough Nature Reserve

This permit will be carried at all times whilst undertaking any visits to the reserve and will be shown to any Warden on request.

Please see reverse for any special conditions applicable to this particular study project.

Authorised by…. M G Walker.

On behalf of the Sites Committee of Nottinghamshire Wildife Trust

On ….10th May 2013

If a renewal of this permit is required for ongoing study or research please allow up 28 days to process.

Please address all correspondence to:-

Nottinghamshire Wildlife Trust, The Old Ragged School, Brook Street, Nottingham, NG1 1EA
Tel. 0115 958 8242

Email. mwalker@nottswt.co.uk

APPENDIX 9: SPECIES DATASET

Quadrat number	Location	Location 2	Site info	Management	Time since creation	Whole Site area (ha)	Subsite area	lat	lon
1	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252371	-1.4391929
2	8	8.1	Calcareous	Annual cut	41	40.5	3	52.25221	-1.4399383
3	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252291	-1.4400545
4	8	8.1	Calcareous	Annual cut	41	40.5	3	52.25282	-1.4397548
5	8	8.1	Calcareous	Annual cut	41	40.5	3	52.25309	-1.4397075
6	4	4	PFA	Annual cut	21	1.05	1.05	52.940447	-1.1691898
7	4	4	PFA	Annual cut	21	1.05	1.05	52.940567	-1.1696637
8	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.381582	-1.4345425
9	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.381887	-1.4345533
10	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.381934	-1.4349788
11	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.379964	-1.4403808
12	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.380233	-1.4344863
13	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.380655	-1.4343487
14	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252471	-1.4400229
15	8	8.1	Calcareous	Annual cut	41	40.5	3	52.253146	-1.4382858
16	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252151	-1.438855
17	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252766	-1.4396383
18	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252862	-1.4372933
19	2	2.2	Mesotrophic	Species management	24	87	3.24	52.37814	-1.4330734
20	2	2.2	Mesotrophic	Species management	24	87	3.24	52.378748	-1.4323017
21	9	9	Mesotrophic	None	4	43	43	52.526444	-1.501919
22	9	9	Mesotrophic	None	4	43	43	52.527183	-1.5041645
23	9	9	Mesotrophic	None	4	43	43	52.527097	-1.5030158
24	9	9	Mesotrophic	None	4	43	43	52.526771	-1.5025183
25	3	3	Calcareous	Species management	29	43.99	43.99	51.902179	-0.5329107
26	3	3	Calcareous	Species management	29	43.99	43.99	51.901338	-0.5318044
27	3	3	Calcareous	Species management	29	43.99	43.99	51.902981	-0.5388298
28	3	3	Calcareous	Species management	29	43.99	43.99	51.901563	-0.5368554
29	3	3	Calcareous	Species management	29	43.99	43.99	51.900605	-0.5371772
30	2	2.2	Mesotrophic	Species management	24	87	3.24	52.378111	-1.4325596
31	9	9	Mesotrophic	None	4	43	43	52.526033	-1.5021876
32	9	9	Mesotrophic	None	4	43	43	52.525985	-1.4993287
33	9	9	Mesotrophic	None	4	43	43	52.526239	-1.4979255
34	1	1.1	Mesotrophic	None	47	274.96	3.54	52.896074	-1.2235825
35	1	1.1	Mesotrophic	None	47	274.96	3.54	52.896402	-1.2255983
36	1	1.1	Mesotrophic	None	47	274.96	3.54	52.89647	-1.2264444
37	1	1.1	Mesotrophic	None	47	274.96	3.54	52.896457	-1.2272028
38	1	1.1	Mesotrophic	None	47	274.96	3.54	52.896574	-1.2272453
39	1	1.1	Mesotrophic	None	47	274.96	3.54	52.897162	-1.2207981
40	1	1.1	Mesotrophic	None	47	274.96	3.54	52.898241	-1.2209572
41	1	1.1	Mesotrophic	None	47	274.96	3.54	52.899135	-1.2214912
42	1	1.1	Mesotrophic	None	47	274.96	3.54	52.899656	-1.2214521
43	1	1.1	Mesotrophic	None	47	274.96	3.54	52.899937	-1.2218336
44	5	5.1	Mesotrophic	Species management	10	60	3.26	53.785071	-0.6653717
45	5	5.1	Mesotrophic	Species management	10	60	3.26	53.785853	-0.6652511
46	5	5.1	Mesotrophic	Species management	10	60	3.26	53.785919	-0.6651767
47	5	5.1	Mesotrophic	Species management	10	60	3.26	53.786112	-0.6653492
48	5	5.1	Mesotrophic	Species management	10	60	3.26	53.786074	-0.6655556
49	5	5.1	Mesotrophic	Species management	10	60	3.26	53.786081	-0.6656678
50	5	5.1	Mesotrophic	Species management	10	60	3.26	53.786388	-0.6653569

