DOCTOR OF PHILOSOPHY

Utilisation of analogous climate locations to produce resilient biodiversity plantings for infrastructure developments

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UTILISATION OF ANALOGOUS CLIMATE LOCATIONS TO PRODUCE RESILIENT BIODIVERSITY PLANTINGS FOR INFRASTRUCTURE DEVELOPMENTS

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ABSTRACT

Developers have an obligation to biodiversity when considering the impact their development may have on the environment, with some choosing to go beyond the legal requirement for planning consent. Climate change projections over the 21st century indicate a climate warming and thus the species selected for habitat creation need to be able to withstand the pressures associated with these forecasts. A process is therefore required to identify resilient plantings for sites subject to climate change.

Local government ecologists were consulted on their views on the use of plants of non-native provenance or how they consider resilience to climate change as part of their planting recommendations. There are mixed attitudes towards non-native species, but with studies already showing the impact climate change is having on biodiversity, action needs to be taken to limit further biodiversity loss, particularly given the heavily fragmented landscape preventing natural migration.

A methodology has been developed to provide planners and developers with recommendations for plant species that are currently adapted to the climate the UK will experience in the future. A climate matching technique, that employs a GIS, allows the identification of European locations that currently experience the predicted level of climate change at a given UK location. Once an appropriate location has been selected, the plant species present in this area are then investigated for suitability for planting in the UK. The methodology was trialled at one site, Eastern Quarry in Kent, and suitable climate matched locations included areas in north-western France. Through the acquisition of plant species data via site visits and online published material, a species list was created, which considered original habitat design, but with added resilience to climate change.

KEYWORDS: planting regime, habitat-design, development site, climate change, developer's obligation.

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List of Abbreviations

ALGE – Association of Local Government Ecologists

AOGCM Coupled Ocean-atmosphere global climate model

BAP – Biodiversity Action Plan

BRANCH – Biodiversity Requires Adaption in North West Europe under a Changing climate

CBD – Convention on Biological Diversity

CBNBP – Conservatoire Botanique National du Bassin Parisien

CEM – Climate envelope model

CDF – Cumulative distribution factor

CMIP3 - Coupled Model Intercomparison Project

CORINE – Co-ordination of Information on the Environment

CRU - Climatic Research Unit

Defra – Department for Environment, Food and Rural Affairs

DCLG – Department for Communities and Local Government

EEA – European Environment Agency

EIA – Environmental Impact Assessment

EQ – Eastern Quarry

FAO – Food and Agricultural Organization

GCM- Global Circulation Model

GDP – Gross domestic product

GHG – Greenhouse gas

GWP – Global Warming Potential

HadCM3 - Hadley climate model 3

IEA – International Energy Agency

INPN – Inventaire National da Patrimoine Naturel

IPCC – Intergovernmental Panel on Climate change

JNCC – Joint Nature Conservancy Council

LBAP – Local Biodiversity Action Plan

LCA – Landscape Character Area

LPA – Local Planning Authority

MAVIS – Modular Analysis of Vegetation Information System

MOC - Meridional Ocean circulation

MOHC - Met Office Hadley Centre

MONARCH – Modelling Natural Resource Responses to Climate Change

NCA – National Character Area

NERC – Natural Environment and Rural Communities (Act)

NHC – National Historical Collection

NIA – Nature Improvement Area

NPPF – National Planning Policy Framework

NSRI – National Soils Research Institute

NVC – National Vegetation Classification

ODA – Olympic Delivery Authority

PPE – Perturbed physical ensemble

PPS – Planning Policy Statement

RCM – Regional climate model

SAC – Special Area of Conservation

SDM – Species distribution model

SNCI – Site of Nature Conservation Interest

SPA – Special Protection Area

SRES - Special Report on Emission Scenarios

SSSI – Special Site of Scientific Interest

TCPA – Town and Country Planning Act

THC – Thermohaline circulation

UKCIP02 – UK Climate impacts programme 2002

UKCP09 – UK Climate projections 2009

UN – United Nations

UNEP – United Nations Environment Programme

UNFCCC - United Nations Framework Convention on Climate Change

WCA – Wildlife and Countryside Act

WCED – World Commission on Environment and Development

WMO – World Meteorological Organisation

ZNIEFF – Natural Areas of Ecological Fauna and Flora

1. Introduction

The attribution of recent climate change to anthropogenic forcings is widely accepted, as exemplified by the increase in atmospheric greenhouse gases since the industrial revolution and the consequent rise in global temperatures. Having increased by 0.8°C since the late 19th century, global average temperatures are currently increasing at an unprecedented rate of 0.2°C per decade (EEA, 2004), and they are set to continue increasing. Reports by the Intergovernmental Panel on Climate Change (e.g. IPCC, 2007), along with advanced computer modelling of the future climate all point to a further warming.

In their fourth assessment report (AR4), the IPCC conclude that human activities have *very likely* contributed to recent climate change, and even if mitigation measures were fully implemented to reduce global emissions, the globe is already committed to a certain degree of climate change due to the inherent inertia of the climate system (Schneider and Thompson, 1981). Simulations using global circulation models (GCMs) show that the temperature will rise by between 1.1 and 5.8°C depending on the emissions generated over the next century, i.e. dependant on the intensity of fossil fuel consumption, the uptake of energy efficient technology, amongst other socio-economic factors (Nakicenovic *et al.*, 2000). Other climate variables like precipitation are harder to predict, but given the increase in temperature and the affect this will have on the atmospheric-ocean interactions, precipitation rates will rise, more so in some areas than others. The emission scenarios developed by the IPCC and published in AR4, estimate this to be between 1.3% and 6.8% higher in the final 30 years of the 21st century compared with the period 1961-1990. In Europe, the climate overall will comprise drier summers and wetter winters. Although the 5th IPCC Assessment Report (AR5) has yet to be published, the *Summary for Policymakers* (IPCC, 2013), shows that it will not only support the AR4 findings, but provide more robust evidence of the anthropogenic contributions to global warming and climate change.

The climate is one of the determining factors on the distribution of vegetation types and plant species across the globe (Graham and Grimm, 1990), as illustrated by the different biomes. With the magnitude of climate change expected over the next century, there are concerns over the ability of species to successfully migrate and keep track of their climate space. Paleodistribution analyses studying the migration of species at the start of the Holocene period, when similar conditions existed, show that in general most species responded spatially to the change (Huntley, 1991), with the rate of change dependant on a number of variables. Some species, however, are thought not to be in sync with the current climate (Svenning and Skov, 2007) and thus their future survival hangs in the balance. The effect climate change will have on species and how they will respond needs to be understood, so that adaption plans can be made accordingly.

Species distribution models have been created to project the future climate space of species as a way of determining the possible impacts. They highlight the areas which would be climatically suitable for species, but also project that some species will lose their climate space under climate change, with the possible risk of extinction (Thomas *et al*., 2004). There are limitations associated with these modelling tools however, as they do not always take into account interactions between species, the abiotic effects on plant physiology and a species dispersal capacity, all of which determine the ability of a species to exist in a particular community. Attempts have been made to incorporate a greater number of important factors, but models are still in the relatively early stages (EEA, 2012). A species future fate may not be as positive as the models show, and action is required now when long term planning decisions are made in relation to vegetation and biodiversity. The long life cycle of trees for example (Broadmeadow and Ray, 2005), means that action is required immediately if they are to survive future conditions.

Recent climate change is already known to have had an effect on biodiversity, with the literature providing ample examples illustrating this point, including:

- the migration of many taxa polewards, extending their ranges to higher latitudes and altitudes (Thomas *et al.*, 2004; Walther *et al.*, 2009) at an average of 6.1km per decade over the last century (Parmesan and Yohe, 2003);
- observed changes in species phenology, e.g. first flowering dates, have advanced in line with recent temperature increases (Fitter and Fitter, 2002).

Viner (2006) states that

> "These recent climate changes are likely to accelerate as human activities continue to perturb the climate system, and many reviews have made predictions of serious consequences for ecosystems and for food supplies and food security."

Unless a species is able to adapt in situ or shift its range, extinction may be a likely outcome as selective pressures increase (Jump and Peñuelas, 2005). The loss of habitat and a heavily fragmented landscape add to the uncertainty that species will be able to respond naturally to climate change, with the added problem of increased threat from invasive species (Root *et al.,* 2003).

The services provided by biodiversity are valuable and important, some of which under climate change will become more creditable, including the regulation of air temperature through evapotranspiration, the provision of shade by trees, as well the absorption of CO_2 from the atmosphere and the removal of other pollutants (Broadmeadow and Ray, 2005). Water attenuation during floods and reduction of soil erosion under the expected climate will also be beneficial. Green spaces also provide sense of wellbeing and are linked with recreational activity. These services, amongst others, need to be protected and sustained, and are one of the reasons why action to mitigate the impact of climate change needs to be taken now, and in particular the appropriate adaption plans to keep green areas green.

1.1 A Developer's Biodiversity Obligation

From a practical perspective, planners and developers are currently making investment decisions on vegetation planting schemes, which will survive and flourish over a 50-100 year time horizon. This requires the selection of appropriate species that will withstand the added pressures likely to be experienced over this time frame. Biodiversity has been given more recognition in the planning system over the last half a century, and there is now a requirement for developers to consider the biodiversity aspects when designing proposals (Bell and McGillivray, 2008). Sustainable development also requires that the environment is given equal consideration as economic and social factors. It is not always necessary to consider the environment, but in today's society it upholds companies' reputations and shows their commitment to the environment. Inaction to respond to climate change will cost the environment as well as the economy (HM Treasury, 2006).

1.2 The Origin of the Research

Planting decisions are typically guided by biodiversity action plans (BAPs) at both the national and regional level, the principle of which being to maintain and enhance the local indigenous flora. These species, however, are characteristic of a previous climate and they may not be appropriate for the climate of the 21st century given the change in abiotic factors expected, e.g. higher average temperatures, reduced summer moisture availability. Sustainable planting decisions need to be made so that developments maintain their investment into habitat creation, particularly when developments are of a large scale and entail 60 year life designs. Developers therefore need the appropriate guidance to consider climate change in their plans.

Middlemarch Environmental Ltd, an ecological consultancy company, is often involved with large property developers who require advice on various biodiversity aspects, including planting regimes. With concerns over the selection of suitable plant species, which will satisfy the long term investment obligations of their clients, Middlemarch saw a need to rethink currently accepted habitat creation and planting design practice, so that they can be appropriately informed. Large brownfield sites, typical of their site profiles, also have an added disadvantage in that they often are characterised by poor soil conditions with limited water retention characteristics, with subsequent stressful edaphic conditions. With warmer summers predicted for the UK and decreases in precipitation levels, these problems are only going to exacerbate under climate change.

A project of particular concern to Middlemarch, was the Thames Gateway project, a long term development in the South East, where large scale housing provision is proposed to be built within a disused chalk quarry along with the associated habitat creation and biodiversity enhancement. Current practice would recommend a mosaic of calcareous habitats as specified by the BAP, but over the lifetime of the project the climate is predicted to change to mirror that currently experienced on the nearby continent and southern Europe – consequently, decisions made need to reflect this. Research was therefore urgently required which, based on the most recent predictions of climate change, would establish appropriate planting provenance to both guarantee long term viability and minimum maintenance cost for this and similar schemes.

1.3 The Research Proposal

The research project was initiated with a view to developing a methodology for the creation of planting assemblages that will be adapted to the climate of the UK in 2050. This research would thus provide suitable environmental and financial solutions for developers and planners involved with large scale developments and long-term management plans involving biodiversity provision.

1.3.1 Project Aim

The aim of the proposed project is:

> 'to develop a process to enable the production of species lists for the habitat creation and planting design associated with large scale development sites subject to climate change.'

1.3.2 Project Objectives

The aim of the project would be achieved through meeting the following objectives:

i. undertake a literature review to understand the climate science and modelling of the future climate;

ii. obtain the most recent climate change predictions for the UK for the time period 2050, in particular temperature, precipitation and emission scenario projections, and select an appropriate climate change scenario for study;

iii. undertake a literature review to ascertain the impact climate change is having on biodiversity, in particular the distribution of vegetation and species composition;

iv. employ a case study approach to test the methodology by selecting a range of suitable development sites across the UK with a requirement for biodiversity, and published site landscape designs;

v. determine the views of ecologists regarding the research proposals, non-native species and planting design via a questionnaire;

vi. develop a climate matching technique to identify areas on the continent which currently experience a similar climate to that predicted for given locations in the UK in 2050;

vii. obtain species lists for identified European sites and chosen habitats through site visits and desk studies, where appropriate;

viii. interrogate the species lists to compile vegetation assemblages and species lists for each of the case study sites, taking into account habitat proposals, species' environmental preferences and soil considerations;

ix. consult an expert ecologist to refine the resulting species lists for recommendation to planners and developers.

1.4 Thesis Structure

Chapter 2

The rationale behind climate change provided in this chapter looks at the main forcing agents, both natural and anthropogenic which have influenced the climate system. The evolution of global circulation models is also discussed, as these produce projections of the future climate. The IPCC marker emission scenarios are also introduced, as well as the most recent climate projections developed by UKCP09.

Chapter 3

This chapter identifies measures taken for protecting the environment within the planning system at the international, European and national level, as often such agreements to protect the environment and biodiversity are made at the international level, but are enforced through regulation at the national level. The requirement for developers to consider biodiversity when proposing site plans is also discussed.

Chapter 4

The past, present and future effect climate change is having on biodiversity is examined in Chapter 4, to highlight the need to consider and protect biodiversity. Studies have shown that unless efforts are made now to reduce the impact of climate change, there could be dangerous consequences for biodiversity across the globe in the future.

Chapter 5

This chapter introduces the research methodology employed, and the steps taken to reach the findings, including the climate matching technique. A case study approach is adopted to test the framework developed to create robust planting assemblages suitable for the future climate.

Chapter 6

The questionnaire design, results and evaluations are given in this chapter. An online questionnaire was sent out to local government ecologists to ascertain their perceptions of climate change effects on biodiversity, the decisions made in relation to planting on brownfield sites, and their views on the wider implications of this research.

Chapter 7

The five case study development sites selected to test the methodology are described in Chapter 7, including the history of each site, the site conditions, the site proposals and the biodiversity elements incorporated into them. The landscape surrounding the site is also considered as this can influence planting design and decisions.

Chapter 8

European locations which currently experience the climate predicted for each of the case study sites in 2050 were identified in this chapter. UKCP09 climate projections were used along with current day meteorological conditions across Europe to identify these. A GIS was employed to visually show how well the locations matched the climate for each case study. The best matched locations were identified through a visual inspection and comparison of monthly rainfall and temperature distributions, when considered alongside other relevant factors.

Chapter 9

This chapter details the steps taken to identify and obtain the appropriate vegetation data from the selected European sites, including site visits and desk studies. The data collected was subsequently classified into the broad habitats proposed for the development sites, with further consideration of the species' environmental preferences.

Chapter 10

The discussion chapter relates the findings of this research to the wider context of the field, the issues which would likely be encountered, the reasoning behind and evaluations of the decisions taken. In light of the limitations a framework is proposed which would provide developers and planners with species lists that take into account climate change.

Chapter 11

The thesis concludes with a summary of the research and the consequent development of the framework, highlighting the reasoning behind the project and why it is important for the sustainability of biodiversity. Recommendations are made in relation to further developing the framework.

2. Climate Change and Climate Models

2.1 Introduction

Over the last half a century, changes to the climate have occurred at an unprecedented rate; noticeably the increase in temperature has been at 0.17 ± 0.05°C per decade, believed to surpass any 100-year rate of warming during the past 1000 years (EEA, 2004). Understanding of the climate system and how interactions between the land, ocean and atmosphere can affect the climate has shown that there are radiative forcings which act to modify the energy balance and thus the climate experienced on Earth. There are natural forcing agents or events like changes in the orbit of the earth, but there are also human induced forcings, e.g. the emission of gases from industry, which have radiative properties. Recent climate change is assumed to have been caused by more than just natural causes (Stott *et al.*, 2000), and with the CO_2 concentrations rising significantly since the pre-industrial period, anthropogenic sources are seen as being partly responsible for deviations in the climatic mean .

The need to address climate change, to prevent irreconcilable damage to the environment, has been recognised through international agreements with the intention to mitigate the world's impact on the environment. Contracting parties have to fulfil objectives and meet targets through implementing schemes to stabilise greenhouse gases, and commitments to sustainable development. With economic development underpinned by the natural capita of the earth, studies have investigated the damage that the economy could encounter if inaction to limit climate change prevails (HM Treasury, 2006).

Complex mathematical models representing the climate system have been developed to illustrate the climate response to increased greenhouse gas emissions (Randall *et al.*, 2007). There are many limitations associated with the models, due to the complex nature of the components they model, and therefore outcomes are riddled with uncertainty. Model advances since the start of this century, however, like the inclusion of atmospheric and ocean dynamics and those incorporating the carbon cycle (Cox *et al.*, 2000), have increased the model confidence and the projections they produce, which ultimately provides the best estimate for how the climate may change over the 21st century. Some models predict that there may be a cooling over north western Europe as a result of weakening in the ocean circulation in the northern North Atlantic (Broecker, 1987; Jacob *et al.*, 2005), yet many models project a climate warming, in line with the trend observed over recent decades.

The International Panel on Climate Change (IPCC) have developed a range of emission scenarios based on potential future events over the 21st century in terms of the demographics, energy source and intensity, economic development and social structures. These emission scenarios drive climate models and thus produce the likely climate scenarios of the future. Depending on what assumptions are employed, the global temperature is estimated to rise between 1.1 and 6.4°C (IPCC, 2007) in the future. UKCP09 have produced climate projections utilising the IPCC scenarios, and it is these projections which underlie this research.

2.2 The Climate

The climate of an area is defined by the average of weather accumulations over a given period of time (Burroughs, 2007), i.e. it is statistically derived. The climate system is made up of, and influenced by complex interactions between the atmosphere, the ocean, land, ice and the biosphere (Solomon *et al.*, 2007), all of which are looked at in more depth throughout the chapter with regards to their effect on the climate. The flow of energy within the climate system also influences it.

2.2.1 Climate Change

The climate is always fluctuating, but the term climate change refers to a change in the state of the climate, through either a drop or increase in the average of a parameter (Burroughs, 2007), such as temperature or rainfall, over typically a prolonged period of time. This can be as a result of natural variability or due to human activity (Le Treut *et al.*, 2007). In relation to current climate change, the mean temperature is increasing at a rate that suggests the climate is being affected by more than just natural variability (Stott *et al.*, 2000); other external forcings may be mediating the change. Although this chapter covers some of the science behind climate change, more detailed scientific information on climate change can be found by consulting Le Treut *et al.* (2007).

2.2.1.1 Greenhouse Gases

The discovery that greenhouse gases (GHG) alter the amount of long wave energy radiated back to space and thus affect the climate of the earth, came about in 1859 when John Tyndall carried out experiments in his basement laboratory (Hulme, 2009a). He discovered that different gases commonly found in the atmosphere have varying absorptive properties when radiant (infra-red) heat is passed through them. Water vapour, carbon dioxide, nitrous oxide, methane and ozone, all naturally present in the atmosphere, were later collectively called ‘greenhouse gases’ for their warming effect as they capture the heat radiating from the earth; they are an external forcing on the climate. The planet would be considerably colder if these gases did not perform such a function (Hulme, 2009a). The GHG all have varying attributes, some capable of absorbing more heat than others, but their atmospheric concentration will also determine the extent of climate change. CO_2 has the smallest global warming potential (GWP), but as it is the most abundant GHG in the atmosphere (Blasing, 2010), it is known to be the major contributor to climate change out of the main gases.

2.2.1.2 Insolation

The climate can be altered by other natural influences like changes in incoming solar radiation (insolation), which occurs as a result of changes in the orbit of the earth or by the characteristics of the sun. Variations of the climate between ice ages and warmer periods over the past million years or so can be partially explained by variations in the Earth's orbit and the amount of radiation received by the sun, a theory devised by Milankovitch (Nasa, 2008). The cycles correspond with the majority of climate transitions, but not all, and conversely their direct heating or cooling effect is small, not wholly explaining the temperature changes over time. For instance, insolation has remained relatively constant over the past 50 years (Randall *et al.*, 2007), highlighting its relatively minor role in climate change over the last half a century.

2.2.1.3 Feedback Mechanisms

There are a number of feedback mechanisms in the climate system, which can either amplify (positive feedback) or reduce (negative feedback) the climate variability. The fraction of radiation that is reflected back from the earth's surface can be affected by the albedo of the land surface (the measure of how strongly land reflects light from light sources), land cover, aerosols and sulphur emissions from volcanic eruptions in the atmosphere (Randall *et al.*, 2007). One possible cause of climate change is even the ice itself; it has an albedo of around 0.8 on average (Perovich *et al.*, 2008), reflecting around 80% of the electromagnetic radiation from the sun falling on the surface. When vast ice sheets start to shrink, less of the suns electromagnetic radiation is reflected back into space, thus accelerating the warming process.

2.3 Biogeochemical Cycles

2.3.1 The Carbon Cycle

With CO_2 being a radiative forcing on the climate, its sources and sinks must be understood when looking at climate change. Its concentration in the atmosphere, as mentioned, will affect the atmospheric temperature.

The flow of carbon and its interactions in the biosphere, atmosphere, hydrosphere, lithosphere and pedosphere is known as the carbon cycle. Plants and other producers are both sources and sinks (stores) of CO_2. The gas is taken in for photosynthesis whereby the carbon is used as a building block for the plant, which also emits CO_2 into the atmosphere via respiration. The consumers that then eat the plants, facilitate the carbon to continue up the trophic hierarchy, until it is eventually returned to the Earth during decomposition or added back to the atmosphere during respiration. Soil can act as a carbon sink, but if the temperature increases and the soils warm, respiration of CO_2 back to the atmosphere increases (Cox *et al.*, 2000).

The ocean (seawater and ecosystems within it) acts as a sink, but its storage capacity can be affected by the temperature, as well as actual concentrations of the gas in the ocean. Dependant on these variables the ocean can also act as a source of CO_2 (UKCP09, 2010a). The burning of fossil fuels, typically in industry, also returns the biological carbon back into the atmosphere. Transport and changing land use, e.g. deforestation, are other factors which release CO_2 back into the atmosphere, both of which have increased greatly over the past 50 years. The cycling of carbon through land and water is illustrated in figure 2.1.

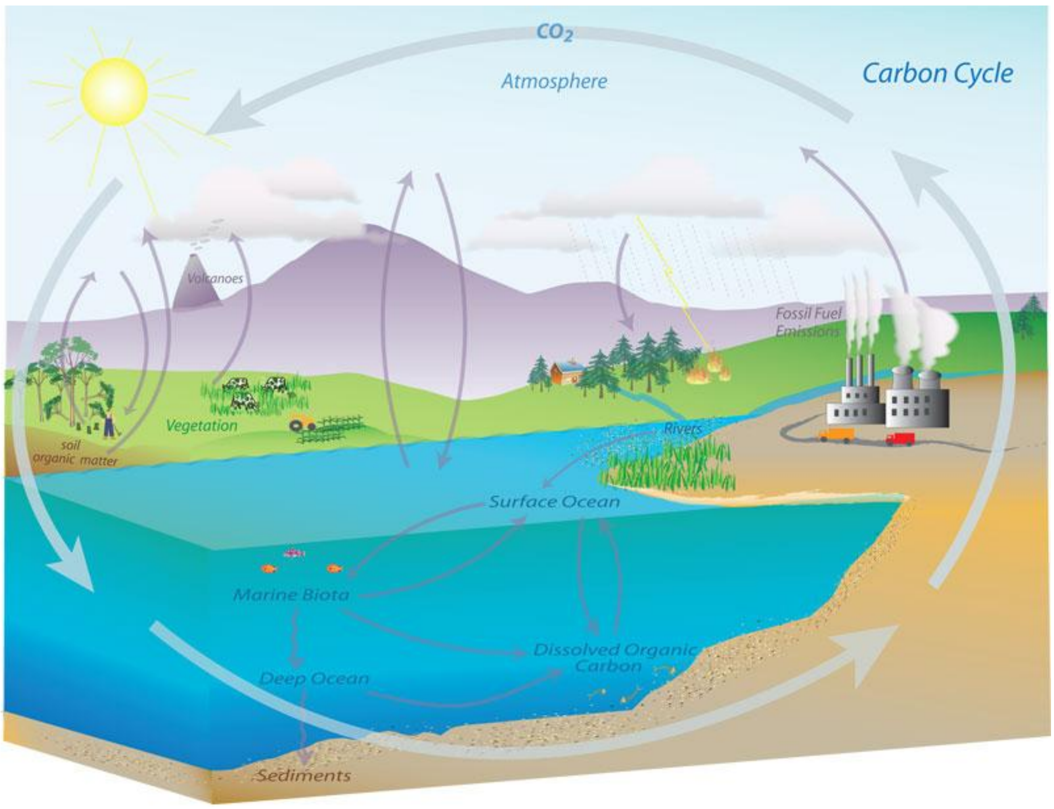

Figure 2.1 The Carbon Cycle (NOAA, No date)

2.3.2 The Sulphur Cycle

Sulphur is another agent which acts to modify the climate. Sulphur gases are released with the combustion of fossil fuel gases, but also naturally from the oceans. Once in the atmosphere, chemical reactions take place to convert the sulphur gas into sulphate aerosol. These aerosols do not persist for long in the atmosphere as clouds and rain remove them, but they do cause a temporary cooling effect on the climate, both directly and indirectly, which can be quite substantial. The direct effect is due to a suspension of aerosols reflecting back some of the incoming solar radiation. The indirect effect is when the sulphate particles act as additional nuclei on which water vapour condenses to form clouds; the increase in cloud total surface area resultantly reflects more solar radiation, creating a further cooling effect (UKCP09, 2010a).

2.4 Recent Climate Change

This section is based on the IPCC Climate Change Synthesis report 2007 (IPCC, 2007). The following observations are evidence for recent climate change, with figure 2.2 illustrating the change for 3 of the parameters since 1850:

- The atmosphere is warming 0.13°C each decade, with the eleven years between 1995 and 2006 ranking among the twelve warmest years in the instrumental record of global surface temperature (since 1850).
- 1.3 times as much CO_2 is entering the atmosphere compared with just 20 years ago.
- The oceans have warmed to an increased depth of 3 kilometres since 1961, with the ocean absorbing over 80% of the heat being added to the climate system.
- The sea level has risen on average about 1.89cm each decade over 1961 to 2003, with the last 10 years of this period averaging at a rise of 3.1cm. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder.
- Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 shows that the annual average Arctic sea ice extent has shrunk by 2.7% per decade, with larger decreases in summer months of 7.4% per decade.

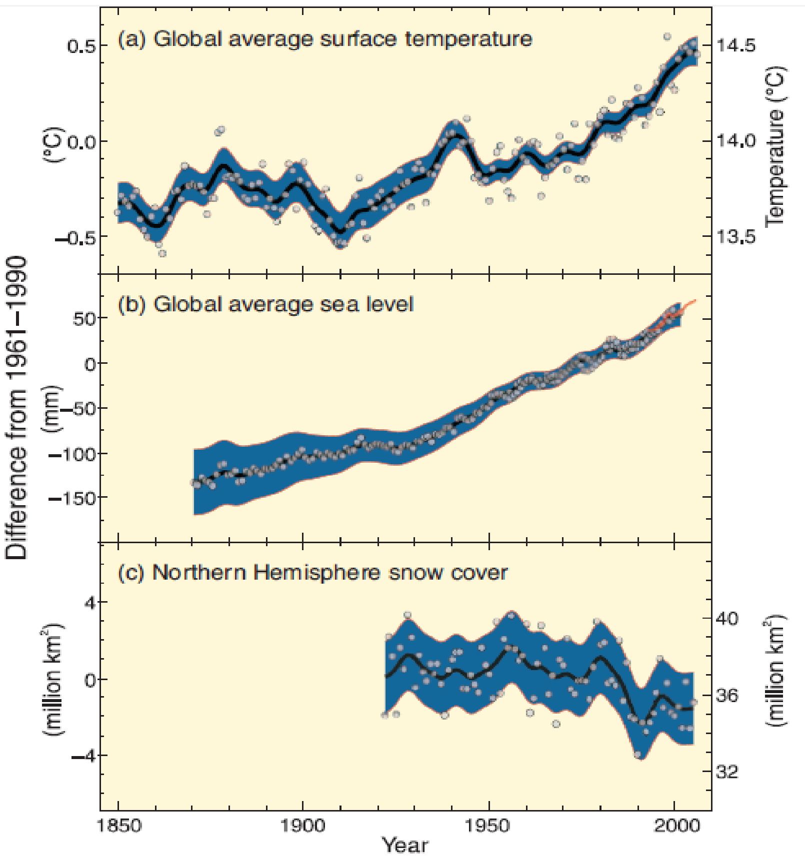

Figure 2.2 Changes in temperature, sea level and Northern Hemisphere snow cover (IPCC, 2007)

2.4.1 Anthropogenic Climate Change

Climate Change is nothing new, it has been happening on all time scales, and Burroughs (2007) suggests that "past changes are etched on the landscape, have influenced the evolution of all life forms, and are a subtext of our economic and social history". However, recent changes to the climate cannot be fully explained by natural forcings (Stott *et al.,* 2000), and the IPCC (2007) believe that 'most of the observed increase in global average temperatures since the mid-twentieth century is very likely (i.e. more than 90 percent chance) due to the observed increase in anthropogenic greenhouse gas concentrations'. Figure 2.3 shows the global surface temperature variation 1880-2012. The 10 warmest years have occurred since 1990 including each year since 1997.

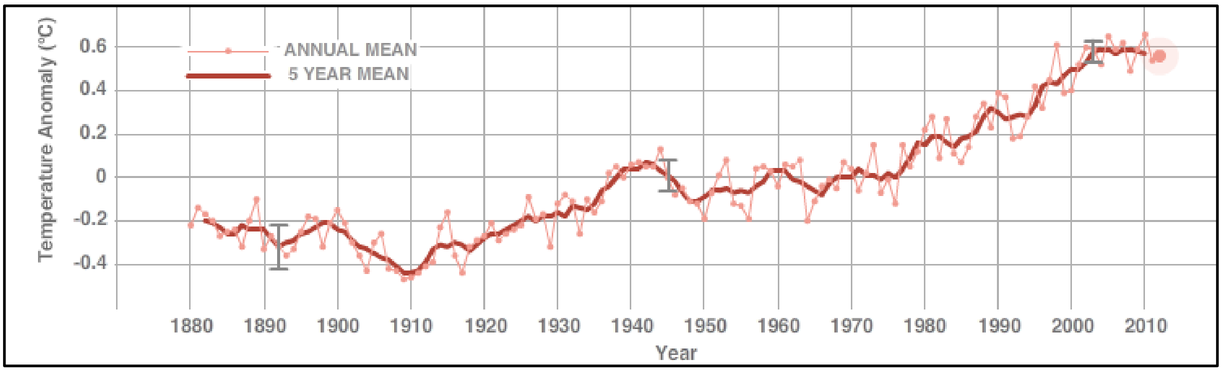

Figure 2.3 Detailed global surface temperature variations 1880-2012 (NASA, 2013)

2.4.2 CO_2 Concentrations

CO_2 emissions from human activity are relatively small compared with most natural sources, but it has been shown, through the analysis of ice cores, that for the past half-a-million years CO_2 concentrations have remained fairly stable at between 180 and 300 parts per million (ppm) (Brahic and Le Page, 2007), only to have risen to nearly 400ppm since the industrial age began (18-19th Century), which is almost a 50% increase over a relatively short time period. Hulme (2009a) reports sites for monitoring CO_2 in the mid 1950s were arranged by scientists Revelle and Suess, and with the help of a young post-doctoral scientist, Charles Keeling, they were able to establish a reliable 'baseline' carbon dioxide level with anticipated continuous monitoring. Mauna Loa Observatory in Hawaii, based at the top of the world's largest volcano, was the location of one site, with another based at the South Pole. Measurements commenced in 1957, and it was evident even after eighteen months, that concentration of the atmospheric gas was rising by about 0.5 and 1.3ppm per year, respectively at both sites. Continuous recording of the concentrations still take place today, and as figure 2.4 shows, its abundance in the atmosphere has increased by about 80ppm since the recording began only 50+ years ago.

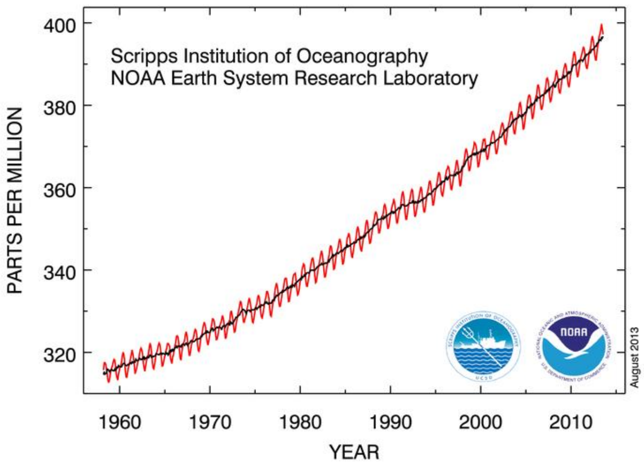

Figure 2.4 Atmospheric CO_2 at Mauna Loa Observatory (NOAA, 2013).

The increase in CO_2 can be correlated with the increase in human activity since the industrial age, thus pointing to anthropogenic influences on the climate. Emissions may have been previously balanced through natural sinks (natural reservoirs that accumulate and store some CO_2 for an indefinite period), but in recent years more CO_2 has been entering the atmosphere than can be absorbed by the natural sinks, as shown in the end net accumulation in figure 2.5 (IPCC, 2007). Consequently an excess of CO_2 is left in the atmosphere, which in turn enhances global warming.

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Figure 2.5 Carbon Dioxide Sources and Sinks (IPCC, 2007)

Figure 2.6 shows how human activity since 1750 has had the largest radiative forcing in comparison to natural processes, with CO_2 responsible for the greatest forcing effect on the climate at 1.6 W/m^2.

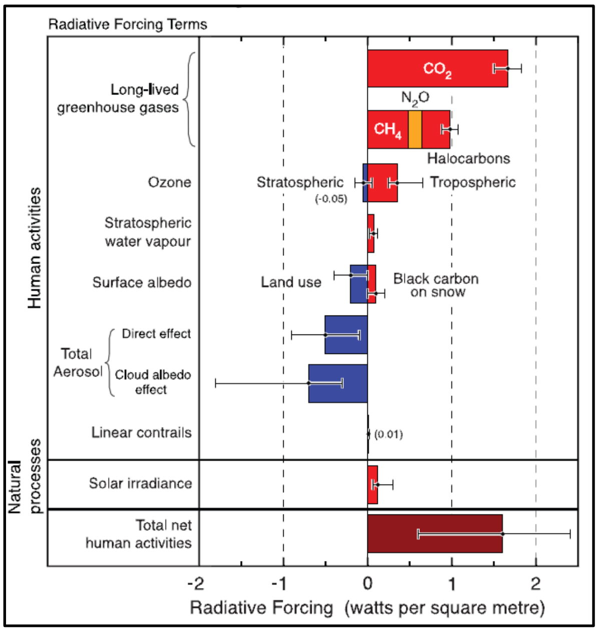

Figure 2.6 Global average radiative forcing of climate 1750-2005 (NASA, 2013)

The additional CO_2 in the atmosphere and the recent unprecedented rate of climate change has shown how the climate can be affected by more than just natural forcings. Anthropogenic influences on the climate, particularly since the industrial revolution, have amplified the forcing effect on the climate causing imbalances in biogeochemical cycles. Some feedback processes have also acted to exacerbate the warming effect, highlighting the sensitivity of the climate system to external forcings.

2.5 Addressing Climate Change

The continuous increase of greenhouse gas emissions over the 20th century and the observed global temperature increase was a call for action, with the perceived threats to the environment due to these activities being recognised. Flooding of low-lying land from polar ice cap melt and the increase in extreme weather events across the globe are some of the activities being linked to climate change (HM Treasury, 2006).

Even though various studies have shown the impacts, both environmentally and economically, that inaction on climate change can create, there is still much disagreement about climate change. Much uncertainty surrounds who is responsible for recent climate change, and who should take action. As Hulme (2009a) remarks climate change is an 'environmental, cultural and political phenomenon which is reshaping the way we think about ourselves, our societies and humanity's place on earth', with some reasons for disagreement down to peoples differing beliefs and attitudes about their 'duty to others, to nature, and to their deities'. Governing the climate in response to the danger it poses, has occurred through international bodies and conventions with the intention to try and regulate the system and bring the situation under control.

2.5.1 Establishment of the IPCC

The Intergovernmental Panel on Climate change (IPCC) was jointly established in 1988 by the World Meteorological Organisation (WMO) and United Nations Environment Programme (UNEP) to carry out international assessments of scientific, technical and socio-economic knowledge in relation to human-induced climate change and the potential risks it posed (IPCC, No date). It is world leading for such assessments. The plethora of publications by the IPCC are now benchmark references, acknowledged by policymakers, scientists and other experts. Four major assessments have been carried out every five years or so from 1990, with the most recent being that in 2007, with voluntary contributions from thousands of scientists based across the globe. The reports are extensively reviewed by scientists all around the world prior to publication, to ensure the content and knowledge 'are a fair reflection of the views of the whole scientific community' (BBC, 2007). This gives validity to the conclusions of the IPCC reports.

2.5.2 International Mitigation Measures

International agreements have been developed to address climate change (Bell and McGillivray, 2008); with it being a global problem there needs to be a concerted effort by all countries. Developing countries have contributed little to greenhouse gas emissions over time, as opposed to the likes of the USA and Europe whose CO_2 emissions due to energy production have totalled 70% of global emissions since 1850 (HM Treasury, 2006). This is recognised in the agreements, and although developing countries have a right to develop and thus emit greenhouse gases (Hulme, 2009a), efforts need to be made so that they develop within the means of the globe's environmental capacity. The main concept of the agreements is mitigation.

2.5.2.1 The UN Framework Convention on Climate Change (UNFCCC)

In 1992, as a result of the IPPC's first annual report, the UN Framework Convention on Climate Change (UNFCCC) was adopted at the Rio Conference, with 50 countries (including the EC and the UK) initially ratifying the agreement (Bell and McGillivray, 2008). A 'common but differentiated responsibility' approach towards mitigating climate change underlies the Convention, with onerous responsibility placed on parties listed in Annex 1 – the industrialised nations. The main principle of the UNFCCC is to

"achieve...Stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system...to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (UN, 1992b).

2.5.2.2 The Kyoto Protocol

The Kyoto Protocol, negotiated in 1997, is linked to the UNFCCC, and Annex 1 parties must mitigate for climate change through internationally binding emission reduction targets (Bell and McGillivray, 2008). It took 8 years before the Protocol was in force after many years of complex negotiations surrounding political disagreements; a countries economic development was in the balance (Hulme, 2009a). Through a collective scheme Annex 1 parties had to cut emissions by 5.2% relative to 1990 levels at some point between 2008 and 2012. This could be achieved through variable emission trading between countries and investment mechanisms, including the clean development mechanism. Carbon credits can also be gained through afforestation, reforestation and forest management (Bell and McGillivray, 2008). A major flaw of the Protocol and its effectiveness is that it has not been endorsed by China, the USA and India, three of the four main greenhouse gas producers.

2.5.3 The Economics of Climate Change

Economic development has often come at the cost of high greenhouse gas emissions, and this is where one of the controversies has arisen when it comes to addressing climate change. The Stern Review (HM Treasury, 2006) on the economics of climate change highlighted that it would be more cost-effective to take action now, as oppose to dealing with the problems later on. The damage to economic growth globally was estimated to be 'between 5 and 20 per cent global gross domestic product (GDP) each year, now and forever' if climate change was not mitigated for, i.e. if a business-as-usual scenario continued. The economic analysis of Stern's findings, however, received much criticism (as discussed in Hulme, 2009a), in particular the weighting given to the welfare of future generations to that of our own, and that estimates were unreasonable. Nonetheless the warning given was clear and it gave economists an idea of the cost of inaction.

2.5.4 The Need for Climate Models

To illustrate just how severe climate change could be over the next 100 years, climate models have been developed to demonstrate the effect CO_2 is having on the climate. Although mitigation measures are in place to curb emissions, people still speculate on the need to change and favour a business as usual approach; climate models, as discussed in the next section, facilitate the warning required to make people realise the likely extent of future warming.

2.6 Global Climate Models

General Circulation Models, more commonly known as Global Climate Models (GCMs), represent the climate system mathematically, and are used to calculate future climate parameters. They simulate the atmosphere, ocean, ice and land surface processes, based on the known laws of physics, describing the motion of energy and moisture (Hulme and Carter, 1999) and the conservation of mass, energy and momentum (Randall *et al.*, 2007).

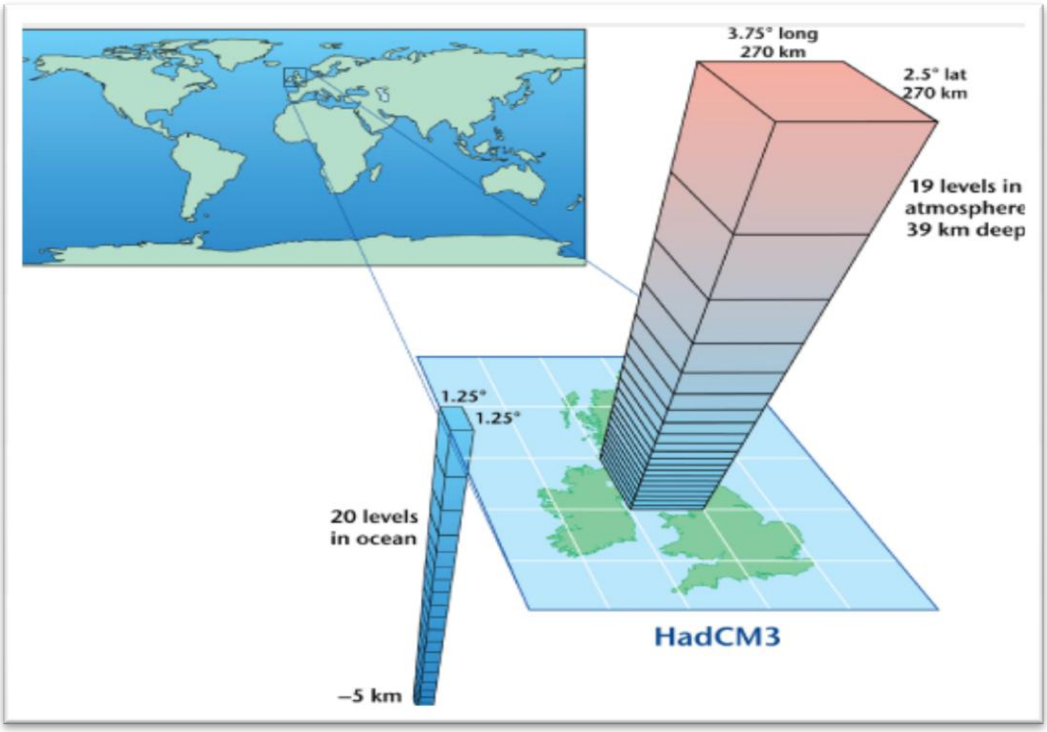

Figure 2.7 The horizontal and vertical structure of the HadCM3 climate model (UKCP09, 2010a)

In a GCM the surface of the earth is broken up into a number of latitude/longitude grid boxes, with the atmosphere divided into layers between the surface and the stratosphere, and the ocean divided up between the surface and the deepest waters (figure 2.7). It is at the points of this three-dimensional grid in the atmosphere, that a number of equations derived from the basic laws of physics are solved to describe the large-scale momentum, heat and moisture parameters. A similar process is ensued with the ocean, but with different variables. The third Met Office coupled Atmosphere-Ocean Global Circulation Model (AOGCM), HadCM3, has a resolution over land areas of 2.5° latitude x 3.75° longitude, with 19 vertical levels in the atmosphere and four layers in the soil. The ocean model has 20 vertical levels and a grid size of 1.25° latitude x 1.25° longitude (UKCP09, 2010a). In total there are about a million grid points covering the globe in the model.

2.6.1 Evolution of Climate Models

The continuous evolution of GCMs over recent decades has been facilitated by a capacity increase in computer power, with supercomputer speeds increasing by roughly a factor of a million in the three decades from the 1970s (Le Treut *et al.*, 2007). Manabe and Wetherald performed the first three-dimensional model simulation showing the global climate response to a doubling of atmospheric carbon dioxide concentration (Hulme, 2009a), and although this work was ground-breaking there were significant flaws. Spatial resolution of the models was 500km and ocean dynamics were omitted, i.e. a 'wet surface' or simple 'slab' covering 70 per cent of the Earth's surface mimicked the ocean, with evaporation occurring to an infinite amount of water. Nevertheless, such model experiments led the way for further developments in climate modelling, with increases in complexity reflected in both the length of simulations generated, as well as the spatial resolution.

The more complex coupled ocean-atmosphere models which followed on from the earlier slab models, and the climate projections they make can investigate time-dependent scenarios of climate evolution, sometimes including interactive chemical or biochemical components. The replacement of 'slab' ocean models by fully coupled ocean-atmosphere models at the end of the twentieth century may have constituted one of the most significant leaps forward in climate modelling (Trenberth, 1993). Simpler models, however, are still used in a hierarchical manner, along with more complex computer models, as a 'hierarchy of models' is the only way to provide a linkage between theoretical understanding and the complexity of realistic models (Held, 2005). Models, nonetheless, do not provide a perfect simulation of reality, because the capability of resolving all necessary spatial and temporal scales is not entirely possible even with today's technology, and with the behaviour of such a complex nonlinear system being generally chaotic, it proves difficult to predict reality.

Figure 2.8 illustrates the progression of climate models over time, showing that CO_2 and rain were the only main parameters included in the mid-1970s. FAR, SAR, TAR stand for first, second and third assessment reports respectively, as published by the IPCC in 1990, 1995 and 2000. AR4 refers to assessment report four published in 2007. It can be observed how the complexity of the models has increased greatly from the initial stages of modelling, with the inclusion of many more components, processes and interactions (IPCC, 2007a).

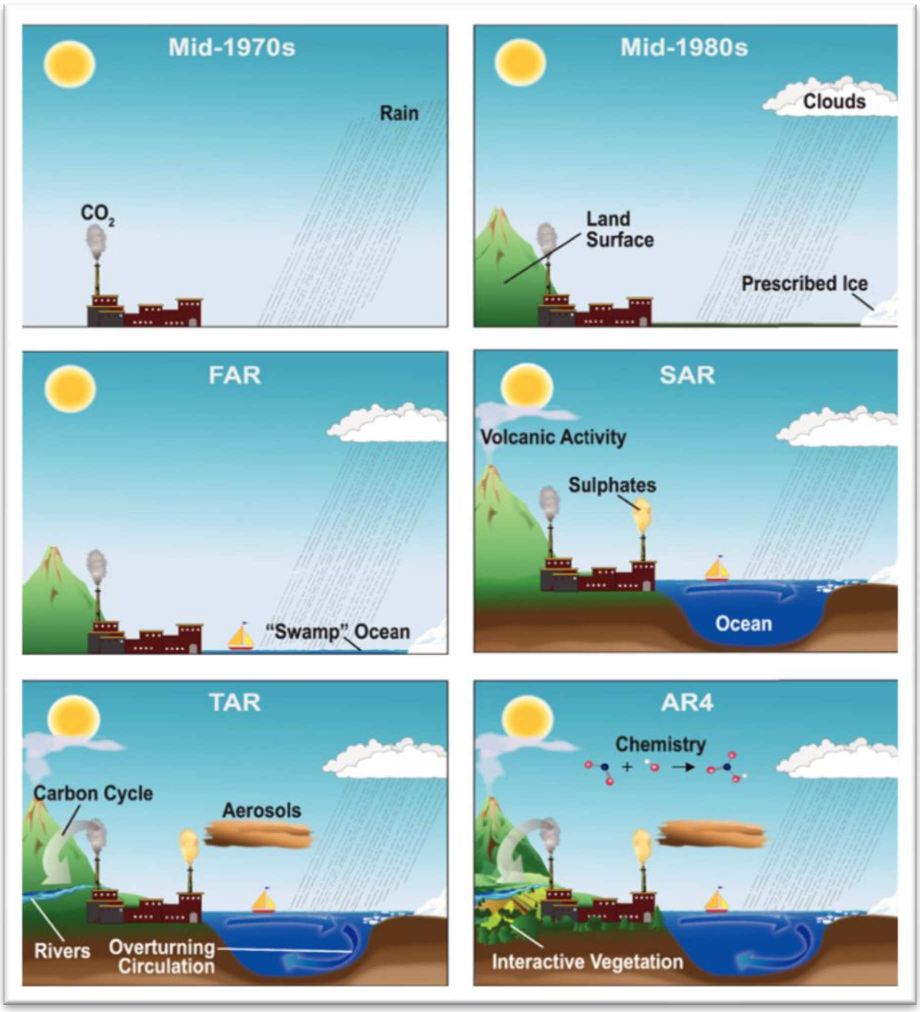

Figure 2.8 Pictorial images denoting the increase in complexity of climate models over the last few decades (Randall *et al.*, 2007).

2.6.2 Confidence of Climate Models

The fact that the underlying basis of the climate models is accepted physical principles, lends confidence to the models and the simulations they produce. Confidence can also be gained through their ability to reproduce current climate and paleo-climate changes, such as the warm mid-Holocene of 6,000 years ago or the last glacial maximum of 21,000 years ago 'but such opportunities are much more limited than are those available through weather prediction...as there are no precise past analogues for future predictions' (Randall *et al.*, 2007). Models are often justified by simulating the observational records and give a realistic representation of the climate system, responding to its anomalies (Cox *et al.*, 2000). There is a cascade of confidence in the projections made by climate models; at the continental scale, confidence is moderate, whereas at the finer 25 km resolution, local conditions such as mountains and coasts are represented and they modify the large scale changes thus increasing confidence levels. Confidence is also higher for certain climate variables in the model estimates (e.g. temperature) than for others (e.g. precipitation), due to the complexities and scales of predicting such parameters (Randall *et al.*, 2007).

2.6.3 Limitations of Climate Models

Even though computers have advanced considerably over time, there are still limitations in their ability to represent the climate system accurately. The confidence in climate models has undoubtedly increased over the last decade, but there are still significant errors, which are mostly apparent at the smaller scale. Problems that still remain at the larger scale include deficiencies in the simulation of tropical precipitation and the El Nino southern oscillation (Randall *et al.*, 2007). There are vacant gaps of knowledge in understanding scientific aspects of the climate, along with the availability of detailed observations of some physical processes, e.g. clouds. The rounding of errors and averaging also adds to the uncertainty of the mathematical models, as deviation from the truth increases as more and more equations are involved. As a result of the limitations, and the various methods models employ, the range of possible climate changes simulated, in response to specified greenhouse gas forcing, is considerable.

The limited resolution ability of global models results in some important physical processes being inaccurately represented: e.g. the formation and precipitation of cloud droplets that operate at a scale too fine to be modelled (Lovejoy and Hannah, 2005). Consequently these processes have to be parameterised (an element of 'up-scaling' has to be applied to such variables in the model). Grid scaled variables like wind, temperature, humidity, etc. 'which are explicitly described in the model' (UKCP09, 2010a) are used to estimate the sub-grid scale processes to be parameterised. A combination of physical theories, observations, experimentation and expert judgement are applied to various equations, for example, in trying to portray the statistics of the cloud field (e.g. the fractional cloudiness or the area-averaged precipitation rate) so that such climate processes can be represented in the climate model. As "realistic parameterizations of cloud processes are a pre-requisite for reliable current and future climate simulation" (Randall *et al.*, 2007), it is important that these up-scaling processes take place.

The feedback processes in the climate system can act to either amplify (positive) or reduce (negative) the initial effect, whether it be warming or cooling. The uncertainty in modelling the future climate is exacerbated with the incorporation of feedback processes, and this, along with differences in the methods employed to simulate these feedbacks in GCMs, results in a range of climate sensitivities and predictions for a future with increased greenhouse gas concentrations. In certain models, artificial corrections (known as flux adjustments) are imposed, as components of the climate system can only be approximate representations of the real world. When these are coupled together, the simulated climate tends to drift further away from reality (Hulme and Carter, 1999). A greater number of climate models, however, are now being developed that do not alter the surface heat, water and momentum fluxes artificially to maintain a stable control climate (Randall *et al.*, 2007).

2.6.4 Predictions and Recent Improvements

Despite the clear limitations of GCMS, they do however provide the best information available on how global and regional climate may change as a result of increasing atmospheric greenhouse gas concentrations (Hulme & Carter, 1999). "Models are unanimous in their prediction of substantial climate warming under greenhouse gas emissions" (Randall *et al.*, 2007), with their continuous development providing a consistent and robust picture of climate warming. The increase in computational capacity and power over the last few decades has further enabled the reliability of such models.

The comprehensiveness of models is also increasing with regards to the treatment of the climate system, with recent model improvements including (Randall *et al.*, 2007):

1. Dynamical cores (advection etc) have been improved, and the horizontal and vertical resolutions of many models have been increased.
2. The representation of physical and biophysical processes and interactions at a greater, more in depth level.
3. The inclusion in some GCMs of plant responses, ocean biological and chemical interactions, ice sheet dynamics, the modelling of aerosols and land surface.
4. The parameterisations of physical processes have been improved – for example most of the models no longer use flux adjustments.

The incorporation of all these advancements will be important for improving predictions of climate change.

2.7 Coupled Climate Models

Most GCMs neglect the feedback between climate and the biosphere and the complex carbon-cycle feedbacks that are involved. As Randall *et al.*, (2007) states, however, "coupled climate models perform generally better than atmosphere-only models, and reveal the amplifying roles of ocean and land surface feedbacks in climate change". The ocean is as important a feature of the climate models as the atmosphere, since ocean currents transport vast amounts of heat from the equator to the poles, as well as having a very large thermal inertia (Lovejoy and Hannah, 2005). Also, the exchange of heat, momentum and water vapour between the ocean and atmosphere plays a part in regulating the climate. Representation of such features in coupled atmosphere-ocean models has, only in the last decade or so, been used to portray an overall picture of the climate for the future.

Coupled climate models are an essential tool, for both making predictions, and for increasing the understanding of feedbacks and sensitivities. Only about half of the current emissions of carbon dioxide are absorbed by oceans and ecosystems, but the facilitation of such processes is climate dependant. The future atmospheric CO_2 concentration is therefore not easy to predict in relation to working out future climate change (Dufresne *et al.*, 2002). The rising concentrations of the gas is believed to cause an increase in plant photosynthesis (DeLucia *et al.*, 1999) and carbon dissolution in water (Oeschger *et al.*, 1975), whereas the related climate change associated with rising CO_2 emissions is known to reduce ocean carbon uptake (Sarmiento *et al.,* 1998) and the terrestrial carbon uptake (Cramer *et al.*, 2001), resulting in a positive feedback.

The inclusion of the terrestrial biosphere model, that replicate changes in terrestrial carbon sources and sinks, into fully coupled climate models, is a leading development in climate science, resulting in new and potentially important feedback into the simulated climate system on time scales of decades to centuries. Some coupled climate/carbon-cycle models are also linked to a dynamic global vegetation model (DGVM), so as well as the exchange of CO_2 between the atmosphere and the ocean, and the relationship between soil carbon and atmospheric levels of CO_2, the dynamics and extent of up to five functional types of plant within grid boxes of the models are also considered. As Cox *et a*l. (2000) infers, this allows the interplay between factors of the climate system and external forcings to be fully represented.

2.7.1 Coupled Carbon-cycle/Climate Model Studies

The first two studies to investigate the effect of incorporating an interactive carbon-cycle into an AOGCM discovered that there was a positive feedback response, with an acceleration of global warming being the outcome (Friedlingstein *et al.*, 2006). Cox *et al.* (2000) used a fully coupled, three dimensional carbon-climate model – the HadCM3, which was also coupled to an ocean carbon-cycle model (HadOCC) and a DGVM, with the atmospheric physics and dynamics consistent with the HadCM3. Emission scenario IS92a (from the first set of IPCC scenarios) was used for the transient simulations between 1860-2100, reproducing observational records and thus lending the model validity. Sulphate aerosols, however, and their radiative effects were neglected, a possible flaw due to the cooling effect created when these aerosols are formed. Three varying simulations were run to demonstrate the effect of climate-carbon cycle feedbacks. Dufresne *et al*. (2002) used an AOGCM - Institute Pierre Simon Laplace model IPSL-CM2, coupled to land and ocean carbon models to simulate the progression of climate and atmospheric CO_2 between 1860-2100; a control simulation was run with no anthropogenic CO_2 sources. The simulation used IPCC SRES98-A2 emission scenario from 1990 to 2100 (Nakicenovic *et al.,* 2000), which is an updated version of the earlier IPCC IS92a scenario. Both studies used similar methodologies, although Dufresne *et al*. (2002) applied no restoring term of flux adjustments and they did not use a terrestrial model that accounts for vegetation dynamics.

In Cox *et al.* (2000) simulations it was predicted that, as emissions of CO_2 increase and thus atmospheric levels increase, by 2050 the land biosphere becomes a strong source of CO_2 rather than a sink, with 'widespread climate-driven loss of soil carbon'. Normally the rates of photosynthesis as well as terrestrial carbon stocks increase when there is an increase in atmospheric CO_2, as Hughes (2000) discusses, with CO_2 having a direct fertilisation effect on plants. However, with the indirect effect of CO_2 being warming, other factors like plant maintenance and soil respiration consequently increase and thus reverse the initial increase in terrestrial carbon storage levels, leading to the land biosphere becoming a source of CO_2 (Cox *et al.*, 2000). This becomes more apparent when temperatures increase dramatically midway through the 21st century, with a reduction of terrestrial carbon by about 170GtC between 2000 and 2100, and a consequent increase in the rate of CO_2 in the atmosphere (Cox *et al*., 2000). Figure 2.9 shows that the terrestrial biosphere takes up CO_2 at a decreasing rate from 2010 onwards, becoming a net source at around 2050. By 2100 this source from the land almost balances the oceanic sink, so that atmospheric carbon content is increasing at about the same rate as the integrated emissions (Cox *et al*., 2000). Both Dufrense *et al.* (2002) and Cox *et al.* (2000) forecast that the CO_2 induced climate change will reduce the land carbon uptake, with a bigger percent of anthropogenic CO_2 left in the atmosphere.