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Location 2	Site info	Management	Time since creation	Whole Site area (ha)	Subsite area	lat	lon
51	5	5.2	Mesotrophic	Species management	10	60	3.06	53.784617	-0.6604511
52	5	5.2	Mesotrophic	Species management	10	60	3.06	53.785149	-0.6612262
53	5	5.2	Mesotrophic	Species management	10	60	3.06	53.785391	-0.6609581
54	5	5.2	Mesotrophic	Species management	10	60	3.06	53.785951	-0.6615397
55	5	5.2	Mesotrophic	Species management	10	60	3.06	53.786464	-0.6611581
56	5	5.2	Mesotrophic	Species management	10	60	3.06	53.786496	-0.6619608
57	3	3	Calcareous	Species management	29	43.99	43.99	51.903119	-0.5383456
58	6	6.1	Calcareous	Annual cut	28	121.4	0.23	51.538701	-3.6237397
59	6	6.1	Calcareous	Annual cut	28	121.4	0.23	51.538564	-3.623879
60	6	6.1	Calcareous	Annual cut	28	121.4	0.23	51.538404	-3.623758
61	6	6.2	Calcareous	Annual cut	28	121.4	1.59	51.544877	-3.6167055
62	6	6.2	Calcareous	Annual cut	28	121.4	1.59	51.545181	-3.6155695
63	6	6.2	Calcareous	Annual cut	28	121.4	1.59	51.545144	-3.6162247
64	6	6.3	Calcareous	Annual cut	28	121.4	1.53	51.544854	-3.6176831
65	6	6.3	Calcareous	Annual cut	28	121.4	1.53	51.544514	-3.6188703
66	6	6.3	Calcareous	Annual cut	28	121.4	1.53	51.545023	-3.6185134
67	6	6.3	Calcareous	Annual cut	28	121.4	1.53	51.544748	-3.6182296
68	3	3	Calcareous	Species management	29	43.99	43.99	51.900875	-0.5292903
69	3	3	Calcareous	Species management	29	43.99	43.99	51.901231	-0.5397877
70	3	3	Calcareous	Species management	29	43.99	43.99	51.902062	-0.5423045
71	3	3	Calcareous	Species management	29	43.99	43.99	51.901194	-0.5332045
72	4	4	PFA	Annual cut	21	1.05	1.05	52.940511	-1.1706468
73	4	4	PFA	Annual cut	21	1.05	1.05	52.94074	-1.1711931
74	4	4	PFA	Annual cut	21	1.05	1.05	52.940494	-1.1707662
75	4	4	PFA	Annual cut	21	1.05	1.05	52.940471	-1.1713619
76	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.381884	-1.4357434
77	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.382103	-1.4365046
78	2	2.1	Mesotrophic	Annual cut	24	87	4.31	52.381978	-1.4347725
79	4	4	PFA	Annual cut	21	1.05	1.05	52.940452	-1.1698891
80	4	4	PFA	Annual cut	21	1.05	1.05	52.940661	-1.1701976
81	4	4	PFA	Annual cut	21	1.05	1.05	52.940744	-1.1705085
82	4	4	PFA	Annual cut	21	1.05	1.05	52.940591	-1.1704965
83	5	5.3	Mesotrophic	Grazed	1	60	4	53.784048	-0.6564994
84	5	5.3	Mesotrophic	Grazed	1	60	4	53.783363	-0.6593186
85	5	5.3	Mesotrophic	Grazed	1	60	4	53.783984	-0.6590131
86	5	5.3	Mesotrophic	Grazed	1	60	4	53.783969	-0.658615
87	7	7.3	Mesotrophic	Annual cut	18	12.4	1.9	52.351188	-1.4483785
88	7	7.3	Mesotrophic	Annual cut	18	12.4	1.9	52.351194	-1.4476737
89	7	7.3	Mesotrophic	Annual cut	18	12.4	1.9	52.351488	-1.4471709
90	7	7.1	Mesotrophic	Grazed	18	12.4	0.4	52.353434	-1.4461335
91	7	7.1	Mesotrophic	Grazed	18	12.4	0.4	52.353361	-1.4458261
92	7	7.1	Mesotrophic	Grazed	18	12.4	0.4	52.353066	-1.4459896
93	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252025	-1.4388127
94	8	8.2	Calcareous	Annual cut	41	40.5	0.4	52.251852	-1.4458555
95	8	8.2	Calcareous	Annual cut	41	40.5	0.4	52.251365	-1.4458083
96	8	8.2	Calcareous	Annual cut	41	40.5	0.4	52.251569	-1.4459521
97	8	8.1	Calcareous	Annual cut	41	40.5	3	52.252206	-1.4376479
98	7	7.2	Mesotrophic	Grazed	18	12.4	3.3	52.352214	-1.4446806
99	7	7.2	Mesotrophic	Grazed	18	12.4	3.3	52.352594	-1.4453659
100	7	7.2	Mesotrophic	Grazed	18	12.4	3.3	52.352346	-1.4461178

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Achimill	Agrieupa	Agrocani	Agrocapi	Agrogiga	Agrostol	Alopprat	Anisster	Anthodor	Anthsylv	Anthvuln	Arrhelat	Artevulg	Bare.Earth	Bellpere	Betupend	Blacperf	Brizmedi	Bromhord	Calaepig	Calysepi
1	8		1																			
2	8		1																			
3	8		5					15			1		1									
4	8		5					1					5									
5	8		1																			
6	4											1			1							
7	4	15										1	1									
8	2	5																				
9	2	1																				
10	2							1							5							
11	2														1							
12	2																					
13	2												1									
14	8		1										1									
15	8		1										1									
16	8		1										5									
17	8	2											5									
18	8																					
19	2						5						1			1						
20	2																					
21	9	1													5							
22	9	1					5	1														
23	9							1							35							
24	9						1															
25	3									5		15			25							
26	3														3		5					
27	3									1					3							
28	3											5			1							
29	3											15	1				1					
30	2						1															
31	9						1															
32	9							1					1									
33	9												5									
34	1										1		35	1								1
35	1										1		6									
36	1												75	5								
37	1				1	1		1			1		3									
38	1												3									
39	1				1				1											1		
40	1												6									
41	1																					
42	1										1		4									
43	1				2				1				3									
44	5	1					25						3									
45	5						1						1				1					
46	5												5		2		1					
47	5						2						2									
48	5						5															
49	5						5						1									
50	5						5															

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Achimill	Agrieupa	Agrocani	Agrocapi	Agrogiga	Agrostol	Alopprat	Anisster	Anthodor	Anthvuln	Arrhelat	Artevulg	Bare.Earth	Bellpere	Blacperf	Brizmedi	Bromhord	Calaepig	Calysepi
51	5						1					25								
52	5						15													
53	5						1					4								
54	5											3								
55	5						1													
56	5				1		25													
57	3																			
58	6				1															
59	6				1							1					1			
60	6				1		1					15								
61	6						1							1						
62	6													15						
63	6						1							5						
64	6						1							5						
65	6						15													
66	6																			
67	6						1													
68	3													1						
69	3						15													
70	3													1		1				
71	3													5						
72	4											3								
73	4											1							7	
74	4											1								
75	4	15										5							1	
76	2	1			35		5					1								
77	2				45							5								
78	2																			
79	4	1			1						2			5						
80	4				1						3			15						
81	4											5								
82	4	5										5								
83	5				5		15								15					
84	5						8	5												
85	5			1	15		1													
86	5				5		2								5					
87	7					2	2					25								
88	7					1	1													
89	7					1	5					45								
90	7						25					15								
91	7						1													
92	7					1	1					15								
93	8	5	1																	
94	8		15													1				
95	8		5						5			65								
96	8		5									6								
97	8		1									1								
98	7						2					35								
99	7	1				25	5													
100	7						25													