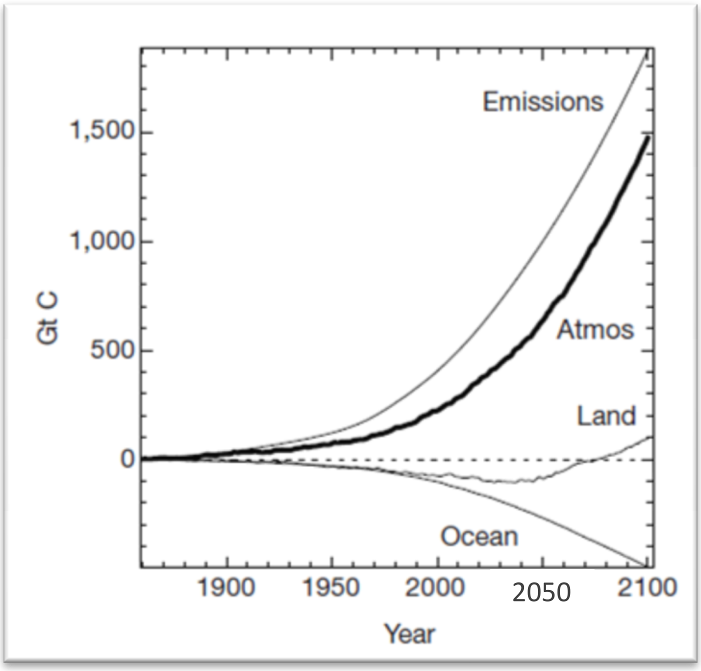

Figure 2.9 Budgets of carbon during the fully coupled simulation (Cox *et al.*, 2000).
The thick line shows the simulated change in atmospheric CO_2. The thinner line shows the integrated impact of the emissions, and of land and ocean fluxes, on the atmospheric CO_2 increase with negative values implying net uptake of CO_2 (Cox *et al.*, 2000).

In the experiment reported by Cox *et al.* (2000) concentrations of carbon in the model reach around 980 ppmv (parts per million by volume) by 2100, compared to about 730 ppmv calculated using the IS92a scenario. As a result the global-mean land temperature increases by about 8 K between 1860 and 2100, with the rise being only 5.5 K in the standard non-coupled scenario, exemplifying the difference a coupled climate model can make (Cox *et al.*, 2000). In the Dufresne *et al.* (2002) scenario simulation, it was found that by 2100 the atmospheric CO_2 concentration is 770ppmv, with a global temperature increase of 3°C (4.4°C over the continents) and a small precipitation increase (4%). The oceanic circulation shows a small but significant reduction of the thermohaline circulation, and of the deep convection at high latitudes. The warming in the Hadley model may be larger due to the fact that Cox *et al.* (2000) account for more than just CO_2 emissions (CH_3, N_20 etc), whereas IPSL only accounts for CO_2. It is not due to differences in the IPCC forcing scenarios, but rather to large differences in the model sensitivities (Friedlingstein *et al.*, 2003).

In Cox *et al*. (2000), although the oceanic CO_2 uptake over the 21st Century does increase overall, the efficiency of the uptake decreases to some extent because of the 'nonlinear dependence of the partial pressure of dissolved CO_2 on the total ocean carbon concentration'. As Sarmiento *et al*. (1998) discuss, climate change may be a contributing factor to this reduction, as the consequent warming and increased stratification on the ocean has an effect on the downward flux of carbon, with solubility of CO_2 decreasing relative to a constant climate control scenario. When Sarmiento *et al*. (1998) used an AOGCM (simulating the observed temperature record) coupled to an ocean carbon only model, they found that climate change reduces ocean carbon uptake, which contradicts with the findings of both Dufresne *et al*. (2002), and Cox *et al*. (2000). This indicates that atmosphere and ocean carbon models may be more reliable; they find that reduced land uptake of CO_2, through enhanced atmospheric CO_2 results in increased ocean uptake, a feedback that must be neglected in ocean carbon only studies (Dufresne *et al.*, 2002). It is important to consider the feedbacks between the climate system and the global carbon cycle simultaneously.

Reasons for reduced land CO_2 uptake over time are due to reductions in net primary production (NPP) for both models with the associated warming and soil drying, but the soil respiration rate (SRR) increases much more in the Cox *et al*. (2000) model due to warming, compared with Dufresne *et al.* (2002). Change in landcover due to deforestation is not accounted for in either model, which could indicate the models overestimate CO_2 absorption in regions where deforestation may occur in the future. The effect of temperature on soil respiration is still a debateable topic which puts uncertainty on all results calculated. Changes in landcover and land use, through human intervention, will also play a role in terrestrial carbon uptake and whether it acts as a source rather than a sink over the 21st century (Cox *et al.*, 2000).

Both studies confirm that there is positive feedback between the climate and carbon cycle, as a result of climate impact on the terrestrial biosphere, but that it is the land response to global warming that essentially explains the differences between the Dufresne IPSL model and the Cox Hadley model results, and thus more research into model sensitivities is required. Being the first two studies to investigate the effect of a carbon-cycle incorporated into a climate model, the studies have shown the importance of the climate-carbon cycle, with results showing a substantial increase in temperature when compared to standard non-coupled scenarios. If predictions for future climate change are to be successfully calculated such models need to be utilised.

The ocean plays a vital part in the climate system, distributing heat and acting as a CO_2 sink. The next section describes how the global ocean circulation system can have a strong effect on global climate change, and how some models have shown that there may not be an increase in temperature in years to come, particularly over Europe.

2.8 Global Ocean Circulation & Climate Models

The thermohaline circulation (THC) is a global ocean system, whose currents transfer large amounts of heat (thermo) and salt (haline) around the world. Ocean density is determined by these two important variables. The THC is the engine of the Meriodional Overturning Circulation (MOC), which is a constant overturning of the ocean's deep water from north to south in the North Atlantic, incorporating both thermohaline driven deep-ocean movements, and the wind driven movement of water at the ocean surface. The THC is driven by the sinking of cold dense water in the northern North Atlantic, known as deep water formation, and this is the most important aspect of the circulation (Broecker, 1991); high salinity levels in the surface waters and cold air temperatures increase the density of the water and cause it to sink. As the surface water is converted to deep water, it releases heat to the atmosphere, believed to be responsible for the mild climate over western and northern Europe. The Great Ocean Conveyor (GOC) as shown in figure 2.10 is the combined movement of the THC, the MOC and surface currents.

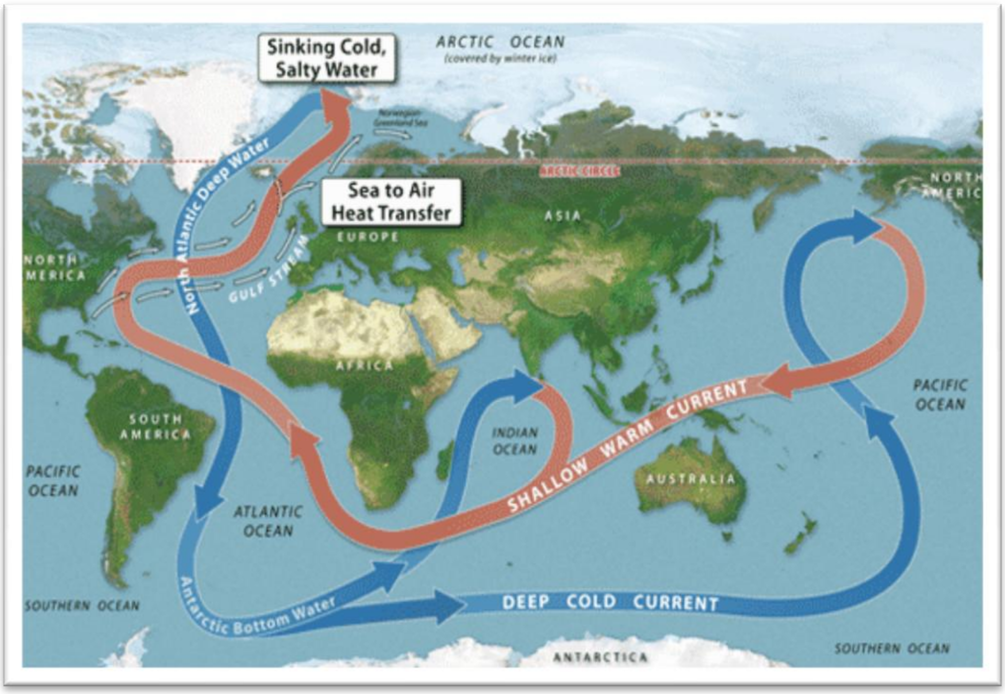

Figure 2.10 The Ocean Conveyor Belt (Smithsonian Institution, No date)

2.8.1 THC Weakening and Global Cooling

The effect that an increase in sea-surface and air temperature resulting from global warming may have on the circulation could lead to a slowing or weakening of the THC, Manabe and Stouffer (2007) report 'the simulated conveyor weakens as global warming proceeds'. Coupled atmosphere ocean models, which plausibly reproduce the conveyor mechanisms, have predicted that the excess heat flux due to increased atmospheric CO_2 could be responsible for about 20% weakening of the THC

(Manabe and Stouffer, 2007). Further weakening could be attributable to increased freshwater input at the surface, from increased precipitation and surface run-off. It is the magnitude of such inputs and the sensitivity of the circulation to this increase that is mainly responsible for the huge variation between models. The low spatial resolution of GCMs also prevents predictions of a suitably comprehensive manner being observed in relation to potential or probable THC-induced climate change in Europe. Understanding of the conveyor, however, suggests that a collapse of the THC in the North Atlantic could cause cooling over northwest Europe (e.g.Broecker, 1987), a factor which needs to be considered when understanding likely future climate change.

A study undertaken by Jacob *et al*. (2005) shows that a weakening of the THC could lead to much lower temperatures around the northern North Atlantic, disagreeing with observations from a majority of GCMs and palaeo-observations of a climate warming. Using a GCM they carried out a THC-slowdown sensitivity experiment, by comparing a 50% weakening of the MOC, with the associated control experiment.

Regional sensitivity and control climate models for Europe were then constructed from the two global simulations, to produce detailed future projections. Regional models and their higher resolution allow for better simulations of physical geographical features, and thus better weather predictions. These models, however, use an externally imposed additional freshwater flux into the northern North Atlantic, which as discussed in section 2.6.3, can cause excessive climatic drift. Greenhouse gas emissions were set at pre-industrial levels, the use of which is justified by the Couple Modelling Intercomparison Project (PCMDI, 2012) and its defined protocol. An additional 0.1 Sverdrup (Sv – a unit of measure of volume transport, in relation to ocean currents) of freshwater is incorporated into the flux adjusted model, which is equivalent to 1/6 of the Greenland ice sheet melting over 100 years.

Results show that there is a weakening of the THC strength from a mean of 15 Sv in the coupled control simulation, to 8 Sv in the flux perturbation run. This decrease leads to a reduction of the maximum meridional heat transport, with a consequent cooling in the North Atlantic sector of more than 3°C, and thus significantly, for all of western and northern Europe. It is predicted that there will be a larger fraction of snow in precipitation, more so with the regional model outcomes. There is also enhanced snow cover over Europe under the sensitivity experiment, with most parts of Britain experiencing more than ten ‘snow days’ over a year, with a snow day defined as a day with more than 3cm water equivalent of snow. In contrast, the control experiment shows Britain only receiving more than ten days of snow cover in areas of high altitude. Jacob *et al.*’s (2005) model suggests a weakening of the THC, which indirectly initiates a positive feedback loop; with an increase in albedo through more snow cover, it results in more of the sun's energy being reflected thus leading to further cooling.

The models developed by Jacob *et al*. (2005) were addressing the consequences of THC changes in a "current climate" setting, or those following a moderate meltwater discharge, and thus not based on enhanced greenhouse gas emissions as predicted for the future. However, what they do highlight is the difference a regional model nested into a global model can make to climate predictions. This kind of model creates the 25km climate change projections used in this research, instilling confidence in the outcomes.

2.8.2 Concluding the Climate Models

The uncertainty of interactions between the climate components within the models considered has led to a number of outcome predictions for the future. Model uncertainty and differences between models leaves doubt about what may actually happen over the 21st century.

A model which has been used in many climate prediction studies is the HadCM3, the model used to create the climate projections for UKCP09, the projections of which are used in this research. It is a fully coupled three dimensional carbon-climate model, as used by Cox *et al.* (2000); the inclusion of the carbon-climate cycle, as exemplified, is important for future climate change due to the feedback effect this has on the climate system. It also does not use flux adjustments which can distort the outcome. Wood *et al.* (1998) believe that the HadCM3 model has 'reached a level of realism', which adds validity to its use in the projections. HadCM3 was also one of the models used by the IPCC, and it was also used in the Coupled Model Intercomparison Project (CMIP3), the biggest and most comprehensive international GCM experiment ever attempted. HadCM3 was ranked highly in a current evaluation of climate models with observations (Reichler and Kim, 2008), and so it is believed to be one of the best models currently in use. The next section is focused on the range of emission scenarios created, which drive the GCMs to produce various climate scenarios for the next 100 years.

2.9 Climate Projections UKCP09

The UK Climate Projections 2009 (UKCP09) provide climate data and facts, with the aim to help those who need to prepare and adapt in order to mitigate the likely impacts of climate change (UKCP09, 2012d). The information is intended to be suitable to support user decisions in the real world; methods for projections have therefore been rigorously tested. Using a new methodology designed by the Met Office Hadley Centre (MOHC), the UK's official centre for climate change research, UKCP09 have produced the fifth generation of climate change information for the UK including probabilistic projections, utilising HadCM3. As the term 'projection' implies, the climate of the future could be one of many possibilities (Lovejoy and Hannah, 2005), depending on the workings of the climate system.

In comparison to UKCIP02, the previous climate projections, the UKCP09 projections are much more advanced with inclusion of sampling uncertainties of climate system processes in the GCM (Jenkins *et al.*, 2009). UKCP09 considers more feedbacks than previously, and methodically explores the uncertainties related to them. The resolution of UKCIP02 only went as high as 50km, compared to UKCP09's 25km grid resolution, reflecting greater accuracy of local climate feedbacks.

2.9.1 Model Description

HadCM3 is an AOGCM, which uses perturbed physics ensembles (PPE), discussed in section 2.9.1.1, to generate the projections. Both atmospheric and oceanic processes were accounted for in the modelling, 'providing a realistic representation of the climatological processes' (UKCP09, 2012b). The models are also quite advanced in that they consider feedbacks associated with the carbon cycle and the sulphur cycle, as well as some ocean transport processes. As it is unlikely that there will be a drastic change in the Atlantic Ocean MOC this century, only the effects of a gradual weakening of the circulation over time are included in the UKCP09. Variations in external factors like solar activity and volcanic eruptions cannot be predicted, and are not considered in the projections. UKCP09's models comprehensively sample key uncertainties systematically, in carbon cycle processes and downscaling, as well as internal climate variability and uncertainties in atmospheric and oceanic processes.

Sampling uncertainty in processes affecting oceanic uptake of carbon are not performed in the UKCP09 models, which as discussed in section 2.7.1, is expected to increase over the 21st century (Cox *et al.*, 2000). Carbonaceous aerosols, non-aerosol atmospheric chemistry and methane cycle feedbacks are also omitted from the simulations, all of which would have an effect on the forcing of the climate (Murphy *et al.*, 2009). There are nonetheless limits to computational power, modelling capacity and current comprehension and all possible future outcomes may not be captured.

An assumption in UKCP09 (2012a) is that projections of future climate by certain models are deemed to be more reliable if they accurately simulate recent climate observations, at the global scale. Different weights are then placed on these variants accordingly when simulations are run. Consideration at the global scale is important as studies have shown UKCP09 (2012a) that 'large scale processes dominate local responses to forcing'.

2.9.1.1 Perturbed Physical Ensemble

As mentioned in section 2.6.3 parameterisations are used to account for the unknown outplay of some climate system processes. There are considerable uncertainties associated with many parameters, i.e. they are poorly constrained by observations. Parameters regulating principle physical and biogeochemical processes in the HadCM3 AOGCM can be adjusted accordingly to represent different plausible interactions that may occur in earth system processes (Murphy *et al.*, 2009). Practice is therefore to run a set of simulations sampling each relevant parameter combination, giving different possible model variants. This is phrased a Perturbed Physical Ensemble (PPE), which is the method adopted in the UKCP09 projections, with a climate change projection generated for each variant (Murphy *et al.*, 2009). These outcomes are then weighted using historical observations. There are of course parameter errors in its representation of the real climate system. Exploration of the full range of variability of each model parameter is computationally not possible, but an evaluation of earth system modelling uncertainty and internal climate variability on feedbacks expected to have a considerable effect on climate change over the next century, is quantified through the use of a PPE (Murphy *et al.*, 2007).

Murphy *et al*. (2007) note that a Bayesian statistical framework underpins the ensemble simulations, whereby prior distributions for uncertain model parameters are approximated by experts based on their knowledge of the relevant physical processes. For more information on the methodology for climate change projections using perturbed physics ensembles the reader is referred to the paper by Murphy *et al*. (2007).

2.9.1.2 Multi-model Ensemble

The UKCP09 projections incorporate projections from other GCMs, more specifically 12 of the GCMs used in the IPCC's Fourth Assessment Report, to create a multi-model ensemble. This allows the integration of structural error (the difference between the real world and the model projections) in the projections, giving a more inclusive range of uncertainties than the HadCM3 on its own could provide. As the UKCP09 (2012a) methodology states ‘It prevents the models from being too heavily biased by the way in which one model is structured’.

2.9.1.3 Regional Climate Model

Projections were downscaled to a 25km grid over land areas of the UK, using the regional climate model (RCM) HadRM3 to produce high resolution climate change projections (UKCP09, 2012c). RCMs take into account the smaller scale topographical features not detected by GCMs, and thus the local climate change is projected more realistically and at a scale more preferable for decision making. The RCM is essentially nested into an AOGCM, which has a corresponding simulation with ‘spatial scales skilfully resolved by the latter’ (NERC, 2011), known as the downscaling process. As Denis *et al.* (2002) states “Nested RCMs have been shown to generate skilful fine-scale information in idealised predictability studies”, exemplifying their practicability for decision making.

Uncertainty is introduced when downscaling projections, but this aims to be captured by the model from an ensemble of 11 different simulations of HadRM3 (NERC, 2011). This is a similar process as performed for HadCM3 whereby parameters are varied to represent the different possible physical processes of the climate system. Greater confidence can then be assigned to the method used to produce the climate change projections.

2.10 Emission Scenarios and Climate Predictions for the Future

2.10.1 What are Emission Scenarios?

Emission scenarios are plausible representations of the potential future discharges to the atmosphere of substances (both natural and man-made) that affect the Earth’s radiation balance, such as greenhouse gases and aerosols (or aerosol precursor emissions like sulphur dioxide), (Nakicenovic *et al.*, 2000; Moss *et al.*, 2010). When emission scenarios are developed in relation to climate change, they are not forecasts or predictions, but mirror the expert judgement attained through research done on socioeconomic (changes in population, GDP and energy use), environmental, and technological trends and developments (Moss *et al.*, 2010). These are the driving forces and they take into account emissions generated from energy, industry and land-use change. Climate scenarios developed using emission scenarios portray likely future climate conditions, such as temperature and precipitation. It is these climate projections which are used in this research.

2.10.2 The Special Report on Emission Scenarios

The IPCC in 1992 created the first global emission scenarios - IS92, providing estimates for the whole range of greenhouse gases. Since then, however, there has been a greater understanding of possible future greenhouse gas emissions and climate change, and a new set of emission scenarios now exist, published in 2000 in the Special Report on Emission Scenarios (SRES) (Nakicenovic *et al.*, 2000). The changes in understanding over the original scenarios relate to factors considering the carbon intensity of the energy supply, the income gap between developed and developing countries, and sulphur emissions:

"They include improved emission baselines and latest information on economic restructuring throughout the world, examine different rates and trends in technological change and expand the range of different economic-development pathways, including narrowing of the income gap between developed and developing countries" (Nakicenovic *et al.,* 2000).

In order to create the emission scenarios an extensive literature assessment was undertaken, various modelling approaches were utilised, and an 'open process' was conducted, whereby many groups and individuals were requested to participate and provide feedback. This can be seen as a very subjective approach, albeit a much rationalised one, constrained by scientific facts.

2.10.2.1 The SRES Storylines

The projections of the SRES incorporate a 'storyline' or a narrative of the future into their scenarios, facilitating their interpretation, thus making them widely popular (Nakicenovic *et al.,* 2000). The four emission scenario families developed under the IPCC SRES are A1, A2, B1 and B2 (see figure 2.11): in all there are 40 SRES scenarios branching from the initial four qualitative storylines. These initial four scenarios are known as 'marker scenarios'; they are of equal likelihood as any other scenarios, but the SRES writing team believe they represent a particular storyline. There are 6 scenarios groups drawn from the four families; one group each in A2, B1 and B2, and three groups in A1 each reflecting alternative developments of energy technologies. The wide range of scenarios produced consider all possible shares of the energy mix, with high dependency on fossil fuels, oil and gas or coal, to those governed by non-fossils. A1 and A2 are more market-oriented, as opposed to B1 and B2 being more environmentally aligned. A1 and B1 place more focus on global solutions, whereas A2 and B2 are more regionally oriented (Murphy *et al.*, 2009).

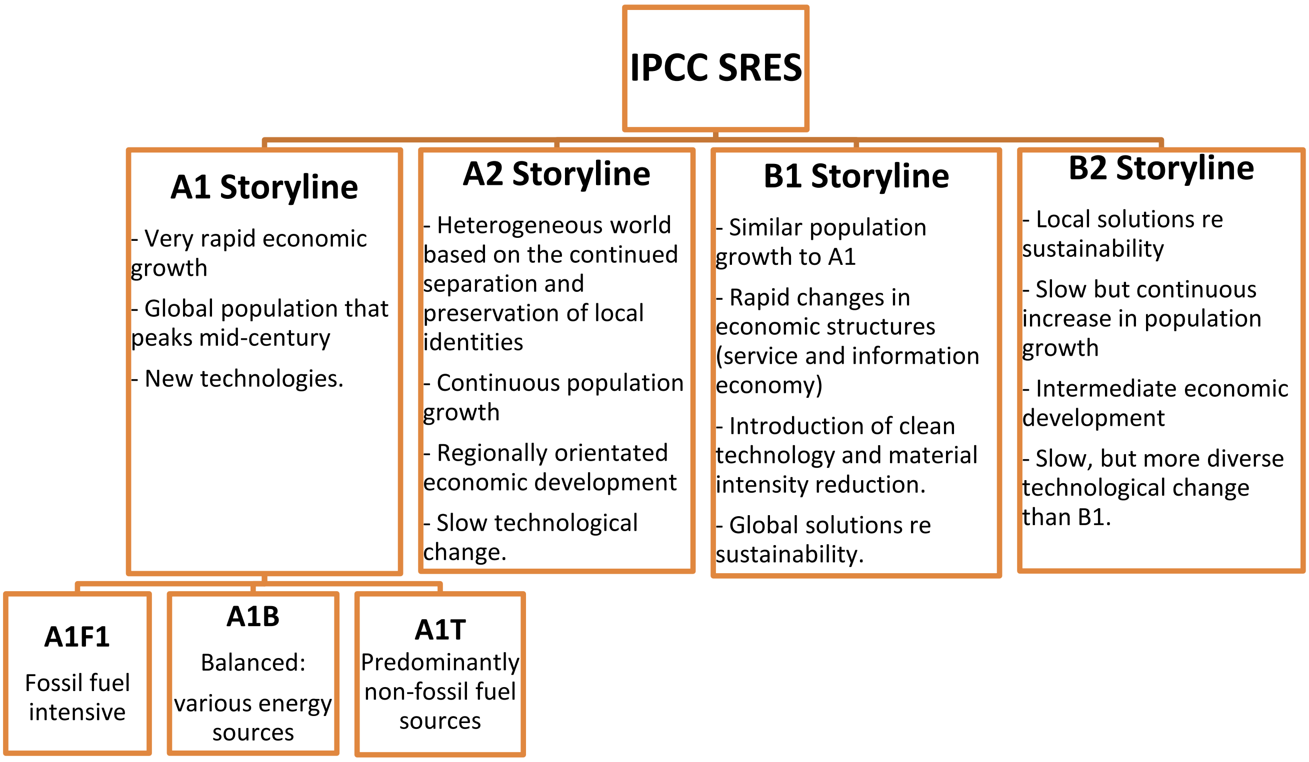

Figure 2.11 The IPCC SRES marker scenario storylines (based on (Nakicenovic *et al.*, 2000)

The scenarios are 'alternative conceptual futures' (Murphy *et al.*, 2009). A probability of occurrence cannot be attached to the different emission scenarios, but neither are they to be assumed as equally probable. The scenarios do not account for any future political action aimed at reducing emissions for climate change mitigation, i.e. the scenarios do not assume implementation of the UNFCCC or the emission targets of the Kyoto Protocol (Nakicenovic *et al.*, 2000). However, non climate change policies relating to development, resource use and pollution control, may influence GHG emission drivers at varying degrees, and this is portrayed to some extent in the scenarios.

A new generation of scenarios for climate change research and assessment have been developed by Moss *et al.* (2010). Although these reflect new economic data, information about emerging technologies, and observations of environmental factors like land use and land cover change, no climate scenarios have been developed using these emission scenarios, and they are therefore not considered any further in this present research. At the time the literature review was undertaken, the SRES were therefore the best scenarios to use.

2.10.2.2 The SRES Storylines: CO_2 and Temperature Projections

Figure 2.12 shows the variation in CO_2 emissions between the 4 main IPCC SRES including the 3 that constitute the A1 storyline. It can be seen that the B1 storyline results in the lowest amount of CO_2 emissions over the 21st century, in comparison to the A1F1 and A2 storylines emitting the most CO_2. This reflects how the storylines will develop over the next century, with the scenarios increasingly diverging after the 2040s as the differing scenario narratives proceed.

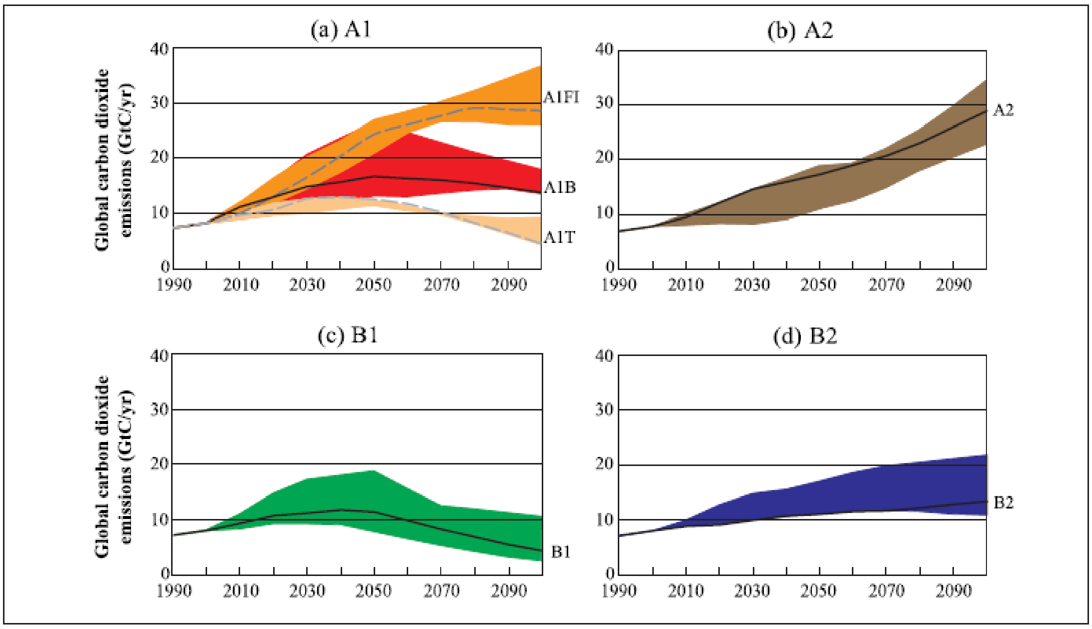

Figure 2.12 Total global annual CO_2 emissions from all sources (energy, industry and land-use change) from 1990 to 2100 (gigatonnes of carbon (GtC/yr) for the four IPCC marker scenarios and six scenario groups. (a) A1 (A1F1, A1B and A1T); (b) A2; (c) B1 and (d) B2. (Nakicenovic *et al.*, 2000)

The width of the colour band represents the range for that scenario family, encompassing all 40 scenarios between them.

Based on the varying CO_2 emissions over the 21st century, figure 2.13 shows the range of global surface warming (relative to 1980-1999) for the SRES. With the A1F1 relying heavily on fossil fuels for energy supply it results it the climate warming being the greatest, as opposed to the B1 scenario with the lowest expected warming due to the high uptake of low carbon technologies in this storyline. All scenarios will be subject to a degree of increased warming over the next few decades as a result of past CO_2 emissions and the inertia of the climate system. Across all 6 scenarios, the range of global mean temperature change between 2090 and 2099, relative to 1980-1999, is 1.1 to 6.4°C (IPCC, 2007). Warming over land will additionally be larger than the global mean, particularly over the high latitudes of the northern hemisphere. Globally averaged precipitation is expected to increase, as well as evaporation rates. Snow cover and sea-ice extent are projected to decrease.

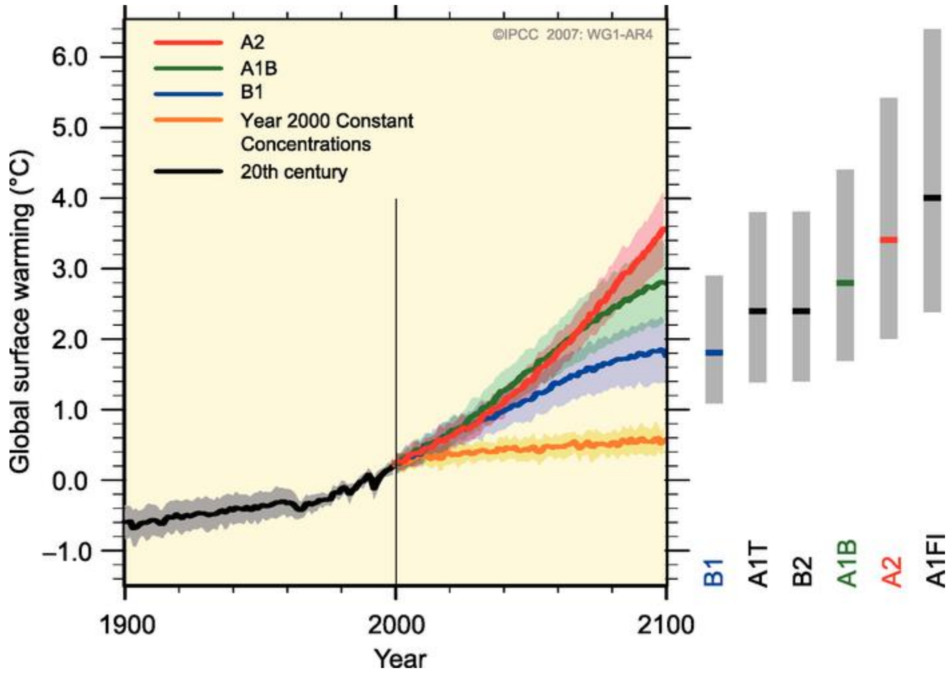

Figure 2.13 Global averages of surface warming (relative to 1980-1999) for the emission scenarios (SRES), shown as continuations of the 20th century simulations (Solomon *et al.*, 2007).

The Grey bars indicate the best estimate and likely range for the six SRES scenarios

2.11 UKCP09 Usage of the IPCC SRES

UKCP09 use the SRES to drive their GCMs leading to the generation of climate scenarios. They are known to be the most advanced climate scenarios in the world (UKCP09, 2010c). UKCP09 have developed climate scenarios for a number of variables under 3 of the IPCC's special report on emission scenarios, and have been labelled according to relative greenhouse gas emission levels: high (A1F1), medium (A1B) and low (B1) to show how the different emission pathways will affect future climates.

The underlying figures for the 3 IPCC scenarios used in UKCP09 are shown in tables 2.1, 2.2 and 2.3. The full range is given in Nakicenovic *et al.* (2000). These tables show the values for the illustrative scenarios.

Table 2.1 Main primary driving forces in 1990, 2020, 2050 and 2100 for the 3 emission scenarios used in UKCP09 (Source: Nakicenovic *et al.*, 2000)

Table 2.2 Main secondary scenario driving forces in 1990, 2020, 2050 and 2100 for the 3 emission scenarios used in UKCP09 (Source: Nakicenovic *et al.*, 2000)

Table 2.3 GHG, SO_2 and ozone precursor emissions[a] in 1990, 2020, 2050, and 2100, and cumulative carbon dioxide emissions to 2100 for the 3 emission scenarios used in UKCP09 (Source: Nakicenovic *et al.*, 2000)

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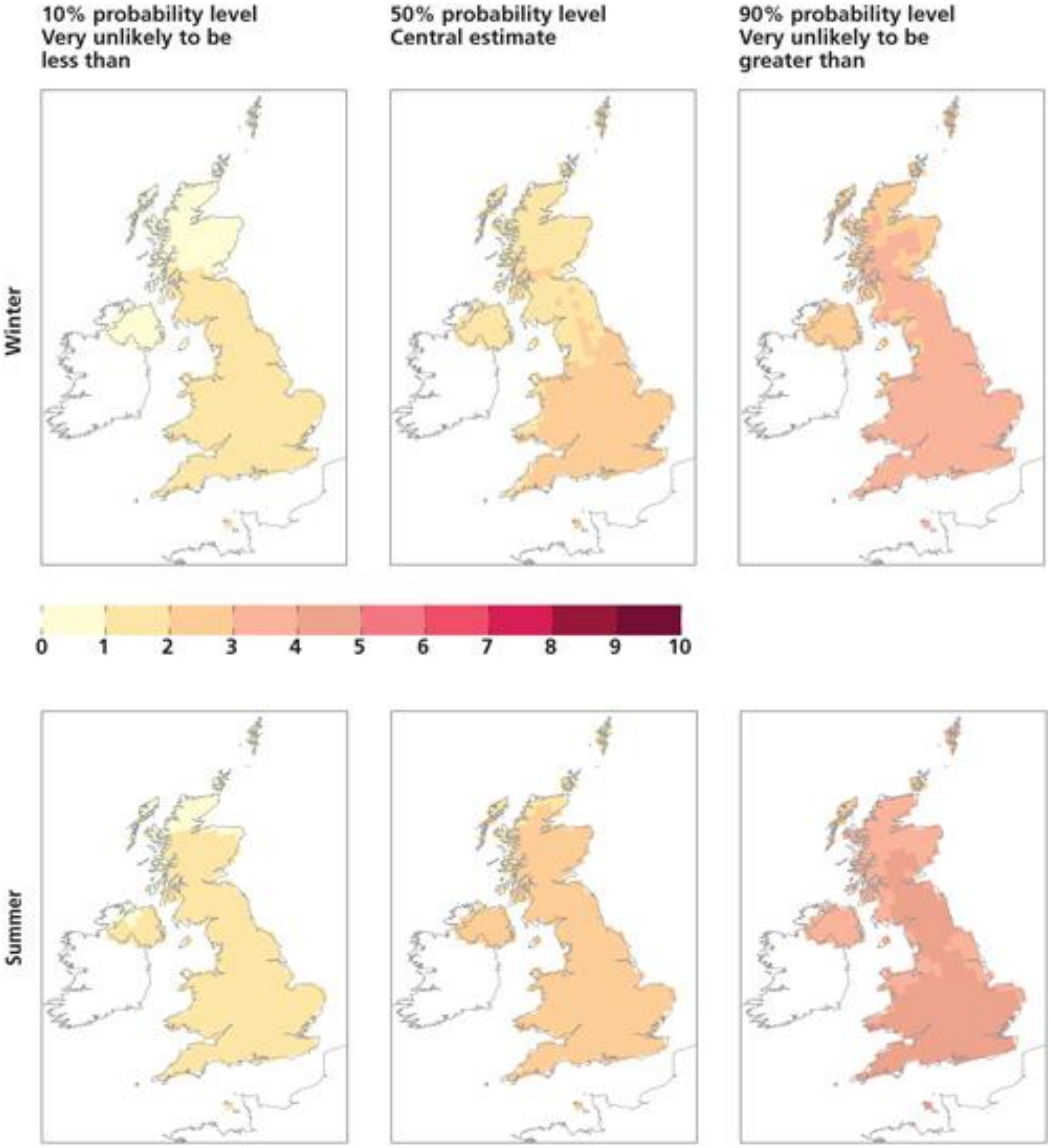
2.11.1 Projected Climate Changes

This section includes the projected temperature and precipitation changes under a medium emission scenario (A1B) in 2050 for the UK, based on change relative to a 1961–1990 baseline. The reasoning behind this emission scenario selection can be found in section 5.3.3. They are presented in maps of the UK with colour bars showing the change, with all maps being taken from UK Climate Projections 2009 data. The 10%, 50% and 90% probability levels for the future climate change are given.

Figure 2.14a shows that there will be a 1-2°C increase in winter mean temperature in the UK, under the central estimate, with possible increases of 4°C at the 90% probability level showing. Figure

2.14b shows that there will be an overall 2°C increase in summer mean temperature across the UK under the central estimate, with it very unlikely being greater than 3-4°C.



a)

b)

Figure 2.14 change in a) winter mean temperature (°C) for the 2050s under a medium emission scenario, and b) summer mean temperature (°C) (UKCP09, 2010c)

Figure 2.15a shows that there will mainly be a 20% increase in winter mean precipitation in most parts of the UK under the 50% probability level, with a 10% increase in more northerly parts. At the 90% probability level it is very unlikely that the increase will be greater than 30% in southern parts of the UK, with between a 10% and 20% increase in precipitation for the rest of the UK. Figure 2.15b shows mainly a 10% decrease in summer mean precipitation under a central estimate for the UK, with the 90% probability level showing generally a 10% increase in precipitation across the UK.

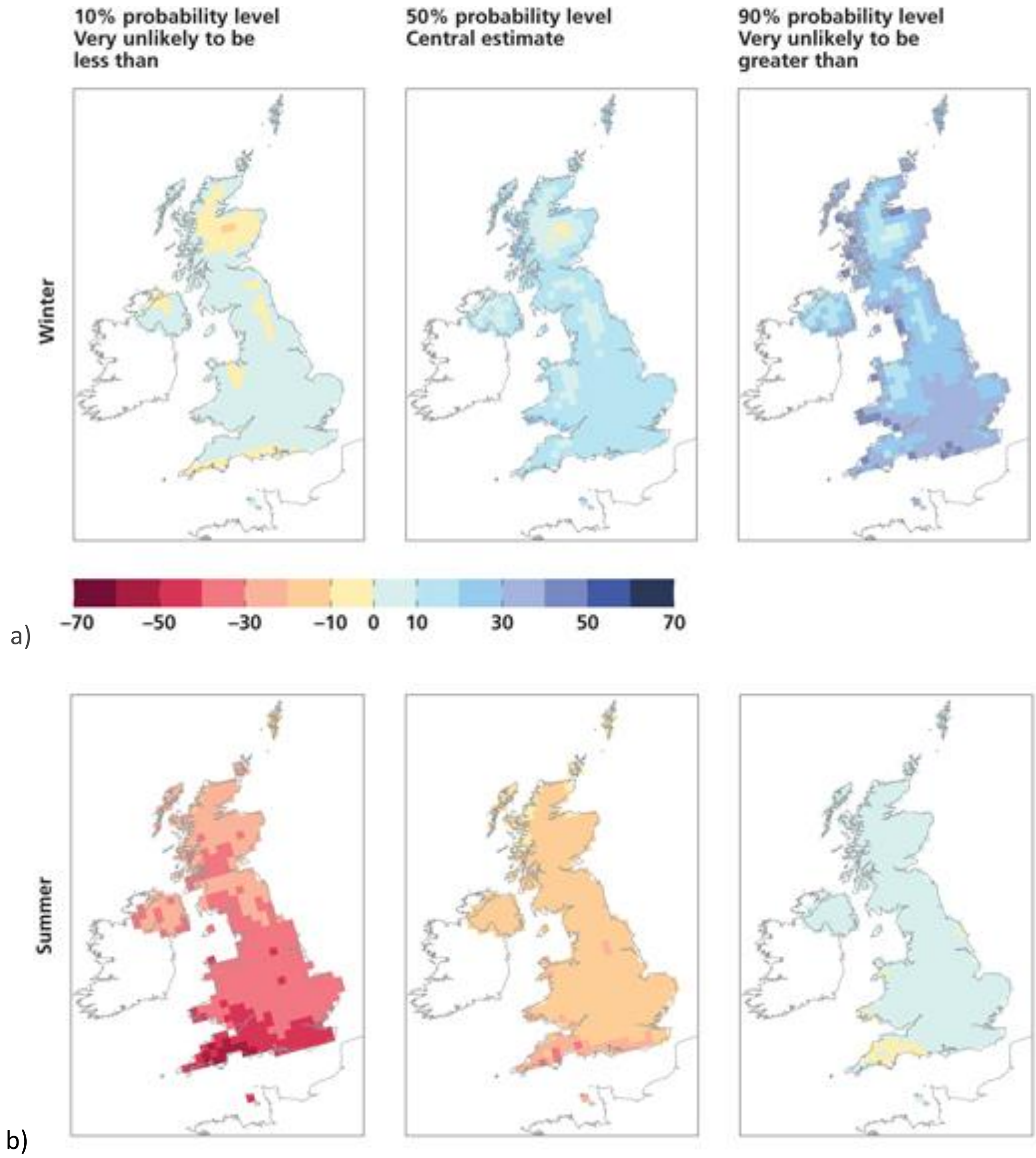


Figure 2.15 change in a) winter mean precipitation (%) for the 2050s under a medium emission scenario, and b) summer mean precipitation (%) (UKCP09, 2010c)

Figure 2.16 shows the change in summer mean temperature at the 10%, 50% and 90% probability levels under the low, medium and high emission scenarios to highlight the range in the resulting projections. Subtle temperature changes can have an effect on vegetation, as discussed in chapter 4, and so considering the possible variations for future projections of climate change is useful. Monitoring of the climate over the years to come will be necessary to observe which projection the UK is leaning towards.

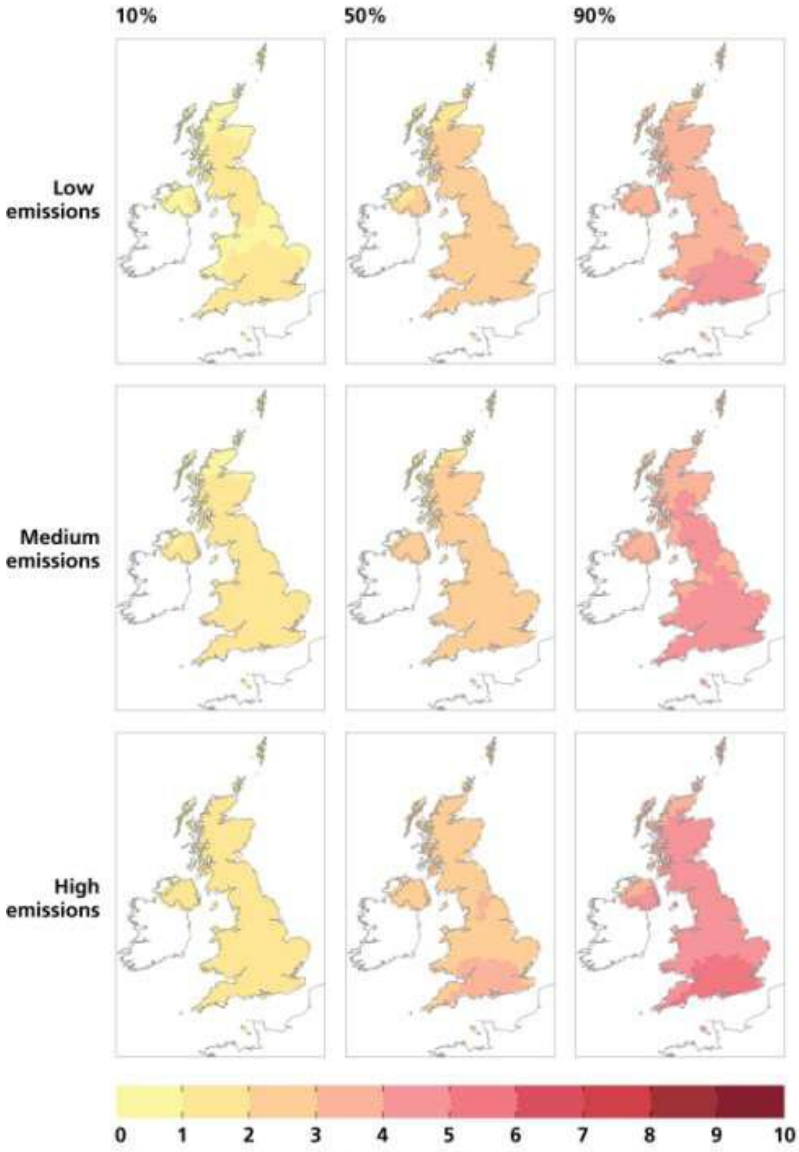


Figure 2.16 The change in summer mean temperature (°C) in the 2050s, over the 3 emission scenarios (UKCP09, 2010c).

2.12 Conclusion

Evidence has shown that climate change is having an effect on the Earth, with anthropogenic sources likely to be responsible, albeit in part, for the changes. Any mitigation measures implemented through international agreements will not be felt for a period of time, due to the inertia of the climate system and its response to past CO_2 emissions (Schneider, 1981). The problem has, however, been recognised and governments are seeking ways to limit the potential impact of climate change.

Although the climate system is made up of complex interactions between the atmosphere, the oceans, ice, land and the biosphere, it has been possible, through advancement of technology, and improved understanding of the various systems, to create global climate models for predicting future climate scenarios with relatively high confidence. The inclusion of the carbon cycle in the models, including HadCM3, has been of particular importance, due to its effect on the climate system (Cox *et al*., 2000). Models considering this cycle, project that the global warming effect will be enhanced in comparison to other models, due to the land becoming a carbon source half way through the 21st century. Climate warming could potentially weaken one of the main ocean circulation systems and in turn this could reverse the climate warming in some parts of the world (Broecker, 1987), illustrating the complex nature of the climate system and the feedback processes that operate within it. There are evidently discrepancies between the models created, but the majority of models project a climate warming over Europe, including the UK. The UKCP09 scenarios used throughout this research, the most up-to-date climate projections, indicate a climate warming in the UK with varying precipitation rates throughout the year.

The degree of climate change is not known, as this all depends on future emission scenarios which in turn depend on such variables as demographics and the development of clean technologies (Nakicenovic et al., 2000), but what is certain is the effect climate change has already had on the environment. Many of the planets' species are responding to the changes at varying rates, with certain ecosystems of the world likely to suffer more than others, as is discussed in the next chapter. The biodiversity of the planet must be protected due to the important services it provides.

3. The UK Planning System and Biodiversity

3.1 Introduction

Over the 20th century recognition of the need to protect the environment became evident. In the UK this has been achieved through the efforts of conservation movements and advances within the planning system, which over time has placed more obligations regarding the effects on the environment on infrastructure developers. UK policy has been heavily influenced by legislation developed at the EU level, with the EU being at the forefront in terms of commitment to protecting the environment (JNCC, 2011). In times when the need for economic prosperity has prevailed, and through careless actions, impacts to the environment have been significant, and in some cases damage has been irreversible, leaving the global environment in a poor state of repair (MEA, 2005).

Only near the end of the 20th century did the topic of biodiversity become an international concern, with the consequence that regulations pertaining to the sustainable use of biological resources across many nations have been tightened (UN, 1992a). Biodiversity awareness has increased, and a more sustainable ethos is now practised, with the environment given equal weight along with the economy and social factors when planning decisions are made. Sustainability needs to prevail and the environment preserved, so future generations can live in a world as previous generations have.

3.2 An Overview of Environmental Protection and Nature Conservation

Environmental protection measures through public control were developed as a result of the Industrial Revolution and the impacts to the land, water and air that were associated with this period of time. In relation to town planning provisions, the non-obligatory Housing, Town Planning Act 1909 was created in response to public health pressures and quality of life, which was followed by the Town and Country Planning Act (TCPA) 1947 (Bell and McGillivray, 2008). This act gave additional power to local authorities through the mandatory countrywide system of town and country development control. Although there was some consideration for the environment in these laws, less so in the early stages, voluntary organisations initially made sure nature was conserved as much as possible.

Recognition of the need for environmental protection, through the likes of the Wildlife Trusts (formally the Society for the Promotion of Nature Reserves), led to the creation of a legislative framework for nature reserves through the 1949 National Parks and Access to Countryside Act (Bell and McGillivray, 2008). Subsequently, a series of protected sites across the nation were established under the Act, including National Parks, National Nature Reserves (NNRs) and Sites of Special

Scientific Interest (SSSIs), which built upon the casual approach formally adopted through private land acquisition.

Following the 1970s and 80s boom of agriculture and development, many sensitive sites were devastated despite efforts from The Wildlife Trusts to control this. Funding was consequently sought to 'save our natural heritage for future generations' (The Wildlife Trusts, 2011). After campaigning for better habitat protection, in 1981 the Government granted increased protection to all SSSIs through Great Britain's first comprehensive legislation for wildlife – the Wildlife and Countryside Act (WCA). The deciding rules for protecting sites and species are now actioned through EC directives and international conventions (Bell & McGillivray, 2008). Amendments have strengthened the original laws passed in 1949, with the emphasis being on safeguarding designated sites through the legal process, rather than the previous voluntary approach (Bell and McGillivray, 2008). The Joint Nature Conservation Committee (JNCC) is a statutory advisor to the UK Government and the devolved administrations, with the aim of contributing to UK-wide and international nature conservation.

3.3 The UK Planning System

3.3.1 The Development Control Process

Since the TCPA 1947 Act development proposals are permitted through a case-by-case review system in Britain (Cullingworth and Nadin, 2002), with most developments requiring planning permission from the local planning authority before they can proceed. This is known as the development control process, and specialist environmental regulatory agencies are normally involved.

The definition of development is found in TCPA 1990, s.55(1) –

'Development...means the carrying out of buildings, engineering, mining or other operations in, on, over or under land, or the making of any material change in the use of any buildings or other land' (England and Wales Town and Country Planning Act, 1990).

Development plans are non-binding documents produced by Local Planning Authorities (LPAs) for their respective areas and influence development in the area (Cullingworth and Nadin, 2002). The 1947 Act defined a development plan as 'a plan indicating the manner in which a local planning authority propose that land in their area should be used'. Environmental protection is considered in these plans in line with central government policy guidance, i.e. which is currently enforced through the National Planning Policy Framework (NPPF) (DCLG, 2012). The development plan, the wider government policies and any other material considerations are taken into account when making a decision on planning applications. Even when planning permission is granted, the local planning authorities can still impose some form of control over the development activities through setting conditions and entering into agreements (Cullingworth and Nadin, 2002). Planning policy in relation to biodiversity is discussed in section 3.9.

The recognition of the need to conserve nature in the planning system has improved over the last few decades, but the clash between economic development and protecting our green areas has caused much controversy of late, and a suitable compromise is always being sought. Monetary values are now being placed on the environment as a way of making people realise its value through the services it provides, see for example TEEB (2012), but this can only follow after a full investigation of potential planting regimes.

3.3.2 The Conservation of Nature in the Planning system.

3.3.2.1 Impact of EU on UK Planning for the Environment

Protection of the environment at the UK level has been largely influenced by the fundamental environmental policy and legislation developed at the EU level. Approximately 80% of all UK environmental legislation is derived from EU law, with excess of over 200 legal acts in force pertaining to a range of environmental factors (JNCC, 2011). The EU is a major source of environmental law, and threatened habitats and species are a key consideration for biodiversity conservation. Targets for their protection are in theory to be attained through the legislative protection they receive, with the EU and member states having joint legal capability and accountability in creating and actioning environmental legislation.

3.3.2.2 Protection of Species

An understanding of the protection awarded to species and habitats is needed for this research, as identifying species for habitat creation can be limited by certain legislation.

There are two EC Directives influential on UK conservation law, and which will continue to be so;

- Directive 79/409/EC on the Conservation of Wild Birds (the 1979 Wild Birds Directive), and
- Directive 92/43/EC on the conservation of Natural Habitats and of Wild Fauna and Flora (the 1992 Habitats Directive).

The Wildlife and Countryside Act (WCA) 1981 implements these EU Directives, protecting the Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) in the UK which contribute to the EU Natura 2000 network (JNCC, 2010).

Certain species are awarded individual protection through the WCA 1981, and laws dealing with relevant EC directives. This is normally due to their vulnerable conservation status; a species may be endangered or suffering decline in population size or range, either within the UK or the European Union. Part 1 of the WCA 1981 (sch 5 and 8) and the Habitats Regulations are the two main parts of legislation protecting wild species of flora and fauna (ODPM, 2005a).

3.3.2.3 Protection against Invasive Species

Given that climate change may result in the recommendation for non-native species, legalities around non-natives may be very significant. Invasion by non-native species is a global issue and one of the major threats to biodiversity (Sala *et al.*, 2000). The protection of communities against invasive non-native species, deliberately introduced, is administered through legal measures dealt within Section 14 and Schedule 9 of the WCA 1981. Section 14(2) of the Act prohibits the planting or spreading of certain invasive non-native plants into the wild in Great Britain; it is an offence under section 14(2) to “plant or otherwise cause to grow in the wild” any plants listed in Part II of Schedule 9 to the Act (which includes some established invasive non-native plants). Some, however, argue that the list is only limited to a few high risk species (Dehnen-Schmutz, 2011).

Although WCA 1981 is the principal legislation which regulates the release of non-native species, there are also international obligations to address problems posed by non-natives. The main international conservation agreement is the Convention on Biological Diversity (CBD), with 184 contracting parties (its role is discussed later in section 3.4.2). Under Article 8h, each contracting party is under obligation to

“*as far as possible and as appropriate prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.*” (UN, 1992a)

In relation to plants, the UK Government is also obliged under article 22 of the Habitats Directive to regulate the introduction of non-native species so as not to prejudice natural habitats or wild fauna and flora, with prohibition of introductions where deemed necessary. This is actioned through section 14 of the WCA 1981 in GB.

The EC Wildlife Trade Regulations regulate the import and sale of species which pose an ecological threat to native species, and the EC Plant Health Directive aims to safeguard native species from imported organisms, such as pests, parasites and diseases (Defra, 2003). There are also restrictions on the use of specific imported provenances of regulated tree species, as enforced by the EC Forest Reproductive Material Directive, to avoid the risk posed by non-native genotypes.

3.3.2.4 Environmental Assessment

There is an anticipatory element in the planning system, whereby a planning decision on certain projects cannot be made unless an environmental impact assessment (EIA) has been carried out under Environmental Assessment regulations. These identify any potential harmful environmental impacts that may arise as result of the development, including those to the ecology of the site or the surrounding landscape. Environmental effects are typically a material consideration of the planning process before permission is granted or refused (Bell and McGillivray, 2008), but there are certain developments which require a more rigorous assessment before construction commences, e.g. power stations. The underlying philosophy is that prevention is better than cure, with any environmental effects being taken into account as early as possible when projects are being planned.

3.4 Sustainable Development

Sustainable Development is a relatively recent term, but its principles have been around a lot longer. It was first formally used by the World Commission on Environment and Development (WCED) (the Brundtland Commission) in its report, *Our Common Future*, in 1987 (WCED, 1987), where it was defined as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Although slightly ambiguous, the central point of the definition is clear, today's generation must progress, whether this be economically, environmentally or socially, by using resources efficiently and with caution so that future generations can live as previous generations have or better. The concept of sustainable development ran parallel with the period of time when nature conservation was becoming more prominent and recognised in policy, shaping the world as it is known today. One of the outcomes of the growing recognition of the need for sustainability was the Rio Conference on environment and development.

The UN conference on Environment and Development held in Rio in 1992 was a significant milestone for sustainable development (UN, 1997). The Summit achieved a great deal, with agreements, listed in table 3.1, being signed by many governments including the UK.

Table 3.1 Agreements signed at the Rio Earth Summit (Source: UN, 1997)

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The creation of the Convention on Biological Diversity (CBD) at the Rio Earth Summit positioned biodiversity at an international scale. Its main objective is the conservation of biological diversity, and the sustainable use of its components, including genetic resources, habitats and ecosystems (UN, 1992a). The CBD treaty was the first of its kind to provide a legal framework for the protection of biological diversity. Those who signed the agreement, initially 159 governments including the UK, were required to produce and put into effect national strategies and action plans to address the conservation of biodiversity in their communities, as well as enhancing it where possible (JNCC, 2012).

3.5 Biodiversity Action Plans

As an international policy commitment, under Article 6 of the 1992 CBD, the first UK Biodiversity Action Plan (BAP) was produced in 1994. BAPs marked an important stage in national conservation policy since the 1981 Act (Bell and McGillivray, 2008), with the overall goal being:

"To conserve and enhance biological diversity within the UK and to contribute to the conservation of global biodiversity through all appropriate mechanisms" (HMSO, 1994)

The document detailed the process through which biological resources would be conserved and enhanced across the UK, including identification of priority species and habitats, the setting of targets for their recovery and how the targets would be met. The UK policy that followed was steered by this fundamental document, and many habitat and species action plans were subsequently produced, listing those species that were most threatened and requiring conservation. A review of these lists was carried out in 2007 in the *Species and Habitat Review* report: a monitoring and review process allows changes to be made to species inclusion, targets and actions as and when necessary; there are currently plans for 1,159 species of plants and animals, and 65 habitats (JNCC, 2013). Awareness, monitoring of key species and integration between public sector agencies have been the main intentions of the scheme. The UK BAP was superseded by the 'UK Post-2010 Biodiversity Framework', which was published in July 2012 (JNCC and Defra, 2012), Practitioners use BAP species lists for implementing biodiversity considerations on a development site, as shown in the questionnaire analysis in chapter 6. The adoption of the UK BAP also resulted in the development of Local Biodiversity Action Plans (LBAPs) being put into practice throughout the UK to conserve and enhance biodiversity at the local level.

3.6 International Targets for Biodiversity

The creation of biodiversity targets at the EU and global level is addressed, in part, through the array of legislative measures which have been discussed. In June 2001, the target to halt the rate of biodiversity loss by 2010 was agreed at the EU Summit in Gothenburg, Sweden (IUCN, Unknown). Even before the deadline, however, The Millennium Ecosystem Assessment (MEA) reported that an exceptional effort would have been required if the 2010 biodiversity target was to be met in full (MEA, 2005). One of the MEA findings was that over the last 50 years, humans have exploited and altered ecosystems at an unprecedented rate, mainly to meet ever increasing demands for food, fresh water, timber, fibre and fuel. After failing to meet the 2010 target, the UN Aichi targets were agreed at the 10th Conference of the Parties to the CBD in Nagoya at the end of 2010 (CBD, 2011).

3.7 General Biodiversity Duty

There is now a general biodiversity duty in England and Wales for public bodies to consider the impact of their decisions on nature conservation (Bell and McGillivray, 2008), both in relation to certain designated sites (where the ruling is to further and enhance conservation), and across the wider countryside, through the more recent duty to have regard to conserving biodiversity. In Scotland, the duty only applies to protected sites.

The duty is set out in Section 40 of the NERC Act 2006, and states that:

"Every public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity"

Public bodies include local authorities who make the majority of decisions on planning applications; biodiversity should therefore benefit from this duty. Local authorities also carry out many other functions, with the aim of conserving and promoting biodiversity across a range of fields, and with the intention of raising the profile of biodiversity. The ultimate goal is to facilitate the practice of biodiversity conservation into all relevant policies and decisions made by public authorities. The predominate tool, which local authorities use to guide biodiversity measures, is the Biodiversity Action Plan (Defra, 2010). The local biodiversity indicator NI 197, essentially a performance indicator, has also had a role in the way local authorities consider biodiversity and protect it, as they had a statutory duty to report to central Government on the indicator. "Biodiversity is ultimately lost or conserved at the local level" (Natural England, No date, a), which along with the creation of local BAPs, illustrates the importance that is placed on conserving biodiversity locally.

3.8 The State of Nature in the UK and the Restorative Approach

3.8.1 The Restorative Approach

The last two decades have been fundamental in reconstructing the way the world views and values the environment. Even though the conservation movement accomplished great gains for the environment, what was achieved was not enough to halt losses and reverse many years of damage, mainly because of the lack of legislation and resources needed. The building blocks have been present for many years, and finally a shift has now occurred towards a restorative agenda rather than a protectionist one (Bell and McGillivray, 2008). Landscape scale conservation initiatives are being implemented both by wildlife NGOs and the Government, including the likes of Nature Improvement Areas (NIAs), and The Wildlife Trusts' 'living landscapes', of which there are 112 schemes across the UK (The Wildlife Trusts, 2009). These schemes are a solution to the effects of climate change on biodiversity and the intensity of habitat fragmentation, discussed in chapter 4, as it means isolated pockets of wildlife can spread and flourish from secluded areas.

The *Making Space for Nature* report (Lawton *et al.*, 2010), exemplified how England's collection of wildlife sites do not provide the ecological network system that is needed to ensure England's biodiversity can cope with the challenges of today and the future. The fragmentation of the landscape by human activities is largely to blame for this, with significant declines in some species groups through land use change and consequent habitat loss, as discussed in section 4.6. Four words in the report sum up the approach needed to rebuild biodiversity: more, bigger, better, joined (Lawton *et al.*, 2010). This is an approach which can continue to effectively provide the services society depends on it for, as well as allowing species to adapt better to change - most importantly to climate change. The Lawton report was fundamental in making the Government aware of the action needed; with added weight from the Wildlife Trusts, as well as being endorsed in the *Biodiversity 2020* strategy for England, it influenced the creation and outcomes of the National Environment White Paper (NEWP).

3.8.2 The Natural Environment White Paper of 2011

The Natural Choice (HM Government, 2011) was the first white paper on the natural environment in 20 years. The three themes of the NEWP are: protecting and improving the natural environment, growing a green economy, and reconnecting people and nature (HM Government, 2011). It is acknowledged that the natural environment supports economic growth, and that the two are 'mutually dependant'. This is important and positive to note, as often natural capita can go unnoticed, when it actually provides many of the services needed for growth and regeneration. The NEWP is therefore ambitious in its aims, and it is yet another positive step in the right direction for the level of protection that should be awarded to the natural environment and the services it provides.

3.9 Planning Policy Frameworks

The National Planning Policy Framework (NPPF) is the current framework for land use planning, reflecting the governments' aims and objectives for the planning system and what to deliver on, and is to be used by planning authorities in creating their local plans. This is discussed more in section 3.9.2.

3.9.1 Planning Policy Statement 9

Before the NPPF, a principal document used for guidance in relation to protecting biodiversity through the planning system was *Planning Policy Statement 9: Biodiversity and Geological Conservation PPS9* (ODPM, 2005b), published by the then English Nature. It provided the prospect that planning policies and decisions would seek not just to conserve, but to enhance biodiversity, and it exemplified the government's commitment to sustainable development. PPS9 emphasised that when a planning application is decided on, the biodiversity value of a site, and the importance of the site at the country-wide and worldwide level, are most definitely material considerations. It also implied that if developments cause irrevocable damage that cannot be avoided, mitigated or compensated for, then the development should not go ahead.

PPS9, along with many others, is effectively void after the publication of the NPPF, and although the NPPF builds on PPS9 and applies similar principles, it is thought that the policies of the NPPF do not replace those of PPS9 sufficiently (Wilson and Simpson, 2012).

3.9.2 National Planning Policy Framework (NPPF)

The NPPF was published in 2012. It was developed with a view to streamlining the planning system and making planning approval processes simpler and quicker. It sets out the Government's planning policies for England and how they should be applied. Local planning authorities and decision makers must take the NPPF into account when preparing local and neighbourhood plans, and it should be a material consideration when deciding on planning applications (para 2 of NPPF).

3.9.2.1 Sustainable Development

A presumption in favour of sustainable development is the basis for every local plan, with 'the purpose of the planning system being to contribute to the achievement of sustainable development' (para 6) in both plan-making and decision-taking. The NPPF makes reference to all three 'pillars' of sustainable development –environmental, economic and social (DCLG, 2012) - being incorporated. Paragraph 8 states that these three roles are 'mutually dependant' on each other, and therefore should not be viewed in isolation. Certain phrases throughout the NPPF, however, can be seen as being contradictory to this statement; local plans should still 'plan positively for development' (Para 157), 'decision takers at every level should seek to approve applications for sustainable development where possible' (Para 187) (Wilson and Simpson, 2012). Para 9, nonetheless, does state that 'moving from a no net loss of bio-diversity to achieving net gains for nature' (a NEWP target) as a way of pursuing sustainable development, in relation to seeking positive improvements in the quality of the built, natural and historic environment.

A core planning principle of the NPPF in relation to biodiversity is that "Planning should contribute to conserving and enhancing the natural environment and reducing pollution" (Para 17, sub-para. 7). Local plans, in relation to biodiversity and climate change should (DCLG, 2012):

- consider the long term effects of climate change, including factors such as changes to biodiversity and landscape (para 99)
- deliver on climate change mitigation and adaption, conservation and enhancement of the natural environment (para 156)
- aim to establish 'coherent ecological networks that are more resilient to current and future pressures'

3.9.2.2 Re-using Land

A core planning principle of the NPPF (para.17) is to 'encourage the effective use of land by reusing land that has been previously developed (brownfield land), provided that it is not of high environmental value'. This last point is of particular importance, as it brought up as a recurring concern in the questionnaire analysis (chapter 6). Brownfield land has been noted for its sometimes high biodiversity value (mentioned also in NPPF para 111), but by using brownfield sites it reflects an understanding and acceptance of the need to use resources effectively and sustainably. The policy has however changed slightly since 1995, when it was a 'brownfield first' policy, whereas now it can be inferred that other sites, brownfield or greenfield, can be sought if brownfield sites are of high biodiversity value. With the population for the UK projected to increase from 62.3 million in 2010 to 73.2 million by 2035 (ONS, 2012), the effective use of land is fundamental, especially with other competition for space, e.g. food production, energy crop growth and renewable energy infrastructure. If it is not done correctly and without caution, there will be more habitat fragmentation across the landscape.

3.9.2.3 Incorporating Biodiversity in and around Developments

With many more housing developments needed across the UK, and the Government encouraging the idea of incorporating biodiversity in and around developments when the opportunity arises (NPPF para 118), consideration must be given to how this biodiversity element can be incorporated. Creation of biodiversity elements within a development should be compulsory, as this would ensure a continuation of habitats across the landscape, rather than just 'blocks of concrete' hindering species movement.

3.9.2.4 Landscape Scale and Priority Species

The ministerial forward mentions that species that have become isolated can be reconnected through the agendas of the NPPF. Reference to BAP species is also found in para 117in that planning policies should 'promote the preservation, restoration and re-creation of priority habitats, ecological networks and the protection and recovery of priority species populations, linked to national and local targets', thereby relating back to fulfil the requirement of section 41 under the NERC Act. This wording however is restricted to priority species, as oppose to protecting biodiversity in general (e.g. common or locally rare species), which was a consideration of the now redundant PPS9 (Wilson and Simpson, 2012). It is inferred that special habitats, e.g. ancient woodland, or designated sites will be under protection, but other areas of high biodiversity with no designation may not fair so well.

3.9.2.5 Concluding the NPPF

Through the NPPF it is now a requirement for local authorities to consider all pillars of sustainable development in planning and decision making. The NPPF sets out to not just protect biodiversity, but also to improve it, which is a step in the right direction for the planning world. There is also an emphasis on gains for biodiversity through the planning system, and this would put the country on track for meeting biodiversity targets. There is also encouragement for local authorities to plan for the development of ecologically coherent networks, which is essential for habitat continuation in a currently very fragmented landscape, echoing the thoughts of the Lawton review. There are doubts, however, as to whether the NPPF will deliver on its biodiversity aims, as even though sustainable development is the basis for every plan, the main objective of the NPPF is to streamline the development process and plan positively for growth, which may come at the expense of the environment. Para 19 states 'significant weight should be placed on the need to support economic growth through the planning system', which may result in negative consequences for the environment, as it can be interpreted that the economic pillar has more prominence over the other pillars of sustainable development.

3.10 Developers Obligation to Biodiversity

Through the environmental legislation discussed in this chapter developers are obliged to consider their impacts on the environment and mitigate or compensate for any harm as a result of their development. If a LPAs local plan has certain biodiversity elements that it wants to achieve for their area, or to contribute to meeting biodiversity targets, which the government specify in the NPPF, then the developer should include such provisions in their applications. Since the incorporation of biodiversity into developments is a consideration of the NPPF, if a developer is proposing an extensive development it will be in their best interests to do so. Typically, large development sites, e.g. for housing, do incorporate biodiversity and green spaces into their schemes, with the intention to increase the attractiveness of their development, giving residents access to nature.

A study by Barber (2011) found that once developers have provided biodiversity enhancements in response to the regulatory system, they are more inclined to carry out the same practice on subsequent schemes, even in the absence of regulatory requirements. By incorporating biodiversity, developers can also encounter benefits such as improved company image, which may bring in more custom and potential commercial benefits if this is advertised. In a study by Calow (2009) it was found that some businesses use a sympathetic working approach to biodiversity, so as to avoid breaching environmental legislation which often entails hefty fines.

BREEAM is a global environmental assessment method for sustainable buildings (BRE, No date), which is widely used by practitioners to demonstrate their environmental awareness, - although it is voluntary. Ecology is an aspect of the method, and developers who use BREEAM may implement biodiversity measures on site which go above and beyond that required, illustrating how biodiversity is now widely acknowledged as an important service, which delivers on sustainable development and much more.

3.11 Achievements and Future Challenges

The plethora of environmental based documents, reports and policies published over the last decade or so, illustrates the recognition that is now being given to biodiversity and the natural environment in planning and policy, which has come a long way since the 1949 TCPA. It is now a "factor to weigh in the balance when considering policy everywhere" (Bell & McGillivray, 2008), and environmental objectives are now more integrated into the planning process. It is a routine material consideration in land-use planning decisions, with both planners and developers understanding the benefits biodiversity considerations can bring. This is either through grants or financial incentives to farmers, the need for public bodies to carry out impact assessments, or a requirement to fulfil conservation objectives through appropriate actions. There will, however, always be conflicts between land-use and the continuous challenges of protecting the natural environment (Bell & McGillivray, 2008).

Climate change presents a challenge to nature conservation and the methods which are currently used in the field, particularly as many of those involved in conservation are only interested in preserving existing species and habitats. It needs to be understood that "nature conservation interests cannot be frozen in time, because they are constantly evolving and adapting to changing environmental circumstances" (Bell and McGillivray, 2008), therefore practices need to evolve which allow more flexibility when it comes to species acceptance. This is discussed further in the next chapter, with the need for spatial planning to also adapt for a changing climate. A more open-minded approach to non-native species is also required; an issue which may be difficult to accomplish, but one which is in agreement with the views of Bell and McGillivray (2008), that the UK may need to mitigate species that will be unable to tolerate their new climate conditions.

3.12 Conclusion

Consideration of biodiversity in the planning system has improved considerably over the last couple of decades, with the true value of nature being recognised. However, there is still a long way to go in protecting the biodiversity which provides society with many benefits and services. As the NEWP states "human wellbeing is intimately connected with our natural environment" (HM Government, 2011), and the need to protect this is great.

Through the Environmental Assessment Regulations, developers now consider the effect their development may have on the environment through EIAs, often providing mitigation for potential biodiversity loss, and sometimes going beyond that required. The NPPF aims to give equal weighting to the environment when developments are proposed, and sees an opportunity for biodiversity to be incorporated in and between developments. The NPPF also makes reference to biodiversity and climate change, with the need to adapt and create resilience.

The ability for species to migrate along natural corridors is being hindered and habitat fragmentation, along with climate change, presents an added challenge. Efforts are being made to rectify this, with the creation of NIAs and planners being urged to take a landscape approach, but how this is mirrored in reality and the weighting given to the environment will dictate the state of nature in the future. The next chapter looks at the effect climate change is already having on biodiversity, with changes in species distribution, phenology and abundance all having been observed.

4. Species Distributions – Past, Present and Future

4.1 Introduction

The effect of climate change on biodiversity has been studied both in relation to past warming events at the end of the last glacial, as well as the more recent changes which have occurred during a period of unprecedented climate change. Given that the earth has warmed by 0.6°C over the past century, the impact on biodiversity, particularly over the last 50 years, leads to the presumption that there will be many more far-reaching consequences for species and ecosystems in response to the predicted increases in temperature (Root *et al.*, 2003). Even if major reductions in greenhouse gases are made, changes to biodiversity will continue to occur, due to inertia in the climate system (Schneider and Thompson, 1981). Climate change poses a serious threat to biodiversity over the 21st century.

The main changes to biodiversity have been shifts in species distribution, the timing of natural life-cycle stages (phenology), and a greater number of interactions with non-native species as they migrate with the climate, all with subsequent effects on ecosystem balance (Fitter and Fitter, 2002). Local government ecologists have also observed changes in biodiversity during their years in the profession, as ascertained through the questionnaire discussed in chapter 6. Computer models have attempted to simulate species' future distributions based on observations, and projections point to some degree of biodiversity loss depending on the extent of future climate change (Thuiller *et al.*, 2005). As mentioned in chapter 2 habitat fragmentation over the 20th century has left the environment in a poor state. A specie's ability to find suitable climate space in such a landscape may further exacerbate the challenges biodiversity face; a migrational route needs to be present.

Conservation practices and policies over the 21st century will need to be flexible and acknowledge that species will change distributions. Inevitably some species can cause more harm than good, and caution still needs to be exercised when monitoring changes in distribution. The NPPF, as discussed in section 3.9, recognises the link between climate change and biodiversity, and recommends that planners should be aware of this in their local plans. This chapter examines the effects of climate change and other drivers of change from past to present to future, covering multiple taxa, but with more focus on plants where studies exist. As studies observing impacts of climate change on biodiversity are an ongoing activity, there is currently limited published information available.

4.2 Distribution Change and Spatial Scale

Climate has long been recognised as a limiting factor for species distributions at continental and sub-continental scales (Grinnell, 1917; MacArthur, 1972), whereas at the regional scale soils and habitat are thought to be the main drivers of distribution change (Pearson and Dawson, 2003). The biotic interactions (i.e. with surrounding species, invaders) have a greater influence than climate and soils at the local level, illustrating how the differing spatial scales can determine the location in which a species resides. The life-history of a species, dispersal ability and land-use, along with climate, can all limit a specie's ability to move at the larger scales.

4.3 Species Response Rate to Past Climatic Change

The study of paleoecological events during previous climatic upheavals can help with the understanding of possible migrations and adaption processes of flora and fauna in the changing climate of the future.

4.3.1 The Fossil Record and Evidence of Spatial Responses

The Quaternary fossil record provides an abundance of data relating to terrestrial organisms responses to past climatic changes. There have been many studies on the fossil pollen and spores of higher plants preserved in peats and lake sediments, refer to Huntley (2007) for more on this, and the evidence points to species responding spatially to past rapid climatic changes, following their climatic niche and thus shifting their geographical range (Graham and Grimm, 1990; Huntley, 1991). There would have also been adaptive genetic responses of the population at any given area where climatic change occurred, as a result of the specie's overall spatial response to climate change (Huntley, 2007). The rate at which species were required to respond was often a function of the surrounding landscape, the variation in topography, and the ability of a species to exploit this. Species unable to spatially and/or genetically respond to climate change suffered regional or global extinction (Stuart, 1993). A negative of using the fossil pollen record is that it is sometimes too coarse to identify the effect on small populations (McLachlan *et al.*, 2005).

4.3.2. Magnitude and Rates of Change

Estimates have been placed on the magnitude and rates of species' responses to climatic changes between the last glacial stage (10-20,000 years ago) and the post-glacial or Holocene period. Over most of the European continent, the magnitude was estimated to have been one to two thousand kilometres (Huntley and Birks, 1983). Estimates of yearly average range margin displacement for most trees, the group with the best data available, were 200-500m yr^{-1}, with some taxa from both Europe and America in rare circumstances reaching rates as much as 1-2 km yr^{-1} (Huntley and Birks, 1983; Ritchie and MacDonald, 1986). Concern arose around these findings years later as even species with poor seed dispersal or long generation times had high dispersal rates (McLachlan *et al.*, 2005). Rates have recently been found to be a lot slower as discussed in section 4.3.5.

4.3.3 Reid's Paradox

Pitelka and Plant Migration Workshop Group (1997) accepted the theory that certain species in the postglacial warming period had the ability to advance rapidly. They support the belief held by Clark *et al.* (1998) that migration is accomplished by 'rare long jumps that escape our observation', in order to explain how trees could move so fast and leap broad obstacles. 'Reid's Paradox' is a term associated with this concept of rapid migration, as the Victorian botanist Clement Reid faced difficulty in understanding the postglacial spread of oaks into the UK (Clark *et al.*, 1998). The original theory or plausible explanation for the paradox was that dispersal of the seeds over long distances must have been accomplished by wind updrafts and by birds in nest material. Later modelling studies went on to conclude that rapid migration rates depended on the dynamics of seed distribution, rather than the mean dispersal distance (Clark *et al.*, 1998).

One example of the long-jump-and-outlier model of spread would be that of the Norway spruce (*Picea abies*) and its western migration across northern Europe during most of the Holocene, particularly it's migration 3000 years ago across western Sweden (Bradshaw and Zackrisson, 1990). In this migration, isolated trees hundreds of kilometres ahead of the migrating front, appear to have been the foci for the consequent invasion of *Picea* and the reason why Scandinavia's landscape is dominated by this species (Pitelka and Plant Migration Workshop Group, 1997).

4.3.4 Macrofossil Evidence

Varying evidence from macrofossils (e.g. fruits, seeds) suggested alternative theories and that the rates may have been slightly under-estimated. Tree taxa were present up to a millennium before their pollen increased in quantity (Kullman, 1998), and in some instances overestimated as some temperate taxa may have had glacial areas of distribution that extended north of the main European mountain chains (Kullman, 1998; Willis and van Andel, 2004), and even isolated areas of persistence in northern Europe (Kullman, 2006). This implies range-boundaries from pollen and spores data may, in some circumstances, be under-estimating or over-estimating the species potential rates of change to future projected climatic changes (Huntley, 2007).

4.3.5 Molecular Evidence

More recent techniques have been to use modern chloroplast DNA to deduce tree distributional change, as mutation rates are low in the chloroplast genome, and there is little gene flow into established tree populations (Pearson, 2006).

It has been demonstrated that the modelling for the theory of extremely rapid tree migration rates (Clark *et al.*, 1998), mentioned above, was based on idealistic ecological assumptions and that the actual historic rates of range shift may actually have been slower than previously thought. By using modern life history data and molecular evidence (chloroplast DNA), McLachlan *et al.* (2005) suggested that the migration rates of two North American tree species - American beech (*Fagus grandifolia*) and red maple (*Acer Rubrum*) at the end of the last glacial were considerable slower than had been deduced from fossil pollen records, which was 100-1000 m/yr for temperate tree species (Huntley and Birks, 1983). McLachlan *et al.* (2005) believe that small amounts of pollen may have travelled to sediments far outside a specie's range and thus indicate or make it apparent that migration rates were quicker. These low density 'isolated' populations are believed to have been "driven by local dispersal from disjunct glacial refugia", i.e. areas where species reside, a place of refuge, particularly during times of climatic upheaval or biological stress (Pearson, 2006). When the regional climate is unsuitable, these places can shelter ecology of high biological diversity in a microclimate. This points to there being an overestimation of migration rates, with the average rate more likely to have been <100m yr^{-1}.

4.3.6 An Overall Long-term Average Rate

Considering all the available evidence, including those from extensively glaciated areas, a range of 2-20km per decade has been given as the overall long-term average rate of shift in tree range margins (Huntley, 2007). With the extent of future climate change not known, a specie's ability to keep pace with their climatic gradient is uncertain. Some species are thought not to be in synchronisation with the current climate, with negative implications for their future survival, as is discussed in the next section.

4.3.7 Species Lag due to Past Climate Change

Much debate surrounds the extent to which species' past rates of change lagged behind climate change at the start of the Holocene (Davis, 1989), i.e. how much of their climate space was yet to be reached. Prentice *et al.* (1991), however, showed that those tree taxa that appeared to be lagging, based on eastern North American data, could have just been a reflection of their varying climatic requirements/tolerances, and that they would respond at different times accordingly as the climate continued to change throughout the Holocene.

4.3.8 An Overview of Species Responses to Past Climatic Change

Given the different theories and models for rates of migration during the early Holocene epoch (Huntley and Birks, 1983; Ritchie and MacDonald, 1986; Clark *et al.*, 1998; McLachlan *et al.*, 2005), it is not currently possible to gauge at what rate current species will migrate to stay within their climate envelope, especially as climate change at present appears to be unprecedented. Species intrinsic dispersal potential and the surrounding topography will have an effect on their response to current climate change in trying to colonise suitable areas. Today's biodiversity face many challenges to keep pace with climate change.

4.4 Species Response to Recent Climate Change

There is uncertainty surrounding the ability of some species to keep pace with future climate warming, and that their potential range extent will be limited (Thomas *et al.*, 2004; Thuiller *et al.*, 2005). The literature relates largely to trees, and a limited number of other species, which needs to be considered when making reference to species response rates and climate change.

4.4.1 Idiosyncratic Rates of Range Shift

The rates of range shift in response to climate change varies within and between species groups, and this is true for observations more recently (e.g. Holzinger *et al.*, 2008 as discussed later), and for those from the Quaternary; species respond individualistically (Huntley, 1991). This may lead to complete changes in community composition, i.e. non-analog communities (Kullman, 2006), and could lead to the alteration of species' known niches (Thuiller *et al.*, 2005). Le Roux and McGeoch's study (2008) found idiosyncratic expansion rates have occurred at Marion Island in South Africa, leading to altered, previously unknown community compositions at intermediate and high altitude rates.

4.4.2 Variation between species

Different species have different patterns and rates of growth, and thus will respond accordingly. Seed plants are at more of a disadvantage than the likes of ferns whose spores are easily dispersed, while tree dispersal rates may be slower in comparison to that of herbs, as they take longer to reach reproductive maturity (Normand *et al.*, 2011), with consequent longer response lag times. Their capability to keep track of rapid climate change therefore decreases, with the unfortunate likelihood of them being stranded in unfavourable climates. A study by Lenoir *et al.* (2008) also found that species with certain characteristics have shifted the most over the last century including species with faster life cycles, quicker maturation rates and smaller sizes at maturity, mainly the life forms of herbs, ferns and mosses, in comparison to trees and shrubs who display distribution shifts of a lesser magnitude. There is, however, not always a strong correlation between these two factors.

Araujo & Pearson (2005) analysed breeding birds, amphibians and reptiles and ca 20% of the European vascular flora. They found that the reptiles and amphibians grouping were the least at equilibrium with their climatic niche, whereas plant assemblages were comparatively closer. Whether plants will be able to migrate at the rate required depends on their ability for long-distance dispersal (LDD), with there being a notion that plants may be more mobile than initially thought (Nathan *et al.*, 2002). A plants potential for LDD will affect their ability for significant range expansion and thus the extent, if any, of their migrational lag (Normand *et al.*, 2011).

4.4.3. Constraints on Range Expansion

It is assumed that many taxa, during post-glacial migration, were unable to follow their climate space and are currently in disequilibrium with the current climate (Normand *et al.*, 2011). Normand *et al.* (2011) assessed the constraints on species range for 1016 European plant species and found that climate was vital for all species, but the magnitude of postglacial colonisation has meant the range of more than 50% of the species is lagging. The constraints on range expansion can be assigned to a number of factors, true for both previous and current day climate change: a specie's inability to co-exist with previously established vegetation, soil development, geographical barriers, interference of land-use by humans, limited dispersal and reproductive age as is discussed in 4.4.2.

4.4.4 Accessibility to Expand

It was found in the Normand *et al.* (2011) study that Mediterranean and temperate species in southern Europe were more restricted in their location, with accessibility (or lack of) being more important than climate for between 20-60% of the species. The mountainous landscape and separation of land into many peninsulas in southern Europe is an aspect of the accessibility restriction, impacting long-term dispersal. Northern European species may be more at equilibrium with the climate, as climate is more important than accessibility for these species.

A study by Svenning and Skov (2007) also found that the postglacial expansion of European tree species was limited, linking back to the realistic rate of <100m/yr as estimated by McLachlan *et al*. (2005), consequently putting them at disequilibrium with the current climate. Svenning & Skov (2007) state that "geographical accessibility from glacial refugia explains most of the variation in tree diversity in central and northern Europe". There are locations which would appear to be climatically suitable for some species, but their absence could be a reflection of the migrational lag. Today, anthropogenic barriers and dispersal limitations means that small-range species remain associated with their Last Glacial Maximum refugia and are unable to migrate.

4.4.5 Potential Range Filling

The bioclimatic envelope "describes the conditions under which populations of a species persist in the presence of other biota as well as climatic constraints" (Thuiller *et al.*, 2005). The bioclimatic envelope modelling work undertaken by Svenning and Skov (2004) found that the likes of *Quercus robur,* is one of few trees keeping pace with the climatic changes. In comparison, the likes of *Fagus sylvatica* and *Quercus cerris* have failed to keep track due to postglacial migration limitations, as shown in figure 4.1, and consequently potential northern range limits have not been met. Forest herbs are of a similar disposition; they are known to have migration rates at a slow 20m/year or less (Honnay *et al.*, 2002), therefore herbaceous forest flora in Europe may well have been of a different composition today if such species would have been able to fill their potential climatic range, as also demonstrated by bioclimatic envelope modelling (Svenning and Skov, 2004).

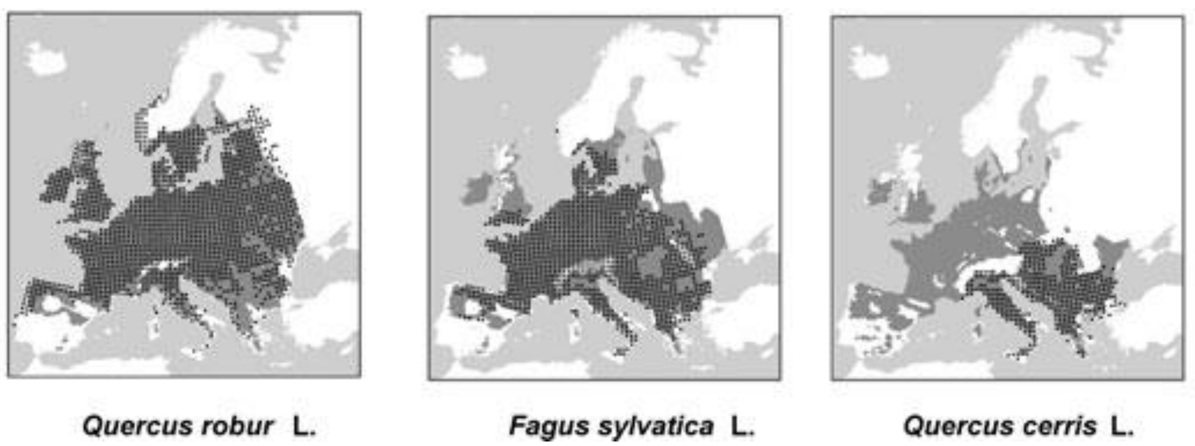

Figure 4.1 Current native distribution of three temperate tree species (dots) and their climatic potential range (shading), estimated using bioclimatic envelope modelling from Svenning & Skov (2004). (Svenning and Skov, 2007)

With many species unable to efficiently expand their range after the last glacial, and thus 'lagging' behind climate warming, there is doubt whether species will be able to respond appropriately over the next century to the expected rate of climate change. The ability of a species to adapt, or their life-history traits, will be important in their range expansions (Svenning and Skov, 2007). Species at the northern margin of their range may overcome any restriction of dispersal by undergoing evolutionary processes, with climatic changes being a driver for such processes. Although these studies have been for taxa apart from plants (Pateman, 2012), it nonetheless highlights the adaption processes taxa are developing in response to climate change and dispersal limitation.

Although a considerable amount of research looking at rates of range shift has been carried out in Europe, the theory relating to species traits could also be applied to species in the UK, as species with higher reproductive rates have the ability to "increase propagule pressure and hence the probability and number of species reaching new areas, facilitating population establishment" (Pateman, 2012). An assumption, therefore, is that species with these characteristics are more likely to prosper in the UK, taking full advantage of their potential range filling. As the UK is made up of islands, however, there is the possibility that species may run out of future space with resultant likely losses.

4.4.6 Lag times and Extinctions

The composition of a specie's population across a landscape is known to change over a long time-scale (Pateman, 2012). Those species at the trailing margin of a shifting distribution may lag in comparison to those at the leading edge of the margin as a result of environmental changes (Brook *et al.*, 2009). The individuals in some species which exhibit a long life span, and the seed banks and rhizomes which are able to remain dormant in hostile conditions, explains the natural resistance of many plant species to extinction (Eriksson, 1996). Trees are such an example as they can experience especially long lag times for local extinction, even when their ideal climatic niche moves over time. Some can survive for lengths of time at their warm range boundary, they may just be unlikely to reproduce, or seedlings be unlikely to establish (Pateman, 2012).

The climatic tolerances of small-leaved lime (*Tillia cordata*) have for example limited its range, as at its northern range in northern England, the temperature is not warm enough for complete pollen tube formation (Pigott and Huntley, 1981). The tree therefore produces sterile seeds and reproduction is hindered. The tree will, however, have a long lag time for local extinction as it is able to survive, just not able to reproduce.

4.5 Recent Range Shifts

Despite several species experiencing migrational lag over the past four decades, species across various taxa have extended their ranges to higher latitudes and altitudes in many parts of the world, in line with the direction expected from climate warming, i.e. a polewards migration (Thomas *et al.*, 2004). This illustrates how species are shifting their distributions to track their climatic niche (Bradshaw and Holzapfel, 2006), rather than adapting *in situ*.

A European survey showed that out of 35 non-migratory butterfly species, 22 species have shifted northward by 35-240km over the 20th century, with only 2 species having shifted south. Temporal scales across the 20th century used in this study varied within and among countries, e.g. for Britain this was since the 1950s, for Estonia this was since the 1980s, but for northern Africa (southern margins of some European butterflies) this was since the early 20th century; for exact dates of change see Parmesan *et al.* (1999) . Two thirds of the species showing extensions at their northern boundary had southern boundaries that remained stable, thus effectively expanding their range (Parmesan *et al.*, 1999).

Poleward range expansions have also been reported for birds in both Europe and the USA. The northern margins of 59 bird species with distributions in the south of Britain, have moved further north by an average of nearly 19km over a 20 year period; 1988-1991 compared with 1968-1972 (Hughes, 2000). Butterflies and birds are more mobile than the likes of plants, and such observations relating to climate change are easier to spot, but distribution changes have also been observed in certain plant ranges.

4.5.1 Changes in Composition – Alpine Communities

Changes in community composition have been observed, with cool adapted species on mountain ecosystems reacting to climate warming. A study by Pauli *et al.* (2007) discovered a change in vascular plant species richness on high peaks of the European Alps between 1994 and 2004, with an increase from 11.4 to 12.7 species per plot, a similar finding to that of Grabherr *et al.* (1994). The altitudinal preferences of plants were reflected in the species change figures; there were significant declines in subnival to nival plants, whereas alpine pioneer species increased at their leading edge. If this trend continues then alpine biodiversity is severely at threat with cold adapted species being driven out of their distribution range, and the consequent possibility of extinction. The climate warming at the Alps has recently been twice as high as the global average and thought to be the main reason for such changes (Pauli *et al.*, 2007).

A study by Holzinger *et al.* (2008) also had similar findings to Pauli *et al.* (2007), with there being a common trend of ascending migration rates in the Alps of several metres per decade over the last 120 years of historical records. Another study spanning the entire elevation range (0 - 2600 metres above sea level) of 171 forest plant species in West Europe between 1905 and 1985, and 1986 and 2005, also confirmed a 'significant upward shift in plant species optimum elevation averaging 29 meters per decade' (Lenoir *et al.*, 2008). Upward movement of subalpine species has also been extensively reported, with young trees found at elevations or altitudes further than the current treeline. This is particularly apparent in most of western North America, where there is an upward expansion of the forest margin after 1890, with establishment peaks between 1920 and 1950 (Peterson, 1994). An observation in Holzinger *et al.*'s study (2008) was that the increase in alpine migration occurred more on calcareous bedrock, with a presumption of there being more micro-habitats on such bedrock. Many studies looking at shifts in altitudinal gradients in plants have been carried out in Europe, but a study by Britton *et al.* (2009) on species richness in the Scottish mountains revealed that southern generalist species are also increasing and northern specialist species are decreasing, as would be expected as a consequence of climate change.

The first ever pan-European study into the response of mountain vegetation to climate change found that between 2001 and 2008, the abundance of thermophilic species increased significantly (Gottfried *et al.*, 2012), a process the researchers have termed 'thermophilization'. A total of 867 vegetation samples above the treeline, from 60 different summits in all major European mountain systems, including the Cairngorms in Scotland to as far south as the mountain ranges in Crete, were analysed for species occurrence and cover. As found in regional studies, cold-adapted species are declining, with no further mountain space to inhabit, whilst warm-loving plants are increasing; the continental scale of this study, however, just reinforces the impact climate change is having, transforming alpine plant composition even over such a short time period. This frames the future of alpine biodiversity as uncertain, with extinction more than likely for species at the end of their range.

4.5.2 Arctic Communities

The effects of climate warming have also been observed in the Antarctica, where the distributions of the only two native vascular plants, *Colobanthus quitensis* (Antarctic Pearlwort) and *Deschampsia antarctica* (Antarctic hair grass) have shown dramatic increases in numbers from 1964-1990, with greater rates of seed germination and seedling survival (Smith, 1994). Normally such activities are limited by the number of degree days above 0°C and by the water supply during the cold growing season, so this exemplifies a slight warming. At Galindez Island, *D. Antarctica* increased from 500 individuals in 1964 to 12,030 individuals in 1990, with similar increases observed at many other locations. This time period included warm summers in the mid 1950, early 1960s, early 1970s and mid-to-late 1980s, with winter temperatures also increasing greatly (Hughes, 2000).

4.5.3 Meta-analysis for Multiple Taxa

The distributions of all terrestrial species studied have shifted their latitudinal and altitudinal range by a median rate of 16.9km and 11.0m per decade respectively (Chen *et al.*, 2011), with the more predominant range shifts being where warming has been the highest. These rates are significantly greater than a previous meta-analysis (Parmesan and Yohe, 2003), which reported a shift of range boundaries at ca 6.1km per decade towards higher latitudes, and 6.1m per decade to higher elevation. Although the scale of this study was considerably smaller than Chen *et al*.'s (2011) and the data includes species of varying mobility, together they demonstrate that species are responding to climate change.

4.5.4 Future Colonisations and Translocations

Some species will be spatially restricted in their ability to shift distribution. Species in the UK with a northern distribution may face extinction if at their northern margin they end up with nowhere to go, i.e. no suitable habitat, or if they occupy mountain tops. Species from continental Europe may colonise the UK if a suitable climatic niche becomes available, assuming they can reach the UK with no dispersal barriers. New colonisations in the UK already include species of bats, damselflies, and several species of birds (Pateman, 2012), with the respondents of the questionnaire (chapter 6) also identifying new species in their local region. These colonisations, however, may not be solely attributable to climate change (other drivers of change are discussed in section 4.9.2). Species extinctions as a result of climate warming have not been observed at the national scale in the UK.

Successful butterfly translocation studies (Pateman, 2012) have shown that they are able to survive beyond their current cool range boundaries. This demonstrates that they are experiencing a migrational lag, and that a suitable climatic niche exists for the future survival of such species.

4.5.5 Overview of Range Extension Studies

The studies reported indicate that the effects of climate change, including the changes to species traits, will be more prominent at higher latitudes and altitudes where the temperature change will be the largest. Yet, climate change is just one of the factors which has an influence over the distributions and health of populations and trait changes.

4.6 Habitat Fragmentation

Habitat fragmentation is a major threat to biodiversity, as it can prevent or slow down species migrating along environmental gradients, and consequently dispersal into suitable habitats both naturally and in times of upheaval; there needs to be connectivity (Doxford and Freckleton, 2012). Landscapes have greatly altered since the early Holocene, the last significant migration, with humans on many occasions having created barriers between natural landscapes, normally through urbanisation, with consequent habitat loss. In fragmented landscapes, the patterns of spread will depend on variables such as the local topography as well as the 'plants intrinsic dispersal potential' (Pitelka and Plant Migration Workshop Group, 1997).

As habitats become fragmented and thus smaller in size, the population carrying capacity and overall species diversity decreases (Rosenzweig, 1995); species are unable to find new suitable habitat to add to the diversification that comes with natural range change. Suitable habitat may have disappeared for some species, and others will inevitably die out as population numbers decline (Kuussaari *et al.*, 2009). Although this will affect rarer, specialist species more, it will also affect wide ranging species.

4.6.1 Dispersal

The processes which allow the movement of seeds may break down in a fragmented landscape, resulting in shorter seed dispersion distances, and furthermore a proportion of the seeds may be deposited in habitats unsuitable for recruitment (Higgins *et al.*, 2003). Seed production and survival are limiting factors to rapid rates of migration in response to climate change. The fact that man also inhibits the migration of some species, and accelerates others, will result in future communities being different to the composition of todays.

4.6.2 Species Threshold to Land-use Change

The colonisation ability of a species and its habitat requirements will ultimately dictate the degree of habitat loss a species will be able to encounter along its migrational route. Travis (2003) shows that a threshold exists before a species will rapidly decline and eventually become extinct. A similar threshold exists for species with respect to the rate of climate change; if the rate is too great then species' minimum patch occupancy quickly drops, until the inevitable happens - extinction. In the current day situation, where climate change and habitat loss are occurring simultaneously, the outcome for some species, e.g. specialists, will be poorer than for others. The likelihood of this occurring depends on the life-history traits of a species; if a species can tolerate many habitats and colonise quickly, it will be resilient to the effects of climate change (Travis, 2003). A study by Opdam & Wascher (2004) highlights the need to consider the underlying landscape patterns and the spatial cohesion of areas in conservation management, as these have an effect on a species ability to increase its range in response to climate change.

4.6.3 Suitable Habitat Space

Access to and presence of suitable habitat is important for plant species, as the majority have limited dispersal (Cain *et al.*, 2000). Land use change has impacted negatively on habitat quality over the 20th century (Thompson and Jones, 1999), and increases in habitat segregation has meant colonisation rates are lower than would be expected for some species and their potential for distribution change is limited (Doxford and Freckleton, 2012). For those species with less specific habitat requirements, e.g. generalists, however, this is less of a problem, and they achieve wide-spread colonisations – possibly also true for recently introduced species (Preston *et al.*, 2002; Hulme, 2009b).

4.7 Colonisations and Extinctions – Doxford & Freckleton Study (2012)

Doxford and Freckleton (2012) have used presence/absence data on 1,781 British plant species to examine distribution shifts in the 20th century. This was over two time periods: 1930-1960 and 1987-1999, to correspond with the atlas data they consulted. Using a fitted set of four generalised linear models to contrast the various mechanisms of distribution change (rather than the extent of change), it was discovered that the majority (82%) of distribution change occurs through a *phalanx-spread* process – 'the diffusion-like spread of a population through localised colonisations'; i.e. species established at one site will colonise sites at its immediate edge, as opposed to random colonisation, or colonisation of adjacent habitats (*localised phalanx*). This illustrates that the distribution of surrounding habitat, and localised dispersal, are important for species spread. On the whole, rates of extinction and colonisation over the time period were low, but highly variable; it depends on the spatial structure of the established distribution.

4.7.1 Patch Occupancy and Extinction

There was a strong relationship between extinction rates and total occupancy. It was found that high extinction rates had low occupancy and were likely characterised by specialist species possibly hindered from reaching suitable habitat because of geographical barriers, an inability to colonise new habitats, and/or fewer dispersers. In addition, high occupancy had low extinction rates and the species involved were likely to be habitat generalists and hence resistant to habitat changes. Long-distance dispersal events appear to be rare, emphasising a plants lack of mobility, which under future climate change could present a huge threat. It must be recognised though that the changes in species distribution may be a function of differences in recorder effort between study periods, as well as biotic interactions like invasion and extinction.

4.7.2 Implications of Study

Low rates of extinction observed in the study could be due to length of lag time for a species or their inherent resistance to extinction as discussed in section 4.4.6. Access to suitable habitat space discussed in section 4.6.3 and species' dispersal capabilities has and will dictate a species colonisation rate. The outcomes of Doxford and Freckleton's (2012) research illustrates that the recommendations of the Lawton *et al.* review *Making Space for Nature* (2010), i.e. connecting habitats, discussed in section 3.8.1, will benefit species distribution. Ecological networks will be fundamental to the dispersal ability of many species, allowing species to colonise suitable habitat nearby, in response to environmental change (Hilty *et al.*, 2006).

4.7.3 Study of Temperature and Rainfall on Distribution Change

Doxford and Freckleton (2012) also applied climate data - rainfall and temperature, to an additional set of three models. It is recognised by Doxford and Freckleton (2012) that the pertinent distribution change cannot be fully signified by the two climate variables used, as there are of course other environmental factors to consider. However, they do state "in terms of environment, these are particularly significant variables, for example, sites that are warmer are often dryer, two phenomena with opposing effects on plant growth" a point which is also of relevance to this research project, as just rainfall and temperature data were also used. Resultantly, it was believed that the primary climate indicator would be revealed in the data "when accounting for the role of site dynamics and spatial arrangement of the sites".

The results showed that climate had an effect on c. 45% of the species, with rainfall and temperature seeming to have separate or independent impacts on distribution change. There was a signal that could not be explicitly linked to either of the climate variables for the remainder of the species. Climate can change habitats (on a decadal scale), with the extent of such changes happening at a fairly slow rate. The effect of climate change on distribution could be masked by the more governing role of habitat (availability) and land use effects.

4.8 Climate Effects on Phenology

Phenological events which occur in the spring are most sensitive to climate fluctuations, and research carried out by Sparks and Smithers (2002) provides evidence that spring is getting earlier as a result of climate change. In astronomical terms, spring is defined strictly by the position of the sun over the equator, whereas the general public conceive the term 'spring' and its beginning in terms of biological events (Sparks and Smithers, 2002).

4.8.1 Temperature Trends and First Flowering Dates

Temperature is not the only influence on phenology, but phenological events are most sensitive to temperature (Fitter and Fitter, 2002). Although there is variability in the mean annual temperature of the UK, the temperature does appear to be on the increase, with there being a significant warming trend since the mid 1980s, as indicated in chapter 2. The year 2006 experienced the warmest year in the Central England Temperature (CET) series, which goes back 350 years (Sparks, 2012). Figure 4.2 shows the records over the last century (trend as determined by Lowess smoothing), with cold winters still being experienced like that of 2010. As data relating to phenological events is not always consistent, records of a minimum of 20 years are recommended for making assumptions between climate and such events. Correlations can then be made between the data. Recently, first flowering dates have advanced in line with noticeable increases in temperature, evident in the CET record from around 1975 (Fitter and Fitter, 2002).

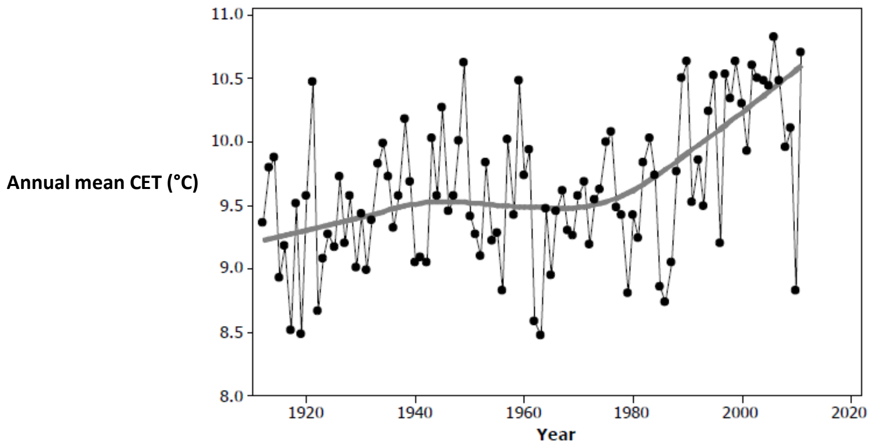

Figure 4.2 Annual mean Central England Temperature (°C) over the last century (1912-2011)
The thick grey line represents the underlying trend (Sparks, 2012)

The recording of spring events for the UK date back to 1736 (Sparks and Carey, 1995), with phenology therefore being the longest written biological record (Sparks and Smithers, 2002). The change is most apparent in 'early' spring species. Figure 4.3 displays the relationship between wood anemone (*Anemone nemorosa*) flowering and March temperature (with historical Royal Meteorological Society data and current data identified separately). It exemplifies that flowering and leafing events have advanced by 6-8 days for every 1°C rise in temperature, and the trend implies that data of this kind can be used to predict future change of species that have been recorded historically (Sparks and Smithers, 2002).

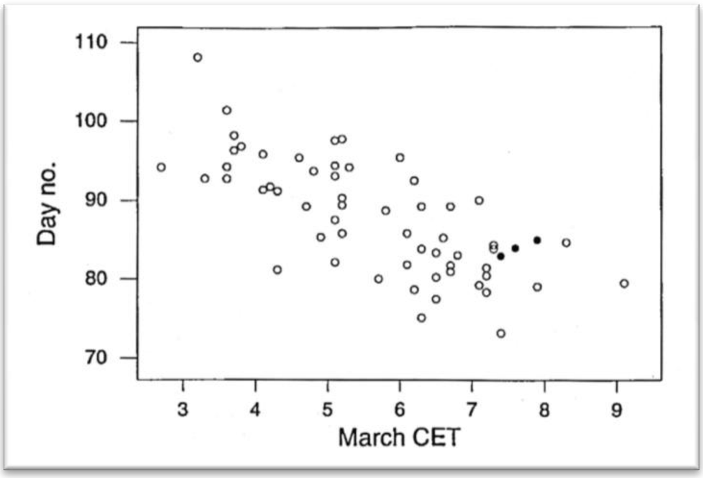

Figure 4.3 National mean first flowering date of wood anemone relative to March Central England Temperature (CET, °C) (Sparks and Smithers, 2002). Open circles represent data from 58 years of the RMS phenological reports, filled circles are data for 1998-2000 from the UK Phenology Network

Figure 4.4 shows trends in the flowering of garden snowdrop (*Galanthus nivalis*) from Northumberland and Norfolk. Environmental differences between the areas, as well as Northumberland being at a higher latitude, results in different rates of advance, but a similar trend is shown for both series over the last 50 years (Sparks and Smithers, 2002). Rates of advance inherently vary across spatial climes (Schwartz *et al.*, 2006).

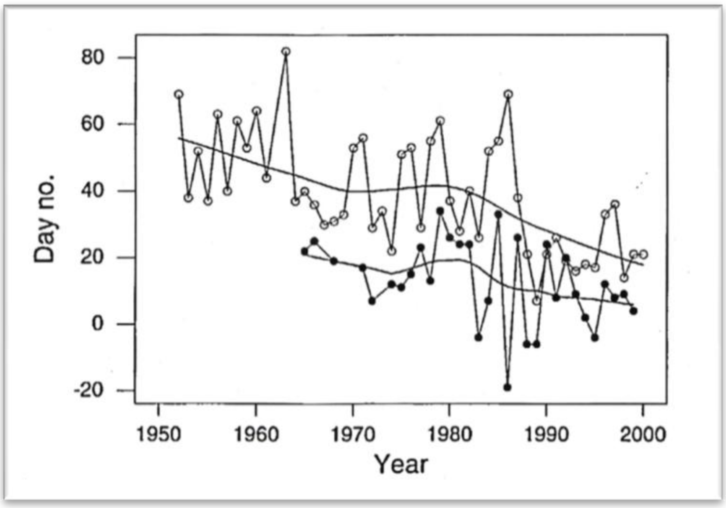

Figure 4.4 First flowering dates of snowdrop in Northumberland (upper) and Norfolk (lower); smoothed lines superimposed (Sparks and Smithers, 2002)

Amano *et al*. (2010) looked at first flowering dates over a 250 year index for 405 plant species in the UK, and also found climate change is having an effect on multiple species at multiple sites. Current flowering dates for the most recent 25-year period being 2-13 days earlier than any other respective time period since 1760. Fitter and Fitter (2002) also illustrated that in the last decade of the 20th century flowering dates have advanced for 385 British plant species on average by 4.5 days compared to the 4 decades before it (1954-1990), with 16% of species flowering considerably earlier by 15 days. There is much variation between species, but it was observed that annuals flowered earlier than perennials, and insect-pollinated species more than wind-pollinated species. Globally, there has been evidence to show an advance in phenology across multiple species (Parmesan and Yohe, 2003), but changes are not always consistent and can lead to asynchrony between species (Sparks, 2012). This is discussed in the next section.

4.8.2 Effects of Phenological Changes

Changes in first flowering dates can have several knock on impacts including likeliness of pollination success if the pollinating insects are no longer in synchronisation with such dates, possible alteration of interactions between coexisting species, and increases in the probability of hybridisation. The latter is likely if flowering dates between species gets closer, as illustrated with 12 calcareous grassland species (Fitter and Fitter, 2002). Effects on pollination will also impact the animals that rely on pollen, nectar and seed as a resource.

An empirical study on the interactions between plants and their animal pollinators with phenological shifts after a doubling of atmospheric CO_2, led to reduced flora resources for 17-50% of all pollinators, reduced overlap between plants and pollinators and decreased diet variety of the pollinators. Extinction of both plants and pollinators is the expected outcome when there is a disparity in interactions (Memmott *et al.*, 2007).

4.8.3 Trees Fruiting Earlier

Data recording carried out by the public for the Woodland Trust (2011) showed that native trees are fruiting earlier than they were a decade ago, and that this may be a potential response to recent warming. Compared to the period 2000-2012 acorns are ripening 13 days earlier, beech nuts 19 days earlier and rowan berries nearly one month earlier.

4.8.4 Onset of Summer

The onset of summer also appears to be advancing, with 60% of summer flowering plants blooming earlier in the 1990s than in the period 1954-1963 (Kirbyshire and Bigg, 2010). Pollen release also appears to be occurring earlier, in line with spring temperatures, as found in a European study looking at the Birch pollen season (Emberlin *et al.*, 2002).

4.8.5 Phenological Differences between Differing Provenances

When comparing phenology processes between varying provenances of Hawthorn (*Crataegus monogyna)* in mid-Wales, Jones *et al.* (2001) found that non-local provenances encountered bud-burst in some cases up to 5 weeks before local provenances, illustrating that even genetic differences can have an effect on phenological events. Deans and Harvey (1995) also found that budburst dates varied by more than 3 weeks when assessing phenologies of 16 European provenances of Sessile Oak (*Quercus petraea*) at a site in Scotland. Correlations between budburst and altitude, and budburst and latitude, showed that those provenances of southerly latitudes and high altitudes burst bud earliest. This emphasises the sensitivity of phenological events across scales.

4.8.6 Flowering Phenology and Distribution Change

In a study by Hulme (2011), by looking at the phenology (first flowering date recorded between 1970-2000) of 347 species he found that those with earlier flowering responses to spring temperatures had changed their distributions over the same period across the British Isles, a link previously not observed.

The onset of phenological events marks the start of the reproductive phase of the plant's life cycle, with the "reproductive success of a population each year, the growth and the survival probability of individuals" (Cleland *et al.*, 2007) determined by such events. It is assumed then, that with an earlier flowering time in response to warming, certain plants will be at an advantage and their probability of occurrence greater; they will exploit the longer growing season, may have improved interactions with pollinators (Walther *et al.*, 2009) and resultantly be more favoured to increase range. Conversely, earlier flowering may lead to a greater risk of damage by late frosts and thus poorer reproductive output (Miller-Rushing and Weltzin, 2009).

Species that are later flowering may be at a disadvantage to those species that have flowered earlier and utilised the available resources, therefore being out-competed (Miller-Rushing and Weltzin, 2009) with likely poor plant performance and reproductive output (Hulme, 2009b). However, plants which flower earlier and perform better have experienced declines in their range due to other environmental factors – namely the effect of agricultural intensification on arable weeds (Hulme, 2009a). Plants may also flower earlier in comparison to others but not increase their range to the extent that those flowering later have, and this can also be down to factors affecting distribution other than climate, e.g. soil fertility, pH.

4.8.7 Apparent Climate Signal

Increase in native species' ranges can be down to other environmental variables (as is discussed in section 4.9.2) allowing them to persist in the environment, or because of human intervention, but there is an apparent climate signal between climate change and earlier flowering dates, especially as those natives having later flowering responses declined in distribution (Hulme, 2009b). In 1999 phenological events were accepted by the UK government as indicators of climate change (Cannell *et al.*, 1999) so monitoring of these events will increase the field data relating the two variables.

Phenological shifts illustrate the impact recent warming may be having on biodiversity and that there can be knock on effects on reproductive performance, interactions with other species and ability to track future climate change. Phenological changes along with displacement of species ranges owing to climate change will "alter population-level interactions, community dynamics and have profound ecosystem and evolutionary consequences" (Fitter and Fitter, 2002). Sensitive ecosystems will be more at risk and conservation effort should be focused here, but novel communities will more than likely emerge in the future.

4.9 Monitoring Change in the UK and Drivers of Change

Biological recording of species distribution has come a long way since the 1960s when the *Atlas of the British Flora* was published 50 years ago. Awareness of the need to monitor species, the methods used, the ease of computerising data records and people generally more interested in nature, have all added to the data bank now available. Through these studies those species most at risk/vulnerable can be identified and the requirement for conservation attention flagged. These are often species on the edge of extinction, thermal specialist species physiologically sensitive to change, species lagging dangerously behind current climate change, and plants with poor dispersal abilities. Careful interpretation of the data is, however, required due to recorder difference/effort since the earlier days of recording (Preston *et al.*, 2012).

Repeat atlases have been compared and it is clear that agricultural intensification has led to bird and vascular plant species of arable farmland suffering the greatest declines (Preston *et al.*, 2012). For species in more semi-natural habitats, the causes of change are less clear; studies looking at the ecological traits of species have yielded further insight into differences between species and within habitats, including Grime *et al.*'s (2007) detailed trait analysis of species, and Ellenberg *et al.*'s (1991) indicator values, which were less specific than Grimes, for monitoring change across Europe.

4.9.1 Recent UK Gains and Losses (Changes in British Flora)

The Botanical Society for the British Isles (BSBI) carried out a repeat of surveys done in 1987 in 2004 to map the changes in the British flora; species traits in broad habitats were looked at to identify the variability of range change (Braithwaite *et al.*, 2006). An assessment of calcareous grassland species showed that annual species, preferring nutrient–rich soils, and/or of a southerly European distribution have fared better than the larger groupings of biennial and perennial species that require low fertility habitats. Greater knapweed (*Centaurea scabiosa*) is a typical calcareous grassland species; the results of survey indicate its decline in range by about 26%. There has also been a decrease in Birds-foot trefoil. There are many studies which also make similar deductions of declines in plants favouring nutrient-poor habitats, as well as overall decreases in species diversity/richness (Walker *et al.*, 2009; McClean *et al.*, 2011).

The BSBI Local Change survey also revealed that certain plant species with a southern distribution, such as the Bee Orchid (*Ophrys apifera*) have extended their range northwards, with the Pyramidal Orchid (*Anacamptis pyramidalis*) also increasing its range (Braithwaite *et al.*, 2006). Orchid seeds are much smaller than the majority of vascular plants, and so dispersal could be due to human activities, rather than climate change (Preston *et al.*, 2012). Whilst some orchids are increasing in range, the Burnt Orchid (*Neotinea ustulata*) has undergone significant declines in the British Flora (Plantlife, 2000).

New species are being gained, as areas lose species, but the gains do not compensate for the losses which are mainly native flowers of natural habitats, with a consequent less diverse flora. The gains tend to be commonplace species, typically present in un-natural habitats like road verges and wasteland (Plantlife, 2000). "The increase in species such as cow parsley, brambles, coarse grasses and stinging nettle is linked to an increase in soil fertility as a result of nitrogen pollution from farms, power stations and car exhausts". Rare plants are better protected than scarce ones, through the likes of SSSIs, but even protected sites are affected.

In contrast, the 2007 Countryside Survey reported no evident changes in plant distribution or abundance in those fixed plots surveyed since 1978, relating to those in line with climate change (Carey *et al.*, 2008). Studies monitoring the response of animals distribution in relation to climate change have been analysed by Hickling *et al.* (2006); it was found that 13 of the 16 taxonomic groups studied with southerly distributions in Britain (including both vertebrates and invertebrates) have shifted their range northwards. A study of such scale is yet to have been done for plant species in the UK, which may yet detect changes in response to climate change.

4.9.2 Other Drivers of Change

The change in species distributions may not all be attributable to climate change, there are other factors which could be responsible for some of the changes seen to date. With the increase in urban development, the species that are typically found in habitats associated on urban land may have resultantly expanded their range (Pateman, 2012). The upward shift of Scots pine (*Pinus sylvestris*) in Scotland is more than likely as a result of a decrease in grazing pressure (French *et al.*, 1997), and may explain similar shifts found in other high altitude treeline regions. Plant species which thrive in areas experiencing more nitrogen deposition may have also increased their ranges here (Britton *et al.*, 2009). Conservation programmes aimed at specific species, and better management of land may also have led to the range increase of species, including Plantlife's *Back from the Brink* species recovery programme.