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Cardxsta	Careflac	Caresp	Centnigr	Centeryt	Carefont	Chamangu	Cirsacau	Cirsarve	Cirspalu	Cirssp	Cirsvulg	Cratmono	Crepcapi	Crepvesi	Cruclaev	Cynocris	Cypesp	Dactglom
1	8				15															
2	8												1							1
3	8																			1
4	8													2						5
5	8												1	5						5
6	4																	1		1
7	4																			1
8	2						1			1				1						
9	2						1			1										
10	2						1			1								1		5
11	2						1			5	1									
12	2						1	1		1										
13	2					1	1	1		5	1					1				1
14	8													1						
15	8																			
16	8																			
17	8																			
18	8																			
19	2									5			1							
20	2									1										
21	9						1			1								1		
22	9				25		5			5										
23	9				1													25		
24	9				1		1											5		
25	3								1											
26	3											1								
27	3			1																
28	3			1																
29	3				1															
30	2						1			1										
31	9				1															1
32	9				1															6
33	9						1													1
34	1																			1
35	1																			
36	1							5												1
37	1																			15
38	1																			
39	1																			
40	1							15												
41	1																			25
42	1	5						25												
43	1																			
44	5									1							5			1
45	5									1										
46	5															1				1
47	5									15			1			1				
48	5						1			1							1			
49	5									1						1				
50	5																			

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Caredist	Careflac	Carenigr	Caresp	Centnigr	Centeryt	Carefont	Chamangu	Cirsacau	Cirsarve	Cirspalu	Cirsvulg	Conomaju	Cratmono	Crepcapi	Crepvesi	Cynocris	Cypesp	Dactglom
51	5							1									1			
52	5																			1
53	5										1									
54	5																			
55	5																			
56	5																			
57	3		5												15					
58	6				1															1
59	6					1						5			5					5
60	6					1						1			2					
61	6																			
62	6											1								
63	6											1								
64	6			25							1									
65	6											1							1	
66	6			15																
67	6		1									1								
68	3															1				
69	3										1									
70	3	2				1				5										
71	3													1	1					
72	4						1									1				2
73	4										1									
74	4								1							1				
75	4																			
76	2										1					5		1		1
77	2										5							5		
78	2									1	1									
79	4																			1
80	4								1						1	1				1
81	4								1		1					1				1
82	4						1													5
83	5										2									
84	5					5					1									
85	5					1					1									
86	5					5														
87	7										1									1
88	7																			
89	7																			
90	7																			
91	7																			1
92	7					1														25
93	8					5									1					
94	8									1			1							
95	8																1			5
96	8																			
97	8					25							1		1			1		
98	7																			1
99	7						1													
100	7																			

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Dactfusc	Dauccaro	Desccesp	Descflex	Dipssp	Elytrepe	Equisp	Erodcicu	Euphoffi	Festovin	Festprat	Festrubr	Galialbu	Galiapar	Galipalu	Galiulig	Galiveru	Gentamar	Geramoll
1	8												2					1		
2	8												1							
3	8														1					
4	8												3							
5	8														1			25		1
6	4																			
7	4								1				5							
8	2												15							
9	2												1							
10	2												15							
11	2					5							2							
12	2					1							1							
13	2					1		7				1								
14	8												1					2		
15	8												25							
16	8												25							
17	8												5							
18	8												1							
19	2																			
20	2																			
21	9		1	15																
22	9			1									1					1		
23	9			1																
24	9												1							
25	3		1															1		
26	3	1																1		
27	3																			
28	3		1																	
29	3	1	1										1		1					
30	2														1					
31	9			6									1		1					
32	9												5							
33	9																			
34	1						1											5		
35	1						25													
36	1						1								1					
37	1						1													
38	1																			
39	1														1					
40	1																			
41	1						1								1			15		
42	1														2					
43	1														1					
44	5																			
45	5																			
46	5																			
47	5																			
48	5																			
49	5																			
50	5																			

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Dactfusc	Dauccaro	Desccesp	Descflex	Dipssp	Epilpalu	Epilsp	Equiarve	Erodcicu	Euphoffi	Festovin	Festprat	Festrubr	Galialbu	Galiapar	Galipalu	Galiulig	Galiveru	Gentamar
51	5					1														
52	5																			
53	5																			
54	5		1																	
55	5																			
56	5																			
57	3		1											1	5					
58	6								5					1						
59	6												1							
60	6													1				1		
61	6																			
62	6																			
63	6																			
64	6																			
65	6								1											
66	6						1		1								1			
67	6						1										1			
68	3													15	5					1
69	3																			
70	3		1								1			25						1
71	3													1	1					
72	4													15						
73	4													5						
74	4													15						
75	4								5											
76	2																			
77	2																			
78	2																			
79	4		1	1										1						
80	4		1											1						
81	4								1											
82	4													15						
83	5													1						
84	5							1												
85	5											1								
86	5											1		45						
87	7																			
88	7																			
89	7																			
90	7																		1	
91	7													25					25	
92	7													1					25	
93	8				1									1					25	
94	8																			
95	8													5						
96	8													1						
97	8								1					1					5	
98	7													1					1	
99	7													5					45	
100	7																			