Sometimes organisms are unintentionally transferred to areas which they can survive in and thus boundaries expand to distances not possible otherwise, as seen with the pine processionary moth in a study by Robinet *et al*. (2012). The planting of Alder Buckthorn (*Frangula alnus*) in ornamental assemblages in North Wales has facilitated the range expansion of one of its harbouring species - the brimstone butterfly, and similar plantings may lead to other species range expansions (Pateman, 2012). Such examples illustrate that changes in the climate are not the only drivers of species distributional change.

4.9.2.1 Reasons for Species Decline

Reasons for species decline, as noted by Plantlife (2000) other than climate change, habitat fragmentation and intrinsic dispersal constraints, include changes in management practices, drainage of the countryside, and a decline in water quality. Corn cockles, cornflowers, corn marigolds, corn buttercups, corn cleavers and narrow-leaved hemp-nettles have declined in all but most arable counties. Woodland plants have suffered from neglect, with only shade-loving species now thriving. Agricultural intensification, farm fertilisers and atmospheric pollution have lead to increases in soil fertility, a condition favoured by vigorous hostile plants, leading to declines in wildflowers which prefer naturally infertile conditions (Plantlife, 2000). The biotic constraints to a species colonisation beyond their current range may be inhibited due to the presence of herbivores. The current distribution of some species may be down to a combination of factors, and thus future patterns of spread will be unknown.

4.9.3 Biotic Interactions

With climate likely to affect the abundance and diversity of natural enemies and competitors, an indirect effect of the climate will be the biological interactions it creates between invasive species and native species along climatic gradients (Thomas, 2010), the outcomes of which could differ with climate change. It is unpredictable to say to what degree climate change will alter the distribution capabilities of certain species, and their ability to colonise new communities, as such interactions are complex and each species is different, i.e. dependant on their ability to withstand natural enemies, and their ability to compete for resources (Pateman, 2012).

4.10 The effect of CO_2 on Plants

Aside from climate change, the forcing agent partly responsible for climate change - carbon dioxide (CO_2) will also have an effect on species; levels of atmospheric CO_2 currently exceed any experienced during the past 20 million years (IPCC, 2007). Temperature and CO_2 have a direct effect on the rate of photosynthesis, respiration and consequently growth and tissue composition in plants (Hughes, 2000). Experiments studying the effect of CO_2 enrichment on plants have shown that the effect varies between short-term and long-term experiments, and if the plant utilises a C_3 or C_4 photosynthetic pathway (Woodward, 2002).

4.10.1 Stomatal Conductance

The effect of an increase of CO_2 in the atmosphere, which has occurred since the mid-1800s to the present day, has already been observed (Hughes, 2000). There is evidence that CO_2 levels may be having an effect on stomatal density, and thus stomatal conductance and water use efficiency in many species. Several studies have shown that the stomatal densities of plants collected recently are significantly lower than in herbarium samples of the same species collected between 70 and 200 years ago (Beerling and Kelly, 1997). Fossil records and experimental studies using pre-industrial CO_2 concentrations have mirrored the trends found in these studies (Hughes, 2000).

4.10.2 Photosynthetic Rate

The possible effects of CO_2 fertilisation have also been identified, with observed increases in the yields of conifer plantations since the mid 1800s (Cannell *et al.*, 1998), as well as the increasing rate of tropical trees turnover and biomass since the 1950s, as a result of increased photosynthesis. This biomass increase may help mitigate some of the effects of climate change by acting as a sink for CO_2 (Hughes, 2000). In contrast, some experiments have shown that certain plants experience a down-regulation of photosynthetic rate, i.e. a reduced rate, as they acclimatise to elevated concentrations, they do however benefit from a 40% increase in water use efficiency due to a decline in stomatal conductance (Woodward, 2002).

4.10.3 Multiple Interactions

The CO_2 exchange status of the plant is also associated with the metabolic and physiological pathways, interactions of which are complex. Experiments of varying soil fertility showed that there was no early growth stimulation on a site with infertile soil conditions (Oren *et al.*, 2001). This exemplifies how certain factors, e.g. nitrogen availability, are crucial for growth; trees treated with both nitrogen fertiliser and elevated CO_2 showed a three-fold increase in growth over controls. As Woodward (2002) acknowledges 'the coupled nature of the carbon and nitrogen cycles feeds into whole-ecosystem processes' and as shown in another CO_2 enrichment study by Oren *et al.* (2001), when the nitrogen availability decreased, the fertilisation effect of elevated CO_2 on plant growth became minimal.

4.10.4 Reproduction and Seed

Some studies have shown that under elevated CO_2 levels the onset of reproductive maturity begins earlier and seed production increases, in comparison to the ambient CO_2 concentrations control. Woodward (2002) states that this response may increase a species' chances of tracking climatic change. Conversely, grassland studies with CO_2 enrichment showed that flowering and seed set demonstrated a range of different responses: unaffected, reduced or stimulated. The outcome of this in the future could be changed plant community composition (Woodward, 2002). This is another example of an abiotic interaction yielding different responses between species, and just as has been discussed with regards to how species have and will respond individually to climatic changes, the composition of future plant communities will more than likely alter with non-equivalent assemblages.

4.10.5 Summary of CO_2 Impacts on Plant Physiology

Plants will physiologically respond to the increases in CO_2, including growth responses and changes in water-use efficiency, and it is expected that such responses will improve the reaction of some plant functional types to climate change (Sitch *et al.*, 2003). The intrinsic CO_2 pathway of the plants selected for sites in the UK, and the effect of an increase in CO_2 on such plants, will not be investigated any further in this research.

4.11 The Effects of the 2003 Heatwave on Vegetation

The 2003 heatwave over Europe was one of the hottest summers for more than 500 years (Luterbacher *et al.*, 2004), with a new temperature extreme of 38°C being reached in the UK by mid-august. By observing the effect such climatic events have on vegetation it can be seen which species are more vulnerable and at risk to future climate change, so that adaption plans can be made accordingly. In a study by Jolly *et al.* (2005), with the use of satellite-derived rates of photosynthetic activity, it was discovered that there was a pattern of high elevation growth enhancement as a result of the longer snow free growing season, and low elevation growth suppression as a result of increased summertime evaporative demand and thus water stress, across the Alps. Such climatic events therefore do not just shift the elevation belt of plants upwards, but affect them on many more levels.

Those plants in mid-high latitudes were particularly affected, with there being differential impacts on the vegetation depending on their growing environment. For instance, in the alpine (>2100-2800m) and nival (>2800m) vegetation zones of the Alps, above average photosynthetic activity was shown. Normally only a few specialist plants survive in the nival zones, but it is thought that if prolonged warming was sustained at such altitudes, with enhanced growing conditions, then previously inhospitable areas would perhaps foster subsequent plant dispersal, even for the heartiest of alpine plants (Jolly *et al.,* 2005). Evaporative demand, frost and drought interact to affect the performance of plants during their growing season. Species resistant to drought will be at an advantage if/when similar extreme climatic events occur in the future.

Studies undertaken in 2004 by Gobron *et al.* (2005) evaluating the state of vegetation during and after the heatwave, discovered that the effect on vegetation was identifiable from space as early as March 2003, but that by spring season 2004 the terrestrial environments in Europe had returned to more normal conditions, except for areas affected by fire. This illustrates how species can adapt, but as the extremes of temperature were only for a short period, it is not known how these observed changes relate to the effects of long term warming, which could be far worse for biodiversity.

4.12 Modelling Future Distributions

4.12.1 Species Distribution Models

Species distribution models (SDMs) or climate envelope models (CEMs) are commonly used in assessing the impacts of climate change on species future distributions (Pearson and Dawson, 2003; Guisan and Thuiller, 2005). SDMs are a form of empirical modelling correlating the current distribution of a species with the climate conditions in which it resides, e.g. (Bakkenes *et al.*, 2002; Pearson *et al.*, 2002). When combined with climate projections derived from GCMs, the potential distribution of a species is estimated. This can either be achieved statistically or with genetic algorithms (Pateman, 2012).

4.12.1.1 Ecological Niche Theory

SDMs are based on ecological niche theory. The *fundamental* niche of a species includes the environmental requirements fundamental to the species survival and growth, a concept defined by Hutchinson (Hutchinson, 1957). However, biotic interactions between species and competition results in species occurring only in parts of their fundamental niche, known as their *realized* niche. In the context of SDMs, they can be perceived to be representing only the climatic aspects of a species fundamental niche, i.e. the species climatic niche (Pearson and Dawson, 2003), excluding all other factors which affect a plants existence in nature. As the observed distributions of species considered in an SDM are already being constrained by biotic interactions and limiting resources, i.e. as they exist currently in nature, they are said to be based on the realized niche of the species (Pearson *et al.*, 2002; Guisan and Thuiller, 2005). The assumption here is that these biotic interactions will remain the same under future climate change, which may not be the case.

Some models aim to represent the fundamental niche of a species by mechanistically modelling a specie's physiological response to climate (Pearson and Dawson, 2003; Buckley *et al.*, 2010); these models obviously yield more realistic projections, as the community interactions observed today, reflected in correlative models, are likely to change along with future conditions. As mentioned in section 4.4.1, species are predicted to respond individually to climate change, which will make SDM predictions invalid (Pearson and Dawson, 2003), as community compositions begin to form with no previous analogue.

4.12.1.2 Applications of SDMs

By realising a specie's potential distribution in the future, those species more at risk of losing suitable climate space can be identified and conservation efforts can be focussed on these; Williams *et al.* (2008) propose a conceptual framework of adaption for vulnerable species based on their ecological and evolutionary traits. Alternatively, where future climate space does exist, but colonisation of these areas is hindered by incoherent land-use patterns, SDMS are being created for this approach (Vos *et al.*, 2008; Crossman *et al.*, 2012; Summers *et al.*, 2012), with the outcome of targeting conservation appropriately and creating better connectivity for those species susceptible to this fate. SDMS have also identified species which may have little or no suitable climate space in the future, with the risk of extinction likely if conservation efforts are not addressed towards them, or if sufficient reductions in greenhouse gases are not made (Thomas *et al.*, 2004; Thuiller *et al.*, 2005).

4.12.1.3 Assumptions and Limitations of SDMs

The ability of SDMs to accurately portray future situations has however been questioned (Davis *et al.*, 1998; Pearson and Dawson, 2003; Hampe, 2004), with the methodology being flawed. There are three main factors which are, in the majority of studies, neglected or falsely assumed:

- Biotic interactions between species – a species may be surviving in an area due to its positioning within the surrounding plant community, with distribution in reality not strongly correlated to climate
- Evolutionary change; a species can rapidly evolve adaptive traits in response to environmental change and thus its ability to survive is not as constrained as assumed. However, this adaptive response will not be true for all species when responding to climatic change.
- Species dispersal; the dispersal characteristics of a species will dictate its ability to migrate accordingly, which will also depend on the surrounding cohesion of the landscape.

"The ability to migrate is a function not only of individual species' characteristics, but also the structure of the landscape over which dispersal is occurring" (Pearson and Dawson, 2003). SDMs only portray a specie's potential for survival at a specific location, when in reality this may not be achievable.

SDMs expect species to immediately occur at a site with no account of potential dispersal limitations, they simply treat distributions and vegetation types as 'infleixble units, which snap to a new position' (Doxford and Freckleton, 2012), and this is not realistic. Most studies incorporating SDMs predict distributions under two extreme dispersal scenarios (Thomas *et al.*, 2004; Thuiller, 2004); a 'no dispersal' scenario whereby the species are incapable of dispersing, and a 'universal' scenario, where conversely there are no limits to a species ability to disperse. In reality dispersal ability is likely to be in between the two (Thomas *et al.,* 2004), with projections consequently over-estimating or under-estimating future projections.

SDMs assume that a species current distribution is in equilibrium with the climate, but as discussed in section 4.4.5 some species are experiencing a migrational lag after the last glacial and therefore projections will overestimate/miscalculate future potential distributions. Although climate is an important factor influencing plant distributions (Thomas *et al.*, 2004; Walther *et al.*, 2009), most SDMs assume that, for all species, climate is the main determining factor. Some species are however governed by other environmental factors, and so a future suitable climate space may not actually sustain the species existence.

Models results should be interpreted with caution as, for example, although a CEM created by Pearson *et al*. (2002) projected a good agreement between observed distribution and simulated distribution for hard-fern (*Blechnum spicant*) in Europe, there was only a general agreement for the broad distribution trends of yew (*Taxus baccata*), with the finer details not being captured. The uncertainties of GCMs of which the projections are based on, discussed in chapter 2, and the coarse spatial resolution of the analysis, also need to be acknowledged when interpreting results. Through a combination of factors including nitrogen deposition, the increased possibility of invasion by non-native species, as well as the emergence of more competitive native species, this could result in the alteration of plant communities and the competitive interactions within them, "yielding novel patterns of dominance and ecosystem function" (Thuiller *et al.*, 2005). With computer modelling unable to predict such interactions, the outcomes of the models may falsely predict the distributions of species in the future.

4.12.1.4 Improved Models

Models are being developed, nonetheless, which incorporate biotic interactions like resource competition (Meier *et al.*, 2011), and include realistic models of dispersal (Engler and Guisan, 2009), but it is not known whether increases in model complexity and ecological dynamics will result in more accurate predictions (Thuiller *et al.*, 2008; Pateman, 2012). Computational demand will also need to be considered when many factors are processed in a model. As stated in Pearson and Dawson (2003) "The complexity of the natural system presents fundamental limits to modelling strategies, making predicting errors inevitable", imploring the question of whether models will ever be able to mimic the natural system with 100% accuracy, as understanding the dynamics of nature is a forever learning process.

4.12.1.5 Overview of SDMs

Although SDMs do not always account for factors that limit a species distribution, other than climate, they do demonstrate the potential future distributions of species under climate change. Where it appears species will lose climate space or face the possibility of extinction, conservation efforts or adaption measures can be targeted at those most at risk, preventing irrefutable biodiversity loss; it is a proactive approach. At the least, SDMs are focusing efforts on very prevalent issues, and with time modelling errors will decrease and assumptions can become more realistic.

4.12.2 SDMs and Species Change

4.12.2.1 Species Loss and Turnover

A study by Thuiller *et al.* (2005) project late 21st century distributions of 1,350 European plant species under seven climate change scenarios using a SDM. Rates of species loss and turnover showed great variation across scenarios and it depended strongly on the amount of change in just two climate variables: temperature and moisture conditions. For the A1-HadCM3 model scenario (detailed in chapter 2), where there is an increase of mean European temperature by up to 4.4°C, Thuiller *et al*.'s (2005) study showed there is a mean loss of species of 42% and a turnover of 62%. Species loss could exceed 80% in some areas, such as north central Spain, and the Cevennes and Massif Central in France. The lowest expected mean percentage of species' loss (27%) was under the B1-HadCM3 scenario, which correlates with the fact that this scenarios' CO_2 and temperature increase is the lowest out of all the scenarios studied. Species loss will be low in the Boreal region, with an influx of species from immigration. The most significant changes are likely to be in the transition between the Mediterranean and Euro-Siberian ranges (Thuiller *et al.*, 2005).

As discussed in section 4.12.1.3 there are limitations to SDMs. In Thuiller *et al*.'s (2005) study biotic interactions were not included, and neither were the physiological effects to species caused by increases in CO_2, all of which play a part in plant growth and population dynamics. Other flaws in the study were that the impacts of land-use change, which will have an effect on plant distributions, were not analysed, but Thuiller *et al*. (2005) believe that the effect of land use change would be superseded by the effect of climate change. Research has, however, shown that thresholds exist for both, as discussed in section 4.6.2.

4.12.2.2 Extinction Predictions

With climate change it is probable that there will be reductions in the geographical ranges of certain species, which could potentially lead to an increased risk of local extinction (Thomas *et al.*, 2004). Thomas *et al.* (2004) also performed a similar study to Thuiller *et al.* (2005) utilising a SDM to assess the extinction risks for sample regions that cover some 20% of the Earth's terrestrial surface. Under a mid-range climate-warming scenario (1.8-2.0°C increase in temperature) for 2050, it was predicted that 15-37% of species and taxa in the regions sampled, will be 'committed to extinction'. The extinctions predicted vary across the world and between taxonomic groups. Currently global habitat loss is the biggest cause of species extinction, but over the course of the 21st century climate change is predicted to play a big part in biodiversity loss. A factor not considered in the study, which was also neglected in Thuiller *et al*. (2005), is that of land use; extinction risks might be higher than predicted if future locations of suitable climate do not contain other vital resources, like the correct soil type or nutrients.

4.12.3 SDMs and Likely Biome Changes of the Future

A computer modelling study carried out by NASA and JPL-Caltech (California Institute of Technology) (2011) has revealed that by 2100, climate change across the globe will alter plant communities found on nearly 50% of the Earth's land surface, and will lead to the alteration of almost 40% of land-based ecosystems from one major ecological community type towards another. They used the intermediate IPCC emission scenario which assumes greenhouse gas levels will double by 2100 and then level off. The shift in biomes towards Earth's poles will be most felt in temperate grasslands and boreal forests, and towards higher elevations, mainly the higher latitudes of the northern hemisphere, including the Scottish Highlands. Conservation and adaption action should therefore be aimed at these sensitive regions.

4.12.4 SDMS and Specific Vegetation Shifts over the 21st Century

4.12.4.1 Forest Effects in UK

Forest Research studied the effect of climate change on Skita spruce and Beech in the UK using the Ecological Site Classification, a method which models future species suitability, in this case the commercial suitability of forest trees as a function of climatic and edaphic factors (Broadmeadow, 2002). Figure 4.5 shows the simulations for Skita spruce and Beech, incorporating the medium-high climate scenario. The effect of CO_2 on growth and water use (stomatal conductance) are not accounted for, so a worst case scenario is presumed. 'Very suitable' in the key to Figure 4.5 denotes a 75% yield, 'suitable' denotes between 50 and 75% yield, and 'unsuitable' denotes a less than 50% yield achievable in the UK. The suitability of tree growth for both species decreases in the south and increases in the north, more so towards the end of the 21st century.

Figure 4.5 ESC simulations of suitability of Skita spruce (top) and Beech (bottom) under the UKCIP98 ‘medium-high’ climate scenarios (Broadmeadow, 2002)

4.12.5 MONARCH – Modelling Potential Range Change for UK Species.

The Modelling Natural Resource Responses to Climate Change (MONARCH) project, which ran between 1999 and 2006, used CEMs to assess the impact of climate change on wildlife in Britain and Ireland (Walmsley *et al.*, 2007). The aim was to identify the future climate envelope of species, and thus their future likely distributions dependant on their ability to disperse. In the final phase of MONARCH’s study, the future climate space of 32 BAP species were projected; a small proportion as many BAP species are conservation priorities and thus it is not always climate controlling their distribution, which is the basis of CEMs. Species modelled had good European-level distribution data available to train the model and achieve a good level of agreement between simulated and observed distribution. The UK Climate Impact Programme’s (UKCIP) 2002 climate scenarios under low and high emission for the 2020s, 2050s and 2080s were used in the process and projections were at a 50km resolution.

Table 4.1 shows the four categories the 32 BAP species fall into, based on their future projections of potentially suitable climate space. The ‘gain’ category contains species currently with a southerly distribution in the UK, which are often more abundant in continental Europe. The ‘loss’ category contains species with a predominantly northern distribution, with some species at risk of losing all or almost all of their suitable climate space in the UK by the 2080s under the high emission scenario. Only 3 species fell into the 'no change' category, with the whole of the UK remaining climatically suitable for them; they are also widespread within Europe. Species in the 'shift' category are expected to gain suitable climate space in the north but lose space at their southern margins (Walmsley *et al*., 2007).

Table 4.1 Categories of simulated change in potentially suitable climate space for 32 BAP species (Source: Walmsley *et al*., 2007)

As with all SDM/CEM modelling projections, there are caveats; Walmsley *et al.* (2007) state that the results should be interpreted cautiously and taken to show the general pattern of expected change. There is much variability between the potential distributions of species, but the MONARCH results show the broad effect climate change will have on natural resources and that the majority of species will need to disperse to survive. Conservation policy and management should be flexible to work under a range of circumstances to adapt with the climate.

Although there is a paucity of studies on plant dispersal and migration rates, it is assumed that many plant species will be unable to disperse into new suitable climate space. UK BAPs will potentially need to be flexible in either the species it selects to re-create priority habitats, or provide connectivity between these habitats to allow species to move naturally (Harrison *et al.*, 2001). Whether non-natives will pose a contribution or a threat to nature is a topic also lacking in depth (Harrison *et al*., 2001), as invasive species will be detrimental to conserving biodiversity and counteract meeting biodiversity targets, a point which has not been over-looked in this research.

4.12.6 BRANCH – Biodiversity Spatial Planning for Climate Change

BRANCH stands for **B**iodiversity **R**equires **A**daption in **N**orth West Europe under a **CH**anging climate. The aim of BRANCH, which ran between 2004-2007, was to provide evidence that spatial planning for conservation needs to be a focus of policies and strategies to allow wildlife to adapt to climate change (BRANCH partnership, 2007). BRANCH acknowledge that the fragmented landscape of Europe does and will prevent species moving into future suitable climate space and this needs urgent attention from the European level to the local level. Multiple partners from England, France and the Netherlands collaborated on the BRANCH project, transferring knowledge and expertise to assess current policy and identify the areas which are most at risk, with transferable outputs. The extent, character and distribution of terrestrial and coastal habitats were studied in the south east of England and other parts of North Western Europe.

4.12.6.1 Modelling Potential Suitable Climate Space

The loss and gain of suitable climate space was projected, using a CEM, for 389 species of different taxa across Europe, highlighting the vulnerability of the majority of species, particularly by the 2080s, with 6 species losing all suitable climate space, 11 potentially losing more than 90%, with only 28 species doubling their suitable space (BRANCH partnership, 2007). Trans-national co-operation will be important if species of conservation lose suitable climate space in one country and gain it in another. Unfortunately the future projections (maps) of potential suitable climatic space for the species studied are no longer available to observe, with the BRANCH website having been archived; this is a limitation of BRANCH and limits the message they are trying to convey.

As mentioned for other studies, the gain of future climate space will only be achievable if the species are able to disperse at a suitable rate, and that suitable habitat exists at the future site as well as in-between it. As discussed in section 4.4.2, species with poor dispersal mechanisms and long maturation rates may not be able to take full advantage of their future climate space without some assistance (Berry *et al.*, 2005).

4.12.6.2 Planning Issues and Recommendations

Although the environment is considered in legislation like the Habitats Directive and the EIA Directive (as discussed in chapter 3), reasons gathered from planners for not addressing the issue of climate change and biodiversity earlier were because of (BRANCH partnership, 2007):

- Lack of certainty on the severity and timescales of climate change and uncertainty surrounding the climate model projections;
- Vague sense of leadership to govern issues surrounding climate change;

- Availability of resources like skills, time and money to address the issue;
- Lack of knowledge on implementing the correct adaption measures for wildlife protection;
- Competing land use issues, e.g. between biodiversity and infrastructure plans.

In relation to the questionnaire (chapter 6), it was found that the majority of respondents' thoughts towards climate change were able to have an influence on their work. This could potentially indicate that since research was undertaken by BRANCH, the need to adapt for climate change has become more common knowledge than it was previously, with planners recognising the need to consider biodiversity in their work, but this does not necessarily mean action will follow their thoughts.

Recommendations to address the barriers to planning accordingly included increased integration between different policy sectors, and between plans at all spatial scales of development, longer spatial planning times and a promotion of biodiversity networks and recognition of the benefits biodiversity brings to people and to the economy (Piper *et al.*, 2006). Habitat creation should be a condition of planning permission. Integration of climate change into European Directives associated with biodiversity should also be considered, to provide guidance and allow adaption measures to be taken in due course. With there being little certainty of what the future climate will be like and how biodiversity will respond, Piper *et al.* (2006) believe an element of flexibility is essential in conservation policies and how they are implemented.

4.12.6.3 BRANCH Terrestrial Case Studies

One of the studies that BRANCH (van Rooij *et al.*, 2007) carried out was assessing the effect of climate change in relation to habitat fragmentation in three terrestrial case studies, in Limburg (NL) and in Kent and Hampshire (UK).

4.12.6.3.1 Hampshire and South Downs Case Study

Chalk grassland and lowland heath were studied in Hampshire and the South Downs, characteristic habitats of importance to the area (van Rooij *et al.*, 2007). Species typical of the habitats were selected for the study and climate change modelling showed that species responses vary; for some the local climate becomes more suitable and for others it becomes less suitable. In the long term (2080s) most species modelled are expected to lose climate space, with the composition and character of these habitats changing significantly unless species are able to adapt to the changes. Under the 2020 (high) and 2050s (low and high) scenarios, the key species for the lowland heath (ericaceous species) and chalk grassland (e.g. crested hair grass, meadow oat grass and musk orchid) do not suffer considerable loss, but under the 2080s high scenario all, or nearly all potential suitable climate space could be lost for these characteristic habitat species. Even species which remain, may decline if the species they rely on disappear.

As the climate becomes unsuitable, a species may undergo stress and become unable to function efficiently (i.e. with competitors), resulting in a possible decrease in abundance or localised extinction (Berry *et al.*, 2002). A solution to this would be to manipulate the local climate and uphold a heterogeneous landscape (Berry *et al.*, 2007). BRANCH recommends maintaining favourable conditions and re-creation of habitat which might allow the species to survive in the short-mid term (van Rooij *et al.*, 2007).

It is expected that new species will colonise the case study area as they become more suitable for a different assemblage of species, unless of course habitat fragmentation prevents such activities. New species should be allowed to infiltrate these habitats as otherwise biodiversity may decline, although it is not known whether these new species will bring problems or benefits to the new plant community. Another recommendation is to allow Natura 2000 sites to accommodate change, with land designated for new incoming species, as well as the protection it already offers species of high nature conservation (van Rooij *et al.*, 2007), species which may not remain as the climate becomes unsuitable. In the long term, BRANCH believes this may be the best decision for adaption.

4.12.6.3.2 Kent Case Study

The Kent case study looked at present habitat connectivity and explored the possibilities for creation of an ecological network to enable species to adapt to climate change. Transport, infrastructure and development were identified as the main obstacles for a coherent landscape, but that wildlife corridors could still exist in such a landscape (van Rooji *et al.,* 2007). Alternative strategies will be needed for different species: maintenance of ecological networks will assist those species declining due to a reduction in suitable climate space; 'adaption zones' consisting of suitable habitat of considerable size to maximise colonisation will benefit those species incoming to the area/increasing as the climate becomes more suitable, as well as improved connectivity between habitats for dispersal reasons.

Species indicative of typical Kent habitats were looked at in the study, but this included only three plant species, all of whose climate will remain suitable under the 2020 and 2050 high emission scenarios including wetland species *Gentiana pneumonanthe* (Marsh Gentian) and *Thelypteris palustris* (Marsh Fern), and woodland species *Hyancinthoides non-scripta* (Bluebell). *Thelypteris palustris* is a Kent Red Data Book species, with the edge of its current suitable climate space being in

Kent and here it appears to remain. This suggests that climate is not the determining factor for its distribution (van Rooij *et al.*, 2007).

The aim of BRANCH was to develop a climate change-proof ecological network with key stakeholders, and a transferrable method to illustrate how fragmented landscapes can be addressed and rectified to allow the changing distributions of species to occur when climatic conditions change and become more or less favourable. Spatial planning can be part of the solution for minimising the effect of climate change on biodiversity.

4.13 Forest Research Climate Matching

Forest Research have identified locations that currently have a similar climate to that projected for the UK with the intention to understand the likely effect climate change will have on tree growth (Forest Research, No date). One of their main concerns is identifying the suitability of broadleaved trees for hardwood timber production under the changed climate of the future, so that these trees can maintain their economic importance, as well as their environmental value in the UK. With warmer summers, there will be larger soil moisture deficits and the wetter autumn and winter periods will reduce root growth. It is likely some will prosper in the changed conditions, but others will simultaneously suffer as the conditions become less suitable for them (The National Forest, 2010). Collection of seed material from these climate-matched areas would be used in provenance trials.

Data Used:

CRU 1961-1990 for current European Values and UK baseline values.

UKCIP 2002 (UKCIP02) scenarios for predicted climate values – 50 km gridded data-set.

Emission Scenarios: Low (IPCC SRES B2) and High (IPCC SRES A1F1)

Time Period: 2050s and 2080s

Climate Variables: Mean temperature, precipitation and diurnal temperature range.

Baseline data for the monthly mean climate variables were applied to the UKCIP02 climate change scenarios. Identification of the area (grid square) presently best matched was by using the least squares method, creating a climatic difference index between the current and predicted climate variables. The variables were then weighted according to the annual range values under the current climate to describe the climatology of a given location. Best matched locations are therefore identified which have the smallest difference overall for the year between current and future projections.

Forest Research carried out climate matching for 5 sites across the breadth of the UK in regions where broadleaf species are currently grown for timber, to understand the future range of climate change that could be experienced in these areas. The 5 sites and their matched locations are shown in figure 4.6.

Figure 4.6 Forest Research climate matching results (Forest Research, no date)

The matched locations illustrate how climate and latitude are linked, with southern European areas currently experiencing the climate expected in southern England. The higher the emission scenario level also leads to areas of hotter climates being matched.

National Forest Planting Trial - Forest Adaption to Climate Change

In another study between Forest Research, National Forest Company, Forestry Commission and the Aggregate Industries, tree provenance trials have been established to research adaption options for creating resilience amongst native trees, woods and forests. The plantings are subject to a range of environmental factors in order to select the most appropriate species, suitable provenance(s) and silvicultural practice for adaption to climate change. The location of possible future climate-proofed genetic material for planting was carried out under a similar methodology to that as used by Forest Research, but matches were made in relation to the location of The National Forest, the Midlands. Trees under consideration were Oak *Quercus robur*, Ash *Fraxinus excelsior*, Wild Cherry *Prunus avium* and Sweet Chestnut *Castanea sativa*. Seed was sourced from the climate-matched regions and seedlings then raised at the Forest Research nurseries in Alice Holt, Surrey.

Figure 4.7 shows the best matched grid squares for the 2050s high emission scenario (yellow squares) predominantly being in northern France and occasionally southern England. The 2080s high emission scenario (blue squares) has matches predominantly in southern Italy. Consequently, provenance material would be sourced from southern England, northern France and Italy based on these findings.

Aston University

Illustration removed for copyright restrictions

Figure 4.7 National Forest climate matching results (Barsoum *et al.,* 2009)

According to their schedule planting of the saplings at the two sites were due to start 2012/2013, so it is assumed monitoring of the sites has only recently commenced.

The influence of mixing tree provenance on planting success, woodland stand structure and relative performance of the differing tree types and seed source will be determined in the trials (Barsoum *et* *al.*, 2009). Another desired outcome is to ascertain how non-native provenance may affect biological diversity and the incidence of pests and diseases. Some of the questions posed will be answered through their assessment of the following traits (Barsoum *et al.,* 2009):

- Survival (especially post-frost, post-drought),
- Growth (height, dbh),
- Form (leaf area, branching patterns),
- Phenology (e.g. bud-burst),
- Biomass of flowers, leaves and fruit.

4.13 Conclusion

It is evident that over large time scales climate change has had an effect on biodiversity, altering species' distributions, composition and interactions with both biotic and abiotic factors. Previous migration rates at the end of the last glacial show that some species are capable of adapting to change and dispersing into areas more suitable than others, but that some species are constrained in their ability to disperse either due to lack of accessibility or poor dispersal mechanisms (Svenning and Skov, 2007).

Recent spatial shifts in species' distributions have predominantly been noticed in birds and butterflies, but certain plant species are also increasing their range in ways consistent with those expected as a result of climate change. In Europe species appear to be shifting northwards to higher altitudes, and often species respond individually (Kullman, 2006). The ability to migrate and acquire suitable habitat will ultimately dictate the colonisation and extinction rates of species, along with species-species interactions. Fragmented landscapes and changing land use will have a detrimental effect on the rates and success of species migration in response to future climate change, and spatial planning should address this issue, creating permeability for species to move.

The future distributions of various taxa have been projected using computer models, showing where gains and losses will occur, with the aim to influence conservation priorities. These models, however, make many assumptions and results should be interpreted lightly. Observations and research have shown that the interplay of various factors dictates a species response to environmental change, interactions which models cannot simulate. The outcome may be community compositions in the future having no previous analogue, and the reason why conservation measures need to be flexible, and adaption planned appropriately for both native and non-native species.

As the historic, current and model studies on species distribution all have employed varying methods, variables and species to analyse a specie's ability to track climate change, it is hard to draw comparisons between them. What has been shown, however, is that some species are capable of responding and either adapting in situ or expanding their range, but this may alter given the magnitude of climate change. Based on the outcomes of future climate models, it is hard to predict if the species will be able to reach their suitable climate space as this depends on the degree of habitat fragmentation and habitat loss in the species surrounding area.

Many studies modeling species' responses to climate change have used temperature and moisture variables, with Thuiller *et al.*'s (2005) study stating that these two variables had a large influence on species loss and turnover. This is pertinent to the climate matching technique for climate variables in the next chapter.

5. Methodology

5.1 Overview of the Research Approach

The planned outcome of the research is the creation of resilient planting assemblages for brownfield sites to survive the climate predicted for the UK in 2050, maximising biodiversity robustness and ensuring longevity on such sites. This will be achieved by creating a framework which considers the future climate of case studies throughout the UK and indicates plant species of varying provenance that could be suitable at such locations. The requirement to incorporate biodiversity into development schemes has, as discussed in chapter 3, become more prevalent in the planning system, with some developers actively seeking to create areas of high ecological value on their sites. The research aims to incorporate a climate change adaption element into this biodiversity, with the use of species of non-native provenance, i.e. species which will be suited to the future climate of the UK. As plants are the building blocks of ecosystems, the research is focused at the plant level of biodiversity.

Climate models or GCMs have been developed to predict the climate of the future based on the amount of greenhouse gases in the atmosphere, including natural forcings and anthropogenic influences (Randall *et al.*, 2007), as discussed in chapter 2. The most recent climate projections are utilised in this research to identify locations in Europe with an analogous climate to that which the UK is likely to experience in the future (UKCP09, 2012a).

As discussed in chapter 4, modelling studies have incorporated climate projections into computer simulated models for the projection of specie's distribution in the future based on the specie's climate envelope (Pearson and Dawson, 2003). There are, however, limitations associated with the functioning of these models as they do not consider fundamental interactions between species and abiotic factors, and it is assumed that climate is the primary factor controlling a species distribution. The ability of a species to disperse into their future 'climate space' is also an issue to consider, as the fragmented landscape of Europe has meant many possible migrational routes that species would use, consist of obstructions and isolated patches of land (Honnay *et al.*, 2002). SDMs can highlight species which are more vulnerable, and thus point conservation efforts towards these. The outcomes of SDMs, however, lead to little further else in terms of proactive measures for climate change adaption.

This research method proposes a practical approach to facilitating species' distributions to areas climatically matched. It will provide a tool which developers can use when incorporating biodiversity aspects, through the selection of appropriate species which are adapted to the future climate of the UK. It is a proactive and sustainable measure to ensure development sites, which typically have poor edaphic factors like soil structure, can become resilient to climate change.

5.2 Method approach

The following tasks constitute the approach taken to reach the outcomes of the research:

i. **Determine the future climate of the UK.**
ii. **For a given development site, match the predicted climate data of the site to current European climate, with the use of a GIS.**
iii. **At the matched location explore the current species and habitats.**
iv. **Produce suitable species list resilient to future climate change.**

As point ii. mentions, a Geographical Information System (GIS) will be used in the research to identify climate matched locations. The next section discusses the background of GIS in data handling and manipulating.

5.2.1 GIS as a Tool

Since civilisation began to current day, the gathering of spatial data 'by navigators, geographers, and surveyors has been recorded in a coded, pictorial form by map-makers and cartographers' (Burrough and McDonnell, 1998). The practice of map-making, in some situations however, cannot adequately portray the data in a format that can be easily analysed or updated; there are many limitations to paper maps. Advances in computer-assisted mapping in the 1970s and early 1980s (Burrough and McDonnell, 1998), and the consequent development of GIS has taken static data and made it more dynamic; through a GIS, a computer software package, the world is represented electronically/digitally, with the ability to store, manipulate, analyse, retrieve and update spatial data more efficiently than previously. The increase in computer processing power has further enabled applications of GIS.

GIS is defined as *a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes* (Burrough and McDonnell, 1998).

Location and attribute data are inputted into a GIS, with location spatially referenced to the earth by a known coordinate system. The database behind a GIS map allows the linkages between spatial data and attribute data to be made (Wadsworth and Treweek, 1998).

GIS's versatility means it is used throughout a wide range of sectors and its applications are used, as listed by Burrough and McDonnell (1998), in spatial statistics, soil science, utility networks, hydrology, topographic maps, resource assessment, land evaluation, planning etc. In the environment sector GIS has been used for land evaluation and rural planning, water quality and quantity, air quality, weather and climate modelling and prediction, as well as many more user specific applications. GIS is an interdisciplinary and multi-disciplinary tool and has become a world-wide phenomenon. It is widely available throughout many institutions and industries, making it a well-known, accessible software package.

To perform functions, GIS requires computer hardware (storage devices, an electronic network, plotter, printer), application software modules and a suitably qualified user. Data can then be input, stored, and manipulated with data output and presentation functions; the main components are shown in figure 5.1.

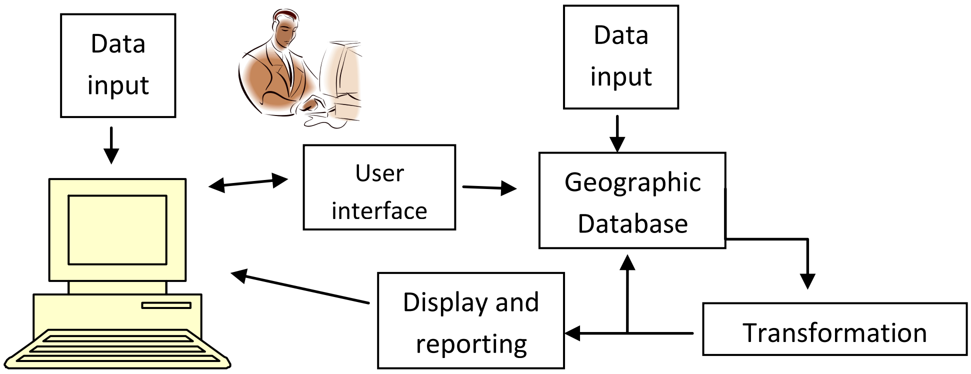

Figure 5.1 The main software components of a GIS (adapted from Burrough and McDonnell (1998))

5.2.2 Use of GIS in the Research

GIS software (ArcGIS) was used in the research as explained in the steps below. Through the use of a GIS, European climate data was analysed to help answer the research questions .i.e. where in Europe has a temperature of x and rainfall of y. The query tools in the GIS enabled the correct information to be sought and the output be communicated through the visualisation capabilities of a GIS.

The research uses a mixture of quantitative and qualitative data to answer the research question. First of all the climate data and the methods for their generation, along with reasons for choice of data used will be looked at.

5.3 Climate Change Projections for the UK

UKCP09 provide the climate change projections used in this research, as discussed in section 2.9, and are based on a change relative to a 1961-1990 baseline (UKCP09, 2012d). UKCP09 recommend use of the Met Office baseline data in conjunction with their data to produce the actual predictions of climate. The Projections were for the medium emission scenario for the time period 2050 (2040-2069).

The UKCP09 25km gridded data-set projections were selected, of which there are 434 grid squares for the UK. As the resolution is 25km^2, local micro climates are not considered in the methodology. The data downloaded comprised of the following factors:

- Resolution: 25km^2
- Monthly data
- Baseline climate variables: Temperature (°C), Precipitation (mm/day)
- UKCP09 Climate change variables: Temperature (°C), Precipitation (mm/month)
- Medium emission scenario
- 2050 time frame

5.3.1 Climate Variable Selection

The variables chosen for this research were the monthly mean temperature (°C), and precipitation (mm). These variables are 'commonly used to determine climate' (Wood, 2005), and as climate is a determining factor for plant distributions (Pearson and Dawson, 2003), they are suitable variables to use. In relation to vegetation studies most only consider temperature and precipitation factors as they are essential for plant growth (Prentice *et al.*, 1992; Martínez-Meyer *et al.*, 2004; Thuiller *et al.*, 2005; Doxford and Freckleton, 2012), and as Walther *et al.* (2009) states:

"Temperature is a key factor limiting survival, growth and reproduction in plants"

illustrating its significance to this research. Water availability also has a strong influence on the productivity of the plant (Wood, 2005), and with species receptive to rainfall variation (Pateman, 2012), it is important that these two variables are considered together in the research.

5.3.2 Baseline data

The selection of the 1961-90 baseline for UKCP09 projections was based on user preference; UKCP09 carried out a consultation with users on which baseline period they would prefer and the vast majority opted for the 1961-90 baseline. The reasons given for this choice were because previous studies have used this baseline and it allows for comparisons to be made with old studies using the new projections.

The Met Office provides the gridded baseline data sets to be used in combination with the UKCP09 data. Perry and Hollis (2005) provide a detailed description of the methods used for creation of the baseline data, a synopsis of which is given here. As archival records for weather observations are created at the 5x5km grid square level, the 25x25 km grid box baseline values for UKCP09 have been produced by averaging the original 5x5 km grid cell values that fall within it over the 30 year time period. Regression and inverse-distance weighted (IDW) interpolation are combined to generate the original values, with consideration of latitude and longitude (to capture spatial variations), altitude and terrain shape, coastal influence and urban land use factors. The distance-weighted method was selected as it captures local variations well.

The station network is irregular, with limited network coverage in sparsely populated areas like the Scottish Highlands, and the density of stations has changed over time, as figure 5.2 shows, although temperature station density is relatively constant. Certain climate variables are represented more so than other variables at different stations across the network. As there is a high amount of variability in daily precipitation, stations were not input into the grid for interpolation if there was data missing in the month. The measures in place to prevent unbiased results, along with the Met Office's quality control procedures, permit a high level of credibility to the data.

Figure 5.2 Station network density between 1961-2001, for precipitation, temperature and sunshine (Perry & Hollis, 2005)

To assess the accuracy of the method for predicting values between station locations, a 10% random set of stations were excluded from the analysis. The calculated values from grid interpolation were then compared with the actual observed values at these stations. The best method for each variable could consequently be utilised dependant on these results, i.e. the smaller the difference, the more accurate that model was at predicting the value. Temperature and precipitation had relative low error values; the reader is referred to the report by Perry and Hollis (2005) for more information. It can therefore be deduced that the interpolated 25km grid of baseline values produced for use in UKCP09 has a good degree of accuracy.

5.3.3 Selection of Emission Scenario

The UKCP09 use three of the Intergovernmental Panel on Climate Change (IPCC) emission scenarios from the special report on emission scenarios (SRES): A1F1, A1B and B1, high, medium and low respectively, all of which are described in section 2.10.2. Selection of an emission scenario cannot be based on the relative likelihood of one scenario occurring, as there is no agreed method of assigning probability to future greenhouse gas emission storylines (UKCP09, 2012a).

The IPCC scenarios were developed in 2000, and as no appreciable changes had occurred by 2007, they were consequently used in the IPCC's fourth assessment report (AR4) and thus UKCP09 (Murphy *et al.*, 2009). Although demographic studies since have shown that population projections are now lower in some countries and higher in others than they were in 2000, the full range of emission scenarios from the SRES, by the IPCC (Nakicenovic *et al.*, 2000) are still deemed to be representative of the range of probable outcomes.

In a study by Grubler *et al.* (2004), it was found that the turn-over of capital stock in the energy sector was not as rapid, and investment into new and advanced technologies was not as prosperous as originally anticipated. Resultantly an expected decrease in energy intensity and increases in technological change are not following their projected trend, but the gain in emissions here is counterbalanced by those emissions lost through population projections.

Medium emission scenario selection

For reasons given below, the UKCP09 medium emission scenario (IPCC SRES - A1B) was selected for the basis of this research project, the projections of which are used to drive the general circulation model (GCM) utilised by UKCP09 to develop the climate scenario. The decision to use this scenario in this research was made in 2009.

The A1 narrative depicts a future world that quickly achieves high economic development, with a population that peaks in 2050 at 8.7 billion, before declining to 7.1 billion in 2100 (Nakicenovic *et al.*, 2000). New and efficient technologies quickly emerge on the scene, with the income gap between regions decreasing greatly. The subgroup A1B represents a balance between fossil fuel and renewable energy sources.

The International Energy Agency (IEA) (2009) believe that it is increasingly likely that governments globally will take rigorous action to address central energy challenges including those relating to climate change, with sustainability playing a key role in their decisions. It is unexpected for the 'do nothing' scenario to be followed. With socio-economic growth rapidly developing in countries such as India and China, it is clear that this will contribute significantly to the amount of greenhouse gas emissions released, and have a high level effect on the world's climate as a whole. It is reasonable to allow such countries to develop economically, but it means that the medium emission scenario is more suitable to use than the low emission scenario when exploring projections for the future climate.

Although fossil fuels still play a heavy role as an energy source in the future, measures are being implemented to mitigate emission levels. The international carbon trading scheme, a governing tool deployed under the Kyoto Protocol, is one such measure, but as it only came into force in 2005, it is too early to judge the effect this is having on the carbon balance of the atmosphere (Hulme, 2009a). The UN programme 'Reducing Emissions from Deforestation and Degradation' (REDD), set up in 2008, aims to offer incentives to tropical countries to maintain the status of tropical forests as carbon sinks, with limits imposed on deforestation activities (Hulme, 2009a). These are all examples of climate mitigation schemes and shows international co-operation is being pursued on the matter. Investments are also being made for renewables and energy efficient infrastructure, but because of the recent recession, funding has declined (IEA, 2009).

For the above reasoning, the medium emission scenario was selected for this research. Other studies which have also used the medium emission scenario include (UKCP09, 2010b):

- De Montfort University studying the impact of climate change on the built environment;
- Oxford City Council for decision making purposes, with reasons for selection being to be neither too cautious nor too dramatic;
- For the assessment of flood risk by the Environment Agency (EA) and JBA Consulting;
- Predicting changes in flow duration curve by the EA and Reading University.

5.3.4 UKCP09 Sampled Data Selection.

The projection data downloaded for this research, from the UKCP09 User Interface, was the 'sampled data'. This data, in excel format, provides 10,000 equally probable model responses for each variable for each month derived from the computational procedure, discussed in chapter 3 of the online climate change projections report (Murphy *et al.*, 2009). The climate variables used were from Batch 1 (UKCP09, No date).

The responses are equi-probable, as the sampling was based on weight ('a relative measure of how well an individual model variant compares to observations') from a much larger number of samples generated by the UKCP09 probabilistic statistical methodology. This method of sampling allows model variants which reflect the past climate more accurately than others to be selected a number of times within the sampled data set. This means responses from the same model variant can produce an identical mean climate change value, i.e. a value can occur more than once out of the 10,000 responses, but the variation is in how the noise was sampled.

Each of the 10,000 responses represents a plausible climate change projection, and consequently there is great variability amongst the responses. In relation to the research this means that for a given 25km grid square, under the medium emission scenario for the time period 2040-2069 there are 10,000 responses given for each variable (temperature and precipitation), for each month. On the User Interface, this request would be actioned through the following criteria:

Variables? Mean temperature, mean precipitation
Climate change or future climate? Climate change
Emission Scenario? Medium
Location? 25 km grid box 1628 (London)
Time period? 2040- 2069
Temporal average? Jan, Feb, Mar...

By using sampled data as oppose to the also available Cumulative Distribution Function (CDF) data, the full range of uncertainty in the projections is considered and thus a more accurate reflection of the projections is given. It also allows more than one variable to be sampled, which is preferable given that two variables were selected in this research; the sampling procedure captures how these variables depend on each other, an important element. As mean temperature and precipitation were sampled by UKCP09 in the same batch (Batch 1) in a multivariate analysis, it means that joint probabilities associated with these two variables can be explored. This would not have been possible with the CDF data. The two EA case studies listed in section 5.3.3 also used the sampled data to carry out their assessments for climate change.

The UKCP09 recommend using "more than just the central estimate from the probability distribution, users should not limit their values to a single value – leads to acceptance of a higher risk than necessary...need to recognise the level of uncertainty". In excel the 10th, 50th (median) and 90th percentiles of the 10,000 responses for a variable were calculated and selected as the range to be used in this research. A sub-sample was essentially selected, but the whole data range was considered. Unlike the mean, the median is not influenced by outliers at the extremes of the data set. With the UKCP09 data having extreme values, these could greatly influence the mean and distort what might be considered typical.

The distribution of the sampled data and the percentiles for an increase in temperature on the baseline, for a given grid square is illustrated in figure 5.3. Based on the histogram:

- There is a 10% probability (i.e. very unlikely) that the temperature increase will be 0.1°C or less, or 90% probability that it will be more than 0.1°C.
- There is a 50% probability that the temperature increase will be 1.6°C or more, or 50% probability that it will be less than 1.6°C.
- There is a 90% probability (i.e. very likely) that the temperature increase will be 3.2°C or less, or 10% probability that it will be more than 3.2°C.

The same principle would apply to the precipitation variable, but the values were in relation to a percentage change on the baseline.

Temperature Increase (°C)	Frequency
-1 - 0	815
0 - 1	2229
1 - 2	3254
2 - 3	2374
3 - 4	1005
4 - 5	323
Total	10000

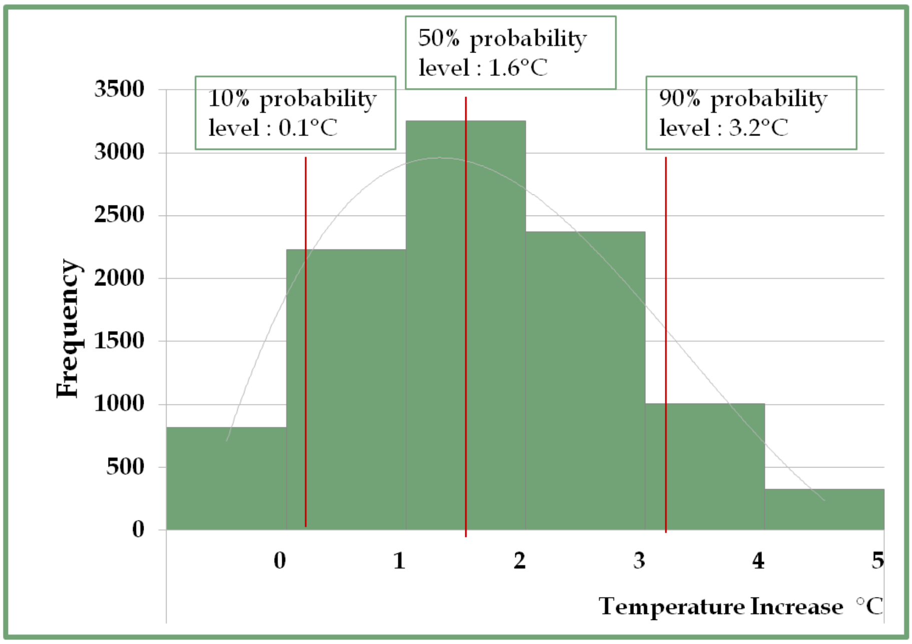

Figure 5.3 The temperature increase for a given UKCP09 grid square based on a cumulative distribution, indicating the 10%, 50% and 90% probability levels.

The future climate change 10 – 90% range values would subsequently be added to the Met Office baseline value to produce the future climate 10 – 90% values. This value for a given grid square is then ready to be entered into the GIS to search for areas in Europe which currently experience a climate within this range. See section 5.5.1 for more detail on this part of the methodology.

5.4 Current European Climate Date

The GIS was used to display the current European baseline data only, but eventually it would be beneficial to create a GIS of the UK climate change projection data to develop the tool. The Climatic Research Unit (CRU) Climatology CL 2.0 10 minute-arc resolution gridded global data set for the period 1961-1990 (Ref: (New *et al.*, 2002) was used here. 10' resolution is equal to about 18km x 18km at the equator, 'with the east-west dimension decreasing to ~16 and ~9 km at 30 and 60° N and S respectively'. The data-set was found on the CRU University of East Anglia website (CRU, 2002), the University of which is linked to the Tyndall Centre known worldwide for their climate change research.

5.4.1 New *et al.*'s Methodology for Creation of European Climate Data

New *et al.* (2002) constructed the 10' (10 min arc) latitude/longitude data set of mean monthly surface climate over global land areas, data of which was collated at the Climatic Research Unit (CRU). Climate variables were interpolated from a data set of station means for the period based on 1961-1990. The eight climate elements include precipitation, wet-day frequency, temperature, diurnal temperature range, relative humidity, sunshine duration, ground frost frequency and wind speed. The 10'arc gridded climatology is an improvement on a previous coarser 30'arc latitude/longitude resolution data set for the same time period, as along with a finer resolution, there are increased station observations and incorporation of local elevation effects as a result of a finer grid. For more information on the methods the reader is referred to *New et al*. (2002).

There were inconsistencies in data retrieved from countries in Africa and Southeast Asia with few or no climatological normals (a climatic average for a defined period) provided, but data from other time periods were used. When the time period contributing to a mean was unknown, a lower weight was allocated to the value in the interpolation stage. As this research is based on matching to places in Europe, there is less concern about these issues, but from a global perspective climate data is under-represented in many countries.

Measurement practices and reporting procedures of climate variables varied within and between countries; methods were used to correct for biases in precipitation, but a more consistent approach to measuring mean temperature was found across the world – the average of the mean maximum and minimum temperature delineated this variable. The distribution and number of stations representing each variable differed greatly across the globe with precipitation and temperature being the most common variables monitored. Mean precipitation was recorded at 27,075 stations and mean temperature was recorded at 12,782 stations - for distribution see figures 5.4 and 5.5 respectively. Quality control checks were carried out on all the data for consistency within and between variables.

Interpolation of station climate data was performed using thin-plate smoothing splines, with elevation, latitude and longitude as autonomous predictors. The use of elevation here increases the aptitude of the interpolation as it enables 'topographic controls on climate that are resolved by the station data to be captured'.

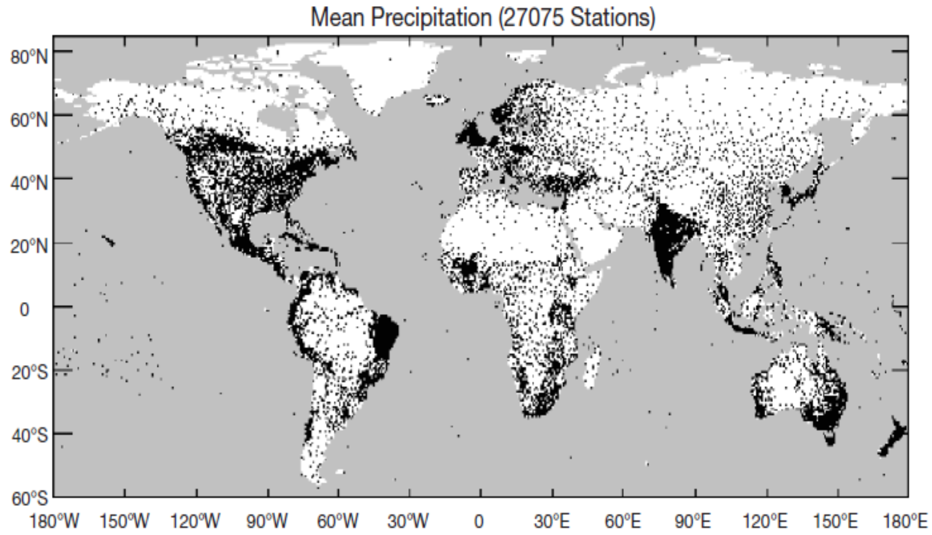

Figure 5.4 Distribution of stations with mean precipitation records (New *et al.*, 2002)

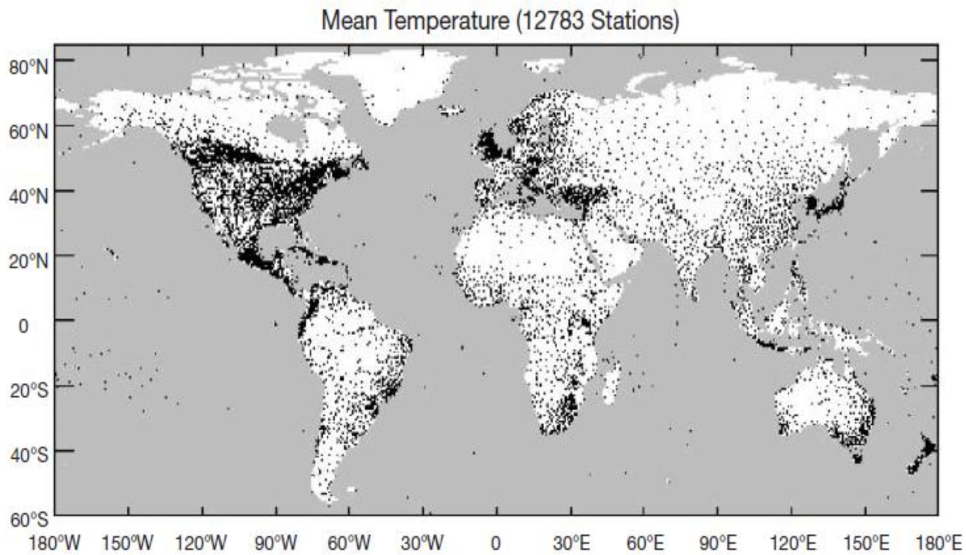

Figure 5.5 Distribution of stations with mean temperature records (*New et al.*, 2002)

5.4.2 CRU Data Download

The CRU data-set for the temperature and precipitation variables were downloaded individually into MS Excel and the files consisted of the variable values for each location point of the globe, i.e. latitude/longitude co-ordinates. By applying column headers to the latitude and longitude values, it was in a format that could be uploaded onto a GIS based on x and y co-ordinates (Grid reference system: WGS84). As inferred the CRU data-set is global and so consequently the climate data points were clipped so that only the European climate data points were displayed. The temperature and precipitation data points were then spatially joined by their co-ordinates, using the join function, so that the two variables could be queried on together. The GIS could now be used to identify areas which currently experience a climate that is predicted for the UK, the method for which is discussed in section 5.5.2.

5.5 Detailed Method Breakdown

Here a detailed breakdown of the overall process will be given, incorporating the climate data discussed in section 5.3 and 5.4:

5.5.1 (i) Determine the Future Climate of the UK

The future climate of the UK was determined using the Met Office baseline values (1961-1990) and the UKCP09 climate change projection data for the mean monthly precipitation (mm) and temperature (°C) variables. The precipitation values are a percentage change value on the baseline, i.e. +/-48% on the baseline. Projections were based on the medium emission scenario for the time period 2050 (2040-2069) at the 25km grid square level, of which there are 434 for the UK.