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Heraspho	Holclana	Holcmoll	Hordmuri	Hyporadi	Juncarti	Juncinfl	Lactserr	Lapscomm	Lathapha	Lathprat	Leonautu	Leonhisp	Leucvulg	Linucath	Lolipere	Lotucorn	Lotupedu	Medilupu
1	8		1								15	1				1				
2	8	1	75									1				1				
3	8	5	6									1								
4	8		5									1				1		1		
5	8	1	15									1				1				
6	4		1												25		1			35
7	4		1	1																1
8	2		25												1					1
9	2		5																	
10	2		2											1	1					1
11	2																	1		
12	2		1															8		
13	2		1										1					1		
14	8		5									1					5	1		
15	8		1									15					15			
16	8		5									15					15			
17	8		5										5							
18	8		1														1			
19	2		1															2		
20	2																25	5		
21	9		1									5					1			
22	9														1			2		
23	9		1					1							1			5		
24	9		1												25			3		
25	3					1										1		15		1
26	3													5				5		
27	3					5										6		1		
28	3					1									1	5		1		1
29	3		1			1								1		1		6		
30	2		25						1				1					2		
31	9		5												1					
32	9																			
33	9		5																	
34	1		4																	
35	1																			
36	1	1																		
37	1																4			
38	1	1	65																	
39	1		5		5												3			
40	1		1														1			
41	1	1															35			
42	1																5			
43	1	1	35														1			
44	5	1	1			1				1				1						
45	5		35																	
46	5		2			1											1			
47	5		25																	
48	5		2									1						15		
49	5		65															1		
50	5		4															35		

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Holclana	Hyporadi	Juncarti	Junceffu	Juncinfl	Junctenun	Knauarve	Lactserr	Lapscomm	Lathapha	Lathprat	Leonautu	Leonhisp	Leucvulg	Linucath	Lolipere	Lotucorn	Lotupedu	Medilupu
51	5	2																		1
52	5	15																		
53	5	1																		
54	5														1					
55	5	35																4		
56	5	4																1		
57	3							1						15		1		2		
58	6	1			2														3	
59	6											4								
60	6					1						3							5	
61	6			5	2		1												2	
62	6	3			25														5	
63	6	25		5		2												4		
64	6	3		1	15														15	
65	6				25	1												25	1	
66	6	5				25												1		
67	6				25	5											1	1		
68	3	25												1		1		35		
69	3	25						1						1				35		
70	3													1				15		
71	3	1						1						15				35		
72	4																			5
73	4																			5
74	4																			3
75	4	1																5		2
76	2	4	1																	
77	2	3	1																	
78	2	1				1														
79	4	1	1															2		
80	4	1	5														1	1		
81	4	5																		3
82	4	1																2		
83	5	5													1			5		
84	5	1															5			
85	5												5				1	5		
86	5	1													1		1			
87	7	5										5						1		
88	7	1																		1
89	7	5																		
90	7	1																1		
91	7																	35		5
92	7																	1		
93	8	15												1						1
94	8	1														1				
95	8	5																		
96	8	2																		
97	8	1												1						5
98	7											3								
99	7	5																1		1
100	7	1										1								5

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Myosramo	Odonvern	Pershydr	Phleprat	Planlanc	Planmajo	Poaannu	Poaprat	Poatriv	Polyavic	Poteanse	Poterept	Potesp	Primsp	Primveri	Prunvulg	Pulidyse	Quersp	Ranuacri
1	8					2			5											2
2	8							2												1
3	8								5											
4	8					3														1
5	8									5										
6	4					1			1				15							
7	4					1			1				5							
8	2					1		5					5		1					
9	2	1						1												
10	2	1				5														
11	2	1											4				25			
12	2												5				1			
13	2	1				1							3							
14	8		1			15														
15	8					15											1			
16	8					15											1			
17	8					3											5			
18	8					4											5			
19	2						5					5					1			1
20	2																			
21	9									1										
22	9			1						1										
23	9				1	1														
24	9					1				1										
25	3																			
26	3					5														
27	3					1														
28	3																			
29	3					1				1										
30	2											1					5			
31	9				5			1												
32	9					1														
33	9					35		1												
34	1																			
35	1																			
36	1																			
37	1				5						1									
38	1																			
39	1				1			1												
40	1																			
41	1				1			1												
42	1																			
43	1																			
44	5					15														
45	5					55		1												
46	5					3		5												
47	5					1														
48	5					35														
49	5					15		1												
50	5					15														

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Myosramo	Phleprat	Picrhier	Piloffi	Planlanc	Planmajo	Poaannu	Poaprat	Poatriv	Polyavic	Poterept	Potesp	Primsp	Primveri	Prunvulg	Pulidyse	Quersp	Ranuacri
51	5					5		1											
52	5					35													
53	5												5						
54	5					4													
55	5					2													
56	5					2													
57	3			1	5	1													
58	6		1			35													
59	6					5												15	1
60	6					2						1							1
61	6															1			25
62	6															5	15		5
63	6																5		
64	6																		1
65	6					1													1
66	6																15		1
67	6																		
68	3				5	1													
69	3					2	1												
70	3																		
71	3					1										1			
72	4					5		1											
73	4								1										
74	4				1	2			1										
75	4																		
76	2					5													
77	2					1													
78	2					5													
79	4			1		1						35							
80	4				1	2						5							
81	4					5						1							
82	4					1			1			15							
83	5																		
84	5					1													1
85	5															5			1
86	5	1				1													
87	7					5													
88	7					75										1			
89	7					1						25							
90	7								1			4							
91	7					1													
92	7					5									1				
93	8		1			5													
94	8											2				1			
95	8					1													
96	8																		
97	8					1										1			
98	7					5													
99	7					5													
100	7					1													

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Ranurepe	Rhinmino	Rosaarve	Rosacani	Rosapimp	Rubufrut	Rumeace1	Rumeace2	Rumecris	Rumeobtu	Rumesp	Sangmino	Seneeruc	Senejaco	Silelati	Stacoffi
1	8	1													5		
2	8	15		1										1	1		
3	8						5		1	1							
4	8	1	1											1			
5	8					1	4										
6	4		15				1										
7	4		1				1								1		
8	2	5					1								1		
9	2	1					1								1		
10	2						1								1		
11	2	1					1										
12	2	1					1										
13	2	1					1			1							
14	8	1											1				
15	8	5													1		
16	8	5													5		
17	8																
18	8				1										1		
19	2				1		1										
20	2						3										
21	9	2									1						
22	9		1							5	1						
23	9	1															
24	9	5						1		1							
25	3																
26	3					1											
27	3																
28	3				1												
29	3													1			
30	2						5										
31	9							1			1						
32	9	5															
33	9		55				5										
34	1						5										
35	1						1										
36	1						5										
37	1																
38	1						1										
39	1																
40	1																
41	1																
42	1																
43	1						5										
44	5	1				1											
45	5	1														1	
46	5	5														5	
47	5	35															
48	5	2															
49	5																
50	5	15															

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Ranurepe	Rhinmino	Rosaarve	Rosacani	Rosapimp	Rubufrut	Rumeace1	Rumeace2	Rumecris	Rumeobtu	Rumesp	Sangmino	Seneeruc	Senejaco	Silelati	Stacoffi
51	5	1															
52	5	15													1		
53	5														1		
54	5														1		
55	5														1		
56	5																
57	3				1												
58	6	1															
59	6																
60	6				1												
61	6																
62	6																
63	6																
64	6																
65	6																
66	6																
67	6																
68	3				1		5										
69	3						1								1		
70	3																
71	3																
72	4														2		
73	4		1														
74	4		1														
75	4		5												2		
76	2														1		
77	2								1						1		
78	2						1										
79	4		25														
80	4		5				5										
81	4		15												15		
82	4		1														
83	5	5										1					
84	5																
85	5	35															
86	5																
87	7																
88	7	5															
89	7																
90	7																
91	7																
92	7																
93	8														1		1
94	8	1													5		
95	8				5										1		
96	8	5			1										1		
97	8				1										25		1
98	7																
99	7																
100	7	1															

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Stacsylv	Succprat	Tanavulg	Taraoffi	Tragprat	Trifcamp	Trifprat	Trifrepe	Trifsp	Tripinod	Trisfave	Unid	Urtidioi	Verocham	Veroserp	Vicicrac	Vicisati
1	8														1			
2	8		5					1							5			
3	8		1											1	1			
4	8							5										1
5	8								5									
6	4				1			5										
7	4																1	
8	2								25						2	1		
9	2								2						65			
10	2								5			1			1			
11	2															1		
12	2								3					1		1		
13	2								2							1		
14	8							1	1									
15	8							1										
16	8																	
17	8							5										
18	8							25										
19	2								2								1	
20	2								35									
21	9							35	2								1	
22	9								5					1			15	
23	9																1	
24	9							5	2								5	
25	3																	
26	3																	
27	3																	
28	3																	
29	3							5										
30	2								1									
31	9											1						
32	9								3			1						
33	9												1					
34	1																	
35	1													15				
36	1	1																
37	1													1				
38	1													1				
39	1																	
40	1													2				
41	1													1				
42	1													1				
43	1																	
44	5																	
45	5								1									
46	5																	
47	5																	
48	5								1									
49	5																	
50	5								1									

Table A9.1: Full species dataset (continues)

Quadrat number	Location	Stacsylv	Succprat	Tanavulg	Taraoffi	Tragprat	Trifcamp	Trifprat	Trifrepe	Trifsp	Tripinod	Trisfave	Unid	Urtidioi	Verocham	Veroserp	Vicicrac	Vicisati
51	5																	
52	5								2									
53	5																	
54	5													1				
55	5																	
56	5																	
57	3				1													
58	6																	
59	6																	
60	6																	
61	6																	
62	6																	
63	6																	
64	6																	
65	6																	
66	6																	
67	6																	
68	3																	
69	3																	
70	3																	
71	3							1					1					
72	4																5	
73	4					1		1									5	
74	4							1	1								2	
75	4					1	1						1				3	
76	2							1										
77	2																	
78	2								7									
79	4					1		1										
80	4			1	1			1										
81	4																2	
82	4			5		1		1										
83	5								15									
84	5									1	1							
85	5								1				1					
86	5								5				1					
87	7								1									
88	7																	
89	7												5					
90	7																	
91	7				1													
92	7																	
93	8																	
94	8																	
95	8																	
96	8																	
97	8																	
98	7																	
99	7																	
100	7							5	4									

Table A9.1: Full species dataset (continued)