The 10%, 50% and 90% probability values of change were calculated from the 10,000 sampled data responses for each variable and then consequently added to the baseline value; a process in Matlab calculated the vast amount of data, i.e. for each UK grid square, for both variables, for each month. The process for a given grid sqaure is shown here: (T stands for temperature and P stands for precipitation.)

T Baseline + 10% T climate change value = Future 10% T value
T Baseline + 50% T climate change value = Future 50% T value
T Baseline + 90% T climate change value = Future 90% T value

P Baseline + 10% P percentage change value = Future 10% P value
P Baseline + 50% P percentage change value = Future 50% P value
P Baseline + 90% P percentage change value = Future 90% P value

Figure 5.6 shows the utilisation of climate change data in diagrammatical form.

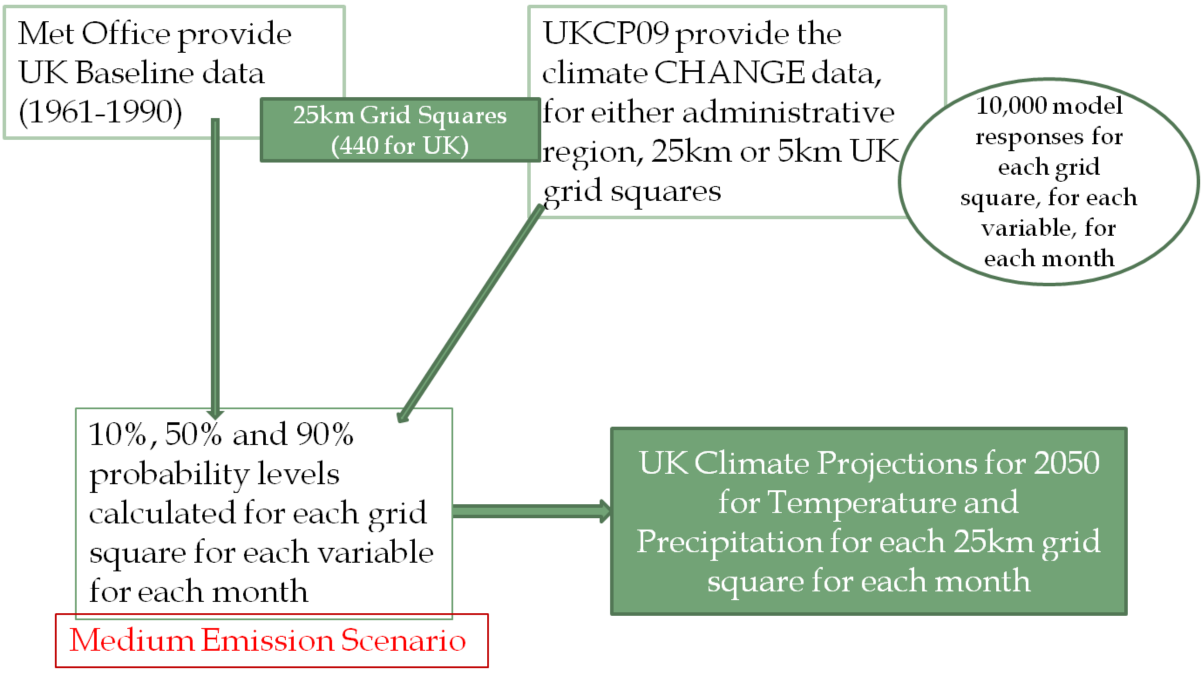

Figure 5.6 Formulation of Climate Change Projections

5.5.2 (ii) Match the Climate Data of the Development Site to Europe using a GIS.

Current climate data (for precipitation and temperature) for Europe was obtained from the CRU climatology records, for the period 1961-1990, based on the latitude/longitude of an area at the 10' resolution, as discussed in section 5.4.

The climate data was imported into a GIS to spatially display the points across the globe. Each month was a separate layer. The location and climate attributes are stored in the GIS database. As the ~18km data points were based on latitude/longitude reference it meant that the outline of Europe was visually displayed on the GIS, further emphasised by applying the Food and Agricultural Organization's (FAO) Country boundaries.

The database was then queried to visually display the areas which currently experience the UK's future climate; the 'select by attributes' function was used to search for areas that matched the climate that a given development site in the UK will have in 2050, based on their UKCP09 grid square future climate projection 10 – 90% values. In the GIS for a given UKCP09 grid square for January with a future temperature value between 4.68 and 8.13°C (10-90% range), and a precipitation value between 49.87 and 75.19mm it appeared as such:

"Jan" >=4.68 AND "Jan" <=8.13 AND "Jan1" >=49.87 AND Jan1 <=75.19

"Jan" being temperature and "Jan1" being precipitation

The GIS then selected/highlighted those European points whereby there was a match, i.e. an area in Europe whose temperature value in January was between 4.68 and 8.13°C, and whose precipitation was between 49.87 and 75.19mm. One could then visually identify where in Europe that was. These were the 'selected features'.

Using the identify feature (a tool in GIS), verified by the world degree system, one could know exactly where that match was, i.e. the latitude/longitude of the area.

As the months of the year were displayed on separate layers of the GIS, they needed to be combined so that the overall number of months matched for a particular grid square could be identified, i.e. to know how many months climate at one given point on the GIS were similar to that of the UK's grid square future climate. The GIS points were therefore converted into a Raster (cell size of 0.1666°), as raster cells store values. A value of 1 was applied to a cell if, for example, it had a January temperature value and a precipitation value that fell within the grid square's January temperature and precipitation 10-90% future climate values range, and if not, a 0 was applied to that cell. The condition is essentially either met or not. By converting the layers to raster it allowed these values to then be totalled up using the raster calculator. If one location, for instance, matched the grid squares climate for all 12 months then a 12 was displayed for the cell. A colour coding scheme was then used for each value between 1 and 12, visually displaying the best matched areas for a given UKCP09 grid square. This data can then be presented as maps, an example of which is shown in figure 5.7.

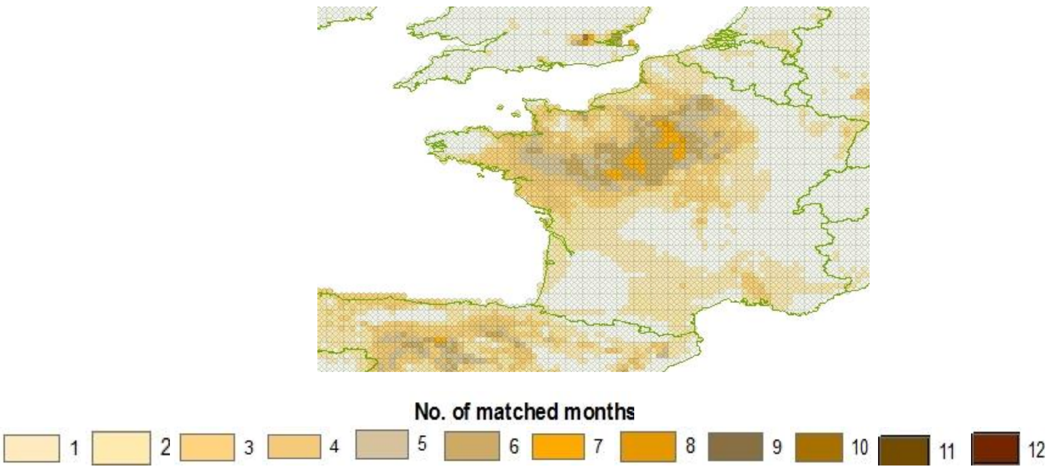

Figure 5.7 The climate matched visual output from the GIS for a given grid square

It must be noted that the monthly precipitation values used in this research do not consider the soil moisture variation, soil drainage properties or the rainfall intensity within the month. Each month's precipitation is essentially an independent event with no transferral of properties between one month and the next. Any precipitation held within the soil is thus not factored into the method.

The results of the climate matching are shown in chapter 8; the areas well matched i.e. with a high value, were further investigated by visual inspection of the overall climate through the creation of graphs displaying exactly where the European climate value fell within the 10 – 90% probability future climate range for a given grid square. Consideration for being a suitable match was also decided by other factors like altitude.

5.5.3 (iii) Explore Current Species and Habitats

For a given matched location:

In order to explore the current species and habitats at the analogous climate location contact was made with ecologists/botanists in the country of interest. Guidance was sought on the general ecological information of these areas and field work was undertaken to obtain data on the flora present. Standard procedures for carrying out survey work, e.g. quadrat sampling in the various habitats were followed (discussed in detail in chapter 9). As field work was limited in its extent, accessible resources were consulted, e.g. archival records, online databases, to acquire published data and species lists relating to these areas.

A summary of these data collection methods:

By carrying out field work, direct observations are made. One can observe the data in real time and understand the spatial extent of the flora. There are however negatives with such data collection: it is time consuming; it is costly from a travelling point, hours needed by those undertaking the field work and any costs for external specialists, e.g. expert ecologists/botanists; the process of recording data is selective as it is not feasible nor practicable to collect plant species data for all locations, extent of fieldwork is therefore limited and biased.

The source to obtain online species data will be country-specific websites, e.g. country level natural history museum online archives or botanical websites relating to specific areas of a country with atlases detailing species present. National Historical Collections (NHC) hold vast data on many taxa of species including their diversity and distributions over time, with records continually expanding the database (Graham *et al.*, 2004). NHC data is utilised across many fields and they are important resources for use in biodiversity studies (Lister, 2011); the available information provided through these online resources will inform this research.

The strengths of using archival records is that they are collected records, the data is stable (Yin, 2003) in that it can be reviewed repeatedly. They have been created for the function of providing botanic accounts of an area, they are exact (often containing names, references – the recorder, and details), with an often broad coverage of countries in such online resources, which will aid in furthering the framework.

Disadvantages: if the website was disabled or was updated then records are lost (temporarily) and retrieval is not possible. Access may also become blocked. It is not known when the last extensive survey was undertaken and how often the results are updated. The online resource will more than likely be in a foreign language, but most web browsers allow for translation, albeit not perfect. The main data required, however, is the plant species - scientific names of which are universally understood.

Other limitations are that one is reliant that the taxonomy of the species has been identified correctly, and there are more than likely biases associated with the spatial coverage of data collection (Graham *et al*., 2004). There is the possibility that data may no longer be present at a historical collection site.

In relation to creating the framework, this would involve a lengthy process of initially carrying out the climate matching, identifying areas which are suitable, visiting the areas if possible, and searching the country specific website for data available on the area of interest. Data pertaining to the area(s) of interest must match up to the initial grid squares matched based on the latitude/longitude, and collecting the relevant online species data.

5.5.4 (iv) Produce Species List

The creation of planting lists for climate change comes from the collection of primary and secondary data, with some convergence between the data sources, e.g. some species were present in both the field data and the online data.

The field data and online data should be collated for the matched area and a suite of suitable habitats/lists created based on the broad habitat types of the flora present and/or original habitat proposals for a given site, as well as sorting on Ellenberg conditions re-calibrated for the country of interest. The habitats originally designated for the development site should be consulted and matched at the habitat level if possible. The vulnerability and suitability of the species should be considered – identify any rare species, species on IUCN lists, species listed under WCA 1981 schedule 9 and Habitats regulations.

Advice from an expert (e.g. botanist/ecologist) on the final species lists should be sought, with regards to the community composition and their suitability for planting on development sites.

5.6 Case Study Approach

In order to the test the above method it was necessary to adopt a case study approach so that all aspects of the process could be trialled. In particular, plant regimes would only be available for sites being developed.

5.6.1 Case Study Requirements

A variation of case study sites was needed across the UK. Varying location was one of the main objectives, as it was assumed that the climate matching of sites would reveal different locations on the continent. Thus the final plant selections would be different dependant where in the UK the site was, illustrating the flexibility of the framework. Other requirements included:

- Brownfield development site, any kind of soil,
- Ideally within the last 5 years, can have already been completed or still in progress,
- Large scale where there is a requirement for biodiversity/habitat creation/landscape design e.g. large scale housing development, building of a factory in a non-urban environment.
- More than just ornamental planting,
- Need to have access to documents on the site conditions, intended use of site, planting documents; it therefore needs to be at this stage in the planning process.

With this range of criteria, it was decided a practical number of 5 sites should be found to fully explore the method.

5.6.2 Site Selection

Planning application documents for development sites held on local council websites were investigated for their potential to be a case study, i.e. matched the requirements stated above. Knowledge of the site is paramount, as knowing the conditions of the site, and the habitats typically planned for the site will dictate the species selected when vegetation matching is performed at that stage in the framework. These documents are freely accessible by an online searching portal. One case study was already in place before the research commenced, which formed the basis of this research, as discussed in section 1.3. Documents held at Middlemarch Environmental Ltd (MEL) were therefore utilised to obtain the relevant information. Overall, there were five case study sites selected which are listed below, and discussed in more detail in chapter 7. Figure 5.8 shows the locations of these sites in the UK on the UKCP09 25km grid square layout.

- Eastern Quarry, Swanscombe, Kent (pink square on fig 5.8)
- Olympic Village, Stratford, London (yellow square on fig 5.8)
- Brogborough Landfill site, Central Bedfordshire (light blue square on fig 5.8)
- Minworth Sewage Works, Birmingham (white square on fig 5.8)
- Wheatley Hall Road, Doncaster (dark blue square on fig 5.8)

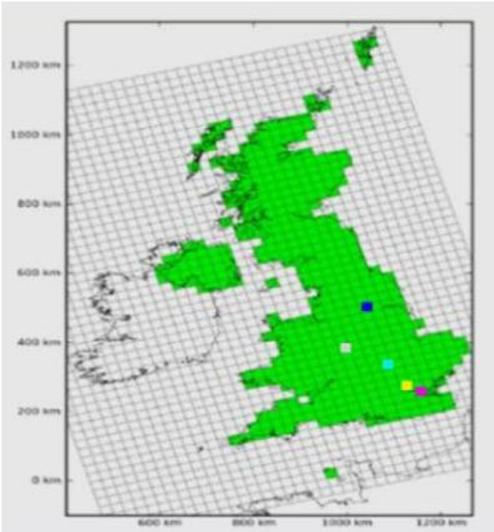

Figure 5.8 The UKCP09 25km grid square layout showing the location of the five case studies.

5.7 Questionnaire

Qualitative data on the research was obtained via an online questionnaire which was sent out to all members of the Association of Local Government Ecologists (ALGE) entitled 'planting assemblages for a changing climate'. ALGE is an association of professional ecologists working in local government in the UK. With the aim to develop good standards of nature conservation, their opinions on the research topic were both valuable and credible.

5.7.1 Purpose of Questionnaire

The purpose of sending the questionnaire was to gauge the perception of ecologists when considering climate change and biodiversity; how much it is considered in their field of work; what action, if any, they can take; and what their thoughts are on introducing non native species into the planting assemblages on brownfield sites, and to creating resilient sites robust to climate change. Foddy (1994), involved in many sociology disciplines, believes it is reasonable for the researcher to treat respondents as peers, and that seeking feedback from the respondents is acceptable.

The overall outcome of this research was to provide planting lists which incorporate species of a non-native provenance into planting assemblages; the purpose of the questionnaire was not to divert the research away from this or guide it. However, by obtaining the ecologists' views, knowledge of their attitude towards this approach could be gained, with an idea of how this research would be accepted by practitioners and others in the field. It was envisaged that the qualitative data collected here would contribute to the case study development, provide direction and add value to this research. By observing the participant's perspective one discovers new information that will 'contribute to the development of empirical knowledge' (Corbin and Strauss, 2008).

5.7.2 Questionnaire Form

Due to the large member base within ALGE, and their varied locations across the UK, a self-completion online questionnaire was created, whereby respondents could reply in their own time. The number of replies would not have been matched if face to face to interviews had been constructed, as these require a greater degree of planning and more time from both parties. The questionnaire was created using Bristol Online Surveys (BOS), with the web link attached to an email sent out to all ALGE members detailing the research aims and what was required of the respondents. The respondents were informed that their identity would remain anonymous to avoid question threat (i.e. unease in answering a question) and to avoid respondents providing incorrect or biased answers (Foddy, 1994).

The main problem with self completion questionnaires is that the interviewer cannot clarify questions; the respondent needs to understand the question, as stated by Foddy (1994) 'in the way intended by the researcher' and equally 'the answer given by the respondent must be understood by the researcher in the way intended by the respondent'. In order for this to happen, people must attribute the same values and meanings to words, and understand the structural component imbedded in the question. This may not always be the case, and is another flaw associated with questionnaires of this manner. More detail on the questionnaire design, content and the analysis can be found in chapter 6, with a copy of the questionnaire in appendix 1.

5.8 Conclusion

The methodology proposed aims to create species lists which will be able to tolerate the future climate better than current recommended habitat design. In formulating this process, a climate matching technique has been developed to identify areas in Europe which currently experience the climate the UK is likely to incur in the future, utilising the most up-to-date projections to do so. Under a medium emission scenario for 2050, the 10-90% probability climate change projection range for temperature and precipitation have been calculated and combined with a baseline to create the future climate values. For visualisation purposes a GIS has been incorporated into the methodology;

those areas climatically matched in Europe are displayed and the most suitable location can then be found on closer inspection of the overall climate match.

Once a suitable location has been found vegetation data can then be sought from these locations through a combination of field work and published data sources. A case study approach was employed in the methodology, to demonstrate its utilisation for any given development site in the UK, with the outcome to meet the long term objectives required for biodiversity at these sites. A questionnaire was developed to inform the research with regards to vegetation matching and planting design, the results of which are discussed in the next chapter.

6. Questionnaire Design, Results and Analysis

6.1 Questionnaire Design

As mentioned in section 5.7 an online questionnaire was sent out to all members of the Association of Local Government Ecologists (ALGE) entitled 'planting assemblages for a changing climate'. The purpose of doing so was to gauge the perception of ecologists when considering climate change and biodiversity, with the outcomes of the questionnaire informing the research.

This section describes the reasoning behind the questionnaire design and content. The questionnaire was divided into four parts and is presented in appendix 1.

6.1.1 Section 1 - About You

The first section of the questionnaire 'About You', subsection 'Your Work and Climate Change', was designed to enable an understanding of the respondent's role and their location. It consisted of 5 single answer closed questions, and one unstructured open ended question. Even though all respondents did not necessarily have 'ecologist' in their job role title, this would be the term used throughout this chapter, for ease of reading.

The purpose of Q5, an open ended question, was to see if the respondents had noticed any significant biodiversity changes attributable to climate change during the time they had been in this area of work. As discussed in chapter 4, the literature indicates that climate change is having an effect on biodiversity, so it would be interesting to see if ecologists active in the field were observing changes and if there are any similarities between those in the literature and those observed by the respondents. This was not specifically aimed at changes to plants, but all of biodiversity, as it would be interesting to note the changes observed across all taxa, if any.

The point of Q6 was to find out the degree of flexibility the respondents' respective councils allowed in making decisions relating to climate change adaption. The responses given would indicate the approach taken by councils and whether there were strict rules staff must adhere to when it comes to decision making.

6.1.2 Section 2 - Development Sites and Planning Involvement

The second section of the questionnaire 'Development Sites and Planning Involvement', subsection 'Brownfield Sites', relates to issues important to this research. To maximise biodiversity on brownfield sites that are to be developed, developers need to be pro-active, as well as there being full involvement of the planning ecologist, to ensure all biodiversity aspects are considered.

Q7 would divulge how often developers, through the 'ecologists' eyes, willingly maximise biodiversity on a development site. The responses would highlight whether developers are actively striving to maximise biodiversity on a site, or whether they chose to do the bare minimum to fulfil planning requirements.

Q8 is an important question as it would relay the stage of development the ecologist is typically involved in. The biodiversity of a site ideally needs to be considered before site plans and designs are created; biodiversity needs to be built in at the first stage, in the pre-application stages, especially if mitigation is an element of the plan. Some ecologists are solely deployed in the construction phase of the development, i.e. as clerk of works, so it is expected that these stages would also be selected in responses. The respondent could check more than one response, as it is assumed that many are involved in more than one stage. In relation to this research, the incorporation of non-native species into planting regimes would need to be considered fairly early, for sourcing purposes, and the designing of the plant schedule.

The attitude of respondents to the use of species of non-native provenance into new planting schedules for brownfield sites, as ascertained in Q9, is central to this research. The outcomes of this research would involve using species of a non-native provenance, based on the climate matching as described in chapter 8. By finding out the ALGE members' feelings on this topic, would be a good indicator of the acceptance of this research and its outcomes.

'Action to Take' is a subsection of this section of the questionnaire. The action respondents would take to tackle the impacts of climate change on biodiversity was explored in Q10. The options given reflect a range of actions which are practised in the field or stipulated in the literature (e.g. translocation is an action used when saving vulnerable or BAP plant species) or actions taken when planning for biodiversity consideration and migration. The responses to this, as in relation to Q9, would reveal the respondents' feelings towards aspects of adapting to climate change. The various actions given would reflect how open minded, or conversely, how cautious, a respondent was towards adaption. By knowing the general consensus, will give an indication of how likely it would be that the outcomes of this research would be utilised in the field.

6.1.3 Section 3 – Planting Selections

The third section of the questionnaire 'Planting Selections', subsection 'Planting Decisions', contains one question which has multiple parts to it. The first part is a dichotomous question to screen out those not involved in selecting planting regimes for brownfield sites. This is followed by 3 linked questions.

The aim was to understand more about the planting selection process, as creating planting assemblages is a stage of this research. In Q11a respondents could select which factors/documents they consult when making these decisions. Three of the options – BAP recommendations (sect. 3.5), Landscape Character Assessments (LCAs) (sect.7.2) and schedule 9 of the WCA (sect. 3.3.2.4) can be consulted by local authorities to consider the surrounding landscape/species of interest. It is, however, not compulsory that they are utilised, apart from the WCA which prohibits the use of certain non-native plants. The NVC lists, provided as an option, describe communities typically found in the natural environment, which ultimately vary across the UK. They are sometimes re-created in nature conservation projects. Soil characteristics and aspect of site were listed as these options are common criteria which are examined when a site is to be developed, often dealt with on a site by site basis. The respondents could also select 'other' as an option and specify which other factors/documents they consult.

The purpose of Q11b, a likert scale question, was to see whether an ecologist could change decisions made by the landscape architects, who tend to be the ones responsible for devising the planting schedules. This would be applicable, in relation to this research, if the architects have not considered species which are resilient to climate change, and the ecologist wishes to modify the lists. From the case studies investigated, when wildlife trusts are consulted, they usually opt for strictly native planting regimes, and it is anticipated that they would be strongly against lists containing non-native provenances.

The open ended unstructured question, Q11c, which concludes this section, aimed to discover what the respondents feel were the most important factors to consider when selecting planting regimes. By knowing what is critical to the selection process, one can make sure it is used in this research as a guiding factor.

6.1.4 Section 4 – Biodiversity and Climate Change

The fourth section of the questionnaire 'Biodiversity and Climate Change' subsection 'Your Opinion' consists of 3 questions.

Since the 2010 EU target to halt biodiversity loss was not achieved, Q12 related to the new 2020 target that has been set, to bring current political agendas into the questionnaire. This was included to see if the respondents felt biodiversity loss could be halted through the use of translocation and intervention measures (e.g. assisted colonisation), in order to compensate for those species that will become vulnerable to climate change.

In Q13 in order to understand the attitude of the respondents in relation to resilient landscapes being the best way to tackle climate change when considering biodiversity, a likert scale was used. It is important to define key concepts (Foddy, 1994), as what people think of as a resilient landscape may differ from person to person, so a 'More Info' button was present so that all respondents could collectively see what was meant by this. It stated 'Resilience is the ability of a landscape to maintain its functions and characteristics after being disturbed or damaged. By including a matrix of both native and non-native species in new planting regimes for brownfield sites, it is hoped a resilient landscape will be formed.' The second sentence in this statement was to assist in the respondent's understanding of how resilience could be created on development sites.

Q14, an open ended unstructured question, ascertained what the respondent felt would make a resilient landscape. This question was included to see if there was agreement with how to tackle the issue.

Subsection 'Comments', the last section of the questionnaire had an optional question (Q15) for respondents to leave their comments or thoughts with regards to this research. The respondents could also leave their contact details if they wished to receive a copy of the results or were willing to be contacted for further questioning.

Throughout the questionnaire there are four open ended questions and two questions which enabled respondents to leave a reply if they selected 'other'. These questions allow respondents to speak their mind 'without being influenced by suggestions from the researcher' (Foddy, 1994), it was therefore a clear decision to have these questions included.

6.1.5 Sample Size and Distribution

The online questionnaire was sent out to 329 email addresses, which were taken from the ALGE member database. ALGE members are based throughout the United Kingdom covering 160 authorities over 12 regions; the number of ALGE members varies across the regions of the UK. Around 50 emails were undeliverable or failed to send, several were out of office and a couple were on maternity leave. The questionnaire was sent out the 24th April 2012 and closed just after 15 weeks, by which point 81 members had completed the questionnaire; this represented 29% of the whole organisation. The next section aims to analyse and decipher the relevant information from the questionnaire to aid the research.

6.2 Questionnaire Results and Analysis

6.2.1 Section 1 'About You'

The professional job titles given by the respondents in Q1, and shown in figure 6.1 ranged from biodiversity officer through landscape architect to carbon landscapes co-ordinator. With such a diverse range of job roles, it would be worthy to note the scope of opinions that were given, and how collective the general opinions were.

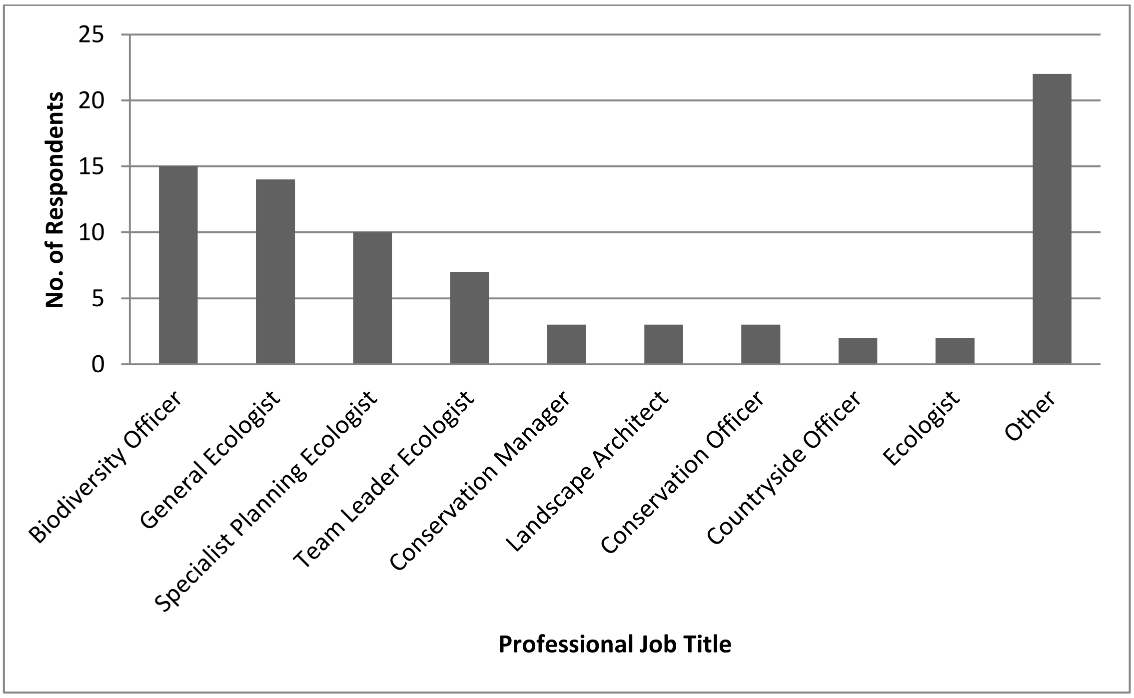

Figure 6.1 Results graph for Q1 - What is your professional job title?

Respondents who worked from all areas of ecology answered the questionnaire, as reflected in the results of Q2, shown in figure 6.2, suggesting the results will not be biased towards one kind of taxa. The same could be said for Q5 as respondents referred to all taxa when giving examples of changes to biodiversity due to climate change. 20% of the respondents stated that they covered all areas of ecology.

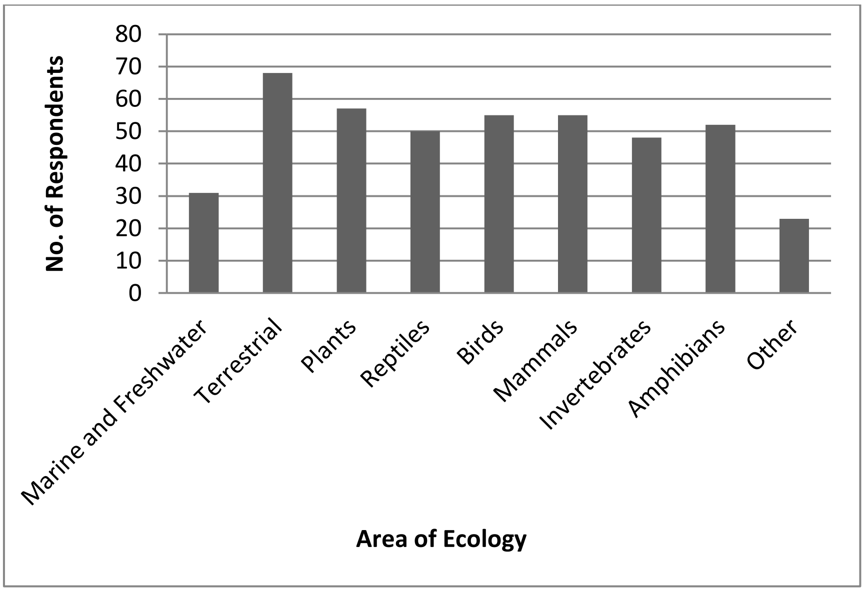

Figure 6.2 Results graph for Q2 - What area of ecology is your work focused on?

As shown in figure 6.3 the largest number of responses was from the south west and south east regions, with 12 from each. There were only 3 responses from Northern Ireland, Scotland and the North East and only 2 from London. This could be down to fewer ALGE members represented in these areas or fewer council areas in these regions, and/or the technical problems with the email distribution as mentioned earlier.

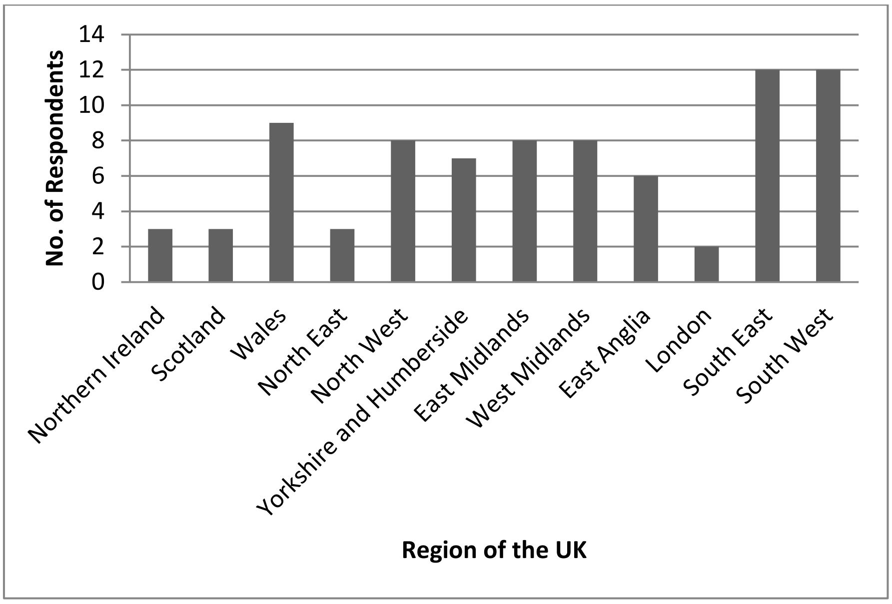

Figure 6.3 Results graph for Q3 - Which region of the UK is your work based in?

67% of the respondents had been working in an ecology related field for 10+ years, with all respondents having worked for longer than a year in ecology (see figure 6.4). Responses were therefore largely informed from experience gained over time.

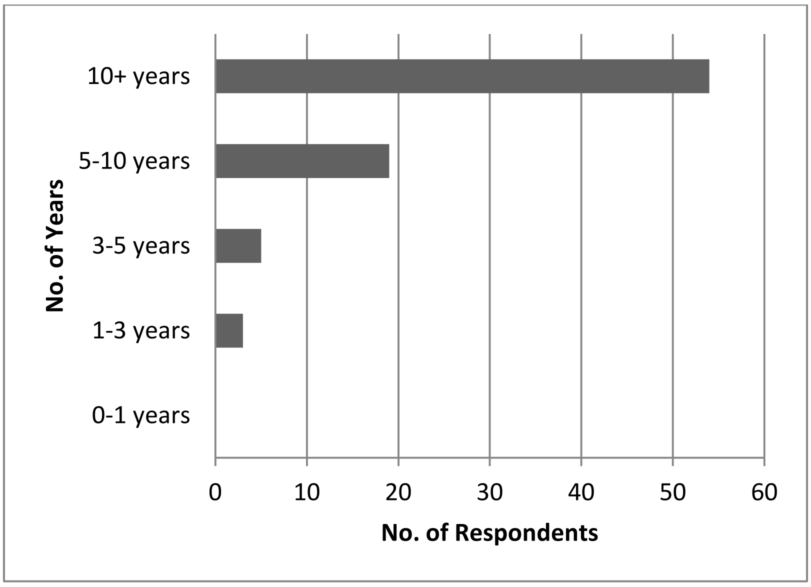

Figure 6.4 Results graph for Q4 - How long have you been working in an ecology related field?

72% of the respondents had noticed significant biodiversity changes attributed to climate change during their time as an 'ecologist' as shown in figure 6.5. This is in accord with observations reported in the literature in section 4.5.

The relationship between length of time in service and changes observed is shown in figure 6.5. 82% of the 10+ years working in an ecology related field category replied 'yes' to noticing significant biodiversity changes. There were more 'no' replies to observed changes in the 1-3 year and 3-5 year categories, but these respondents may not have been in the job long enough to notice changes in biodiversity characteristics.

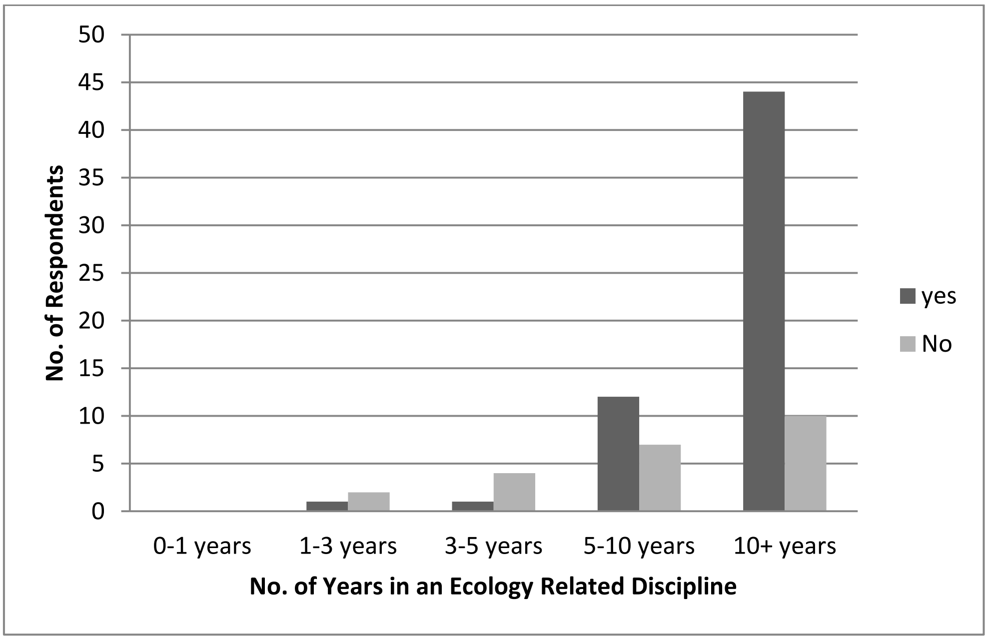

Figure 6.5 Results graph for Q4 cross tabulated with Q5 - Have you noticed any significant biodiversity changes, attributed to climate change, during this time? Against no. of years in an ecology related discipline.

The results from the open ended component of Q5 were tallied into appropriate headings summarising the thoughts of the respondents. The results are shown in figure 6.6. There is more variability in open ended questions than closed ones, but the best way to approach these results is to categorise them into common themes with the main points acknowledged.

Species distribution was mentioned by 23 respondents, with the following phrases and terminology being assigned to this category – ‘’spread and contraction of species’‘, ‘’species moving north’‘, ‘’range increase’‘, ‘’arrival from the south”, ‘’changes in range/distribution”, and ‘’increased levels of species at the northern limit of their ranges”. When changes were referred to in relation to specific species, it included the following: dragonflies (2 times), Orthoptera (3 times, inc. Roesel’s Bush Cricket, short and long winged Coneheads), butterflies (8 times including Speckled Wood and Holly Blue), wintering waders, breeding birds, bats, the spread of plant pathogens, invertebrate movements (4 times), moths (2 times) and plants (2 times). One respondent mentioned that the Gunnera plant on Skye and the Western Isles had spread particularly; “it used to be hard to keep alive in Skye as it died off in the winter, now it is spreading along road ditches and becoming quite obvious”. If this is an observation in Scotland, then it would be expected that places further south, where climate change is likely to be more apparent (UKCP09, 2009), would also be experiencing similar events.

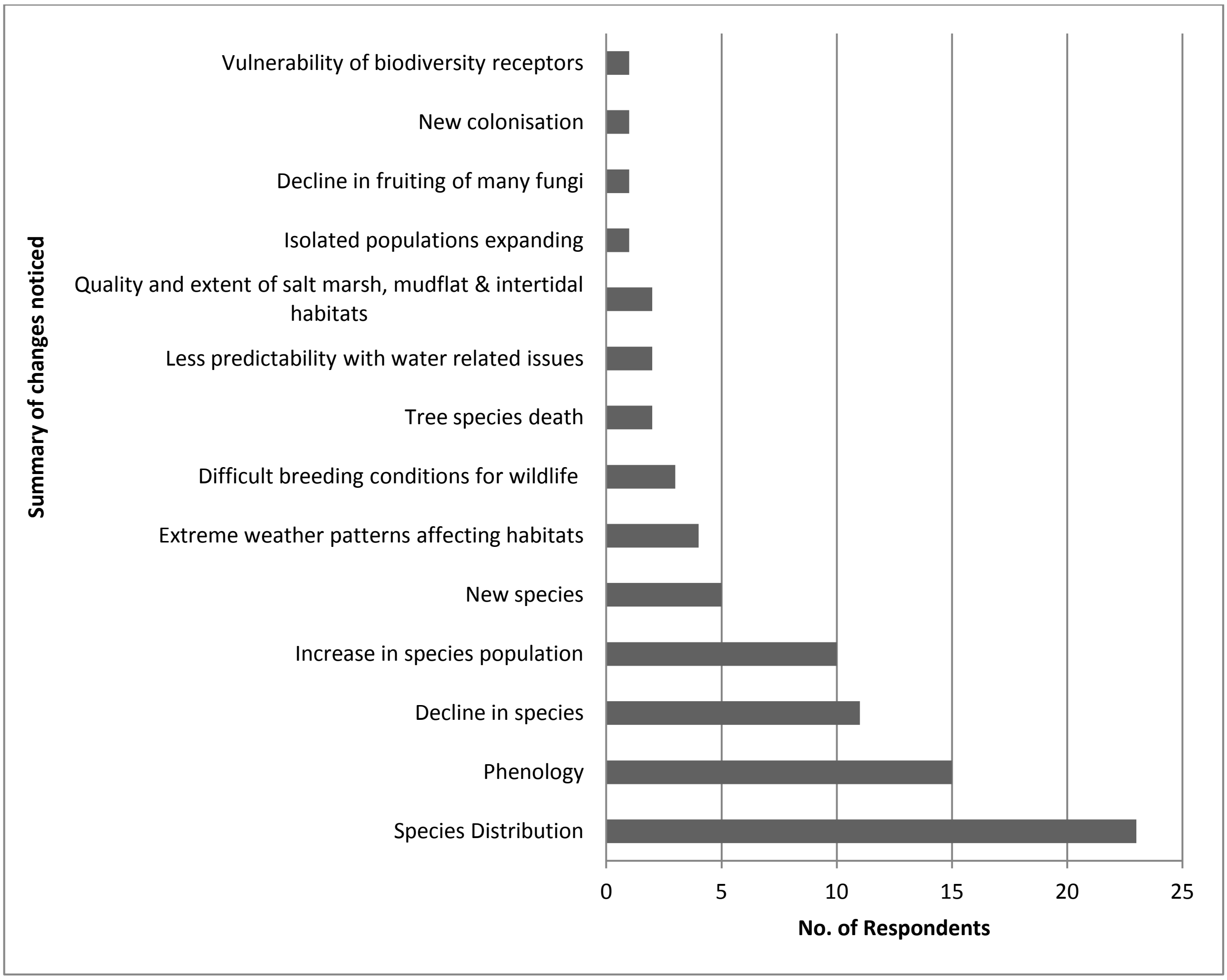

Figure 6.6 Results graph for Q5.a. - If Yes, what changes have you noticed?

Phenological changes were noted by 15 respondents, and when specified, included: earlier amphibian breeding/spawning times; flycatcher breeding times, the sightings of bats in January; a change in migrant arrival times; species growing/becoming active earlier/later in the year, consequently with species often out of synchrony with flowering times etc; changes in timings of bud-burst and flower emergence of certain plants; early laying of nesting birds and thus a longer bird nesting season; and seasonal changes - onset and length. One respondent commented that the extended autumn and early spring has led to a shorter dormant period for woody plants, consequently shortening the planting season for barerooted stock. The phenology of insects has changed, and there have been noted arrival fluctuations of Hirundines.

Decline in species was noticed by 11 respondents with reference to: insects, reptiles, amphibians, nightjar, invertebrates (mentioned twice, with likely migration to the north), butterflies (mentioned twice), freshwater plant species (in relation to saline incursion), and nesting birds. This may be due to the recent succession of poor (wet) years. Decline in species may also be down to pesticide use and habitat destruction. One respondent has noticed the decline in fruiting of many fungi. The decline in species noticed in some areas could be linked to the change in species' ranges, as opposed to a drop in numbers, as they leave the southerly ranges of their distribution in response to climate change or other pressures. A respondent from Scotland states that "many common species of plants and animals are far less frequent and also seem to be in general decline, and many species frequently associated as being southern species, are increasingly being recorded in the various habitats they manage". Species in Scotland may run out of future suitable climate space (a concept discussed in chapter 4), with nowhere else for them to go and an increased possibility of extinction.

An increase in species population, i.e. abundance, has been noticed by 10 respondents, with increases in species such as Banded Demoiselle (dragonfly), Orange Tip (butterfly) and *Bombus hypnorum* (garden bumble bee) being observed by a respondent from Yorkshire & Humberside. A respondent from the South West states there is also an increasing number of colonising invertebrates e.g. Lepidoptera, Odonata, and possibly the invasive Harlequin ladybird. There has also been increased numbers of little egret and hummingbird hawk moth observed in this region. Speckled Wood and Comma butterflies are becoming more commonplace at the furthermost edge of their range as commented by a respondent from East Midlands. One respondent from East Anglia states that as a child "dragonflies were considered one of the groups that had suffered most in our countryside, largely as a result of changes in farming practices and pollution. But now, probably as a result of climate change, we have several more species breeding regularly in the UK, we have more new additions than lost species in earlier times". Two more observations from respondents in the South West included an increase in N tolerant plants, lichens and fungi, and plants such as *Cortedaria sellonana* have produced viable seed which previously had not occurred. A possible reason for this may be the warmer temperatures permitting the reproductive phase of the plants life cycle and thus the production of seeds (Huntley, 1991), which previous temperatures did not allow.

Observations of both species decline and increase could be a result of species expanding their ranges. Ecologists are thus observing an increase in numbers locally as they migrate polewards with climate change, as opposed to a nationwide increase in numbers.

New colonisation of invertebrate species from Europe had been observed by one respondent. New species, including breeding birds and dragonflies have been observed by five respondents. In the South East they are starting to get breeding invertebrates normally associated with Central Europe. In the West Midlands, new species have been recorded including the Lesser Horseshoe bat, and several rare invertebrates. Isolated populations of dragonflies are also expanding.

Difficult breeding conditions for wildlife have been observed by 3 respondents, probably as a result of extreme weather events. One respondent remarked on the recent 5-6 bad summers and 1 very severe winter which occurred when temperatures reached -20°C for weeks. One respondent stated that there was less predictability in relation to river flows, and the natural filling of lakes. On a similar topic, another respondent stated that a drought in early spring meant that when a river rose later on, a swan's nest was washed away before the signets had hatched.

The effect of extreme weather patterns on habitats has been observed by 4 respondents. One respondent stated that the influence of landslips on the landscape was not something they had ever heard of when they were a child 30 years ago, but they are now quite common on a small to medium scale. This may be due to soil erosion as a result of more frequent heavy rainfalls. In the Western Highlands, over the last 7+ years there has been a trend of dry springs to the point where the bog pools start to dry out, in some cases completely. The same respondent mentions that "also in the west highlands, in the spring and summer, there has been a greater tendency for a very high rainfall over a short period causing gravel to be washed out of the rivers, with burns reducing spawning habitat for salmonids. All these events have been caused by the warming trend we have been experiencing for the last 40 years causing more extreme weather events at unusual times of the year". A rise in wildfire incidents has also been observed by another respondent, causing damage to biodiversity (e.g. heathlands) due to the "uncontrolled nature of burn and intensity". The likelihood of unpredictable weather patterns and extreme events becoming more frequent may leave biodiversity vulnerable to the consequences.

The death of certain tree species may be linked to climate change providing suitable conditions for fungal attack, as noticed by 2 respondents. One respondent would consider "the various problems and pests of elm, oak and horse chestnut etc to have some climatic connection". The issue of tree death and the more recent ash dieback are discussed in section 10.2.1.

Salt marsh erosion has been observed, with one respondent stating that "the accelerated rate of this could possibly be linked to climate change induced storminess/wave intensity". Another respondent has stated that "coastal squeeze has affected the quality and extent of saltmarsh, mudflat and intertidal habitats". With changes in sea level, coastal areas in particular, will be vulnerable to the effects of climate change.

Figure 6.7 shows the cross tabulation of Q3 and Q5, and although there were more respondents from the SE and SW that completed the questionnaire, more of these respondents have noticed changes than not. With the South already experiencing greater changes in climate than the rest of the UK, it hints to changes in biodiversity correlating with the changes in climate.

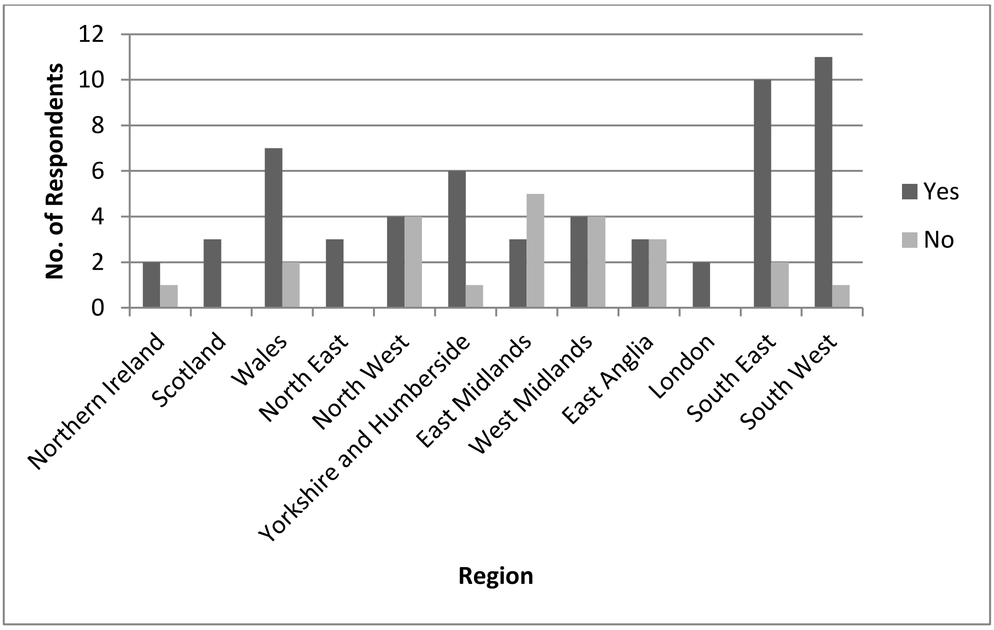

Figure 6.7 Results graph of Q5 cross tabulated with Q3 –'Have you noticed any significant biodiversity changes, attributed to climate change, during this time?' against 'Which region of the UK is your work based in?'

Figure 6.8 shows that 83% of respondents' individual thoughts towards climate change are always or sometimes allowed to influence their work; a high percentage, therefore, can have a say over the biodiversity of their area. In relation to this research, if ecologists could have a say over the plant selection for a development site, then headway could be made in creating resilient landscapes through the selection of appropriate species.

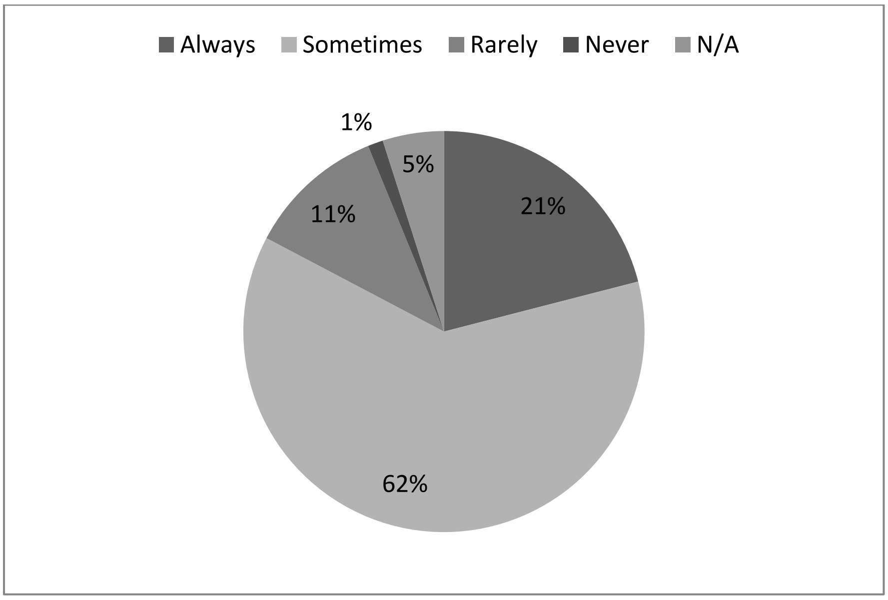

Figure 6.8 Results graph for Q6 - Are your individual thoughts towards adapting to climate change allowed to influence your work?

6.2.2 Section 2 - Development Sites and Planning Involvement

Nearly half of the respondents (44%) for Q7 answered that only in 1-20% of their cases do developers willingly want to maximise the biodiversity of a brownfield site (see figure 6.9), with 'None' being the second most common response (20%). This reflects how more pressure/encouragement needs to be placed on developers to actively enhance or increase the biodiversity aspects of their site, relating to the planning issue discussed in chapter 3, where developers will most often just do the minimum required to obtain planning consent. Some developers do however go further, but this appears only to be a small percent, as reflected in the results of Q7.

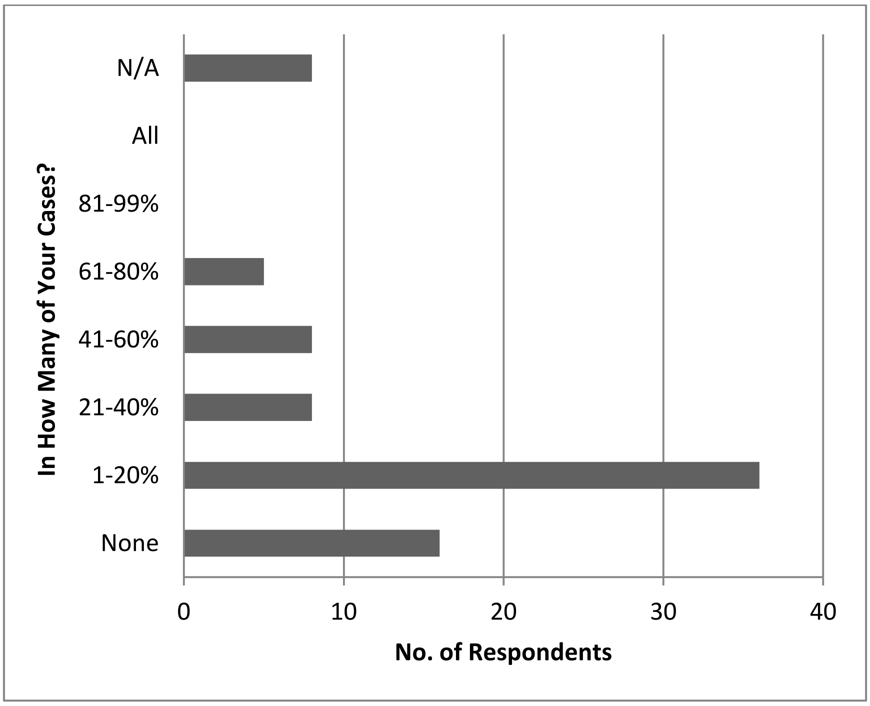

Figure 6.9 Results graph for Q7 - Have you noticed developers willingly wanting to maximise the biodiversity of a brownfield site, if so, in how many of your cases?

Question 8 revealed that 73% of respondents are typically questioned on the ecological/biodiversity aspects of a site during the pre-application stage, and as respondents were allowed to select more than one option, a greater percent (81%) stated that they are questioned during the application process (see fig 6.10). This demonstrates that professionals are consulted before the application gets taken to the design stage, which is crucial for ensuring that biodiversity is incorporated into the development site plans. The 10 respondents that put during the 'operational stage', which by itself is too late down the line to consider biodiversity effectively, had also put other stages of development and not just this stage. Those involved during the operational stage normally undertake the monitoring and management of biodiversity on site, e.g. the clerk of work duties.

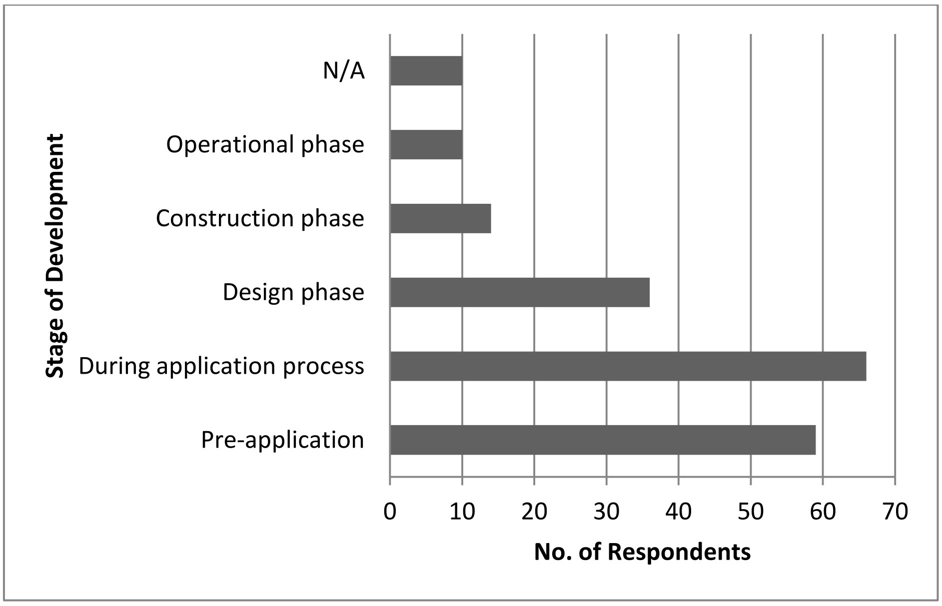

Figure 6.10 Results graph for Q8 - At what stage are you typically questioned on ecological/biodiversity aspects of a site?

Only 12% of the respondents were in favour of introducing species of a non-native provenance into new planting schedules for brownfield sites (Q9), as shown in figure 6.11, with 43% against. 45% of respondents were undecided on the matter. These views may well have been influenced by the many bad connotations associated with non-native species, their potential invasive tendencies and ability to cause damage to native biodiversity, and the costs associated with remediation.

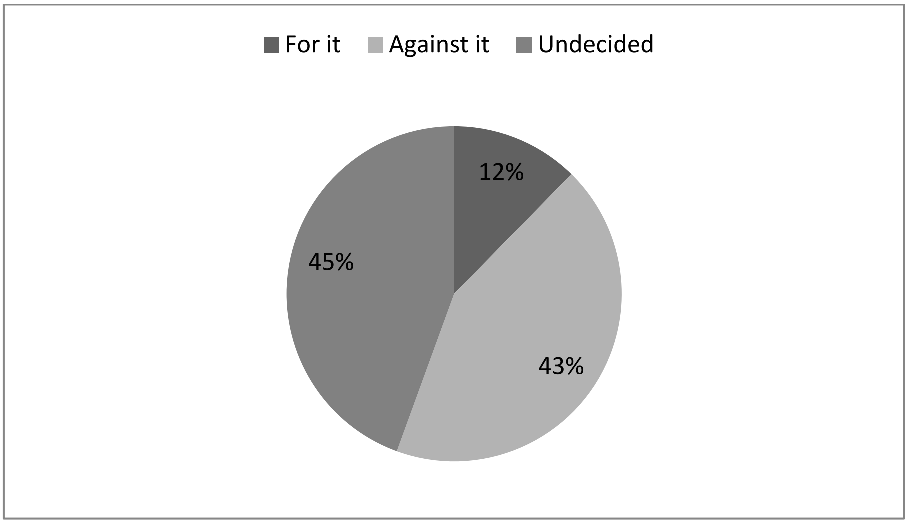

Figure 6.11 Results graph for Q9 - How do you feel about introducing species of a non-native provenance into new planting schedules for brownfield sites?

It was interesting to note the region respondents were from and their views on introducing species of a non-native provenance. As can be seen from figure 6.12, all three of the respondents from Scotland were against it, as were 2/3 from Northern Ireland. Conversely those from the south east and south west gave varied replies, with 'undecided' being the most common answer. No one region had a greater percent for the 'for it' response over the other responses. As those in the south have already observed significant biodiversity changes, as evidenced in figure 6.7, this may well have influenced the responses from those in that region. Scotland recently passed an act which prevents the planting of species outside their native range (Scotland Wildlife and Natural Environment Act, 2011).