Quadrat number	Location	Species richness	Species diversity	Ell.light	Ell.Wetness	Ell.pH	Ell.Fertility	C	S	R	CVS class	NVC1	NVC2
1	8	14	0.81	7.2	5.2	6	4.3	2.94	2.89	2.95	40	MG1a	MG1
2	8	17	0.359	6.9	5.8	6	5.4	2.63	2.53	3.21	52	MG1a	MG1
3	8	16	0.587	6.9	5.6	6.3	5.8	3.2	2.63	2.75	34	MG1a	MG1
4	8	17	0.747	7.1	5.2	6.3	4.9	3.05	2.9	2.61	47	MG1a	MG1
5	8	15	0.744	6.9	4.9	6.2	4.2	3.01	2.67	2.42	40	MG1a	MG1
6	4	15	0.757	7.3	4.4	7.1	4.1	2.15	2.26	3.13	30	OV23d	MG1a
7	4	16	0.714	7.1	5	6.6	4.7	2.75	2.11	3.08	9	OV23d	MG1a
8	2	18	0.792	6.9	5.3	6.1	5.3	2.89	2.44	3.08	40	MG6	MG6a
9	2	12	0.524	6.5	5	6	5.2	2.96	2.72	3.02	30	MG6	MG6a
10	2	18	0.916	7.2	5.3	6.2	5.1	3.01	2.77	2.89	27	MG6	MG6a
11	2	13	0.712	7.3	5.2	6.5	5.1	3.05	2.43	2.91	44	MG6	MG6a
12	2	14	0.266	7	4.4	6.1	3.4	2.37	3.3	2.33	38	MG6	MG6a
13	2	22	0.356	7.1	6.1	5.8	5.2	3.06	2.09	2.86	38	MG6	MG6a
14	8	15	0.912	7.1	4.8	6.3	4.3	3.07	2.77	2.55	30	MG1a	MG1
15	8	11	0.847	7.4	5.3	6.1	5.3	3.09	2.63	2.91	40	MG1a	MG1
16	8	10	0.85	7.3	5.1	6.1	5	3	2.6	3	40	MG1a	MG1
17	8	8	0.855	7.1	5.1	6.1	4.4	3	2.63	3	27	MG1a	MG1
18	8	8	0.765	7.1	5	6.3	4.5	2.99	2.96	3.01	30	MG1a	MG1
19	2	15	0.879	7.1	5.1	6.2	4.7	2.84	2.59	2.69	47	MG11	MG12a
20	2	5	0.722	7.4	4.9	6	5.7	2.95	2.14	2.89	40	MG11	MG12a
21	9	16	0.769	6.7	5.6	6.3	5.6	3.02	2.34	2.84	40	MG9b	MG9
22	9	19	0.852	7.1	5.1	6.3	4.5	2.93	2.49	2.65	20	MG9b	MG9
23	9	13	0.802	6.9	5.6	6.5	6	2.96	2.63	2.77	38	MG9b	MG9
24	9	16	0.797	7.2	4.7	6.3	4.1	2.98	2.65	2.44	38	MG9b	MG9
25	3	10	0.88	7.3	4.8	6.5	4.1	1.88	3.6	2.19	40	CG4	CG4b
26	3	9	0.652	7.1	4.7	6.4	4.1	2.02	3.98	2	40	CG4	CG4b
27	3	7	0.547	7.7	5.3	6.8	3.9	1.21	3.01	2.99	44	CG4	CG4b
28	3	10	0.727	7.8	4.4	7	3.1	1.49	3.59	2.12	44	CG4	CG4b
29	3	17	0.594	7.3	4.4	6.3	2.6	1.97	3.68	2.28	56	CG4	CG4b
30	2	12	0.882	7	5.2	6.1	4.3	2.7	3.02	2.7	30	MG11	MG12a
31	9	13	0.624	6.5	5.7	5.4	4.5	3	2.88	2.29	23	MG9b	MG9
32	9	9	0.545	7	5.1	6.6	6	2.59	2.03	2.41	44	MG9b	MG9
33	9	9	0.567	6.7	5.4	6	4.9	2.32	2.59	2.63	40	MG9b	MG9
34	1	9	0.702	6.9	5.4	6.5	5.9	3.48	2.37	2.36	38	MG1b	OV24
35	1	5	0.555	6.8	5.2	7	7.1	3.98	1.71	2	38	MG1b	OV24
36	1	9	0.42	6.9	5	7	6.8	3.98	1.91	1.92	28	MG1b	OV24
37	1	11	0.724	7.4	5	6.5	6.4	3.49	1.97	2.51	38	MG1b	OV24
38	1	5	0.477	6.9	5.7	6.3	5.7	3.28	2.7	2.53	34	MG1b	OV24
39	1	9	0.647	7.4	5.5	6.2	5.5	2.95	2.55	3.05	40	MG1b	OV24
40	1	5	0.577	6.6	5.2	6.8	6.9	4.17	1.82	1.83	38	MG1b	OV24
41	1	9	0.782	7.5	4.9	6.4	5.4	3.3	2.14	2.51	40	MG1b	OV24
42	1	7	0.732	6.6	5.2	6.6	6.5	3.99	1.49	2.01	43	MG1b	OV24
43	1	8	0.735	6.8	5.4	5.9	5.6	3.28	2.55	2.62	40	MG1b	OV24
44	5	14	0.802	7.1	5.1	6.6	5.5	3.32	2.05	2.63	9	OV23c	OV23
45	5	10	0.574	7	5.4	6	4.5	3.01	2.87	2.98	27	OV23c	OV23
46	5	12	0.82	7	5.5	6.3	5.7	2.89	2.49	3.09	30	OV23c	OV23
47	5	8	0.712	6.8	6.1	6.5	6.2	3.43	1.62	2.57	27	OV23c	OV23
48	5	10	0.762	6.8	5.5	6.1	4.8	2.87	2.56	2.85	30	OV23c	OV23
49	5	8	0.542	7	5.7	6.2	5.1	3.09	2.77	2.89	38	OV23c	OV23
50	5	6	0.67	6.9	5.4	6	4.2	2.68	2.95	2.68	23	OV23c	OV23

Table A9.2: Additional community metrics (continues)

Quadrat number	Location	Species richness	Species diversity	Ell.light	Ell.Wetness	Ell.pH	Ell.Fertility	C	S	R	CVS class	NVC1	NVC2
51	5	10	0.637	6.9	5.4	6.3	5.2	3.18	2.53	2.81	30	MG11a	OV23
52	5	7	0.77	6.9	5.6	6.2	5.3	3	2.19	3	30	MG11a	OV23
53	5	6	0.59	7	4.5	6.4	4.3	3.93	1.95	2.07	30	MG11a	OV23
54	5	6	0.74	6.9	5.1	6.5	5.6	3.42	2.54	2.58	14	MG11a	OV23
55	5	5	0.677	7	4.9	6	3.6	2.58	3.37	2.6	20	MG11a	OV23
56	5	5	0.727	7	5.6	6.2	4.7	2.9	2.58	2.9	40	MG11a	OV23
57	3	14	0.877	7	4.6	6.6	4	2.24	3.61	1.9	44	CG4	CG4b
58	6	11	0.744	7	6.5	5.5	4.1	3.57	2.41	2.21	48	MG9b	MG9
59	6	12	0.787	6.9	5.6	6	5	3.13	2.77	2.42	54	MG9b	MG9
60	6	15	0.774	6.8	5.4	6.1	5.1	3.15	2.81	2.5	54	MG9b	MG9
61	6	8	0.845	7.1	6.9	5.6	4.4	3.56	2.42	2.17	54	MG10a	MG10
62	6	8	0.795	7	6.5	5.8	4.9	3.35	2.63	2.01	54	MG10a	MG10
63	6	8	0.73	7	5.6	6.3	3.8	2.59	3.37	2.07	54	MG10a	MG10
64	6	9	0.79	7	7	5.3	4	3.07	2.91	2.01	54	MG10a	MG10
65	6	10	0.822	7	6.1	5.7	4.1	3.1	2.37	1.93	54	MG10a	MG10
66	6	9	0.87	7	6.7	6.1	4	2.69	3.06	1.54	44	MG10a	MG10
67	6	9	0.667	7	6.9	5.9	4.3	3.12	2.73	1.37	40	MG10a	MG10
68	3	13	0.784	7.2	4.8	6.2	3.6	2.46	3.45	2.55	44	CG4	CG4b
69	3	10	0.752	7	5	6.2	3.9	2.63	3.02	2.63	30	CG4	CG4b
70	3	11	0.842	7.8	5	6.7	4.2	2.26	3.66	2.34	30	CG4	CG4b
71	3	13	0.812	7.2	4.4	6.4	3.6	2.29	3.69	2.29	23	CG4	CG4b
72	4	10	0.8	7.2	4.8	6.6	5.5	3.18	2	2.74	10	OV23d	MG1a
73	4	10	0.492	7.1	6.4	7	5.9	3.17	2.2	2.63	10	OV23d	MG1a
74	4	12	0.807	7.2	4.9	6.9	4.5	2.55	2.39	3.1	14	OV23d	MG1a
75	4	13	0.787	7	5	6.7	4.5	2.64	1.97	3.04	28	OV23d	MG1a
76	2	13	0.699	6.7	5.4	5.6	4.8	3.02	2.71	2.93	30	MG6	MG6a
77	2	9	0.7	6.6	5.4	5.1	4.6	3.14	2.82	2.85	30	MG6	MG6a
78	2	7	0.497	7	5.1	6	5.7	3.02	2.17	2.95	30	MG6	MG6a
79	4	17	0.731	7.2	4.7	6.5	3.8	2	2.8	2.84	14	OV23d	MG1a
80	4	21	0.826	7.3	4.9	6.6	4.4	2.29	2.94	2.53	28	OV23d	MG1a
81	4	13	0.807	7	4.8	6.9	4.5	2.3	1.93	3.28	14	OV23d	MG1a
82	4	14	0.894	7.2	4.9	6.4	4.5	2.9	2.74	2.6	10	OV23d	MG1a
83	5	11	0.872	7.4	5.5	6.3	5.3	3.22	1.9	2.68	40	MG6a	MG6
84	5	11	0.352	7.1	5.9	6.8	6	3.05	1.26	2.95	44	MG6a	MG6
85	5	14	0.827	6.6	6	5.8	5.5	3.09	1.79	2.76	40	MG6a	MG6
86	5	13	0.727	7.6	5.2	6.1	5.2	2.92	2.41	3.02	34	MG6a	MG6
87	7	10	0.85	7	5.6	6.6	6.3	3.32	1.71	2.65	44	MG9b	MG11a
88	7	7	0.415	7	5.1	6.2	4.3	2.81	2.77	3.1	44	MG9b	MG11a
89	7	7	0.717	7	5.1	6.8	6	3.49	2.1	2.51	38	MG9b	MG11a
90	7	7	0.735	7	5.1	6.8	5	3.05	2.07	2.66	23	MG1a	SD8a
91	7	8	0.73	7.3	4.6	6.2	3.6	2.54	3.09	2.57	38	MG1a	SD8a
92	7	10	0.82	7.1	4.8	6.5	4.6	3.28	2.5	2.26	47	MG1a	SD8a
93	8	14	0.877	7.2	4.7	6.3	3.8	2.62	3.26	2.19	34	MG1a	MG1
94	8	10	0.905	6.9	5	6.5	4.9	2.9	2.03	3.07	23	MG9b	MG1a
95	8	10	0.552	7	5	6.9	6.3	3.63	2.19	2.37	44	MG9b	MG1a
96	8	7	0.585	7	5.2	6.6	6.2	3.58	2.29	2.42	44	MG9b	MG1a
97	8	17	0.839	7.1	4.6	6.2	4.3	2.62	2.43	3.18	44	MG1a	MG1
98	7	7	0.725	7	5.4	6.6	5.6	3.41	2.23	2.5	40	MC9	SD8a
99	7	10	0.725	7.1	4.9	6.1	4	2.95	2.35	2.52	40	MC9	SD8a
100	7	8	0.752	6.9	5.5	6.4	5.8	2.9	1.81	3.05	30	MC9	SD8a

Table A9.2: Additional community metrics (continued)