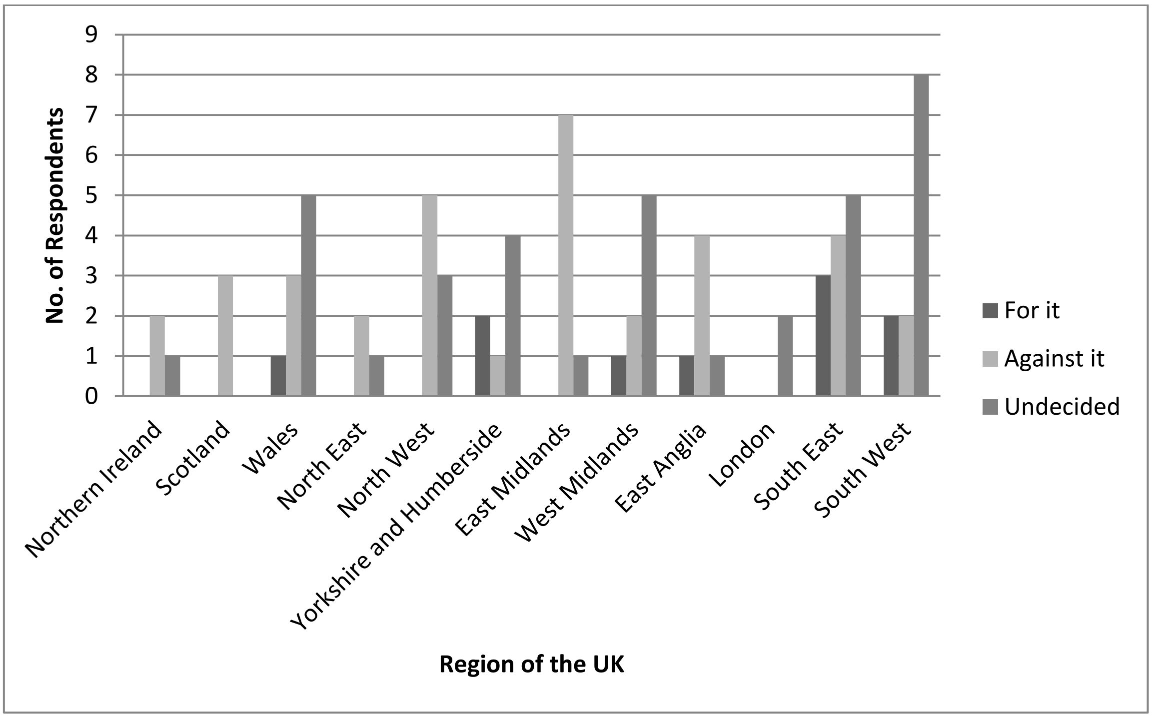

Figure 6.12 Results graph for Q3 cross tabulated with Q9 – 'How do you feel about introducing species of a non-native provenance into new planting schedules for brownfield sites?' Against 'Which region of the UK is your work based in?'

The respondent could tick more than one of the actions to tackle the impact of climate change on biodiversity in Q10, the results of which are shown graphically in figure 6.13. The action 'ecological corridors, stepping stones' was selected by 69 of the respondents, exemplifying that there is a strong support for connecting the biodiversity throughout the country. 'Intervention – translocation of both native and non native' was selected by 14 of the respondents, 15 respondents were for 'intervention – translocation of only native species', and 18 people were for strict conservation practices (native at all costs). This illustrates that there are mixed views regarding respondents views for biodiversity when considering climate change. However, it also confirms the results for Q9 that the respondents are more in favour of maintaining native habitats rather than introducing non-native species.

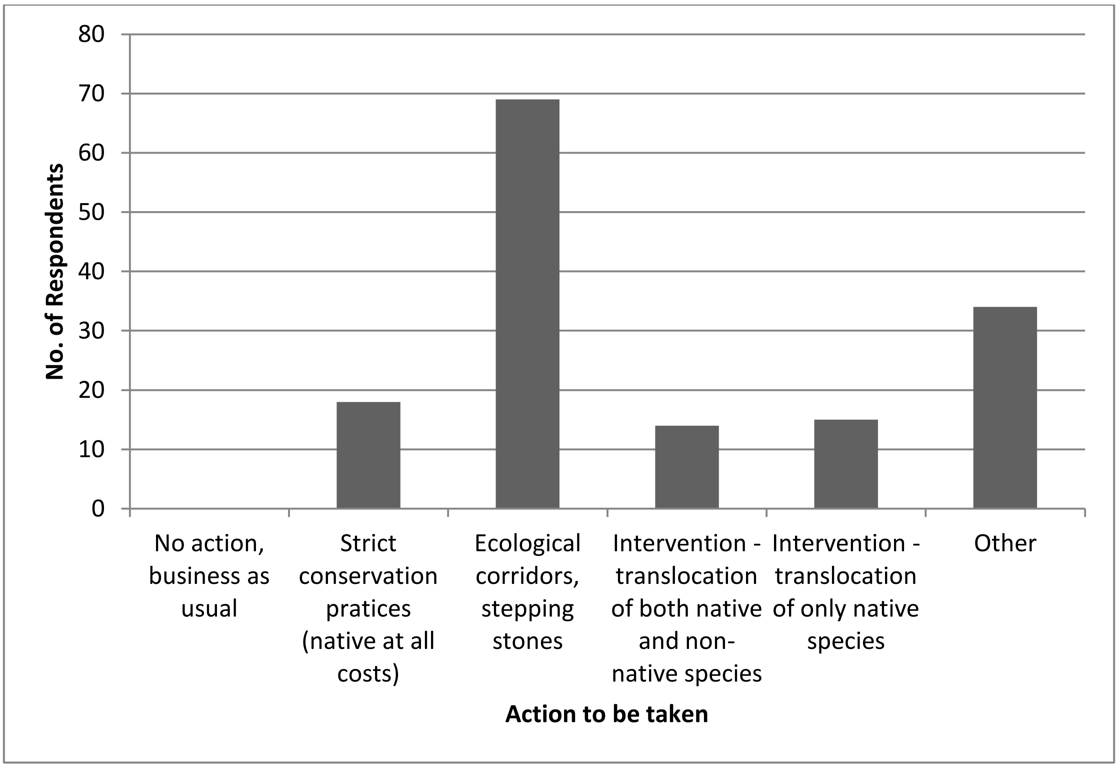

Figure 6.13 Results graph for Q10 - Which of the following actions do you feel should be taken to tackle the impacts of climate change on biodiversity?

In Q10 there was an option for the respondent to write their own ideas of what action should be taken, of which 31 respondents did. Five main themes running throughout the responses were identified:

(1) More research and data on the scenarios and implications of climate change, before valid decisions are made (6 of 31 respondents) - as one respondent says ‘‘there is no point introducing new species if the implications haven’t been fully risk assessed”. It would be irresponsible to introduce a species into an environment if their suitability were not assessed and, as discussed in section 10.2.1, Plantlife (2010) have already created a risk assessment tool for non-native species.

(2) Larger conservation efforts (11 of 31 respondents); maintaining/enhancing what biodiversity we have, creating biodiversity networks to connect ecological areas, and monitoring habitat/species change. Lawton’s principle of more, bigger, better and joined from the *Making Space For Nature* report (Lawton *et al.,* 2010), as discussed in section 3.8.1, was mentioned or inferred by the respondents, with buffer zones also brought up. One respondent stated that a robust methodology needs to be developed for monitoring landscape change. This theme of larger conservation efforts was the most common topic mentioned, illustrating that respondents believe a major way to tackle the impacts of climate change on biodiversity, would be by strengthening what we currently have, and essentially, creating more of a connected ecological map. Habitat fragmentation is in part responsible for the way things stand now, as discussed in

section 4.6, so larger efforts are needed to conserve and re-connect landscapes across the country.

(3) Suitable climate resilient species (6 of 31 respondents); a few of the respondents are keen to consider species which will be resilient to future climatic shifts, with one respondent stating that only ‘‘native, local species that *should be* resilient” should be selected. Another respondent believes that we should ‘‘consider future climate space for species and their current UK range” a thought which is also echoed in a respondent from the north west who stated ‘‘we are not averse to considering species that may be more southern to the UK being used”. Conversely, some respondents are keen to identify those native species whose ranges extend into Europe, with one respondent stating that we should ‘‘introduce individuals from the more southerly extents of their range”, and another respondent with similar views stating we should ‘‘encourage phenotype resilience when selecting plants, as some native species have a European range”. These comments are positive in relation to this research. A few respondents are cautious, and correct in being so, when they say ‘‘only where a clear case is a made” in reference to the introduction of non-natives. As one respondent says, it is not about native versus non-native as ‘‘species will often change their own natural range, and we won’t have much control over those that are mobile anyway”; what naturally occurs as the climate changes will be interesting to note, and as mentioned in section 4.4.1, it is likely non-analogue communities will form.

(4) Natural progression (1 of 31 respondents); one respondent believes nature should be left to take its own course of action and not to interfere, one should just ‘‘manage the physical nature of the site, substrate, topography, bodies of water etc, then leave alone”. However, this raises the question that if species from the continent arrive naturally in the UK and end up on protected sites, would these be accepted and allowed to establish there, or would conservationists intervene. This is also a point raised in the BRANCH project, discussed in section 4.12.6, with regards to the conservation measures on designated sites.

(5) Society and planning (7 of 31 respondents); one respondent believes a ‘‘change in society and the way we think” is needed in order to tackle such problems. This is a pertinent observation, as all those with an interest need to be in agreement in order to make a concerted effort and prevent a collapse in biodiversity, with a gain in biodiversity by 2020. A couple of respondents believe we can tackle this problem indirectly by targeting those that have influence/power: ‘‘at a political level, tackle the false assumption that economic growth can continue indefinitely within a finite world”, or by changing habits of excess energy consumption, and consumption generally, including use of land. A few responses relate to the methods employed for the planning of the environment; green infrastructure plans need to be developed and implemented, sustainable urban drainage systems (SUDs) need to be installed, and invasive non-natives species removed. Agricultural environment schemes were also mentioned with regard to maintaining and

enhancing networks across the farmed environment, which can be linked to the connectivity issue of point (2) above. Agri-environment schemes have bettered some aspects of the environment, with incentives given to farmers in return for this.

6.2.3 Section 3 - Planting Selections

As ascertained by Q11, 72% of the respondents are involved in selecting planting regimes for brownfield sites, which is a significant number. Of those that are not involved, from their job role one would not expect them to be involved in this activity, i.e. coastal officer, carbon landscapes co-ordinator, natural resources manager.

In relation to Q11, Q11.a and figure 6.14 shows which factors/documents people consider when selecting planting regimes. Of the 58 that are involved in planting selections, 52 use BAP habitats and species recommendations to help make their decisions. Soil characteristics and the aspect of the site were also highly ranked, as these vary from site to site. Out of the 58, 26 respondents use National Vegetation Classification lists (NVCs), the same proportion as use Landscape Character Assessments (LCAs). The use of NVCs illustrates that respondents are for re-creating natural habitats on sites. It is felt that authorities which consult NVCs and try to recreate these communities are enhancing the biodiversity of a site at a more natural level, i.e. avoiding typical ornamental shrubs used on development sites, with a much better outcome for the biodiversity of the site. The use of LCAs reflects how respondents like to retain the character of the surrounding area, and ensure that local biodiversity/use of local species are a consideration of the selections. About half of the people who are involved in planting selections also use schedule 9 of the WCA. In using this guide it could be assumed that non-natives are being used, and the ecologists are merely checking that they are not on the prohibited list.

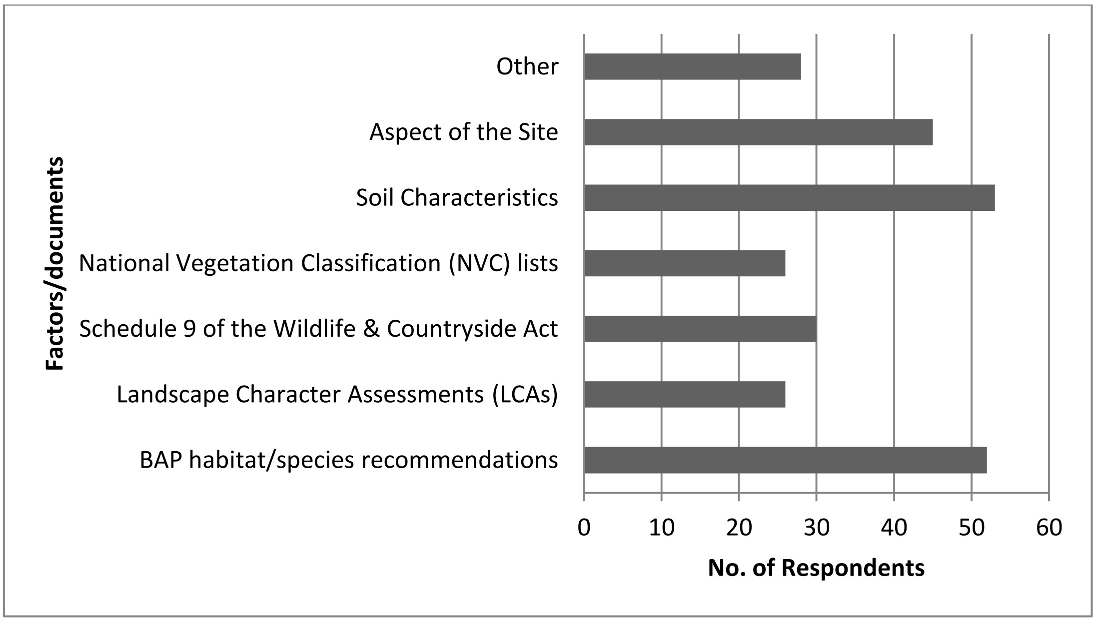

Figure 6.14 Results graph for Q11.a - In making these choices which factors/documents do you consider?

28 of the respondents took advantage of the option in Q11a to enter 'other' documents/factors considered. The responses were tallied into common themes, and the results are shown in figure 6.15. A third of the people mentioned that local species/biodiversity to the area should be considered to help make planting decisions, with one respondent commenting that they "usually base new species mixes on the pre-existing site and that can also be sourced (seed collection or habitat pallets) from the original site". By keeping the seed mix local, it means the genetic pool is maintained, and seed banks will be reasonably near for establishment purposes. One respondent stated that local species should be used but that this "does not exclude non-natives" which correlates with another respondent's acknowledgement of the wildlife value of non-native species. If a non-natives species does not bring any benefits to a habitat, or its advantages do not outweigh the negatives, then such species would not be considered. Pre development conditions were also mentioned, as well as the maintenance and management requirements of the site, and the future use of the site. If there is not enough budget for long term management/monitoring then low maintenance biodiversity schemes are used, as one respondent stated there is ''no point in creating a habitat which cannot be adequately managed". Another respondent commented that "Trees from seed gathered in more southerly locations to try and build in resilience to climate change" should be used. This is a reflection of what this research is trying to create – habitats resilient to climate change, based on species ranges and climate suitability. Westonbirt Arboretum has a section of trees which are of Mediterranean origin, as an example of the trees which are adapted to the climate likely to be experienced in the UK over the next couple of decades.

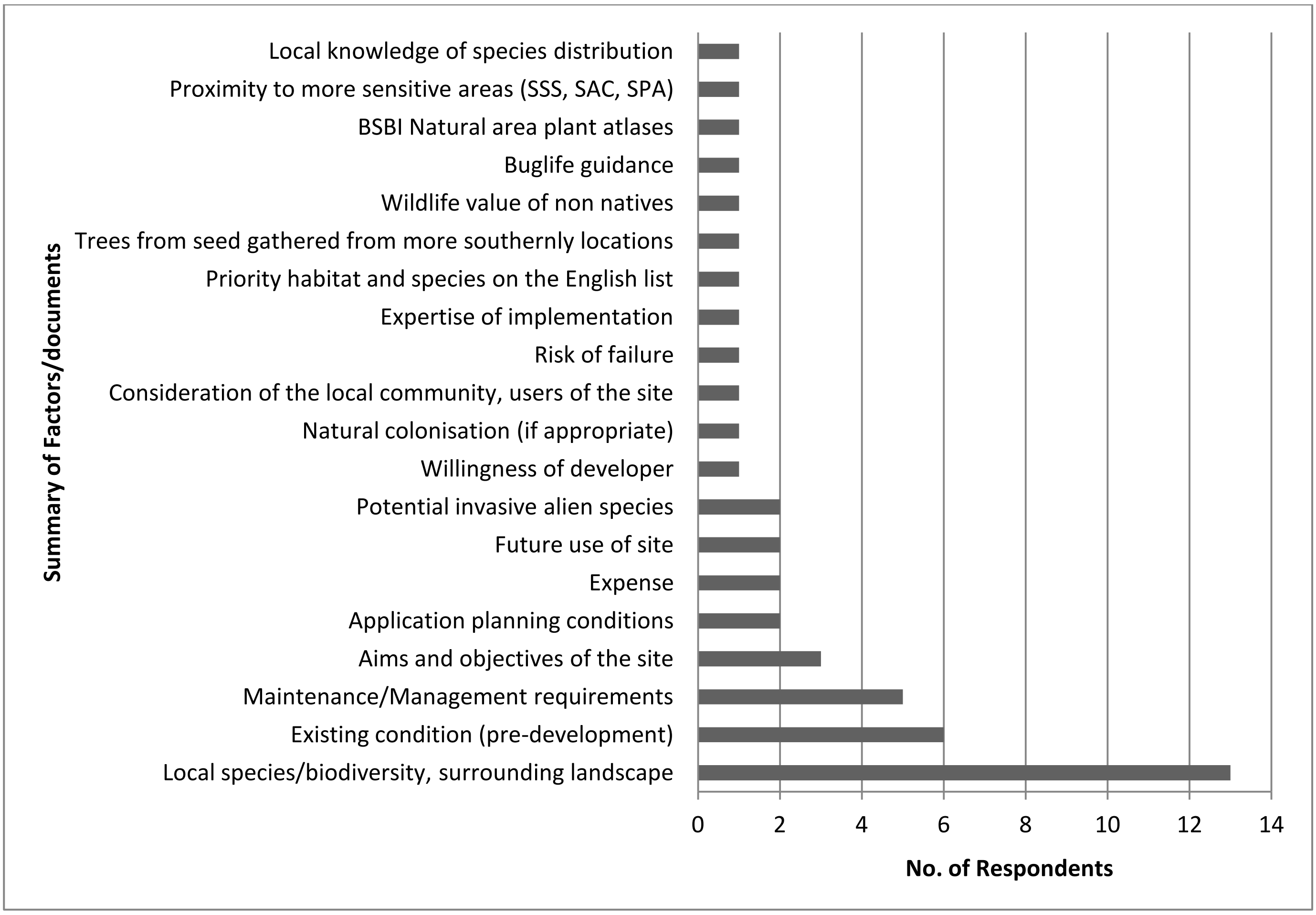

Figure 6.15 Results graph for Q11.a. option – other.

When a landscape architect has created the planting schedule for a site, Q11b (figure 6.16) shows that 74% of the respondents are sometimes allowed to have an influence over these selections, and 21% are always allowed to. Nobody responded with ‘Never’, which illustrates that once planting schedules are created by the architect, they are not final.

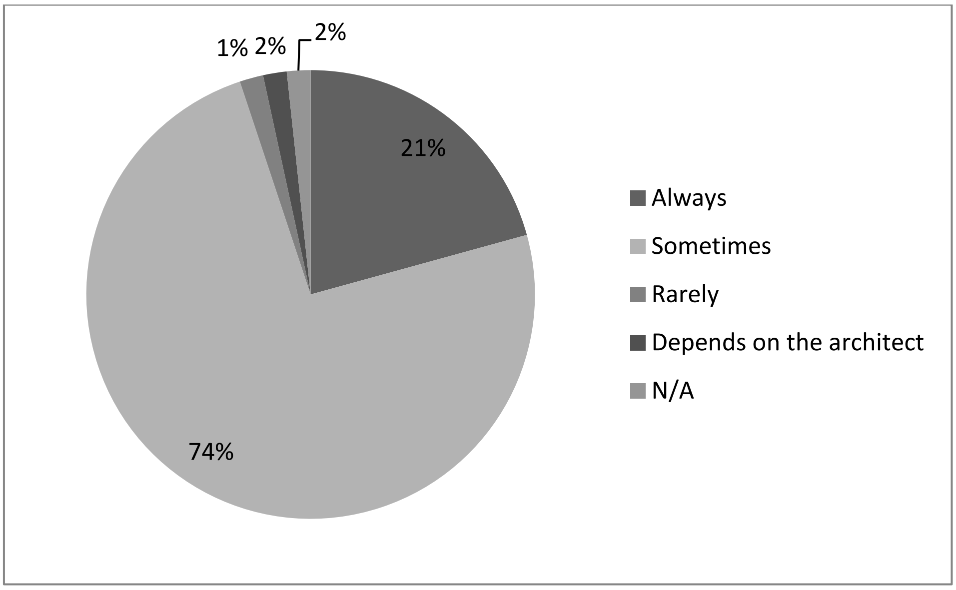

Figure 6.16 Results pie chart of Q11.b - Are you able to have an influence over the landscape architect's planting selections?

The responses to Q11c were similar to those for Q11a. It is an open ended question and 54 people commented, including those that replied they were not involved in selecting planting regimes, demonstrating that ALGEs members have an opinion on this matter regardless of their job role. Responses were once again tallied into re-occurring themes with all the results shown in figure 6.17. The most common response was consideration of the local biodiversity, the surrounding landscape; this is a key consideration as what is planted on site needs to be appropriate and complementary to the adjacent habitats and landscape forms - as one respondent stated the planting needs to be "enhancing local landscape character". This again links to the LCAs, and will be considered in this research as a guide for the planting selections created for the case studies. In relation to this themed response, a sites position in the ecological/green network was mentioned by a couple of the respondents. These kinds of networks are becoming more common and implemented by planners as a way of understanding the ecological zones in their area, and the best way of connecting them. This again echoes Lawton's principles, with 'joined' zones created as a way of improving the countries biodiversity.

The second most common response was consideration of the pre-development habitats and the scope for enhancing/retaining these habitats. If the development plans allow for habitats to be kept, then enhancing such habitats will inevitably be the best course of action, as this causes the least disruption. Species suitable for the sites condition and location was stated by 15 respondents; depending on the underlying conditions of the site – the soil, the geology, the topography, the drainage, possible contamination. Five respondents mentioned that species should be selected to maximise invertebrate potential, with "plant diversity leading to invertebrate diversity".

A lack of clarification of this research was discovered here, as 9 of the respondents all believe that the first consideration should be assessing whether planting is appropriate, and to leave the brownfield site to naturally colonise. They state that brownfield sites should be left alone as they are a diverse kind of habitat "Brownfield sites are often most interesting because they represent early successional habitats…the best option might well be to allow natural regeneration, colonisation and succession to occur, managing only problematic species – or to manage to maintain a certain kind of habitat.' Other comments included ''Is it likely to be developed?" This is all true but this research is looking at planting for brownfield sites which are development sites, i.e. a lot of the site will be destroyed for creating new developments e.g. residential developments, and new planting regimes are required on areas where biodiversity has been lost to the development.

Although 2 of the 54 respondents would only plant native species or native species of local provenance, another 2 were more open to the use of non-natives. One respondent stated that as long as there were no problems with compensating for the loss of biodiversity on site then they were "happy for non-invasive, wildlife-friendly non natives to be used as part of an urban/sub-urban planting scheme", and another observed that "avoidance of alien invasive species, depending on priority species on site, could include non-native nectar/pollen bearing plants". Two respondents also made reference to having species which are "climate change resilient", and "robust native species", demonstrating that species which are more resilient/robust/hardy may be considered. In deciding which species these are, one would need to know the vulnerability of the species under debate.

BAP habitats were mentioned in relation to "target species" that the site could be planted with, as a way of delivering biodiversity gain "current biodiversity value – opportunities for BAP enhancement". This links to Q11a when 52 of the respondents indicated that they use BAP habitats when making planting selections for brownfield sites.

An interesting comment was made by one respondent, which relates to the way people view conservation and the biodiversity of our country: "…but there can be too much emotional attachment to ruderal/transient brownfield site flora, and a longer term picture is required." There seems to be contradicting views between ecologists/conservationists and the extent of protection certain habitats should be awarded, and whether species that are not normally associated with an area should be allowed to be introduced. As one horticulturalist once said ''we need more joy in our habitats'' (Hitchmough, 2011), and if this can be achieved by using flora not normally associated with the area then some thought should be given to this idea.

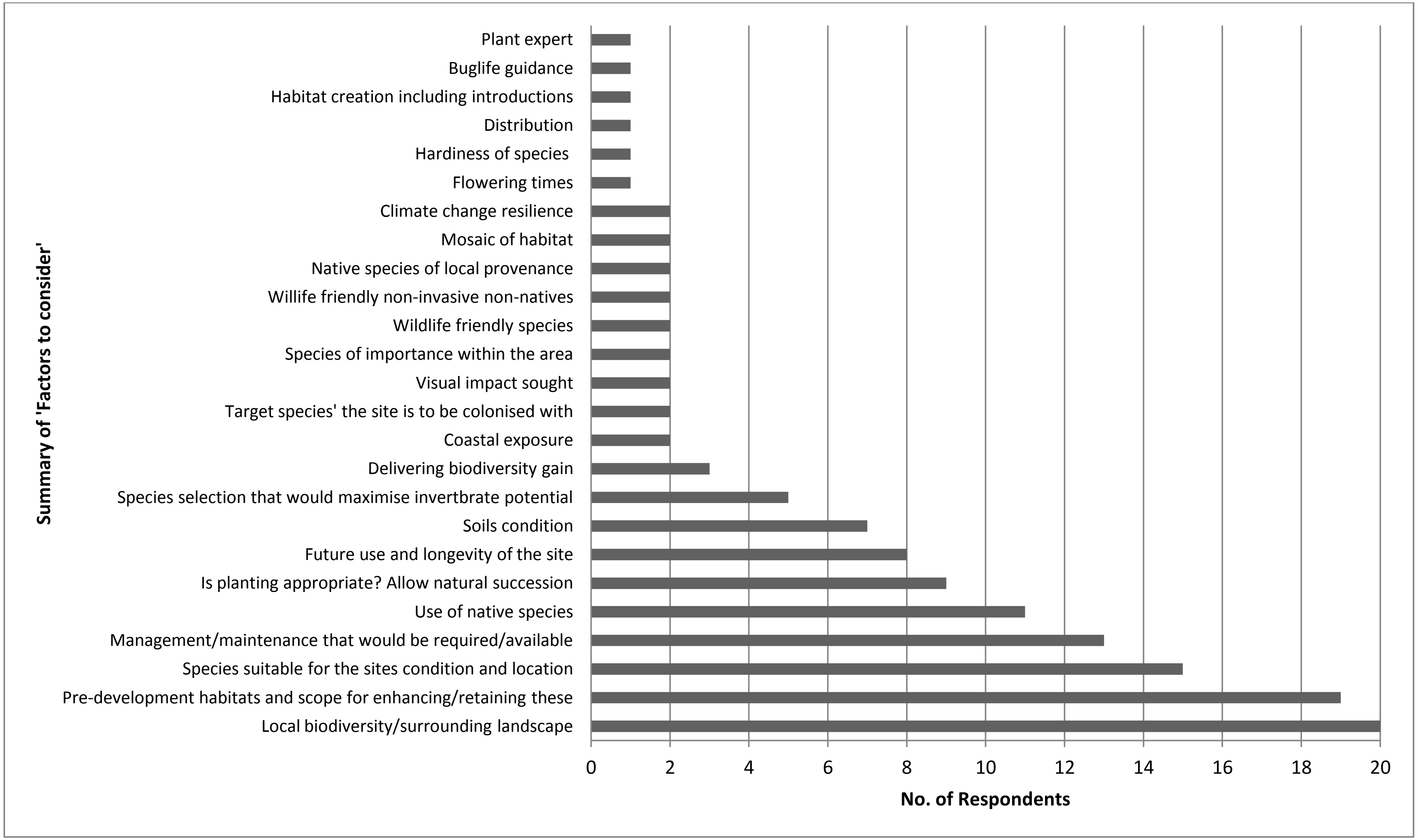

Figure 6.17 Results graph of Q11.c. On brownfield sites, what do you think are the most important factors to consider when selecting planting regimes? Response – Other.

6.2.4 Section 4 - Biodiversity and Climate Change

The results of Q12 show that there is a mixed view from the respondents in regards to achieving no net loss of biodiversity by translocation and intervention. 43% of respondents were undecided on the matter, whilst 36% actually believed no net loss of biodiversity could be achieved via this approach, 21% thought that this was not achievable with such measures.

In Q13 none of the respondents disagreed that a resilient landscape is the best way to tackle climate change when considering biodiversity, with the majority either strongly agreeing or agreeing, as shown in figure 6.18. This is a positive response. Respondents probably have different views of what a resilient landscape is, as suggested by their answers to Q14.

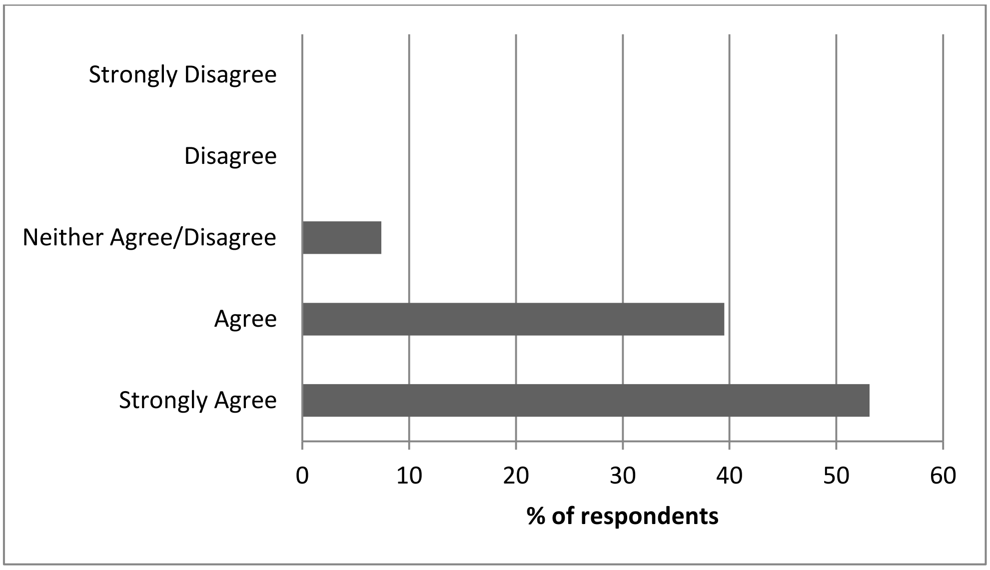

Figure 6.18 Results graph for Q13 - Do you agree a resilient landscape is the best way to tackle climate change when considering biodiversity?

80% of the respondents (65) left a response to the open ended Q14 in relation to what will create a resilient landscape. The positive response rate reflects their passion on the topic. Many of the respondents gave quite lengthy answers, but these could be categorised into prevalent themes running throughout the responses.

The main response was for the use of ecological corridors and connectivity between habitats, both mentioned 14 times. Respondents were keen for these to be more commonplace as they allow for species to move naturally throughout the landscape. The landscape needs to be repaired after years of heavy fragmentation, as one respondent stated, we need to 'reverse' fragmentation. There were 7 references to the Lawton report and his principles (i.e. bigger, better, more and joined up areas), with respondents wanting "bigger, better quality habitat creation and restoration schemes", to include protected areas and local wildlife sites. Some respondents noted that maximising habitat potential/ecological value should be applied to all areas of green space, including urban environments, agricultural land, natural environments, roadsides and developments. A couple of respondents mentioned the use of buffers as a way of enhancing current special sites/nature reserves – "ancient woodland surrounded by 'protective planting'", and again the concept of management and maintenance was rife throughout, with the notion that if habitats are well managed then resilience is maximised.

Eight respondents commented that there should be a mosaic of habitats which would provide diversity and variety and thus create resilience, and that the answer is "not necessarily planting non-native species". A range of plants with different traits are more likely to survive a disturbance than habitats which are uniform and of limited diversity. Linking with this notion was respondents' views that there should be 'a core of species that can tolerate extremes of weather'.

Another theme related to the issue of water. With extremes of weather expected with droughts and heavy rainstorms/flooding, water availability will fluctuate and cause some major problems for habitats. As one respondent commented, the changes in water over time need to be accounted for, particularly for wetland habitats, in order to maintain resilience to climate change. Another stated that abstraction from chalk rivers should be reduced and in relation to flooding there should be a reduction in solid hard surfaces, which relates to another's view that we should use SUDs where appropriate. A strict land-use comment from one respondent was to "stop all employment and housing development in flood risk zone 3 and restore river corridors", and in relation to coastal areas another respondent believes sea level rise should be planned for with "managed realignment of flood defences".

A third theme was that of acceptance and adaptation to climate change. Several respondents were of the belief that change should be accepted and worked with, with one respondent even stating that plant species "from more southerly communities in clearly defined circumstances" should be planted. Another respondent concisely stated that to create landscapes resilient to climate change "intervention, management and appropriate resilient species selection for schemes" is needed. Cautious comments made by some respondents were, firstly, in relation to maintaining the genetic variability of flora and fauna as "to allow the best chance to respond to changing conditions" linking to the earlier mention of plant diversity and the inherent resilience provided. Secondly, better understanding of the likely impacts is needed "so they can be mitigated e.g. to prevent such devastating effects like that of the Dutch Elm Disease in the 1970s".

Land use as a limiting factor for landscape resilience was brought up quite often, and one respondent stated that a resilient landscape "will require considerable effort given the intensity of (competing) land uses". This links to another respondent's view that reducing fragmentation will be very difficult "due to increasing pressures on land for development and intensive agricultural production". With agriculture land occupying over 70% of the UK land surface (Foresight, 2010), the better managed it is for improving biodiversity then the more chance there is of achieving no net loss of biodiversity. Development sites should also be better managed and contribute to biodiversity gain across the landscape, echoed in the National Planning Policy Framework (NPPF), where they suggest biodiversity should be enhanced where the opportunity exists.

A few responses were in relation to the attitude of the government, and the priority that is given to biodiversity in planning policies, as one respondent put it, there needs to be "better integration of biodiversity into policy" and another believed we should ensure "that the environment is given sufficient weight as part of the planning process". The NPPFs principle objective, as discussed in section 3.9.2 is for sustainable development, and sometimes this will have positive consequences for biodiversity, and other times negative. Consideration of biodiversity over the last couple of decades has no doubt improved, but more can be done to ensure it is protected.

Two of the respondents thought that there should be greater financial incentives to landowners for biodiversity enhancement, which inevitably would increase biodiversity across the landscape, but this needs to be in conjunction with other gains for biodiversity. Another two respondents believed that there needs to be "maximised investment" and a "greater appreciation" of biodiversity conservation in the wider countryside, so government funding needs to be delivered here for landscapes to become resilient. Twelve conservation projects were recently launched across the UK as a result of the Lawton report (Lawton *et al.,* 2010) with the creation of nature improvement areas, illustrating that biodiversity loss is being addressed.

A few respondents favoured natural processes/natural regeneration as the best way of creating resilience against climate change, with one respondent stating that there needs to be "capacity to evolve naturally with minimal intervention". Another respondent had similar beliefs but was in favour of preparing to adapt to climate change along the coast, where areas are predicted to be negatively impacted. It is felt that the risk of losing more species could increase if nature is left to take its course, as some species will not be able to migrate in time and track the unprecedented rate of climate change.

Community involvement was another theme raised in the responses, and one respondent stated that if the landscape provides key services to local residents then "they are more likely to look after it" and ultimately management and after-care are key to securing biodiversity longevity. Along similar lines another respondent believed local community resilience projects are the answer, such as woodland creation, food growing, local renewable energy and cultural heritage enhancements.

Good planning was a theme in the responses, along with biodiversity friendly farming, as a way of creating resilience.

The respondents were given the opportunity to leave comments or thoughts on the research in Q15 and 42 did so, with about a quarter of the respondents interested in the research and the results. A few found the research useful and relevant with one respondent stating that the outcomes "should aim to influence policy and decision makers". Some of the feedback was informative, giving direction and pointers, and some were critical of the research.

A couple commented on the topic of translocation, with one respondent stating that translocation would "be a last resort for very vulnerable species, and by their very vulnerability, translocation may not be a practical option because habitats may not be specific enough for them". Another also stated that translocation would be "ok in limited circumstances where there is a good chance it will work". One respondent made a very pertinent observation about how "climatically appropriate non-natives will have a higher probability of becoming invasive, especially if they are naturally limited in their home environment by specific controlling species (e.g. specialist invertebrate herbivores)", a factor which is considered in this research.

One respondent stated "engagement with the landscape design and construction industry will be key, as the dominant aim of landscaping still appears to be limited to visual amenity" which enforces the matter of trying to create areas of high biodiversity on development sites, rather than just for visual amenity purposes. The fact that non-natives are currently used in planting schemes on development sites was brought up, and one respondent stated that a native versus non-native approach is not the approach to be taking, but trying to achieve "maximum ecological gain or benefit whether with or without native species" is encouraged. A respondent with strong views stated that they "do not want to see our local biodiversity evolve into that of another country", and are against the careless design used by landscape architects when they include such species as Laurel and Rhododendron. They also felt that the robust native plants, such as hedgerows and trees are not suffering as a result of climate change, this situation, however, may be different in 2050. Other respondents were very concerned about the inappropriate planting of non-natives.

6.3 Questionnaire Evaluation and Conclusions

Although only 29% of the ALGE members responded to the questionnaire, their responses were nonetheless valuable and informative for the research. Possible limitations of the questionnaire relate to a lack of clarification on the term 'brownfield land', as some have misinterpreted this as referring to brownfield habitats which are often of high ecological value. However, this research relates to brownfield land to be newly developed with new habitat creation, their opinions on some questions are therefore irrelevant to this research. As found by Foddy (1994) misinterpretation is a common problem with the collection of data through a questionnaire survey. The 6 open ended questions in the questionnaire produced a large quantity of data to sort through; this could have been narrowed, and the respondent be asked only for the main reason and not all reasons to provide succinct responses.

The questionnaire has, however, highlighted that the majority of ecologists in the field are noticing changes to biodiversity, but that their means and ways of dealing with the impacts of climate change on biodiversity vary considerably. All respondents believe that some kind of action is required to tackle the problem of climate change, but many are in favour of maintaining native habitats rather than introducing non-native species to create resilience; only 12% were in favour of introducing species of a non-native provenance into new planting assemblages for development sites. A few respondents were also not averse to considering species southern to the UK, acknowledging that some species have a European range. Some respondents are cautious when it comes to non-native species, but only suitable species of a non-native provenance, as selected through the framework, would be recommended in this research. The benefits of non-native species, including a longer flowering season, need to be recognised, with many non-native species already accepted as part of the natural scenery.

Of those involved with planting selections for development sites, the majority consult the BAP habitat and species recommendations for their species selections. The use of the BAP is important, as its existence stems from international biodiversity legislation, but with many BAP species unlikely to be suitable for climate change, their inclusion in current planting schedules should be re-assessed. When considering the suitability of species chosen to create resilience, a judgement needs to based on all considerations, i.e. LCAs, so that the best option for the site is created. The next chapter identifies the site conditions and proposed developments, including the current planting lists, for the case studies selected to test the methodology of this research.

7. Case Studies

7.1 Introduction

As discussed in section 5.6, five case studies have been identified in the UK to understand the current practice with regards to biodiversity requirements on development sites and by which to test the proposed methodology. Using online documents the relevant details pertaining to the case studies were investigated for the biodiversity aspects of each site, particularly the planting regimes and assemblages for each development. Figure 7.1 shows the areas in the UK where the case studies are located.

Figure 7.1 The Location of the Case Study Sites across England

In this chapter each case study is discussed in relation to the site history, site conditions, development plans and biodiversity elements of the site. UK and Local Biodiversity Action Plan (BAP) broad and priority habitat areas will be looked at for the area, as well as the National Character Area that the development falls in, an overview of which is discussed in 7.2. Each case study varies in length of detail discussed, depending on the development type and site conditions, and the documents that were accessible to the public through online portals. The extent of biodiversity elements on each site also varies.

7.2 National Character Areas

England has been classified into 159 National Character Areas (NCAs), as illustrated through the use of colours in figure 7.2, each of which describe the landscape of the country based on natural lines that shape the landscape, as oppose to administrative boundaries (Natural England, No date, b).

Character, in this case, refers to the differential features between landscapes which makes them distinct and recognisable. NCAs provide a framework, based on the natural and cultural features of an area, which facilitate decisions regarding the natural environment to be made. In the questionnaire, 26 of the 58 respondents involved with planting selections for development sites said they considered Landscape Character Assessments (LCAs) in their decision making process. LCAs have not been developed for every area in the UK, these are often carried out at a smaller scale than the NCA, and it all depends on whether the local authority decides to undertake an assessment for their respective region.

NCAs, although at a slightly larger scale than LCAs, are however important in understanding the landscape of the area and for the wider biodiversity objectives. The information given for each area is therefore different depending on the character and the objectives for that NCA. The NCA profiles typically contain information on the land use, geology, settlements, characteristic habitats, farming productivity etc, but only the biodiversity aspects of the NCA and possible influences on plant selection are discussed for each case study in this chapter. However, they are currently being updated and consequently the extent of detail varies for each NCA profile.

Figure 7.2 The National Character Areas for England (Natural England, No date, b)

7.3 Eastern Quarry, Kent

7.3.1 Site Location

Eastern Quarry (EQ) is located to the south of Swanscombe, in the Ebbsfleet Valley in Kent. The towns of Dartford and Gravesend lie either side of the development, with the A2(T) to the south, and the River Thames 2Km north of the site. It is approximately centred at NGR TQ 603 734 and is one of the largest development sites in the Thames Gateway and a major component of the Kent Thameside Development Area (Land Securities, 2007b).

Figure 7.3 Eastern Quarry Site Location

7.3.2 Site History and Description

The quarrying of chalk, for cement and other purposes, at EQ2 has been ongoing since the 1920s, with cessation towards the end of the last decade (Land Securities, 2007b). It presently occupies an area of *c.* 240 hectares.

A large hole in the ground has formed from the quarrying activities, with steep cliffs between 20 and 50m high forming the border on the southern, western and north-western boundaries (Middlemarch Environmental Ltd, 2010). The deposition of overburden has left artificial ground levels in parts of the site. Craylands Gorge, which is also part of the site, extends northwards from the north-west corner as a narrow spur. It is a site of nature conservation interest (SNCI), and was formerly excavated for chalk. It now includes a mosaic of woodland, scrub and grassland.

7.3.3 Proposed Development

EQ2 will be re-developed into a mixed use development (see fig 7.4) including 6,250 residential dwellings across 3 villages, as well as offices, retail, leisure, hotel and community uses, with the total development being 870,000m^2 (87ha) (Land Securities, 2007b).

Figure 7.4 EQ Site Wide Master Plan (Land Securities, 2007b)

7.3.4 Soils and Geology

EQ has chalk soils but Soilscapes revealed that the wider area consists of freely draining slightly acid loamy soils (see fig 7.5). The presence of Thanet may influence this composition.

Thanet sands was the main soil overlying the chalk at EQ. Whilst some of this was removed as overburden during the quarrying activities, some still remains in parts of the site. Near the surface, the pH is 6.5, whilst deeper down the horizon it climbs to 8.5 (Middlemarch Environmental Ltd, 2007). The leaching of basic salts from the top layer may have contributed to this. Overall the soils are poor in nitrogen with variable drainage properties, due to the varying quantities of silt and clay present.

Figure 7.5 EQ Soilscapes Map (NSRI, No date)

7.3.5 The Ecological Context

The ecological context, i.e. the surrounding landscape, county BAP and NCA would typically influence the choice of planting for a development, an outcome ascertained by the literature, field experience and the questionnaire findings of chapter 6. They are therefore discussed in relation to EQ as they inform the proposed planting design specified in section 7.3.6.

7.3.5.1 The Surrounding Landscape

The quarry and surrounding area to EQ are part of the Dartford and Gravesend Fringes LCA, with the region being heavily industrialised and built-up (Land Securities, 2003b). The influence of humans here is very strong, the excavation of chalk at EQ being one example. Fragmentation of land by urban development and transport corridors is also very evident. Electricity pylons and tall chimneys are prominent features of the landscape in this area, and the chalk quarries contribute to the post-industrial setting of the area. In a transition of land-use, open countryside composed of farmland and woodland lies to the south of the A2(T), comprising the rural fringe of the area.

Figure 7.6 shows the habitats in and surrounding EQ, as created by Magic (Natural England, 2013), an interactive tool for observing the natural environment. Darenth Woods, ancient semi-natural woodland SSSI, an area of high conservation value, is located less than 1km south west of the site, as well as many Deciduous Woodland BAP Priority habitats, some of which border the development and which are to be retained onsite.

Figure 7.6 Habitats surrounding EQ as displayed by Magic (Natural England, 2013)

7.3.5.2 National Character Area 113: North Kent Plains

EQ falls into the North Kent Plains NCA which lies between the Thames Estuary to the north and the chalk of the Kent Downs to the south (Natural England, 2012). The land is open, low and gently undulating and characterised by high quality, fertile, loamy soils giving rise to a heavily agricultured landscape. Orchards are a feature in the west of the NCA, but generally the landscape is open and treeless with lines of pylons. A diverse range of coastal habitats to the East are also a definitive feature of the NCA. Palaeogene clays and sands make up the geology of the area, underlain by Chalk and Coal measures. The chalk is exposed in sea cliffs and inland quarries like that of Eastern Quarry. EQ will be developed on the chalk bed of a former quarry.

Swanscombe Skull Site on the boundary of the EQ development is a SSSI and NNR, designated because of the pieces of skull (Swanscombe man) that were discovered in the gravel pits there. These human fossil remains are some of the earliest found in the British Isles, and it is a significant Pleistocene area in Britian. The SSSI designation is therefore for cultural and heritage reasons as opposed to the flora/habitats present.

As part of the NCAs statement of environmental opportunity to create new areas of green space and green corridors, they see a potential action for this could be through restoring disused mineral workings, like that of EQ, through extensive creation of semi-natural habitats and integrating these into the wider landscape, thereby enhancing biodiversity. The geology exposed in the quarry is to be retained for its attribute to geodiversity of the NCA, allowing communities to connect with their local heritage.

Climate change Effects on the NCA:

The SE climate change projections by UKCP09 (the central estimate under the medium emission scenario) indicate that by 2050 the mean temperature in winter will increase by 2.2°C, and 2.8°C in summer, and precipitation will increase by 16% in winter and decrease by 19% in summer. Overall impacts on the biodiversity of the NCA would be (Natural England, 2012):

- alteration in woodland composition with likely droughts affecting Beech populations, as well the impact on the habitat from an increase in invasive species. Tree species may also have to contend with introduced pests and diseases;
- consequences for wetland habitats with hotter, drier summers and
- deterioration of coastal features and habitats with rising sea levels.

BAP habitats present in the NCA include those listed in table 7.1.

Table 7.1 BAP habitats present in the North Kent Plain NCA

Habitat	Area (ha)	% of NCA
Floodplain grazing marsh	1,307	2
Coastal sand dunes	472	1
Lowland Heathland	77	<1
Maritime cliff and slope	93	<1
Fens	40	<1
Lowland meadows	33	<1
Lowland calcareous grassland	27	<1
Reedbeds	14	<1
Mudflats	6	<1
Coastal vegetated shingle	2	<1
Saline lagoons	1	<1

7.3.5.3 Kent BAP

As the NCA only refers to parts of north Kent, the inclusion of all priority habitats for Kent are not addressed. For the district of Kent, as a whole, therefore the habitats as shown in table 7.2 have action plans and are considered important to the area and/or worthy of protection:

Table 7.2 Kent Priority BAP Habitats

Kent Priority BAP Habitats
Lowland Dry Acid Grassland
Ancient Species-rich Hedgerow
Lowland Calcareous Grassland
Native Woodlands
Lowland Wood Pasture and Parkland
Built up Areas and Gardens
Lowland Heath
Lowland Fen
Reedbeds
Lowland Meadow
Standing Open Water

The target for action by Kent County Council (2006) is to 'ensure that development contributes to delivery of biodiversity targets' and does not significantly increase the fragmentation of wildlife habitats. Given the discussions in chapters 3 there is need to implement such measures to prevent species loss. Kent County Council is actively seeking to address this problem through planning and development.

Given the surrounding ecology and BAP recommendations, such factors would typically influence the planting design and ecology proposals for a development. The majority of the respondents in the questionnaire who were involved with planting selections stated that they use BAP habitat and species recommendations to guide species selections, illustrating their importance at the local level. The ecology proposed for EQ is discussed in the next section.

7.3.6 The Ecology at EQ

Quarrying has destroyed many of the habitats that were originally present on the site, but some remain on the periphery alongside habitats which have established more recently as and when quarrying finished (Land Securities, 2003b). A scheme-specific BAP (Land Securities, 2003a) was created for EQ due to the size of the development and the need to reaffirm biodiversity commitments. The main habitats represented at the site consist of arable land, bare and disturbed ground, semi-natural broadleaved woodland, planted woodland, scrub, improved grassland, semi-improved calcareous and acid grassland, wetland and cliffs. The diverse range of habitats present is a result of the varied history of the site and the disturbance to different parts of the site from quarrying, followed by recolonisation. Some of these habitats are to be retained on the site for their conservation value, but as the BAP states the majority of the habitats if left undisturbed would eventually become scrub through natural succession. The ecology of the areas bordering the development has been valued as worthy of protection and enhancement, and therefore they form part of the retained landscape of the site (Land Securities, 2007b). These include the upper slopes of regenerated scrub and woodland vegetation on the prominent chalk cliffs, a feature of the development, as well as the existing hedgerows and woodland along the northern site boundary. Most of the woodland to be lost is relatively young secondary (Land Securities, 2007b).

The wooded areas of Craylands Gorge still remain harbouring a range of scarce plant species including round-leaved wintergreen (*Pyrola rotundifolia*), ivy broomrape (*Orobance hederae*) and green-flowered helleborine (*Epipactis phyllanthes*) (Middlemarch Environmental Ltd, 2010). Dense-flowered fumitory, also present at EQ is recognised as being scarce, and there are plans to enhance the populations of this species, as well as wintergreen and establish arable weed populations within a designated area of the site. The BAP aims to create extensive areas of habitat, with biodiversity being an important aspect of the overall development; wildlife corridors and boundary landscapes will link key ecological reserves (Land Securities, 2003a).

Mitigation proposals for the site include the creation of habitats to support species that would otherwise be lost. The ES indicates that seed collection and sowing and/or translocation of certain species including arable weeds, round-leaved wintergreen as well as mosses and liverworts, are possible measures for this mitigation.

In the development's sustainable development strategy (Land Securities, 2007c), it states that EQ will be a 'good practice sustainable development', which illustrates the developer's commitment to creating a development site that implements sustainable measures in both the built and natural environment. The developers want to go beyond the ideal and this emphasises the point made in chapter 3 that biodiversity is now regarded as an important consideration, and can be more than just a requirement to satisfy planning guidelines. A statement in the document which is of particular relevance to this research is that the developers want to 'sustain biodiversity, and in doing so recognise that the distribution of habitats and species will be affected by climate change'. This demonstrates that there will be an element of flexibility in the management of the site when considering climate change, and thus potentially utilising the outcomes of the research.

The objectives for nature conservation at EQ are to (Land Securities, 2007c):

- enhance the current level of biodiversity;
- ensure long-term conservation value;
- continue to uphold conservation status of important species as favourable;
- provide connectivity between habitats; and
- re-create habitats already found at EQ, including those which have been dug up as a result of quarrying, to continue to support similar species and communities.

Specific objectives in relation to habitats and features include to:

- **enhance or create a diversity of wetlands;**
- incorporate wildlife potential into SUDs;
- enhance the biodiversity of grasslands on site;
- integrate bare and sparsely vegetated habitats into the landscape design.
- **promote the wildlife potential of linear features;**
- utilise new building external space for novel biodiversity features;
- allow birds and bats to roost in new buildings;
- maximise private gardens and allotments for biodiversity benefit;
- promote biodiversity amongst residents of EQ;
- make use of neighbourhood parks and school grounds for biodiversity gain.

The habitat proposals in bold are considered in the vegetation matching discussed in chapter 9.

Planting

Most of the planting species selected are native and have been proposed after discussions held between the developer's ecological advisors and Kent Wildlife Trust (Land Securities, 2007a). The planting assemblages currently for the development can be found in appendix 2 for the habitats of woodland, grassland, meadow, aquatic and marginal. Castle Hill & Weldon is one of the 3 villages to be built on EQ and the village which has been designed and planned for first. Many of the planting documents, therefore, are in relation to this part of EQ.

The habitat proposals for EQ would be taken into consideration when creating species lists suitable for the future climate at the site. By following the original landscape design, those features which are important to the site/local area can be maintained when developing the new assemblages.

7.4 Olympic Park, Stratford, London

7.4.1 Site Location

The Olympic Park is located in East London around the lower valley of the River Lea (see figure 7.7), with the A12 on the northern boundary, extending southwards to Stratford High Street (ODA, 2011e). The River Thames is over 2km south of the site. Its grid reference is approximately TQ 377 848.

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Figure 7.7 Olympic Park Site Location (Natural England, 2013)

7.4.2 Site History and Description

Formerly railway tracks and the location of tanneries, the site was heavy utilised during the industrial revolution, as well as being used as a dumping ground for demolition rubble from the Blitz (ODA, 2011c). Consequently the site is heavily contaminated with petrol, oil, tar and heavy metals such as arsenic and lead. Until construction of the site began, most of the land was derelict. The Sustainable Development Strategy (SDS) states that 'Remediation of the contaminated land on site will bring hitherto inaccessible polluted land back into public use' (ODA, 2011e). The overall size of the site is 2.5km^2, and Stratford has an average altitude of 12m.

7.4.3 Proposed Development

When the development was proposed it was to be the centrepiece of the London 2012 Olympic and Paralympic Games – the Olympic Parklands, with the aim to be the most sustainable games ever held (LDA Design, 2011). Amongst the venues an urban park would be created to accommodate the vast numbers of visitors to the park, with the intention to make the landscaping an attraction itself. The overall site is 2.5km^2, but the target for the amount of green space to be created on the park, as stipulated in the Environmental Statement, was 45 hectares. In the legacy phase, the park is to be transformed into metropolitan open land with permanent parkland totalling 102 hectares.

7.4.4 Soils and Geology

Soilscapes has identified the area where the site is located as having loamy soils with naturally high groundwater (see figure 7.8), which with the area being in the Thames floodplain is expected.

Figure 7.8 Olympic Park Soilscapes Map (NSRI, No date)

Most of the soils on the development were cleaned onsite to remove tannery and heavy metal contamination, but due to the sheer amount the soil was capped 80m below ground. At this point a drainage system was incorporated to prevent groundwater contamination (Landscape Institute UK, 2012). Clean soil was applied to this artificial ground layer and modified depending on the desired outcome. The soils vary over the site dependant on the topography, the drainage conditions and the type of habitat to be created; the soils have essentially been manipulated dependant on this latter criterion. Due to the large amounts of soil required and the timescale, it was not feasible to use natural soils, they were consequently manufactured.

There were 7 major soil types used for the Olympic Park, subsoil and 6 types of topsoil including multi-purpose topsoil, high permeability topsoil for the likes of the spectator lawn, urban tree soils, and low fertility soils for the perennial meadows to prevent competitive grasses growing.

7.4.5 The Ecology

Using the format for EQ as a model example, the ecological context, i.e. the surrounding landscape, county BAP and NCA would typically influence the choice of planting at the Olympic Park, as per EQ. They are therefore not discussed in relation to the Park as they only inform the proposed planting design specified in this section.

Biodiversity was one of the five headline themes set out in the sustainability policy for the aim of protecting and enhancing the biodiversity and ecology of the Lower Lea Valley, and other venue locations (ODA, 2011d). By investing so much in biodiversity, the SDS aimed to encourage the sport sector generally to contribute to nature conservation and enhancing the natural environment.

The three main objectives for the ecology of the site were:

- to protect any retained habitats;
- to provide suitable off-site mitigation; and
- to deliver new and enhanced habitats.

Existing habitats on the site included brownfield habitats of ephemeral and ruderal vegetation, as well as more developed habitats like grassland, scrub and woodland (ODA, 2011d). Invasive species - Giant Hogweed along the River Lea, and Japanese Knotweed were present onsite and would need to have been eradicated. The ecological value of the river corridors and associated habitats was high, consisting of mudflats, reedbeds and marginal vegetation and species affiliated with these. The need to remediate and recontour the site would lead to loss of most habitats with only a few high value sites like waterside and woodland areas being retained. Temporary habitats and sites of wildlife refuge would be created to limit the impact and loss of species.

The target for 45ha of habitat creation on the Park was to compensate for the existing designated sites of nature conservation value, sites of Borough importance that would be destroyed in creating the development. PPS9 and the local plans stipulate that recreated habitat must equal that lost to construction, both in size and quality of habitat (ODA, 2011a). The creation and enhancement of habitats would aim to provide both recreational aspects for the area, as well as ecological benefits (ODA, 2011d). A fundamental aim was connectivity between habitats, both terrestrial and aquatic habitats, and maintenance of these corridors. As part of the habitat creation, over four thousand semi-mature trees would be planted, along with over a quarter of a million wetland plants to improve the river banks and appearance of the water courses (LDA Design, 2011). Figure 7.9 shows the habitat creation for the games and for the legacy, with an increase in habitat size for the latter.

The site is divided into two halves, with lots of green space and natural settings in the North Park, in comparison to the South Park which has a more urban concourse. Improved river restoration works connect the two parts. The River Lea in this part would be returned to its previous more natural state, and through a mosaic of habitats created, including wetland, swales, wet woodland, dry woodland, and meadow, the flood protection measures of this area have been improved and ecological value enhanced (LDA design, 2011). The site has been designed to accommodate a 6mm per year sea level rise due to climate change and has increased flood protection measures (ODA, 2011d).

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Figure 7.9 Habitat creation during the games (left) and for the legacy (right) (ODA, 2011b)

The species selected would predominantly be native species, of local origin and appropriate to the region. The SDS (ODA, 2011d) states that seed would be collected from existing habitats before construction begins. Habitats would include existing native mature woodland, scrub, woodland edge (including tall herbs), wetlands (including reed bed and wet woodlands) and various species-rich grasslands which would require low nutrient substrate. Habitats and hibernacula would also be managed for reptiles and colonisation by reintroduced amphibians. Buildings would also be designed to increase biodiversity opportunities - park wide targets include the provision of nest boxes for black redstarts, house sparrows, starlings, swifts and bats, and the creation of 0.4ha biodiverse living roofs (ODA, 2011a).

BAP

On a development of such size with many aspirations for biodiversity, a scheme-specific BAP was produced to ensure commitments made in the Environmental Statement were implemented onsite. It was a requirement of the section 106 deed of agreement ‘to help achieve biodiversity objectives and protect habitats and species’ (ODA, 2008). In preparing the BAP the National Habitat and Species Action Plans prepared by the UK Biodiversity partnership for the UK, PPS9 and the NERC Act 2006 were consulted, along with other policy documents relevant to London and the South East. The surrounding boroughs have combined as one unit to jointly address the problems, plans and actions for the development.

Targets were set in the BAP for the creation of a variety of specific habitats, which are shown in table 7.3 along with the 6 UK BAP broad habitat types that they belong to (shown in bold), and their target size. A mosaic of riverine, wetland, terrestrial and urban habitats along river corridors and throughout the Parklands are intended to support a range of species specified in the BAP. The BAP (ODA, 2008) has action plans for 28 species including Black Poplar (*Populus nigra betulifolia*), a tree of the floodplain forest largely at threat across the UK due to drainage schemes and destruction of this habitat. It is listed in the British Red Databook as a species of least concern (category LC) and is a London BAP priority species and had been propagated from the original sample onsite (Shearer, 2012).

Table 7.3 Olympic Park BAP Habitats

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The BAP criteria underpins the planting lists, but the NVC lists have been consulted to guide plant compositions that work well together and provide good conditions for invertebrates (Shearer, 2012).

In a discussion with Shearer (2012) from LDA Design, the principle landscape architects for the Olympic Parklands, with regards to consideration of climate change, she states that measures to alleviate flooding have been taken on the development, as well as avoiding species vulnerable to climate change. Willow, Poplar and Alder have been selected to withstand flooding, with only selective use of Ash and Beech, i.e. in free draining soils, due to their vulnerability. Birch stem woodland has been created, but so there was less reliance on Birch, a species susceptible to the impacts of climate change, Oak and Cherry, have also been planted for their longevity. Through appropriate ecological design, London, in this area, has been adapted to climate change (ODA, 2008).

Separate from the more natural settings, the Olympic Gardens are four sections of planting representing the flora from different parts of the world including the north Americas, the southern hemisphere, Europe and Asia. The ornamental gardens have been created as a horticultural celebration and for the recognition of 'unintentional biodiversity' that has been created in urban areas, as stated by Hitchmough (2011), horticulturist for the parklands. With South Africa experiencing similar seasons to the UK, species from this area have been planted in the gardens to illustrate the joyous flora from such destinations. He believes the notion that all non-natives are aliens needs to be challenged, a statement pertinent to this research and its wider outcomes. Plant species in the Gardens will be able to tolerate the change in weather conditions likely with future climate change (ODA, 2011b).

The use of non-natives in some habitats has been allowed, particularly in the Olympic gardens, and with a key outcome of the planting strategy being 'a reasoned justification for the use of appropriate non-native species to broaden the ecological value, visual spectacle and interpretation/education benefits of the planting' (ODA, 2011d), the benefits of non-native species have been recognised at this level of quality landscaping. A selection of non-native species are included in the annual meadow mix as they flower for longer than natives and provide excellent nectar and other food sources; a diverse range of invertebrates and birds therefore benefit greatly (ODA, 2011b). Although there is a strong emphasis on the use of natives, the 'wider ecological functionality' of non-natives has been recognised on this development, particularly in its urban settings, and shows them in a positive light.

The habitat proposals for the Olympic Park would be taken into consideration when creating species lists suitable for the future climate at the Park. By following the original landscape design, those features which are important to the site/local area can be maintained when developing the new assemblages.

7.5 Brogborough Landfill Site, Central Bedfordshire

7.5.1 Site Location

Brogborough landfill site is situated in the low lying Marston Vale, 13km southwest of Bedford, in the Central Bedfordshire district, as shown in figure 7.10. Its grid reference is SP 966 400. Brogborough Lake, a flooded clay pit, lies close to the southeast of the site, with the remainder of the site bordered by agriculture land and sections of woodland (Waste Recycling Group Ltd, 2005a). Marston Thrift, a local nature reserve and SSSI, is located adjacent to the northeast boundary and Holcot wood is situated just west of the site.

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Figure 7.10 Brogborough Landfill Site Location (Natural England, 2013)

7.5.2 Site History & Description

The site was originally used for agricultural purposes until the 20th century when the extraction of the mineral clay from the ground begun to depths of about 25-30m (Waste Recycling Group Ltd, 2005a). This was through the weathered Oxford Clay (Callow) and into the unweathered Oxford clay (Knotts). The clay was used for brick making with the brickworks (London Brick Company) located on site; planning and restoration conditions for continuation of this activity in 1981 were for the filling of the excavated areas. Landfilling of waste therefore commenced in 1983 in accordance with those provisions, but further planning applications resulted in more clay being extracted from un-worked land in 1998. The main activities of the landfill site were waste disposal, leachate collection and re-circulation, and landfill gas collection and electricity generation. Landfilling ceased in 2008 with a programme of restoration works to follow. The site is approximately 194 hectares with an average elevation of 55m AOD. Clay extractions throughout the area have consequently created a distinctive local character.

7.5.3 Proposed Development

A programme of planting and maintenance, along with aftercare and management of the restored site were conditions of the agreement for landfilling. A policy of the Bedfordshire and Luton Minerals and Waste Local Plan states that "all minerals and waste proposals in the Marston vale should contribute to the improvements of the environment of the vale" (Watts, 2008), which shows the consideration of the environment is important to the area. The site will be restored to post-settlement levels through phasing, soil handling and landscaping schemes. In the interests of nature conservation there will be a mixture of restoration habitats created including species-rich meadows, extensive sections of woodland, woodland rides, hedgerows, grazing land and reed bed and marginal aquatic habitats (Waste Recycling Group Ltd, 2005a) as shown in figure 7.11 The development will contribute to the Marston Vale community forest, an environmental regeneration programme in the Bedfordshire region to improve the landscape, wildlife and recreational aspects of the region. Around the edge of the site balancing lagoons will also be established as part of the overall proposed restoration scheme to further enhance the wildlife aspect of the site.

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Figure 7.11 Brogborough Proposed Development (Waste Recycling Group Ltd, 2004)

(Solely use key to inspect image detail)

7.5.4 Soils and Geology

Soilscapes (NSRI, No date) has identified the area the site falls within as having slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils, as shown in figure 7.12. As discussed the site was used for clay extraction.

Figure 7.12 Brogborough Soilscapes Map (NSRI, No date)

The underlying geology is unlikely to affect the plantings proposed for the site, as an engineered cap of clay material will be used to isolate the landfill material from the restoration works. The developers state they have most of the capping and restoration material (approx 1.6 million cubic metres) available on site, but a further 200,000m^3 of soil would need to be imported (Waste Recycling Group Ltd, 2008).

The restoration cap is placed over the engineering cap and provides a growing medium for the restorative planting works planned for the site. This layer will be 1.0m in depth, or 1.5m where the woodland and hedges are to be planted. The heavy texture of the clay will provide adequate soil moisture for the sites intentions and with the incorporation of bio-solids to improve soil quality, vegetation can establish and grow (Waste Recycling Group Ltd, 2008).

7.5.5 Ecology

Using the format for EQ as a model example, the ecological context, i.e. the surrounding landscape, county BAP and NCA would typically influence the choice of planting at Brogborough landfill site, as per EQ. They are therefore not discussed in relation to the landfill site, as they only inform the proposed planting design specified in this section.

The landscape surrounding the site and the sites position within the Marston Vale Community Forest area are acknowledged in the restoration scheme. The ash-maple-oak composition of the adjacent woodlands will be reflected in the sites woodland structure, although it is envisaged that the species mix of these woodlands will influence any future colonisations of the site (Waste Recycling Group Ltd, 2005c).

Central to planning is that the ecology of the area is enhanced, and brings connection to the current fragmented landscape of the Vale, thus improving the nature conservation value of the area (Waste Recycling Group Ltd, 2005b).

There are two important nature conservation areas nearby to the landfill site – Marston Thrift Nature Reserve, a SSSI, and Holcot Wood – an ancient semi-natural woodland. Marston Thrift is an oak-ash-maple woodland, a habitat which has limited cover in Bedfordshire and generally over its natural range in lowland England. It also supports the only colony in Bedfordshire of a nationally rare butterfly species – the Black Hairstreak butterfly (Waste Recycling Group Ltd, 2005c). This butterfly is in decline in the UK owing to its dependency on Blackthorn that is managed on a long coppice cycle, but Blackthorn is more often managed on a short coppice cycle. The spinney woodland already existing on the landfill site will therefore be kept, as well as there being a new area of scrub planting with a high blackthorn content to ensure the provision of suitable habitat to maximise the chance of colonisation by the butterfly; this will enhance the value of the site.

Holcot Wood is mature deciduous woodland, 23ha in size, with damp ash-field maple habitat which has developed on heavy boulder clay (Waste Recycling Group Ltd, 2005c). The environmental statement states that there will be no direct impact upon the SSSI or Holcot Wood from the proposed development. Noise and dust impact on ecological receptors outside of the site will be mitigated for.

As the landscape is currently of low ecological quality, the restoration plans for the site and peripheral areas seeks to enhance the quality and extent of the existing habitats present, along with a more diverse array of habitats including creation of (Waste Recycling Group Ltd, 2005c):

- New standing water and wetland habitats, which will develop and benefit dragonfly and amphibian communities
- A flower rich grassland which will attract invertebrates including butterflies
- 90ha of broad-leaved native woodland with rides and glades on the landfill, along with 30ha of species-rich meadow. Species-rich meadows have declined greatly over the last 50 years so this creation will contribute to enhancing the coverage of the habitat, as well as improving the ecological value of the area.

The restoration programme also entails formation of a wildlife corridor of continuous woodland and scrub habitats between Holcot Wood and Marston Thrift SSSI, which will benefit small mammals and birds, as well as increase the wildlife diversity in the area over time (Waste Recycling Group Ltd, 2005c). The extensive consideration of biodiversity in the planning conditions exemplify that Central Beds council were undertaking their duty for biodiversity and enhancing it where possible. Restoration schemes like that of Brogborough landfill is an exemplar of good practice.

The habitat proposals for Brogborough landfill would be taken into consideration when creating species lists suitable for the future climate at the site. By following the original landscape design, those features which are important to the site/local area can be maintained when developing the new assemblages.

7.6 Minworth Sewage Works, Birmingham

7.6.1 Site Location

The sewage works are located south east of the village of Minworth, to the north-east of Birmingham in the West Midlands region (see figure 7.13), and the River Tame flows south of the site. The site is located at grid reference SP 162 915.

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Figure 7.13 Minworth sewage works site location (Nathaniel Lichfield & Partners Ltd, 2005a)

7.6.2 Site History & Description

Since 1886 sewage has been treated at Minworth sewage works. Sewage sludge drying beds and an operational sewage treatment plant currently occupy the site. The overall site is 300ha but the proposed development is approximately 42.35ha (Nathaniel Lichfield & Partners Ltd, 2005c). The topography of the site is relatively flat, at an average 80m AOD (Nathaniel Lichfield & Partners Ltd, 2005b).

7.6.3 Proposed Development

As a result of technological advances since the sewage works was established, less space is now required for operations at the site. The non-technical summary states that the old sludge drying beds at Minworth sewage works will be redeveloped for a mixture of employment development, accommodating buildings for storage and distribution, general industry and business use (Nathaniel Lichfield & Partners Ltd, 2005c). There is also a proposed environmental buffer to be created on the northern bank of the River Tame, which runs south and south east of the site. A bypass road to Minworth village will also be constructed (see figure 7.14).

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Figure 7.14 Midpoint Park II Minworth, Landscape Plan (Nathaniel Lichfield & Partners Ltd, 2007)

7.6.4 Soils and Geology

The underlying solid geology of the site comprises rocks of the Mercia Mudstone Group (MMG) - mudstones, siltstones and sandstone beds, and River Terrace Deposits (comprised of sands and gravels) overlie the MMG, and cover much of the site (Nathaniel Lichfield & Partners Ltd, 2005b). A silty clay alluvium, which is locally peaty, overlies the MMG in proximity to the river and south of the River Tame. Soilscapes (NSRI, No date) identified the area as having loamy soils with naturally high groundwater as shown in figure 7.15.

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Figure 7.15 Minworth Soilscapes Map (NSRI, No date)

Due to the nature of the site, reclamation and remediation works of ground contamination will be necessary; the land will be returned back into a useful and safe environment for future use by others (Nathaniel Lichfield & Partners Ltd, 2005c). Site investigations revealed that the dried out sludge was fit for end use, i.e. for commercial purposes, and that a programme of sludge removal was necessary to ensure stability for the proposed development. The presence of elevated copper and zinc levels in the underlying made ground also meant a development platform was to be created using an inert infill material to prevent any likely instability problems.

7.6.5 Ecology

Using the format for EQ as a model example, the ecological context, i.e. the surrounding landscape, county BAP and NCA would typically influence the choice of planting at Minworth sewage works, as per EQ. They are therefore not discussed in relation to the sewage works as they only inform the proposed planting design specified in this section.

Over time, a patchwork of habitats have formed across the lagoons on the site, reflecting the various cycles of the sewage sludge process, e.g. the filling, drying and dredging of the sludge beds. These have benefitted a range of biodiversity, but the habitats tend to be widespread and are therefore not of high ecological value (Nathaniel Lichfield & Partners Ltd, 2005b). Areas of swamp and willow scrub located in the proposed development are, however, of greater conservation interest. The developers point to the fact that the vegetation present in the lagoons have only colonised due to the operating processes of the works, i.e. they are artificial habitats. The less frequent use of the lagoons has also meant that the vegetation in this part of the development has changed into a generic scrub habitat of little ecological value, and would de-value more if left unattended. The importance of the site for a number of notable wetland birds would also decline over time with scrub progression in the lagoons. In terms of the potential impact the development will have on vegetation therefore, as required by the EIA regulations, has to be assessed considering the future do nothing scenario, i.e. if the development was not to proceed (Nathaniel Lichfield & Partners Ltd, 2005c).

There are notable plant species of local ecological interest on site including Cyperus sedge (*Carex pseudocyperus*), Club-rush species (*Scirpus sp.*), Greater pond sedge (*Carex riparia*), Aspen (*Populus tremula*) and Wood small read (*Calamagrostis epigejos*), but these will not be adversely affected by the proposed development (Nathaniel Lichfield & Partners Ltd, 2005b). Features of the landscape to be retained include the majority of the trees on the perimeter of the site, as well as those along the River Tame, with further native trees to be planted to enhance the woodland habitat present on site. Compensation measures for the loss of habitats in the lagoons will be to create a new backwater channel on the River Tame which will help control flooding, as well as enhance the environment for riparian plants and animal species (Nathaniel Lichfield & Partners Ltd, 2005c).

The Environmental Statement declares that the river restoration works will benefit foraging bats of several species and be more appealing for water vole, a recovering species (Nathaniel Lichfield & Partners Ltd, 2005b). The remediation of contaminated land and the proposed landscaping plans will also provide adequate refuge for amphibians, but there will be a minor negative impact for invertebrates as a result of the development. The development is justified for its long term benefits ‘The residual ecological impact on habitats and vegetation is judged to be minor negative in the short-term, but potentially strong positive when compared to the alternative longer-term scenarios’ (Nathaniel Lichfield & Partners Ltd, 2005b).

The environmental corridor to be created along the River Tame will include extensive landscaping, as well as restoring the river in that part to its natural state. It currently has limited benefit to biodiversity due to being deepened, straightened and constrained in the past to increase flow rate (Nathaniel Lichfield & Partners Ltd, 2005d). The creation of semi-natural riparian habitats are intended to significantly improve the nature conservation interest and functioning of the river section, as well as provide a boundary between the buildings on site and the river (Nathaniel Lichfield & Partners Ltd, 2005c). One of the aims is to integrate the development into the surrounding landscape and enhance the quality, as has already been created by a similar development at nearby Midpoint Park. The planning statement remarks that the development will make a 'positive contribution to the landscape character' (Nathaniel Lichfield & Partners Ltd, 2005c), which highlights the developers have considered the NCA.

7.6.5.1 Planting

The structural landscaping will include adequate space for plants to establish and thrive, and provide a degree of consistency throughout with valuable habitats contributing to the framework of the development (Nathaniel Lichfield & Partners Ltd, 2007). Once the vegetation has established the development will be screened from nearby residences. Evergreen species (often non-native varieties) have been included in the planting mix here to provide screening over winter, but the majority are native deciduous tree and shrub species.

Plant species for the perimeter of development plots will be wildlife-friendly, native or semi-native species, linking to native species already present and the proposed structural landscape. In contrast the internal areas of the plot landscape will provide colour, texture and form throughout the year through the use of ornamental or semi-ornamental plant species. 'Bold and imaginative' semi-native and semi-ornamental species will be included in the planting scheme for the internal distributor road between the development site perimeter landscape and the more ornamental planting of the development plots. The buffer zone will be comprised of riparian habitats to provide a corridor for wildlife, as well as increase the flood protection measures of the River Tame.

The habitat proposals for Minworth sewage works would be taken into consideration when creating species lists suitable for the future climate at the site. By following the original landscape design, those features which are important to the site/local area can be maintained when developing the new assemblages.

7.7 Wheatley Hall Road, Doncaster

7.7.1 Site Location

The site is located 2.7km north-east of Doncaster in South Yorkshire, and south of the River Don as shown in figure 7.16. It is approximately centred at NGR SE 593 056.

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Figure 7.16 Wheatley Hall Road Site Location (Rapleys, 2010a)

7.7.2 Site History and Description

The site is 41ha with an elevation approximately between 8m and 12m AOD. In the environmental statement (Rapleys, 2010b), a desk study indicated the site had over the years formerly been occupied by a farm, a foundry, a depot, engineering works, buildings of unknown use, and until recently McCormick Tractors. It was also used during the Second World War for the manufacturing of small arms. Two landfills occupy the land in the north-eastern and north-western areas of the site.

There is mixture of industry and residential units in the surrounding area. Wheatley Cut or River Dun Navigation Channel, a section of the River Don which was canalised, runs close to the northern boundary of the site. Associated broadleaved woodland occurs on the north western boundary along with immature regenerating woodland (Rapleys, 2010b). The Old River Don oxbows can be found in two individual areas of the site, the northwest and the northeast corners. The oxbows and their surrounding habitats contribute to these areas of the site being classed as a Site of Scientific Interest (SSI). Acid grassland habitat is found in the northeast part of the site, along with regenerating scrub including bramble and birch, allotment gardens also adjoin the site here (Rapleys, 2010b).

The Environmental Statement (Rapleys, 2010b) describes the broadleaved woodland habitats as dominated by Sycamore (*Acer pseudoplatanus*) with other species including Oak, Elm, Horse Chestnut and grass areas with regenerating Silver Birch (*Betula pendula*). The woodland is protected by a Woodland Preservation Order. The central and southern parts of the site mainly consist of existing and former industrial areas including car parking and building. Cherry, lime and birch line the roadside south of the development, on Wheatley Hall Road, for screening purposes.

7.7.3 Proposed Development

The development seeks to demolish the existing structures and create a mixed use development comprised of storage and distribution, general industry and business units, residential buildings, a retirement village, community hub, leisure use facilities and open space with associated access (Rapleys, 2010b). The masterplan is shown in figure 7.17.

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7.7.4 Soils and Geology

The underlying solid geology is the red sandstones of the Triassic Sherwood Sandstone Group, and the drift geology is alluvial. Soilscapes (NSRI, No date) has identified the area the site falls within as having freely draining slightly acid sandy soils (see figure 7.18). The site is however contaminated.

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Figure 7.18 Wheatley Hall Road Soilscapes Map (NSRI, No date)

Chemical testing carried out on selected soil, groundwater and surface water samples from across the site revealed the following contaminants (Rapleys, 2010b):

- Elevated concentrations of copper, zinc, chromium, nickel, benzo(a)pyrene, naphthalene, leachable PAH and PAH species within the made ground
- Localised elevated concentrations of arsenic, copper, nickel, benzo(a)pyrene, naphthalene, TPH, leachable mercury and speciated PAHs within the made ground
- Asbestos fibres within the made ground
- Locally elevated concentrations of sulphate and TPH within the groundwater
- Elevated concentrations of ammonia within both the groundwater and surface water.

Gas monitoring discovered locally elevated concentrations of methane, carbon dioxide and VOCs in wells installed into both the made and natural ground. The level of contamination is considered to be able to be remediated to an acceptable standard for development.

The remedial strategy deals with the requirements to mitigate the potential impacts to end users, controlled waters and the built environment. The presence of asbestos in the shallow made ground in certain areas of the site render mitigation measures necessary to prevent a high health risk to proposed end users/construction workers (Rapleys, 2010b). This typically involves the use of a subsoil/topsoil cap of at least 1m for gardens/soft landscaping with a dense granular 'no dig' layer along its base or an inert substrate such as clay to isolate the contamination. Soils contaminated with hydrocarbons are to be excavated and treated (e.g. by bioremediation or disposed of in a special landfill facility). This goes beyond the remit of this research and is not discussed any further.

7.7.5 Ecology

Using the format for EQ as a model example, the ecological context, i.e. the surrounding landscape, county BAP and NCA would typically influence the choice of planting at Wheatley Hall Road, as per EQ. They are therefore not discussed in relation to the site as they only inform the proposed planting design specified in this section.

Although over 160 higher plants were identified on site in the botanical surveys undertaken as part of the ES, many were introduced plants and there were no nationally rare or scarce species (Rapleys, 2010b). Most of the habitats present on contaminated substrates are nonetheless to be removed, regardless of conservation value, with soils to be remediated. This is in the health interests of end users of the site, as new access rights to the site will be created as part of the development.

Acid grassland (NVC - U1 *Festuca ovina–Agrostis capillaries–Rumex acetosella* grassland), in the north east of the site is a species-rich assemblage of invertebrates and plants, and due to the national scarcity of the habitat, it is a UK BAP priority habitat, a habitat of county level conservation importance, and a Doncaster LBAP habitat (Rapleys, 2010b). Lowland dry acid grassland is also listed as a habitat of Principle Importance under Section 41 of the NERC ACT 2006. Its permanent loss as a result of the development and the need to remediate soils will cause a significant adverse effect at the County level. Two sedge species also found on the U1c acid grassland, sand sedge (*Carex arenaria*) and prickly sedge (*Carex muricata ssp. lamprocarpa*) are locally rare; sand sedge (also on the Doncaster LBAP) is only found at a few inland locations being a predominate coastal species, and prickly sedge, common throughout Britain, is scarce in the Doncaster area.

Doncaster is particularly keen on enforcing strict biodiversity practices especially when mitigation is not possible for the loss in area of a designated site. Compensation measures must therefore be put in place for the loss of the acid grassland habitat, with the Doncaster Local Development Framework Interim SPD for Biodiversity Mitigation and Compensation stipulating:

"Compensation should be of greater extent that what is being replaced to make up for the fact that as an artificially created habitat it is of lower biodiversity value. This increased amount is set at 25% above the area to be replaced." (Rapleys, 2010b)

The loss of 7.2ha of acid grassland will be part-mitigated for by the creation of 3ha of new acid grassland within the proposed development, along with other habitat creation measures in the interests of nature conservation. The translocation of propagules and/or the collection and sowing of seed by hand of prickly sedge and sand sedge, as part of an acid grassland seed mix (including species typical of U1 grassland) will be carried out to provide mitigation for the two sedge species (BSG, 2010). These will form a new area of acid grassland on the north-western boundary of the site, of which ecological value is low. A programme of management will be needed for its survival. Immature Birch woodland is currently in this area, but its ecological value is low, and the vegetation would need to be removed regardless as the existing contaminated topsoil is to be capped to reduce risk to human health (Rapleys, 2010b). Doncaster have specified an NVC habitat for habitat design, as opposed to broad planting which exemplifies their consideration of the need to create as natural assemblages as possible.

According to the habitat creation method statement (BSG, 2010), a free draining and sandy soil with a very low nutrient content and a pH that is below 5.0 will likely be the best substrate for establishment of the new acid grassland habitat. Green compost material (10% of total volume) will be mixed with the substrate to encourage plant growth, and overall be a depth of approx 0.15m for root capacity. It is a bespoke mix of species, similar in composition to the existing acid grassland and sourced locally to ensure its familiarity to local growing conditions.

In response to the habitat action plan target to halt depletion of mixed broadleaved woodland in the UK, a new woodland plantation of native broadleaved trees and shrubs will be planted where currently Japanese Knotweed stands; a programme is in place for their eradication (Rapleys, 2010b). Although woodland habitat is to be retained on site, the additional planting will increase its extent, and contribute to the connectivity of woodland cover between the SSI area of woodland and the riparian woodland strip alongside the River Dun Navigation Channel. The Old River Don Ox-bows are a designated SSI due to the mosaic of habitats that have formed in and around them; the plantation will contribute to the SSI and the overall nature conservation value of the site. Selected non-native trees and shrubs will be cleared from the plantations to encourage the natural regeneration of native woodland flora (Rapleys, 2010b).

The loss of certain habitats due to their presence on contaminated land has resulted in ecological measures being put in place, including habitat creation, conservation management of retained habitats and the provision of local community access to open green space. Echoing the discussion in chapter 3 for biodiversity requirements on development sites, the proposed development will not be allowed to go ahead, according to Doncaster's planning guidelines and the stipulations of the then PPS9 (now the NPPF), unless biodiversity is mitigated and/or compensated for.

The habitat proposals for Wheatley Hall Road would be taken into consideration when creating species lists suitable for the future climate at the site. By following the original landscape design, those features which are important to the site/local area can be maintained when developing the new assemblages.

7.8 Conclusion

This chapter has presented the site conditions, including planting proposals for the five case study sites used in this research. Four of the sites are contaminated with procedures in place to cap the soil or create new manufactured soils. The extent of planting varies between the sites, but they all consider the surrounding landscape as part of their proposals, with some authorities going above and beyond the legal requirement for planning consent through pioneering habitat design, as was the case with the Olympic Park. The next chapter presents the results of the climate matching for each of the case study sites; the locations in Europe are identified, which currently have an analogous climate to that which each site will experience in 2050.

8. Climate Matching Results

As discussed in chapter 5, climate change projection data produced for the UK by UKCP09 has been developed using the IPCC SRES (Nakicenovic *et al.*, 2000). This section looks at the projected climate (mean temperature and precipitation) of the case study areas for 2050 under a medium emission scenario (SRES A1B). The identification of European locations which currently have an analogous climate to that expected for areas in the UK have been obtained through the use of a Geographical Information System (GIS) and are based on the World's 1961-1990 climate means (New *et al.*, 2002).

8.1 Introduction

The methodology for the climate matching is discussed in more detail in chapter 5, but for convenience a recapitulation will be given here. European baseline climate values (i.e. the 30 year mean) exist as a layer on the GIS in point data with a ~18km resolution. The values are assigned to a location, i.e. a latitude/longitude position, making the regions of Europe visible on the GIS. As a climate match, in location, could be better for one parameter than the other, the temperature and precipitation data behind the points have been spatially joined, so that they exist together and can be queried together. Temperature and precipitation measurements together describe an areas climatology relatively well, as discussed in section 5.3.1, and so these variables are considered together to develop the outcomes of this research.

8.1.1 The UKCP09 Grid and Case Study Sites

The UKCP09 25km-resolution grid climate projection data were utilised in this research, and comprise of 434 25 x 25 km grid squares making up the land areas of the UK, with projections provided for each grid square if interrogated. The case studies and their location in the UK are shown as coloured squares on the UKCP09 25 km grid square layout in figure 8.1. Table 8.1 shows the latitude and longitude of each case study site, the 25 km grid square number that they fall into and the latitude/longitude of this corresponding square, which is taken from the centre of the grid square.

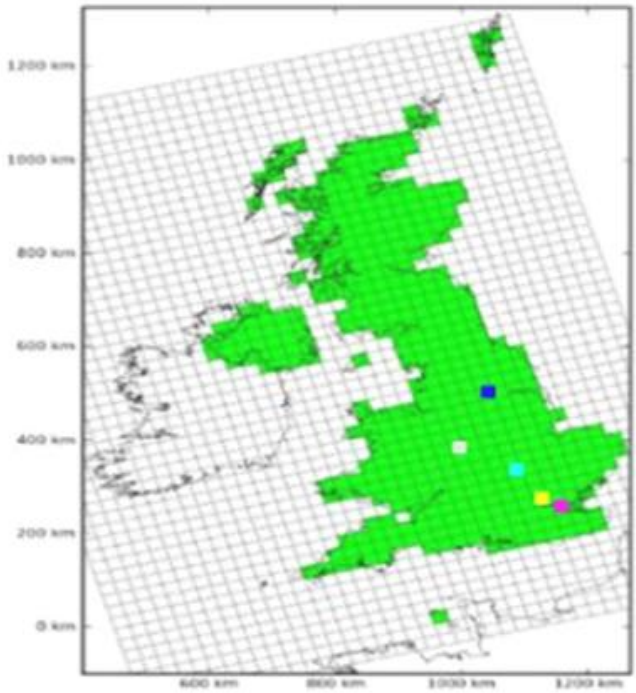


Figure 8.1 The UKCP09 25km grid (see table 8.1 for site identification)

Table 8.1 Case Study Properties

Case Study Location	**Altitude AOD**	**Latitude/Longitude (centre of site)**	**UKCP09 25km grid square no.**	**Latitude/Longitude (centre of grid square)**
Eastern Quarry, Swanscombe, Kent (pink sq)	33m	51.43732, 0.2963	1668	51.41884, 0.29365
Olympic Village, Stratford, London (yellow sq)	12m	51.5428, -0.0124	1628	51.58008, -0.13359
Brogborough Landfill Site, Central Bedfordshire (light blue sq)	77m	52.04998, -0.59272	1549	51.95296, -0.65189
Minworth Sewage Works, Birmingham (white sq)	82m	52.52437, -1.75361	1430	52.4796, -1.61932
Wheatley Hall Road, Doncaster (dark blue sq)	11m	53.54136, -1.10880	1277	53.49898, -0.93631

8.1.2 UKCP09 Probabilistic Climate Projections

UKCP09 create probabilistic climate projections which means likelihood factors are applied to the projections; i.e. a 10% probability means that, for the relevant parameter, there is 10% likelihood that it will be equal to or less than a given value. The 10 to 90% probability range of climate projection values have been used in this research. When analysing the analogous climate locations for each case study, where it is stated that a good match has been found, it refers to the location having a climate which is around the 50% probability projection value for the case study, for reasons described in chapter 5. How the results were obtained is explained in detail in relation to one case study, EQ (section 8.2). The same procedure was employed to obtain the results for each subsequent case study. All projections are given in relation to the time period the 2050s (2040-2069) and under the medium emission scenario (IPCC SRES A1B).

8.1.3 Altitude

Since the main purpose of the climate matching is to identify the vegetation which currently exists in a specific location, as well as matching the climate of the case study site in 2050, other factors, like altitude also need to be considered. As altitude can affect plant growth and give rise to differing plant communities, the altitude of the site under consideration and its analogous climate location must therefore be relatively similar - see table 8.1 for case study altitude. Incident sunlight, which can promote photosynthesis and hence plant growth, increases with elevation (Gale, 2004). Altitude will also affect humidity and evaporation, hence transpiration rates and soil moisture. Plant communities found at higher altitudes therefore tend to differ in composition to the communities found at lower altitudes at similar locations. Areas in Europe which had several months matched to the case study areas, but were found to be at a significantly different altitude were consequently rejected.

8.1.4 Important Months for Plants

Certain months of the year are more important for plants than others, i.e. for growth cycles and reproduction. As Menzel & Sparks (2006) comment the year is broken into growth and non-growth periods, specifically over the winter months (a period of endo-dormancy or (true) dormancy) plants tend to be dormant and less affected by the climate. The most critical months are those of the spring; the warmer temperatures experienced in early-full spring, during the exo-dormancy period, results in bud-breaking and by May, in late spring, the plants go through a growth phase till the end of July. The agreement between the case study projection and the matched location, particularly in the spring months, will therefore take this into account when squares are investigated.

8.2 Eastern Quarry, Kent

Eastern Quarry falls into grid square 1668 and its projected mean monthly temperature and precipitation are shown in tables 8.2 and 8.3, where for each month the baseline value is given, along with the change value and the absolute projection value. The projected temperature of EQ will increase under all probability levels with the greatest change being under the 90% probability level in July, with a 5.2°C increase on the baseline. This is also illustrated in figure 8.2

Table 8.2 EQ's Temperature 10-90% Projection Range in 2050.

		Temperature Change Projection °C			**Temperature Projection °C**		
		Probability Level			**Probability Level**		
Month	**Baseline Temp °C**	10%	50%	90%	**10%**	**50%**	**90%**
Jan	3.99	0.69	2.42	4.14	**4.68**	**6.41**	**8.13**
Feb	4.09	0.90	2.23	3.56	**4.99**	**6.32**	**7.65**
Mar	6.05	0.80	1.97	3.15	**6.85**	**8.02**	**9.20**
Apr	8.19	1.08	2.26	3.43	**9.27**	**10.45**	**11.62**
May	11.58	1.26	2.64	4.03	**12.84**	**14.22**	**15.61**
Jun	14.68	1.19	2.60	4.01	**15.87**	**17.28**	**18.69**
Jul	16.78	0.98	3.11	5.24	**17.76**	**19.89**	**22.02**
Aug	16.56	1.09	2.95	4.80	**17.65**	**19.51**	**21.36**
Sep	14.33	1.19	2.67	4.15	**15.52**	**17.00**	**18.48**
Oct	11.14	1.44	2.71	3.99	**12.58**	**13.85**	**15.13**
Nov	6.91	1.23	2.64	4.04	**8.14**	**9.55**	**10.95**
Dec	4.89	1.02	2.39	3.75	**5.91**	**7.28**	**8.64**

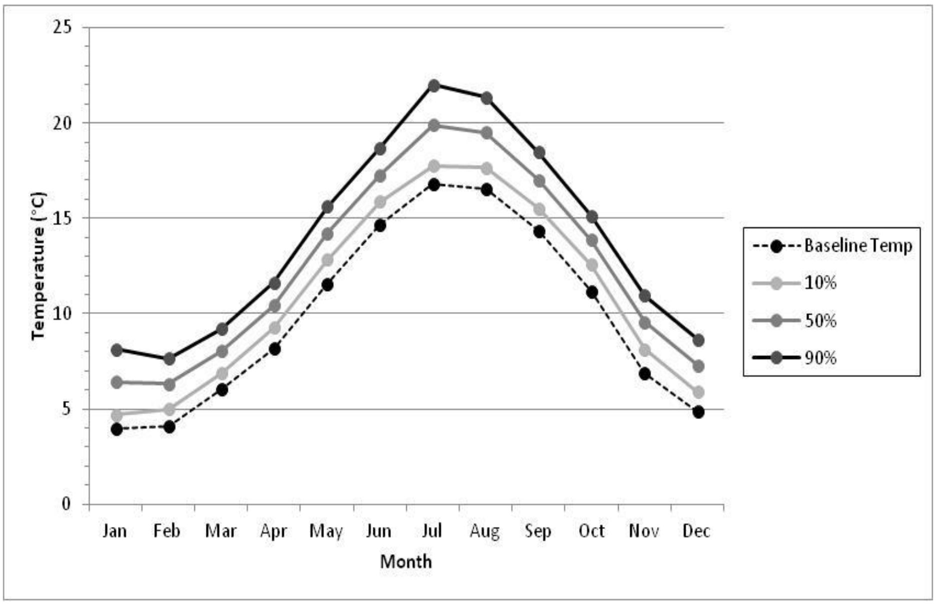


Figure 8.2 EQ's Temperature Projection Range in 2050

Rainfall patterns are generally more uncertain; the precipitation range expected at EQ is a lot wider than the temperature projections, with the range of probabilities showing a decrease on the baseline value for all months at the 10% probability level, but an increase across all at the 90% probability level, as exemplified in figure 8.3. The precipitation trend overall indicates an enhanced seasonal variation with lower volumes in the summer and the greatest increase in the winter. The greatest monthly change is projected for July at the 10% probability level with a decrease on the baseline of -57.37%. At the 90% probability level the greatest change on the monthly baseline is in February, with a 43.10% increase in precipitation.

Table 8.3 EQ's Precipitation 10-90% Projection Range in 2050

Month	Baseline Precipitation (mm/month)	Precipitation Projection Change			Precipitation Projection (mm/month)		
		Probability Level			Probability Level		
		10%	50%	90%	10%	50%	90%
Jan	57.04	-12.57%	9.62%	31.82%	**49.87**	**62.53**	**75.19**
Feb	37.8	-5.56%	18.77%	43.10%	**35.70**	**44.90**	**54.09**
Mar	47.74	-11.49%	2.90%	17.29%	**42.25**	**49.12**	**55.99**
Apr	46.8	-8.52%	2.50%	13.52%	**42.81**	**47.97**	**53.13**
May	48.67	-21.96%	-4.87%	12.22%	**37.98**	**46.30**	**54.62**
Jun	48.9	-41.62%	-14.10%	13.42%	**28.55**	**42.00**	**55.46**
Jul	47.12	-57.13%	-15.83%	25.48%	**20.20**	**39.66**	**59.12**
Aug	48.36	-57.37%	-22.30%	12.75%	**20.62**	**37.57**	**54.52**
Sep	57.6	-34.38%	-6.63%	21.10%	**37.80**	**53.78**	**69.76**
Oct	56.73	-15.04%	0.71%	16.45%	**48.20**	**57.13**	**66.06**
Nov	59.7	-16.20%	10.51%	37.22%	**50.03**	**65.98**	**81.92**
Dec	60.45	-4.89%	12.58%	30.05%	**57.50**	**68.06**	**78.62**

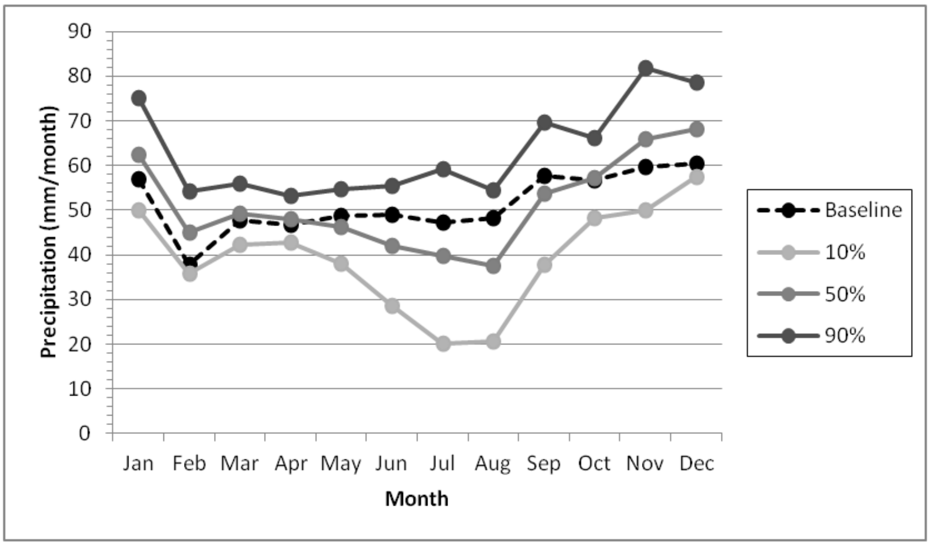


Figure 8.3 EQ's Precipitation Projection Range in 2050

The projected 10 to 90% probability level range of temperature and precipitation for each month for EQ were entered into the GIS as a query, to identify locations in Europe that currently experience these meteorological conditions. This was done for each month of the year, thus creating 12 layers on the GIS.

To find out how many of EQs' months were represented (climate matched) at each European grid square, point data were converted to raster data, and assigned a number 1 for a month match and a 0 for a non-month match; a match defined as the current mean temperature and precipitation for a month falling within the comparable prediction range of 10%-90%. The number of months of agreement for each square could then be totalled up and displayed using a colour key corresponding to the number of months that matched EQs' climate projections. The visual output is shown in Figure 8.4.

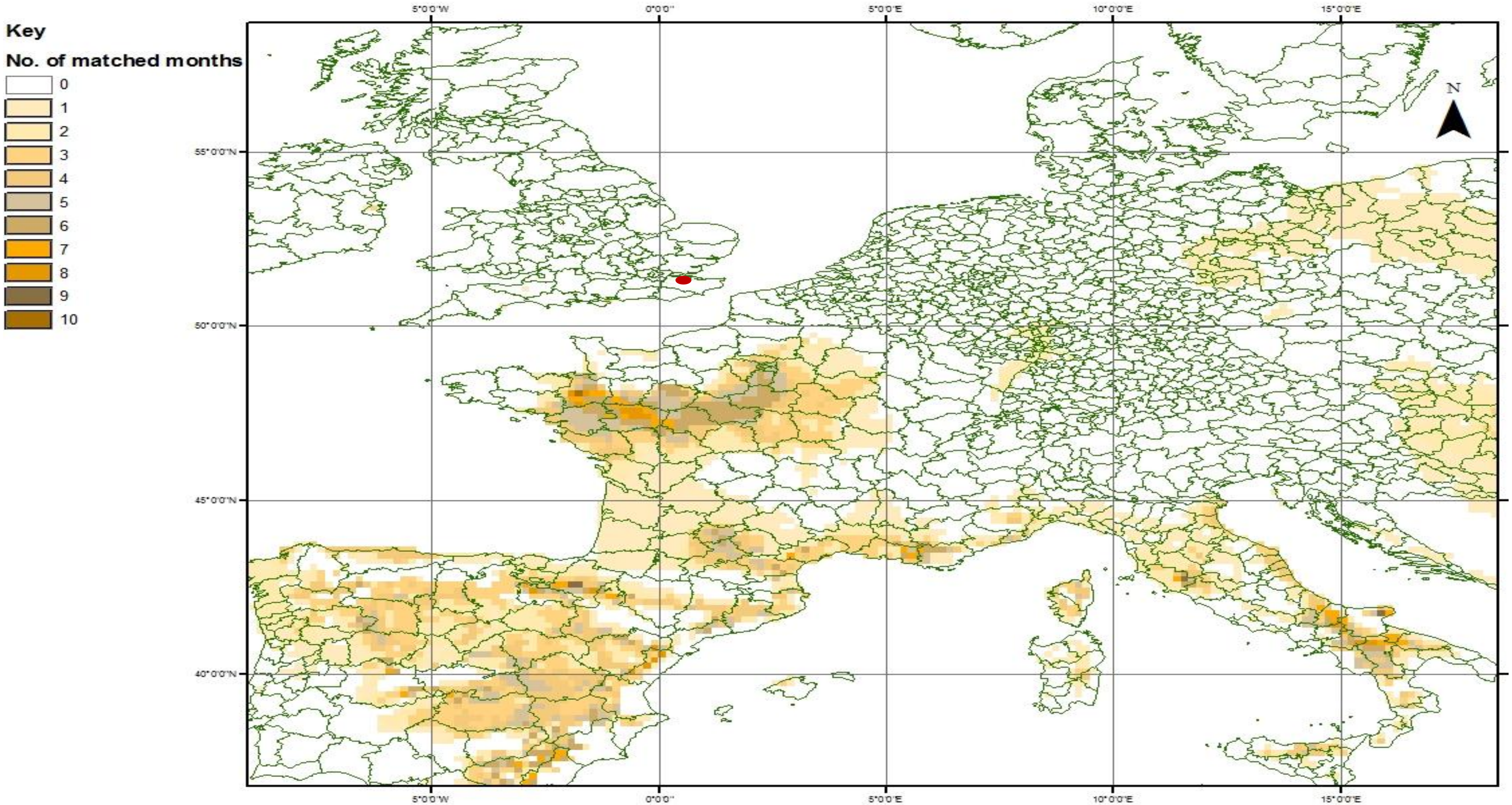


Figure 8.4 Climate matched areas for EQ (red dot)

Table 8.4 shows how successfully, in terms of months matched, European grid squares correspond to the predicted meteorological conditions at EQ, i.e. there are 6481 grid squares which match one month of EQ's future climate. There are no European grid squares which match EQ's climate projection for the full 11 or 12 months, with the best match being 10 months in north western France. There are four grid squares with 9 months matched - the Puglia and Tuscany regions in Italy and the Spanish autonomous community of Navarre. These matches were however not investigated further as they were at higher altitudes (300 and 650m) than EQ (33m).

Table 8.4 The number of European grid squares matched to EQ's climate

No of months matched	**No of grid squares**
1	6481
2	3422
3	1860
4	819
5	323
6	188
7	58
8	22
9	4
10	1
11	0
12	0

Figure 8.5 shows the locations in north-western France, specifically in the Ille-et-Vilaine and the Maine-et-Loire departments, where a cluster of 7 and 8 month matches were found. The elevation of these areas ranged from 54m south of Rennes in Saint-Thurial, to 19m east of Angers in Beaufort-en-vallee, making them compatible with EQ. Consequently because of the density of the number of months matched, and the altitude similarity, these areas were investigated further for their suitability to EQs climate, by seeing where the temperature and precipitation values fall within the range of climate projections for the case study area.

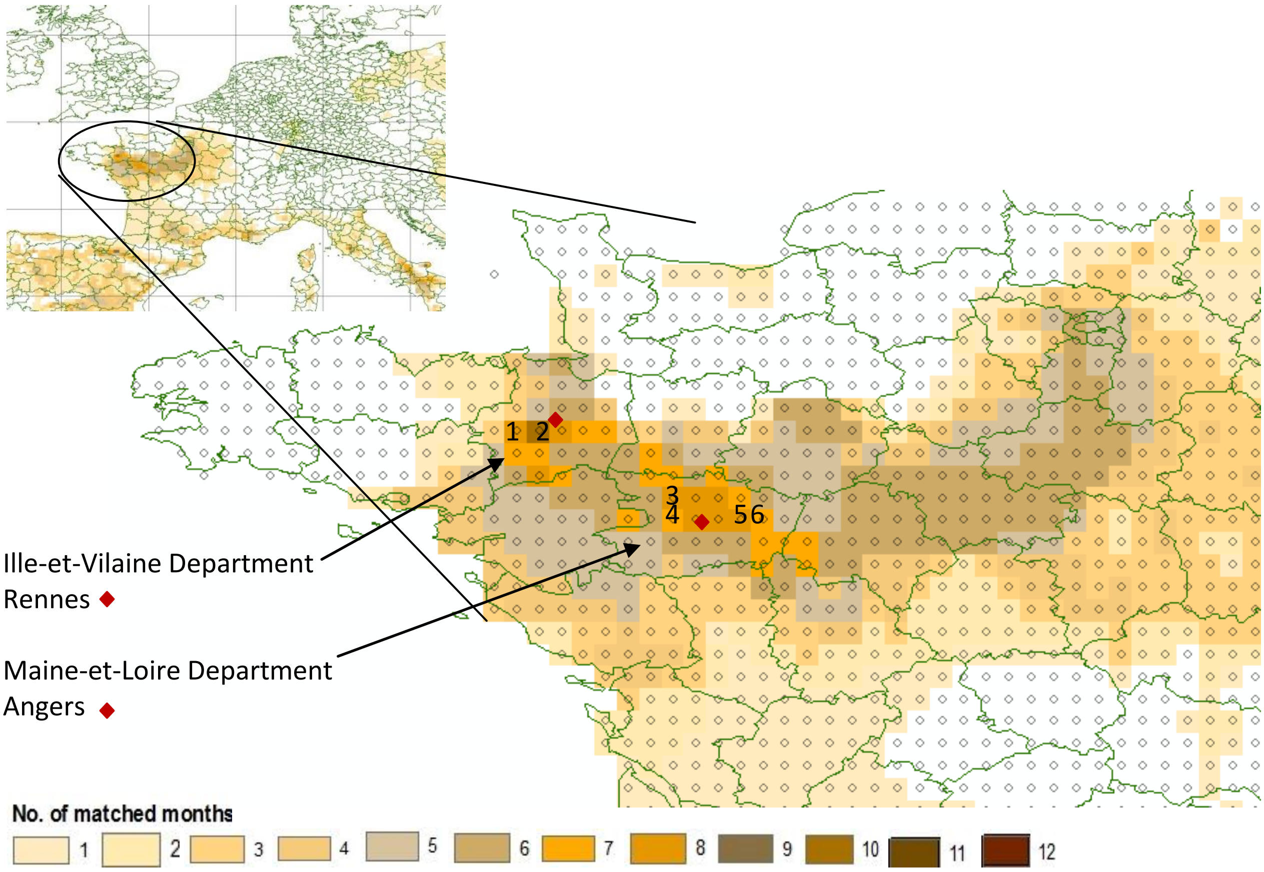


Figure 8.5 Suitable European Areas for EQ Climate Comparison.

The 6 grid squares numbered in Figure 8.5 are examples for discussion; these were not the only squares studied, but they represent the spatial range across the cluster. Table 8.5 lists the properties and the relevant figure to refer to in relation to the 6 selected squares. Figures 8.7 to 8.12 are graphs of the current 30-year average temperature and precipitation at each of the selected grid squares in France, together with the projected values for EQ. For each location temperature and precipitation are shown on a separate figure, but these two variables were considered together in determining the degree of agreement. For example, in figure 8.7 there is a good temperature match for all 12 months, but only a 10 month match for precipitation.

Table 8.5 EQs matched squares for analysis

Square no.	Latitude/Longitude	No. Matched months	Figure No.
1	48.083, -1.917	8	8.7
2	48.083, -1.75	10	8.6
3	47.583, -0.75	8	8.8
4	47.417, -0.75	7	8.9
5	47.417, -0.25	8	8.10
6	47.417, -0.083	7	8.11

Analysis

The area with the best match for EQ's temperature and precipitation is just east of the city of Rennes (square no 2, table 8.5), in the Ille-et-Vilaine department of north-western France, where there are 10 matched months. As shown in figure 8.6a the current average temperature falls predominantly nearer the 10% probability projection for EQ, thus indicating it is lower than is expected at EQ in 2050. The temperatures fall within the 10% to 90% range for all 12 months. The precipitation shown in figure 8.6b tends to fall in between the 50% and 90% probability levels, indicating a closer match for the precipitation than for the temperature. However, the precipitation is higher than the 90% range in the months of February and May by 4.21 and 7.98mm respectively.

Square 1, adjacent to square 2, has 8 months matching EQ, as shown in figure 8.7a, and has a similar temperature pattern to that of square 2, in that it falls close to the 10% probability level, but for May falls outside the range by 0.04°C. The precipitation pattern is also similar to square 2, but has Feb, Mar, May and Oct precipitation slightly higher than the probability projection rate for EQ, as shown in figure 8.7b, and thus unlikely to be experienced at EQ. A similar pattern of trends occurs for the other areas with 7 or more months matching EQ in the Ille-et-Vilaine department.

The cluster of 8 and 7 month matches further south of Rennes, in the Maine-et-Loire department of France has been looked at. Even though 8 months (combined) is the maximum which match EQ here, the area does overall appear to be in better agreement than the squares in the Ille-et-Vilaine department. For square nos 3 and 5, located near Angers, the mean temperature (see figure 8.8a and 8.10a) is closer to the 50% probability projection than the 10% projection, with November and December consistently being the two months that do not match, for example in figure 8.8a they fall lower than the range by 0.24 and 0.51°C respectively. This pattern for temperature match is similar in all the 8 months squares identified in the Maine-et-Loire department. The 7 month matches (represented by squares 4 and 6) are also similar, but the temperature for January also falls out the probability range, as illustrated in figures 8.11a, but this month is when plants are dormant.

Precipitation for Angers, under the 8 month matches, falls predominantly in between the 50% and 90% probability levels, as shown in figures 8.8b and 8.10b, matching the trend over the year quite well. February and May do have higher rainfall than the range, which is by 5.71 and 2.88mm respectively in figure 8.8b, but this is not as large a difference as the Rennes matches (squares 1 and 2). The 7 month matches are matched less by one month in square 4, the one represented in figure 8.9b, with March rainfall only 0.1mm higher than the 90% probability value. The other 7 month matches in the region actually have 10 months matched for precipitation, as shown in figure 8.11b.

A similar analysis was undertaken for all squares with 7 month matches or better, for the French departments.

As plants are normally dormant during November, December, January and February there is less concern over the temperature discrepancies in these regions when considering plant suitability. In terms of visiting a location and/or obtaining plant data in an area climatically matched, the Ille-et-Villaine department is excluded as the Maine-et-Loire climate is in better agreement with EQ's climate projections, with the match being closer to the 50% projection. Although the temperature in Ille-et-Vilaine is more consistent with few outside the range, there is a better match during the growing season for the Maine-et-Loire region. There was effectively no difference between the precipitation of the two regions, with higher than expected rainfall in Feb/May, but the Maine-et-Loire had a more consistent pattern. As no match was going to be perfect, a judgement had to be made, but the May precipitation discrepancy should be considered when making decisions regarding vegetation selections.

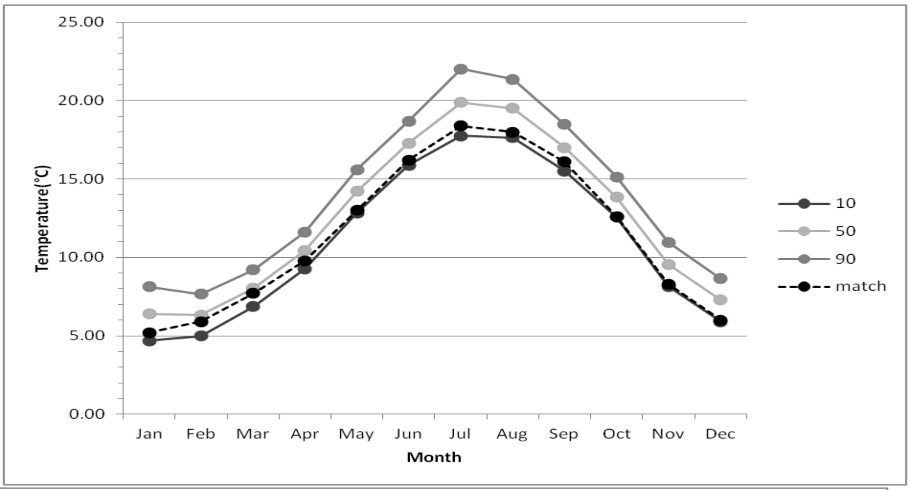
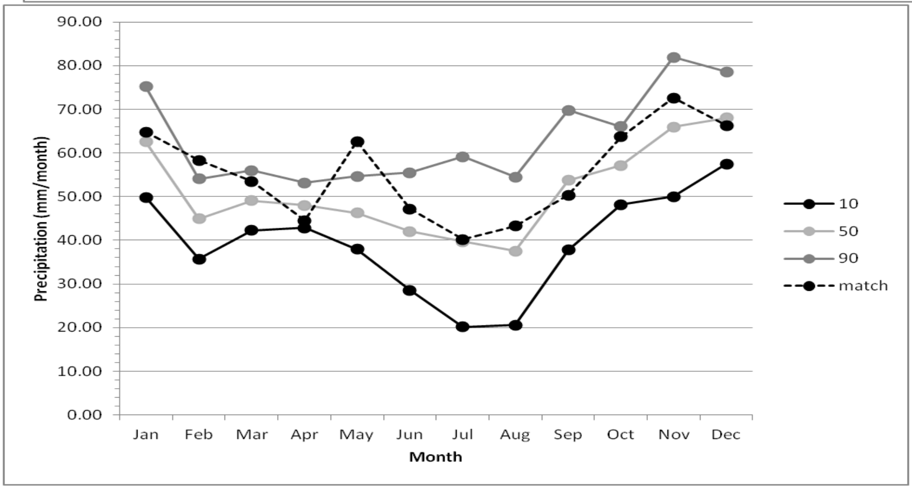


Figure 8.6 Climate comparison of existing conditions at square 2 and EQ projections.

(a) Temperature



(b) Precipitation

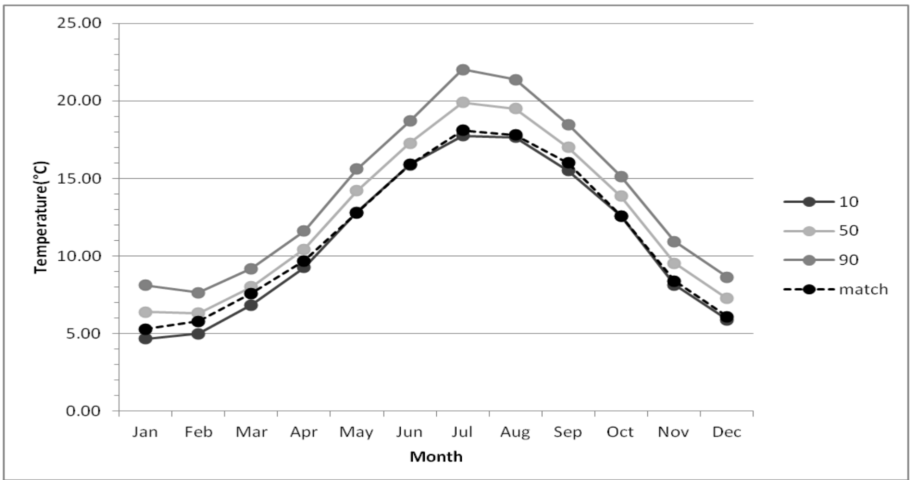
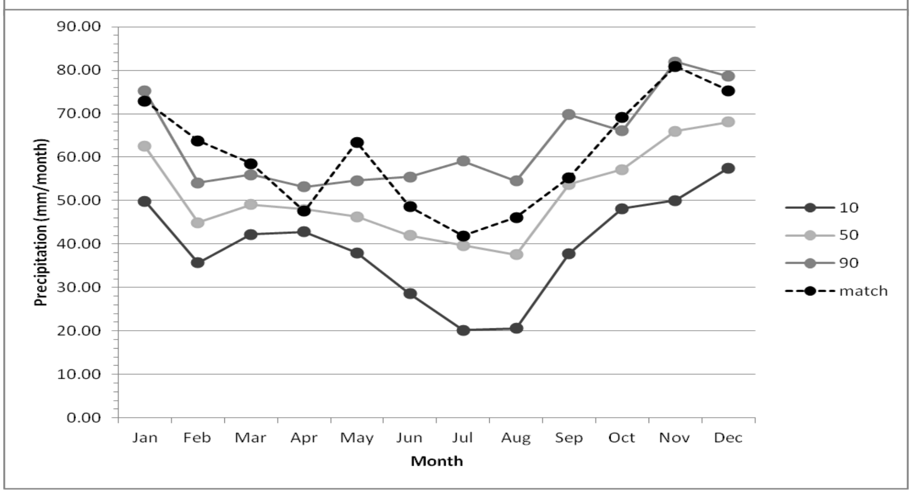


Figure 8.7 Climate comparison of existing conditions at square 1 and EQ projections.