APPENDIX 10: EXTRACTED VALUES FROM ECONOMIC SYSTEMATIC REVIEW

Key	Study no.	Continent	Country	Latitude	Longitude	GDPpercapita	Popdensha	Type	Area_ha	Year	Year0	Valuation_method	Aesthetic	Biological	Carbon	Climate	Erosion	Events	Genetic	Habitats	Pollination	Recreation	TEV	Waste	Water	No_servs	Total
1	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Wet/seasonally wet	16005	2010	20	Abatement/replacement		0.04	0.31	0.74	1.21					0.25			13.9	6	16.43
2	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Alpine/sub-Alpine	5259	2010	20	Abatement/replacement		0.72	0.18		1.21					0.25			9.64	5	12
3	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Grassland	7604	2010	20	Abatement/replacement			0.08		1.21					0.25			8.56	4	10.1
4	1	Europe	Czech Republic	49.7501	15.7501	18861	1.36	Grassland	406	2010	20	Abatement/replacement			0.2		1.21					0.25			12.6	4	14.23
5	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Grassland	530	2010	20	Abatement/replacement			0.12		1.21					0.25			7.48	4	9.06
6	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Grassland	38661	2010	20	Abatement/replacement		0.24	0.2	0.74	1.21					0.25			9.25	6	11.89
7	1	Europe	Czech Republic	49.7502	15.7502	18861	1.36	Grassland	702162	2010	20	Abatement/replacement			0.2		1.21					0.25			5.92	4	7.58
8	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Wet/seasonally wet	99	2010	20	Abatement/replacement			0.16		1.21					0.25			8.56	4	10.18
9	1	Europe	Czech Republic	49.75	15.75	18861	1.36	Wet/seasonally wet	202907	2010	20	Abatement/replacement		0.09	0.31	0.74	1.21					0.25			13.9	6	16.48
25	2	North America	USA	47.5718	-122.356	53143	0.34	Grassland	22878	2005	15	Value Transfer	96.7	30.1		289	162		4.08	942	18.4	1168				8	2710.1
26	3	North America	USA	47.5305	-121.824	53143	0.34	Grassland	6688	2010	20	Value Transfer		35.7		425					1076					6	1536.8
27	3	North America	USA	47.5305	-121.824	53143	0.34	Grassland	6688	2010	20	Value Transfer				13.6	46.3				38.8			135	4.63	6	238.11
52	4	Africa	Botswana	-24.6583	25.9083	7317	0.04	Tropical	NA	2002	12	Value Transfer	5.83													1	5.83
10	5	Europe	Isle of Man	54.25	-4.5	53800	2.63	Grassland	25773	2010	20	Value Transfer	69.2													1	69.22
13	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	61600	2011	21	CVM											8.36			NA	8.36
12	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	40600	2011	21	CVM											31.9			NA	31.89
11	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	5E+06	2011	21	CVM											48.6			NA	48.59
17	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	900	2011	21	CVM											49			NA	49.04
16	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	22600	2011	21	CVM											78.1			NA	78.12
14	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	10500	2011	21	CVM											129			NA	128.91
15	6	Europe	UK	52.6389	-2.30713	39351	2.63	Grassland	79400	2011	21	CVM											336			NA	335.76
18	7	North America	USA	40.0584	-74.4048	53143	0.34	Grassland	235935	2004	14	Value Transfer	2.96				17.7									2	20.69
19	8	North America	USA	40.6332	-89.3981	53143	0.34	Temperate	NA	2013	23	CVM											2.67			NA	2.67
20	9	North America	USA	42.8387	-102.722	53143	0.34	Grassland	2E+07	2004	14	Value Transfer				34.7	288	8.37	55			1200			33.5	6	1619.5
21	9	North America	USA	42.8387	-102.722	53143	0.34	Restored	1E+07	2004	14	Value Transfer				25.1	209	8.37	59.8			1200			22.7	6	1525
22	10	Asia	China	36.8608	109.352	6807	1.45	Grassland	90450	2007	17	Abatement/replacement			124	167	204									3	494.92
23	11	Asia	China	47.0355	87.2534	6807	1.45	Temperate	3E+07	1990	0	Other hedonic											157			NA	156.85
24	11	Asia	China	47.0355	87.2534	6807	1.45	Temperate	3E+07	1990	0	Other hedonic											596			NA	595.96
28	12	South America	China	35	103	6807	1.45	Grassland	3E+08	2007	17	Value Transfer				294	250		28.6					26.4	454	5	1052.1
29	12	Asia	China	35	103	6807	1.45	Grassland	3E+08	2007	17	CVM				224	334		279					197	227	5	1259.5
30	13	Europe	UK	52.552	0.08919	37500	2.63	Grassland	1600	2007	17	Value Transfer	146		90.7		90.7		2.95							4	330.1
31	14	North America	Canada	45.4	-75.6667	51911	0.04	Temperate	NA	2004	14	Value Transfer			208						558					2	766.83
32	15	Australasia	Indonesia	-6.175	106.828	3551	1.36	Restored	2000	1997	7	Other hedonic											272			NA	271.98
33	16	North America	USA	36.8255	-119.262	53143	0.34	Grassland	329587	2008	18	Abatement/replacement			15.6											1	15.61
34	17	Europe	Germany	52.5167	13.3833	45085	2.31	Grassland	5E+06	2012	22	CVM											252			NA	251.79
35	18	South America	Brazil	-19.3721	-43.5227	11208	0.23	Grassland	31618	2010	20	Abatement/replacement							1055							1	1055.2
36	19	Global	Global	NA	NA	12700	1.16	Grassland	4E+07	1997	7	Abatement/replacement			28.2	0.09										2	28.24
38	20	Africa	South Africa	-30	25	6618	0.43	Tropical	4E+07	2003	13	CVM											0.03			NA	0.03
37	20	Africa	South Africa	-30	25	6618	0.43	Grassland	4E+07	2003	13	CVM											0.06			NA	0.06
44	21	Australasia	Australia	-35.308	149.125	67468	0.03	Grassland	NA	2006	16	Other hedonic											347			NA	346.91
39	21	Europe	Belgium	50.85	4.35	45387	3.68	Grassland	NA	2006	16	Abatement/replacement					57.4									1	57.42
41	21	Global	Global	NA	NA	12700	1.16	Grassland	NA	2006	16	CVM				175								207		2	382.06
42	21	Global	Global	NA	NA	12700	1.16	Grassland	NA	1995	5	Other hedonic							0.02							1	0.02
46	21	Australasia	New Zealand	-45.5549	169.942	40842	0.17	Grassland	22000	2005	15	Other hedonic													107	1	106.95
43	21	Africa	South Africa	-30	25	6618	0.43	Grassland	NA	1997	7	CVM										2.17				1	2.17
45	21	Europe	Spain	41.4712	2.1904	29118	0.94	Temperate	37010	1994	4	Value Transfer		58.7		13.7	86.1				62.6			213	9.78	6	443.94
40	21	North America	USA	38.8833	-77.0167	53143	0.34	Grassland	NA	1991	1	Other hedonic					58.4									1	58.37
50	22	Asia	China	49.2116	119.766	6807	1.45	Seasonally wet and w	NA	2006	16	Abatement/replacement											36.8			NA	36.78
47	22	Asia	China	49.2116	119.766	6807	1.45	Alpine/sub-Alpine	NA	2006	16	Abatement/replacement											39.8			NA	39.83
48	22	Asia	China	49.2116	119.766	6807	1.45	Grassland	NA	2006	16	Abatement/replacement											42.4			NA	42.41
49	22	Asia	China	49.2116	119.766	6807	1.45	Temperate	NA	2006	16	Abatement/replacement											64.7			NA	64.66
51	23	Asia	China	22.3663	120.901	6807	1.45	Alpine/sub-Alpine	NA	2008	18	Other hedonic			4.64	9.07			56.2							3	69.87

(With disaggregated figures)

APPENDIX 11: ETHICAL APPROVAL FOR STUDY

Aston Business School

Samantha Cruickshank

ABS Research Student

Date: 27th March 2014

Dear Samantha,

I am pleased to be able to inform you that the ABS Research Ethics Committee has approved your ethics application. For future reference please quote 04:03/14

Best wishes

Professor Jim Love

(Associate Dean of Research)

Cc: Dr G Leask

APPENDIX 12: EXAMPLE NVC RECORD CARD

		NVC record sheet	
Location	**Grid reference**	**Region**	**Author**
Site and vegetation description		**Date**	**Sample no.**
		Altitude m	**Slope** °
		Aspect °	**Soil depth** cm
		Stand area m x m	**Sample area** m x m
		Layers: mean height m m	cm mm
		Layers cover % %	% %
		Geology	
Species list		**Soil profile**	