(a) Temperature



(b) Precipitation

Figure 8.8 Climate comparison of existing conditions at square 3 and EQ projections.

(a) Temperature

(b) Precipitation

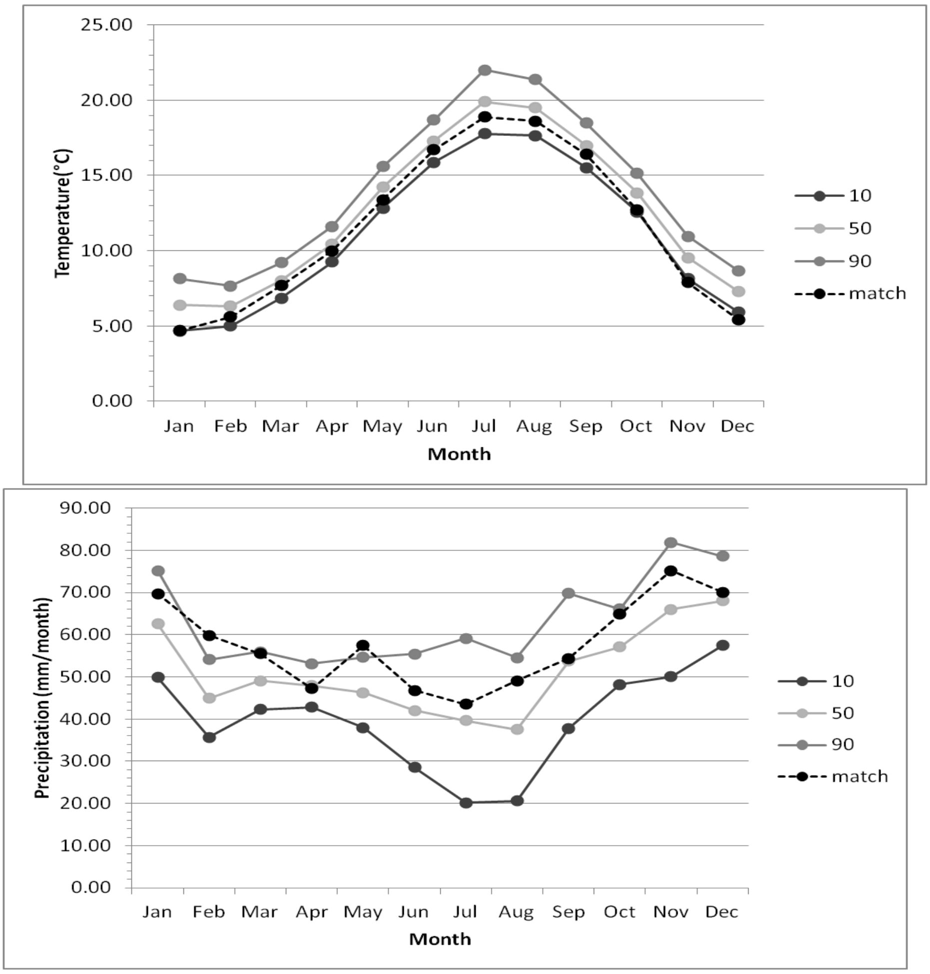
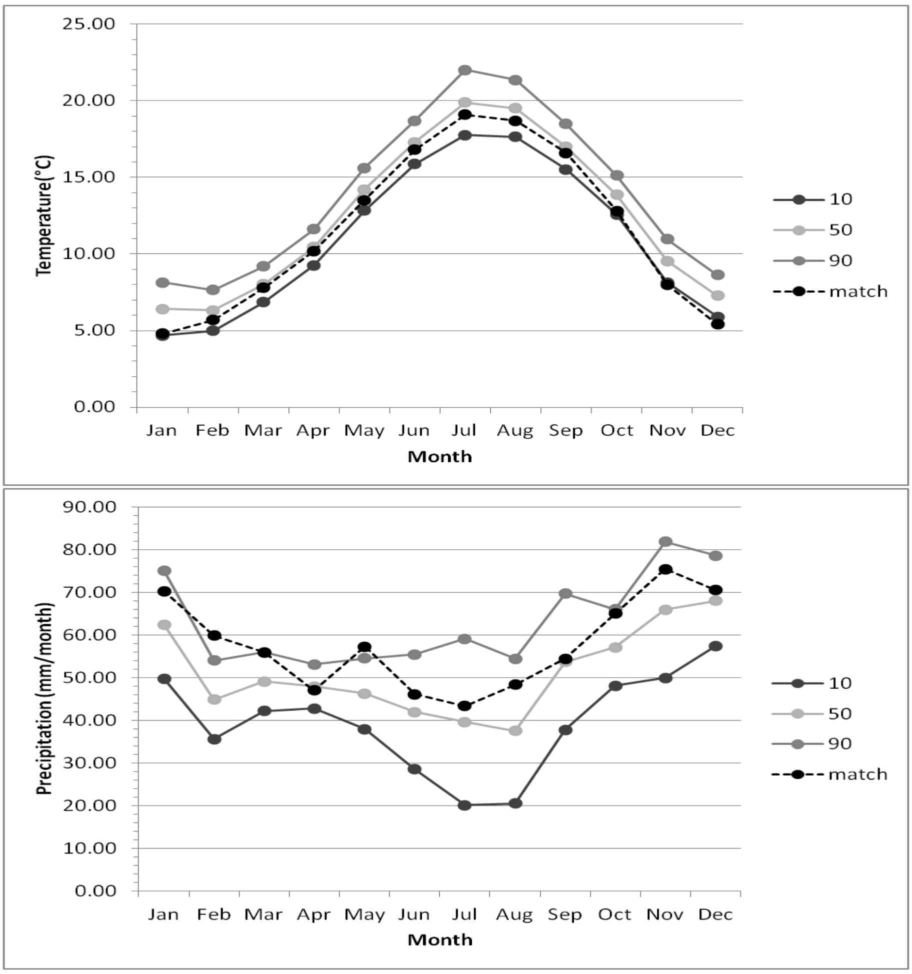


Figure 8.9 Climate comparison of existing conditions at square 4 and EQ projections.

(a) Temperature

(b) Precipitation



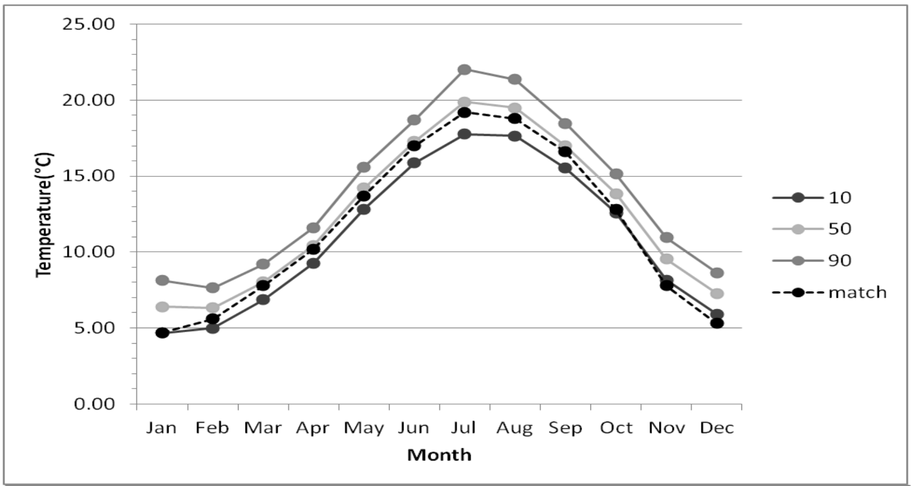
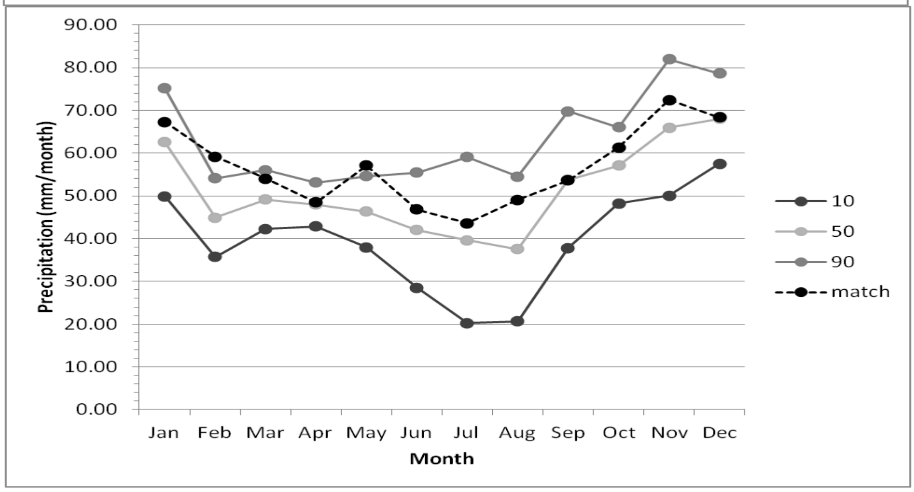


Figure 8.10 Climate comparison of existing conditions at square 5 and EQ projections.

(a) Temperature



(b) Precipitation

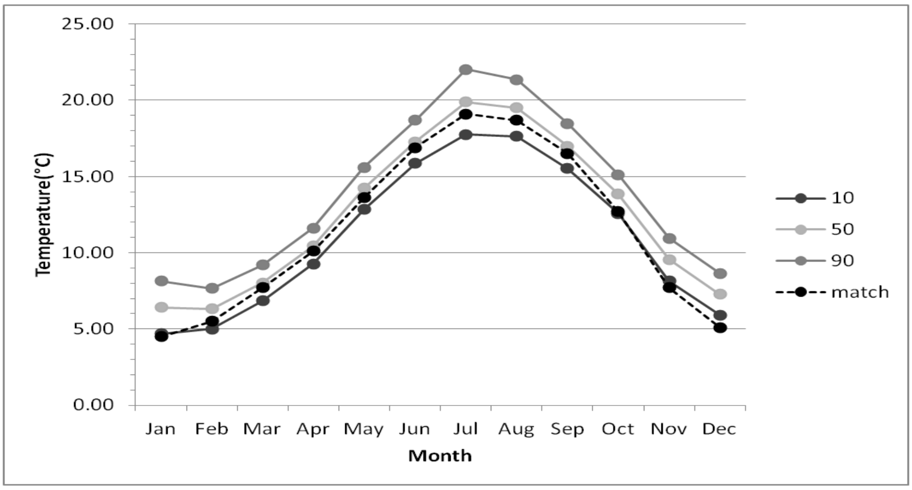
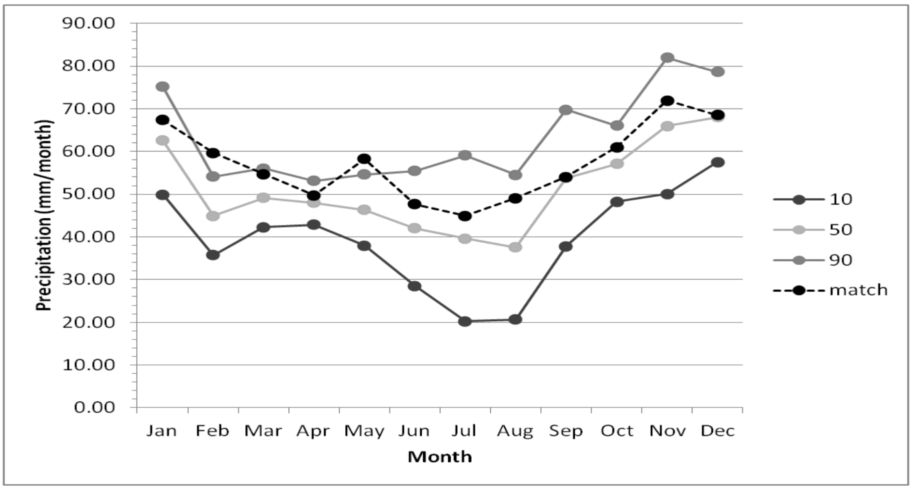


Figure 8.11 Climate comparison of existing conditions at square 6 and EQ projections.

(a) Temperature



(b) Precipitation

8.3 Olympic Park, London

The Olympic Park is located in grid square 1628 and its projected mean monthly temperature and precipitation are shown in tables 8.6 and 8.7. Figure 8.12 shows the areas in Europe and the number of months which have a climate that falls within these projections.

Table 8.6 Olympic Park's Temperature Projection range in 2050

		Temperature Change Projection °C			Temperature Projection °C		
		Probability Level			Probability Level		
Month	**Baseline Temp °C**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**
Jan	4.26	0.68	2.39	4.11	**4.94**	**6.65**	**8.37**
Feb	4.44	0.89	2.21	3.53	**5.33**	**6.65**	**7.97**
Mar	6.51	0.81	1.97	3.14	**7.32**	**8.48**	**9.65**
Apr	8.79	1.07	2.25	3.43	**9.86**	**11.04**	**12.22**
May	12.25	1.25	2.63	4.01	**13.50**	**14.88**	**16.26**
Jun	15.39	1.19	2.59	3.99	**16.58**	**17.98**	**19.38**
Jul	17.45	0.99	3.12	5.26	**18.44**	**20.57**	**22.71**
Aug	17.15	1.11	2.99	4.88	**18.26**	**20.14**	**22.03**
Sep	14.82	1.19	2.68	4.17	**16.01**	**17.50**	**18.99**
Oct	11.57	1.43	2.70	3.97	**13.00**	**14.27**	**15.54**
Nov	7.22	1.22	2.63	4.03	**8.44**	**9.85**	**11.25**
Dec	5.15	1.01	2.37	3.73	**6.16**	**7.52**	**8.88**

Table 8.7 Olympic Park's Precipitation Projection range in 2050

		Precipitation Projection Change			Precipitation Projection (mm/month)		
Month	**Baseline Precipitation (mm/month)**	Probability Level 10%	50%	90%	Probability Level 10%	50%	90%
Jan	56.42	-13.73%	10.61%	34.94%	**48.67**	**62.40**	**76.13**
Feb	38.08	-5.53%	19.81%	45.16%	**35.97**	**45.63**	**55.28**
Mar	50.22	-8.89%	6.14%	21.16%	**45.76**	**53.30**	**60.84**
Apr	48.3	-7.26%	2.44%	12.14%	**44.79**	**49.48**	**54.17**
May	52.39	-23.11%	-5.03%	13.06%	**40.28**	**49.76**	**59.23**
Jun	52.8	-42.37%	-14.60%	13.17%	**30.43**	**45.09**	**59.75**
Jul	49.29	-55.62%	-15.41%	24.79%	**21.88**	**41.69**	**61.51**
Aug	54.87	-58.45%	-22.97%	12.50%	**22.80**	**42.26**	**61.73**
Sep	55.2	-34.15%	-6.30%	21.54%	**36.35**	**51.72**	**67.09**
Oct	59.21	-15.03%	0.75%	16.54%	**50.31**	**59.66**	**69.00**
Nov	59.7	-17.38%	11.58%	40.54%	**49.33**	**66.61**	**83.90**
Dec	60.76	-4.54%	13.57%	31.69%	**58.00**	**69.01**	**80.01**

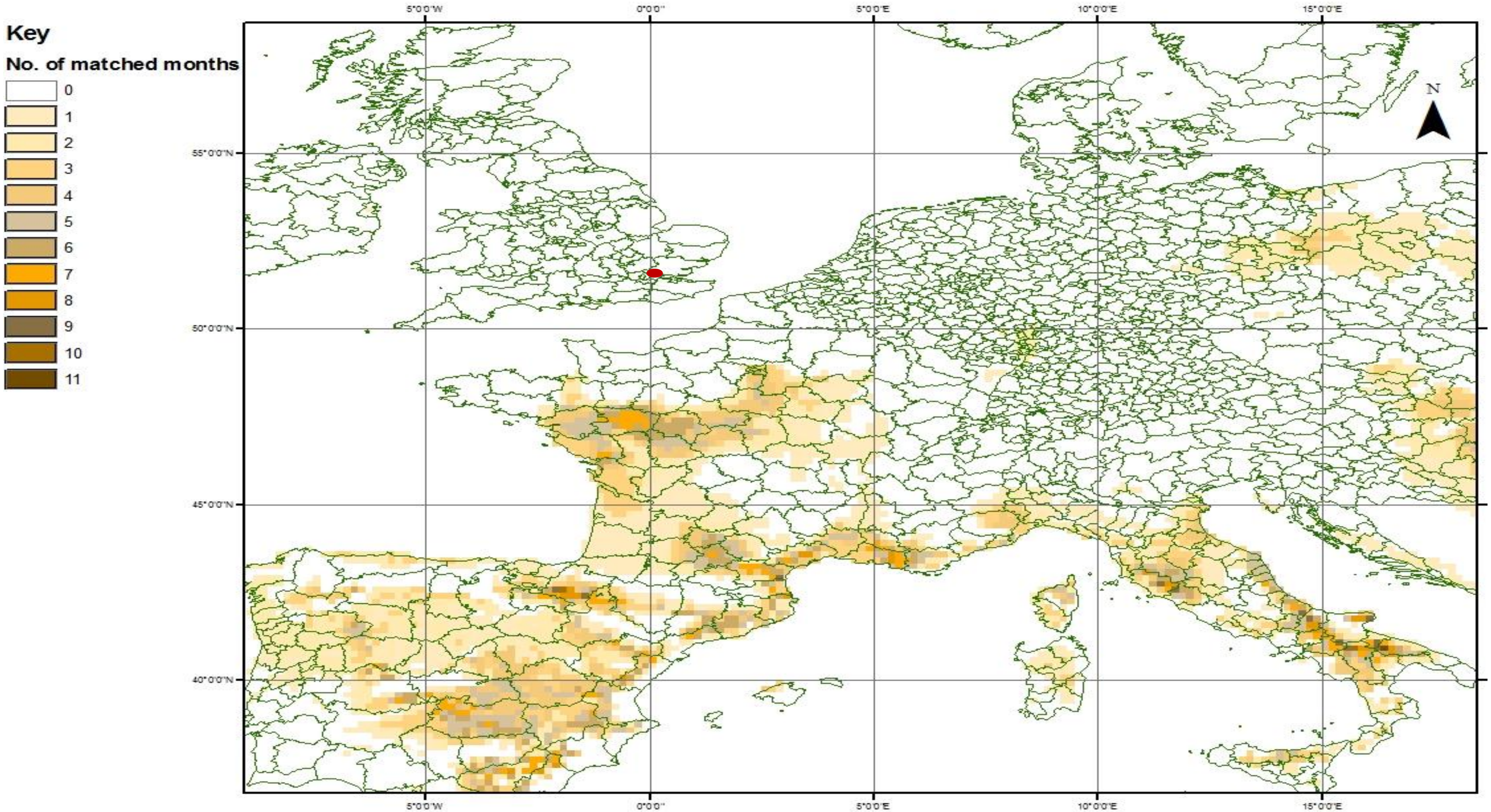


Figure 8.12 Climate matched areas for Olympic Park (red dot)

Table 8.8 shows the number of European grid squares which match each category. There were no areas which matched all 12 months, with the best match being 11 months near 'Gravina in Puglia' in South East Italy (40.917, 16.417). Although there was a relatively good climatic match here, the area had an altitude of 383m AOD and was consequently rejected. The 10 month matches near Ripacandida in south Italy (40.917, 15.75) and near Larraga in northern Spain (42.583, -1.917) also had differing altitudes to the case study site - 497m and 308m respectively. The altitude of the 8 and 9 month matches, which occurred predominantly in Italy and Spain, were also too high to be considered, or were scattered in isolated matches. The areas therefore which were further investigated in relation to the Olympic Park's climate projections, include the cluster of 7 month matches in the Maine-et-Loire department in north-western France, the same area that matched EQ relatively well.

Table 8.8 The number of European grid squares matched to Olympic Park's climate

No of months matched	No of grid squares
1	4978
2	3285
3	2453
4	1402
5	425
6	220
7	108
8	30
9	13
10	2
11	1
12	0

Figure 8.13 shows the cluster of 7 month matches and the 4 grid squares which have been selected as examples for discussion. They are located in and around Angers, the main town in the Maine-et-Loire, extending south towards Saumur. The altitude at Angers is 41m, and 24m at Saumur, making them an ideal match to the altitude at Olympic Park (12m).

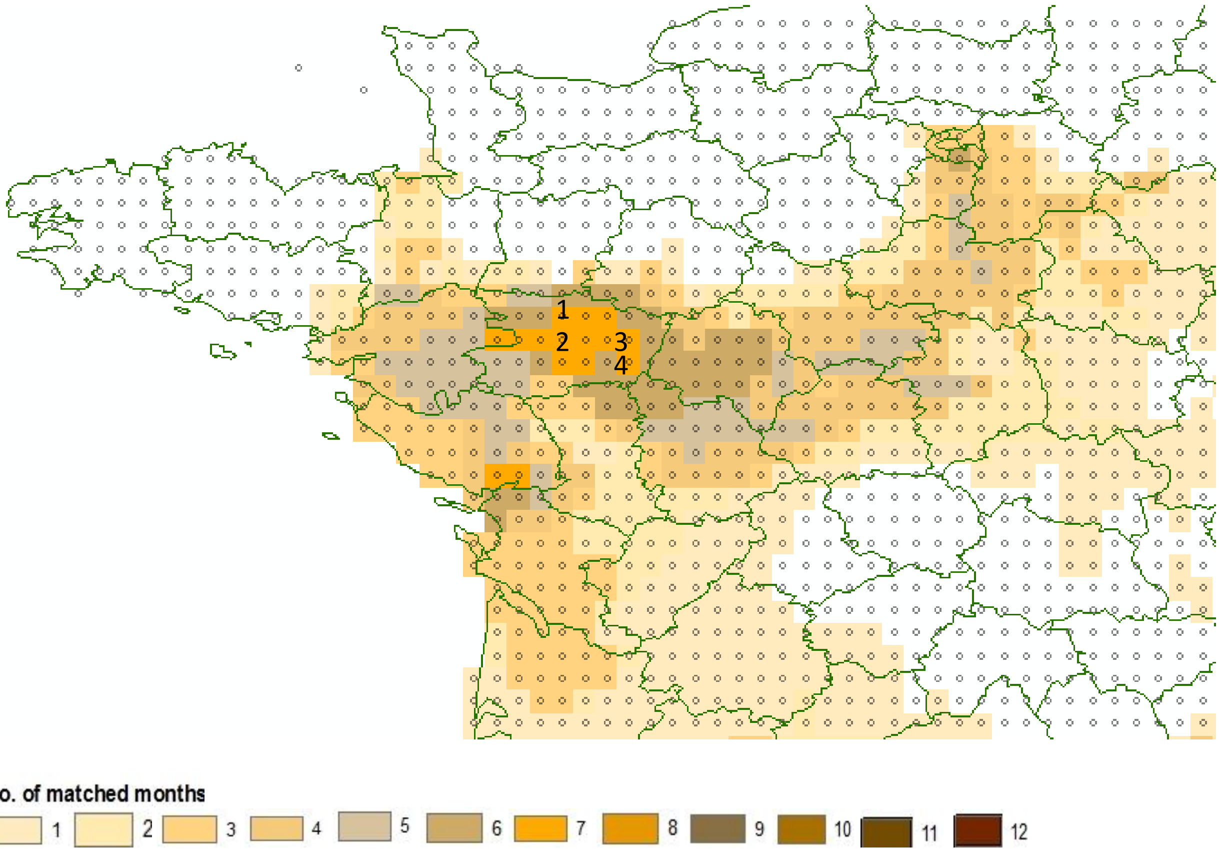


Figure 8.13 Suitable European Areas for Olympic Park climate comparison

Table 8.9 Olympic Park matched squares for analysis

Square no.	Latitude/Longitude	No. Matched months	Figure No.
1	47.583, -0.583	7	8.14
2	47.417, -0.583	7	8.15
3	47.417, -0.083	7	8.16
4	47.25, -0.083	7	8.17

All of the squares with 7 months matching have a similar pattern in that the temperature in Angers (and surrounding) falls within the 10 to 90% range but tend to be near the 10% probability projection values. This suggests that the temperature currently experienced in Angers overall is, based on probability projections, is slightly lower than what will be expected at the Olympic Park in 2050. The temperature for October, November, December and January in Angers falls just out of the range as shown in figure 8.14a by 0.3°C, 0.54°C, 0.76°C and 0.14°C respectively. As already discussed, these months are less important for plant growth, but the temperature in March, a more important month, falls in between the 10% and 50% projection values which is more ideal. The surrounding squares, as shown in figure 8.13, with 6 months matching overall, experience a temperature in May lower than the range of projections.

The precipitation at Angers (and its surrounding area) is a better match than that of the temperature, falling nearer the 50% projection values and in between the 50% and 90% range, as shown in figures 8.14-17b. Angers overall appears to have more precipitation across the year, than that expected at the Olympic Park, but this is only really noticeable in February and May. February is the only month which has a higher precipitation than the range projections, for example as in figure 8.16b, when it experiences 4.42mm more rainfall a month than the 90% projection range. This is not a significant amount, particularly spread over the month, but with a higher than average rainfall generally, when matching the plant selection choices this should be kept in mind.

Given that there is only one region investigated here and all the squares are relatively similar, this area would be accepted as the match for the Olympic Park. It is not perfect as the temperature in particular is closer to the 10% projection, but it does however stay within the range during the growing season.

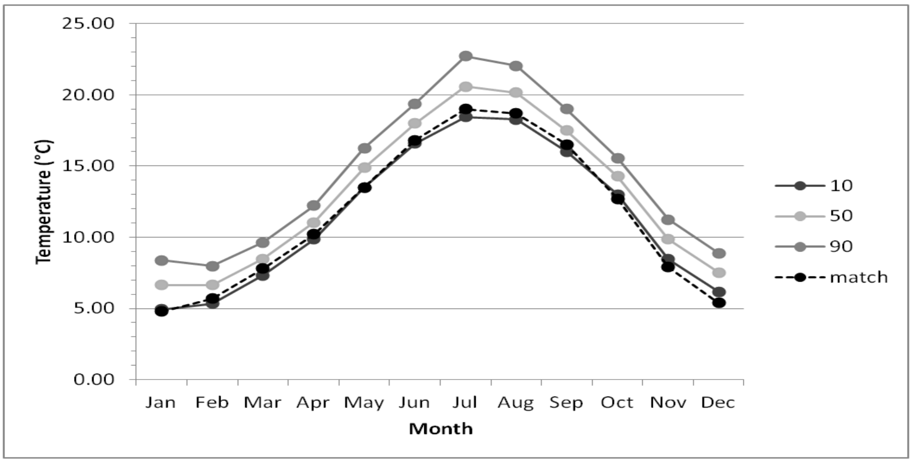
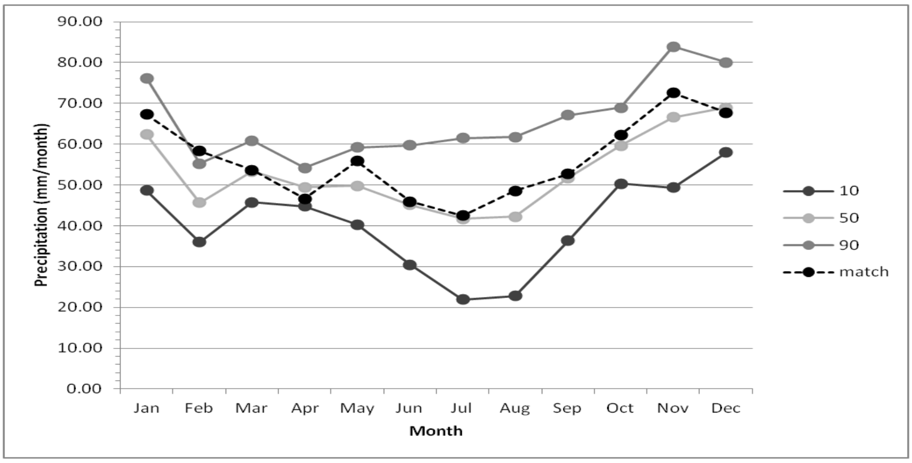


Figure 8.14 Climate comparison of existing conditions at square 1 and Olympic Park projections.

(a) Temperature



(b) Precipitation

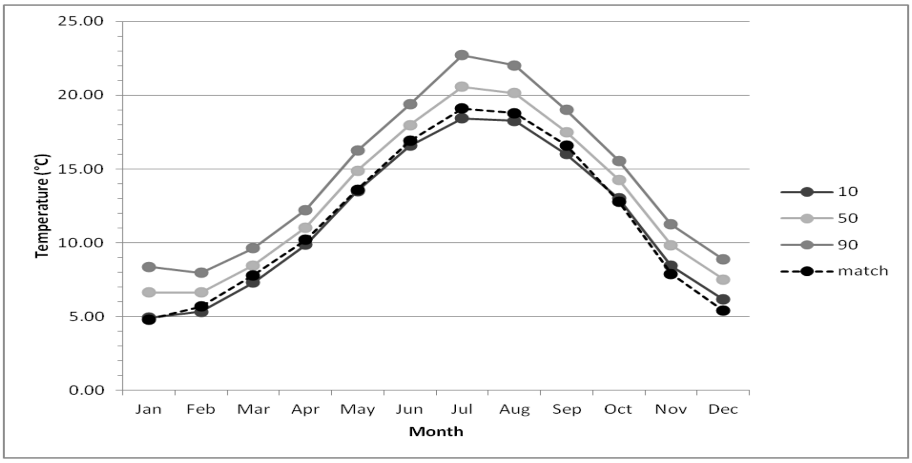
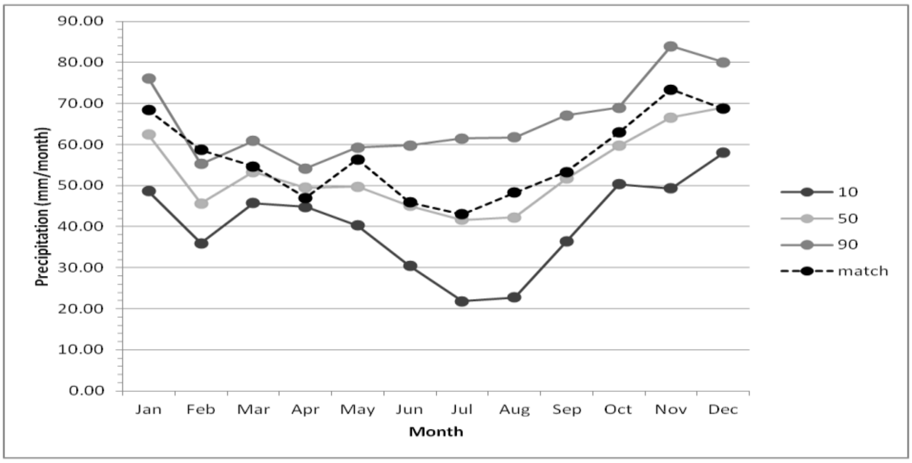


Figure 8.15 Climate comparison of existing conditions at square 2 and Olympic Park projections.

(a) Temperature



(b) Precipitation

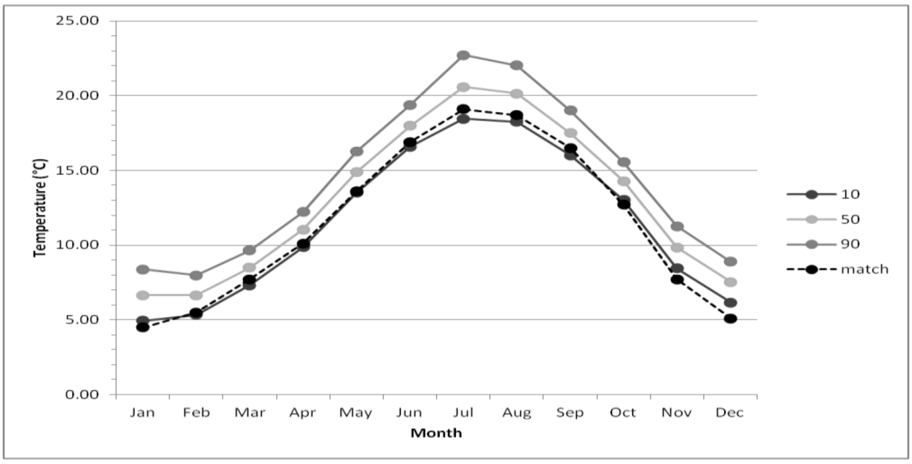
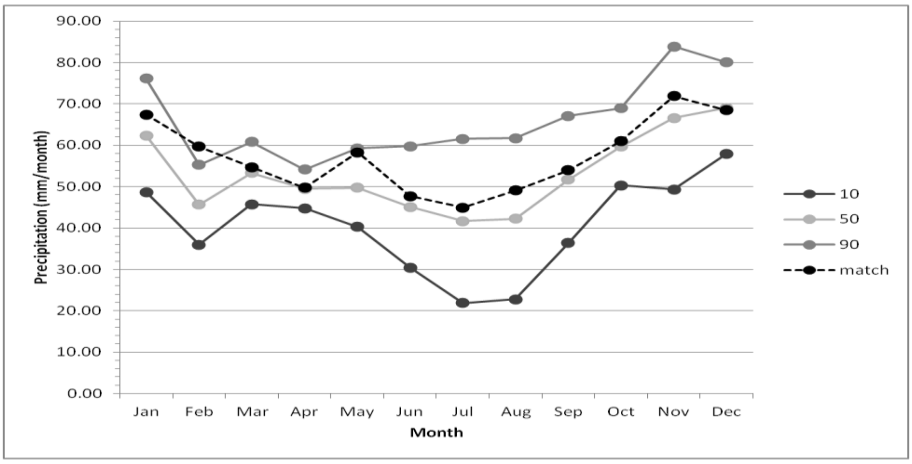


Figure 8.16 Climate comparison of existing conditions at square 3 and Olympic Park projections.

(a) Temperature



(b) Precipitation

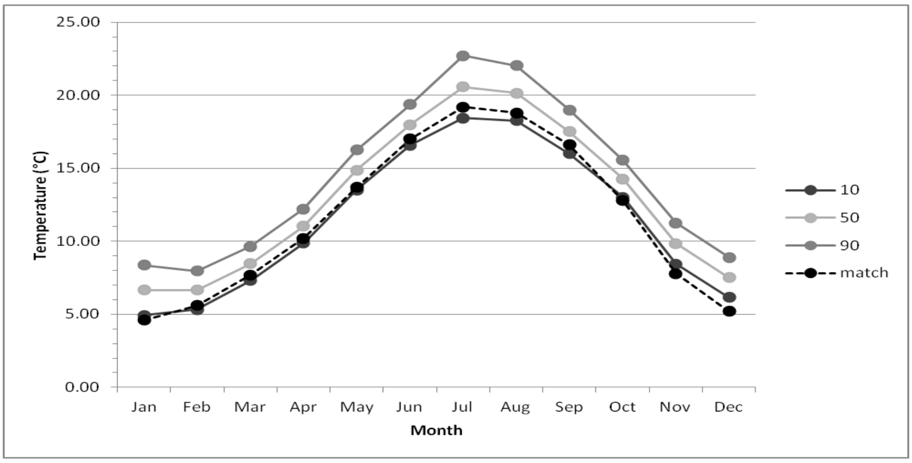
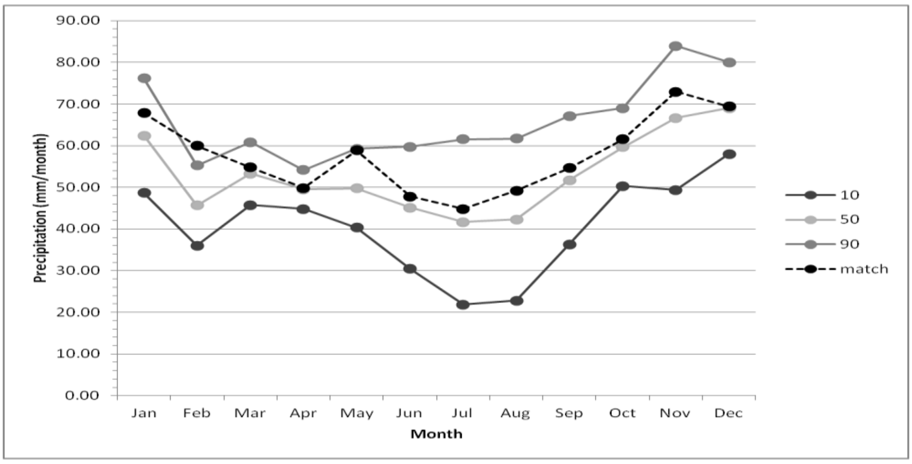


Figure 8.17 Climate comparison of existing conditions at square 4 and Olympic Park projections.

(a) Temperature



(b) Precipitation

8.4 Brogborough Landfill Site, Central Beds

Brogborough Landfill Site is located in grid square 1549 at an altitude of 77m, and its projected mean monthly temperature and precipitation are shown in tables 8.10 and 8.11. Figure 8.18 shows the areas in Europe which have a climate, or part of a climate, that exists within these projections.

Table 8.10 Brogborough landfill's Temperature Projection range in 2050

Month	Baseline Temp °C	Temperature Change Projection °C			Temperature Projection °C		
		Probability Level			Probability Level		
		10%	50%	90%	10%	50%	90%
Jan	3.38	0.67	2.37	4.06	**4.05**	**5.75**	**7.44**
Feb	3.44	0.87	2.18	3.48	**4.31**	**5.62**	**6.92**
Mar	5.46	0.80	1.96	3.12	**6.26**	**7.42**	**8.58**
Apr	7.64	1.06	2.24	3.42	**8.70**	**9.88**	**11.06**
May	10.95	1.24	2.60	3.96	**12.19**	**13.55**	**14.91**
Jun	14.02	1.17	2.52	3.87	**15.19**	**16.54**	**17.89**
Jul	16.04	0.97	3.04	5.12	**17.01**	**19.08**	**21.16**
Aug	15.85	1.10	2.97	4.85	**16.95**	**18.82**	**20.70**
Sep	13.62	1.18	2.65	4.13	**14.80**	**16.27**	**17.75**
Oct	10.46	1.42	2.68	3.94	**11.88**	**13.14**	**14.40**
Nov	6.18	1.21	2.59	3.98	**7.39**	**8.77**	**10.16**
Dec	5.15	0.07	1.41	2.75	**5.22**	**6.56**	**7.90**

Table 8.11 Brogborough landfill's Precipitation Projection range in 2050

Month	Baseline Precipitation (mm/month)	Precipitation Projection Change			Precipitation Projection mm/month		
		Probability Level			Probability Level		
		10%	50%	90%	10%	50%	90%
Jan	53.94	-14.04%	11.08%	36.19%	**46.36**	**59.92**	**73.46**
Feb	39.48	-4.66%	19.72%	44.10%	**37.64**	**47.27**	**56.89**
Mar	51.77	-9.30%	7.17%	23.65%	**46.95**	**55.48**	**64.02**
Apr	49.5	-6.08%	2.16%	10.39%	**46.49**	**50.57**	**54.64**
May	52.39	-22.40%	-5.08%	12.24%	**40.66**	**49.73**	**58.80**
Jun	52.2	-36.02%	-9.75%	16.51%	**33.40**	**47.11**	**60.82**
Jul	50.53	-51.45%	-14.67%	22.10%	**24.53**	**43.12**	**61.70**
Aug	56.11	-58.20%	-23.04%	12.12%	**23.45**	**43.18**	**62.91**
Sep	52.2	-36.04%	-8.48%	19.08%	**33.39**	**47.77**	**62.16**
Oct	56.11	-13.32%	0.59%	14.49%	**48.64**	**56.44**	**64.24**
Nov	56.7	-16.55%	11.31%	39.18%	**47.31**	**63.11**	**78.91**
Dec	60.76	-4.75%	14.80%	34.36%	**57.87**	**69.75**	**81.63**

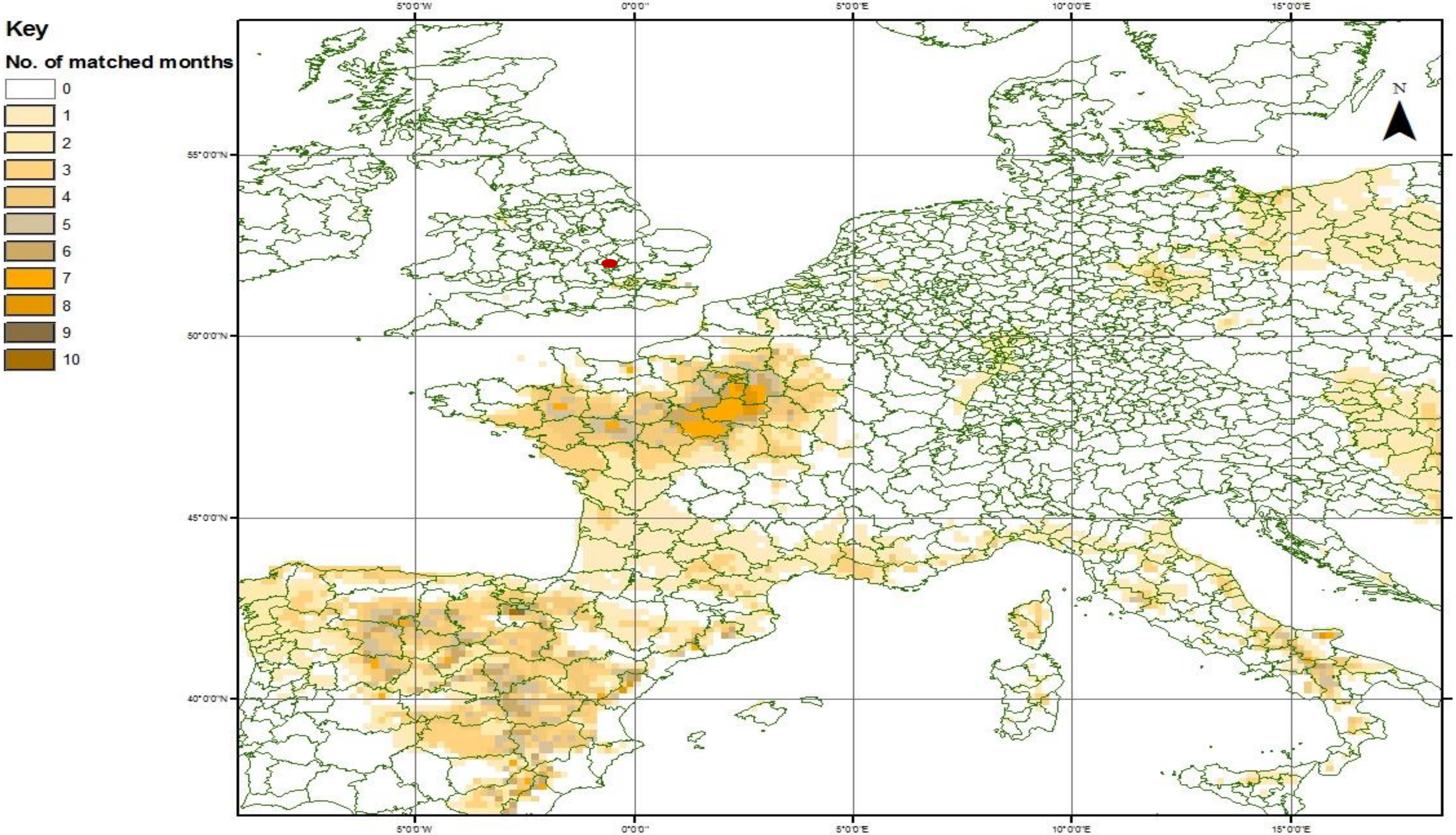


Figure 8.18 Climate matched areas for Brogborough landfill (red dot)

Table 8.12 shows the number of European grid squares which match each category. There were no areas across Europe which matched Brogborough's climate projection for 11 or 12 months, with the best match being 10 months near the municipality of Navarette in the autonomous community of La Rioja in northern Spain (42, 417, -2.75). Although there was a relatively good climatic match here, the area had an altitude of 479m AOD and was consequently rejected. The 9 month match square adjoining this grid square (42.417, -2.583) was also eliminated from further investigation for the same reason. The areas therefore which will be further investigated in relation to the landfill sites' climate projections, include the large patch of 8 and surrounding 7 month squares spread across several departments in north-central France, just south of Paris.

Table 8.12 The number of European grid squares matched to Brogborough landfill's climate

No of months matched	No of grid squares
1	7523
2	3025
3	1433
4	677
5	276
6	146
7	70
8	13
9	1
10	1
11	0
12	0

Figure 8.19 shows the cluster of 8 and 7 month matches and the 6 grid squares which have been selected as examples for discussion. They are located in the Essonne, Seine-et-Marne and Loiret departments of France. The altitude across these areas varied from 34m at Evry in Essonne, to 82 at Nemours in the Seine-et-Marne , to 119m at Pithiviers in Loiret. The altitude at Brogborough is 77m making these areas appropriate with regard to altitude.

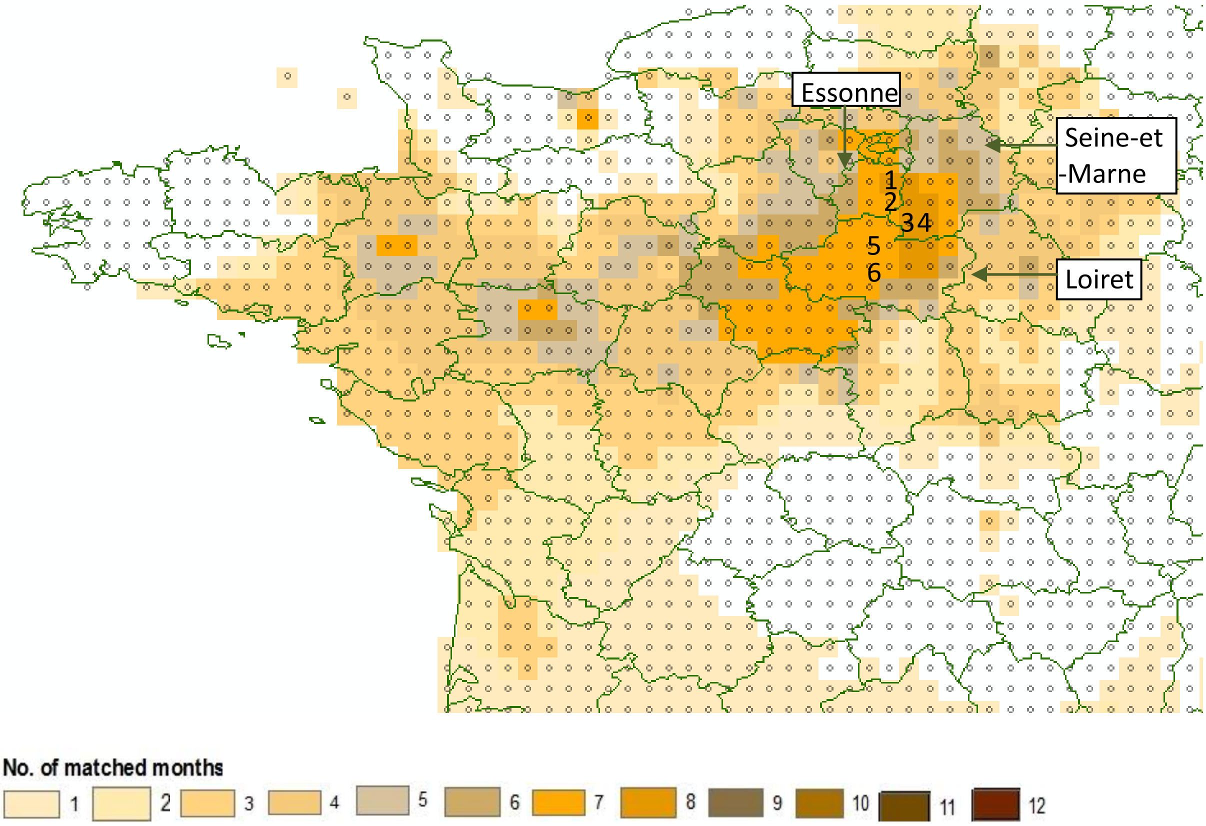


Figure 8.19 Suitable European Areas for Brogborough landfill's climate comparison

Table 8.13 shows the latitude/longitude and relevant figure to refer to in relation to the 6 grid squares numbered on figure 8.19.

Table 8.13 Brogborough landfill matched squares for analysis

Square no.	**Latitude/Longitude**	**No. Matched months**	**Figure No.**
1	48.583, 2.417	8	8.20
2	48.417, 2.417	7	8.21
3	48.25, 2.583	8	8.22
4	48.25, 2.75	8	8.23
5	48.083, 2.25	7	8.24
6	47.917, 2.25	7	8.25

Across the 6 grid squares selected there is a good temperature agreement overall, and the months which are more important for plants (Mar, Apr, May) have a temperature which is close to the Brogborough 50% projection. The temperature in January, November and December falls lower than the range - for example, in figure 8.20a (square 1) the temperature falls lower in these months by 0.35°C, 0.25°C and 0.72°C respectively, with the other squares out by a similar amount, but slightly increasing the further south travelled. The lower temperature in October makes grid squares 2, 5 and 6 less in agreement, as shown in figures 8.21a, 8.24a and 8.25a, but this is only by a small amount, e.g. 0.06°C lower in figure 8.21a. Other than this difference, these squares are very similar to the 8 month matched squares.

Across all 6 grid squares the precipitation overall is higher than the 50% probability projection, but below the 90% projection, particularly at the end of spring and over the summer months (see figures 8.20b - 8.25b). In all 7 and 8 month matches the precipitation in May is higher than the range - for example, by 5.93mm in grid square 1 (fig 8.20b). This difference increases the further south of here, and in square 3 by 9.23mm (figure 8.22b). Square 6 has a precipitation amount in October that goes over the 90% projection by 0.08mm, but this does not occur in all the 7 month match grid squares. The spring months are relatively well matched to Brogborough's projections, it is only the precipitation in May which is higher and this should be considered when selecting plants.

These areas are all relatively similar in compatibility, but as pointed out the difference increases the further south travelled. It would therefore be suitable to select the more northern squares in the Essonne and Seine-et-Marne departments (7 and 8 month matches) to obtain species data from, as better matches exist here.

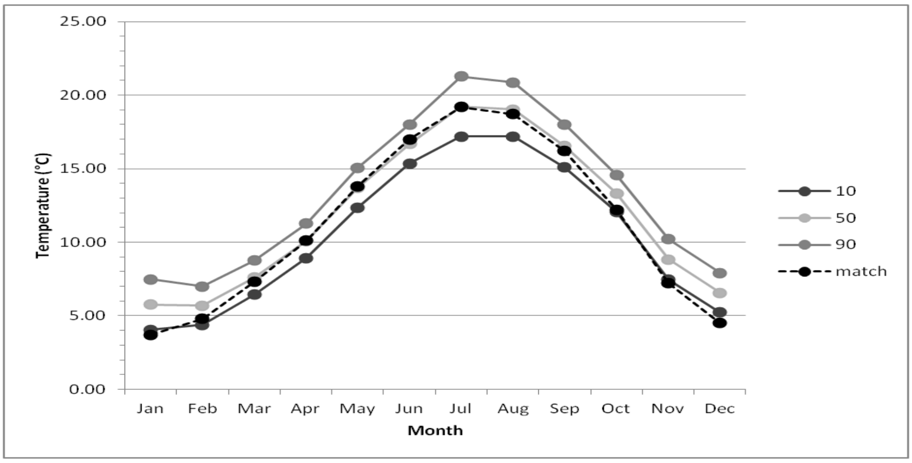
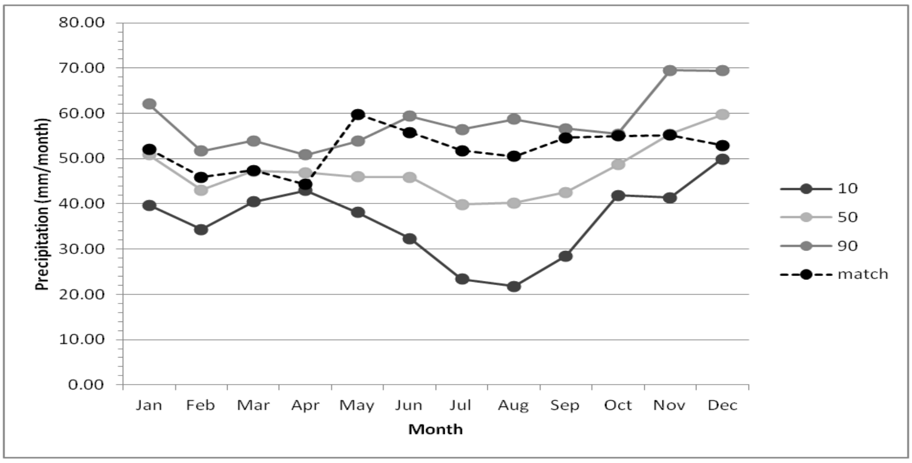


Figure 8.20 Climate comparison of existing conditions at square 1 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

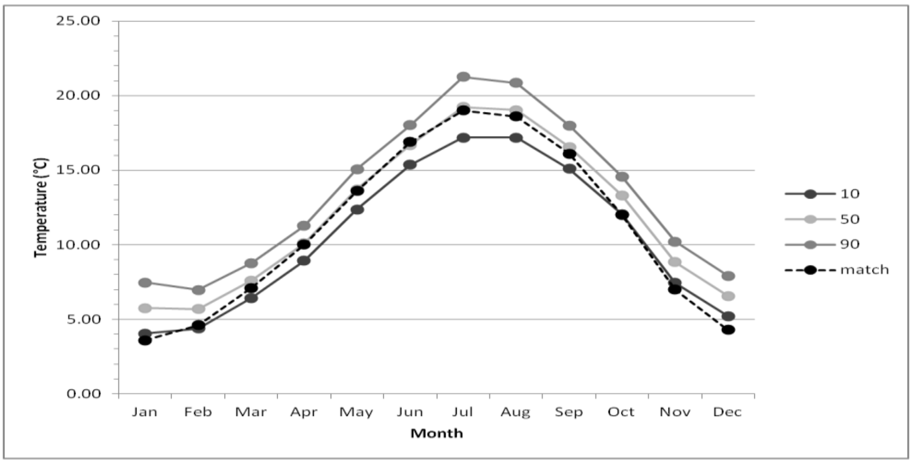
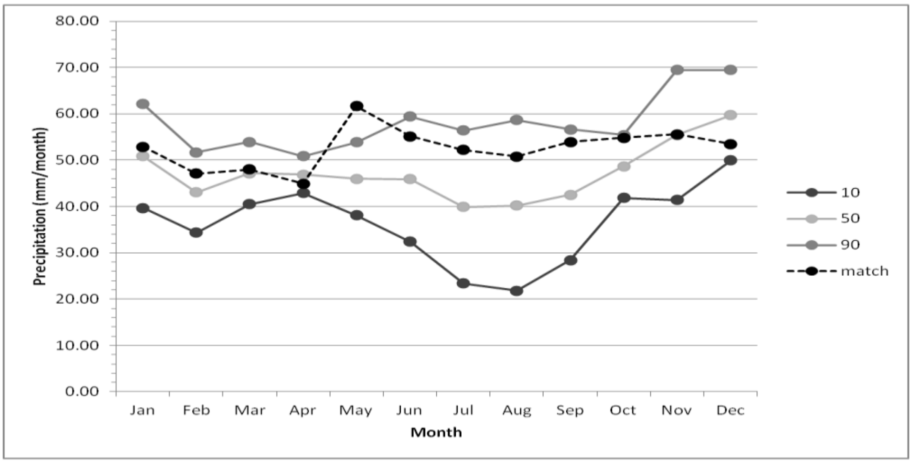


Figure 8.21 Climate comparison of existing conditions at square 2 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

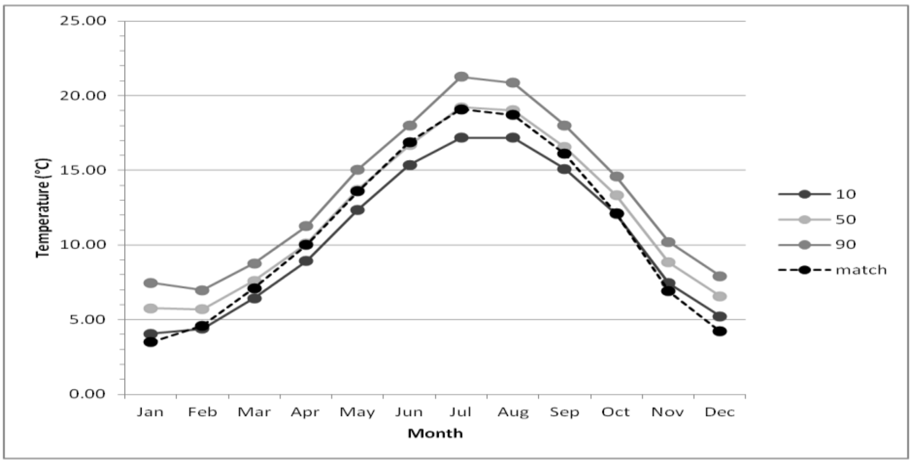
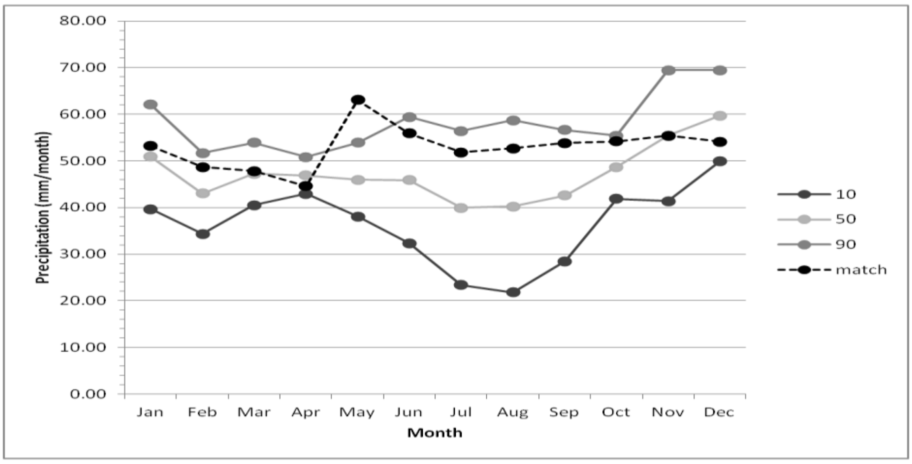


Figure 8.22 Climate comparison of existing conditions at square 3 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

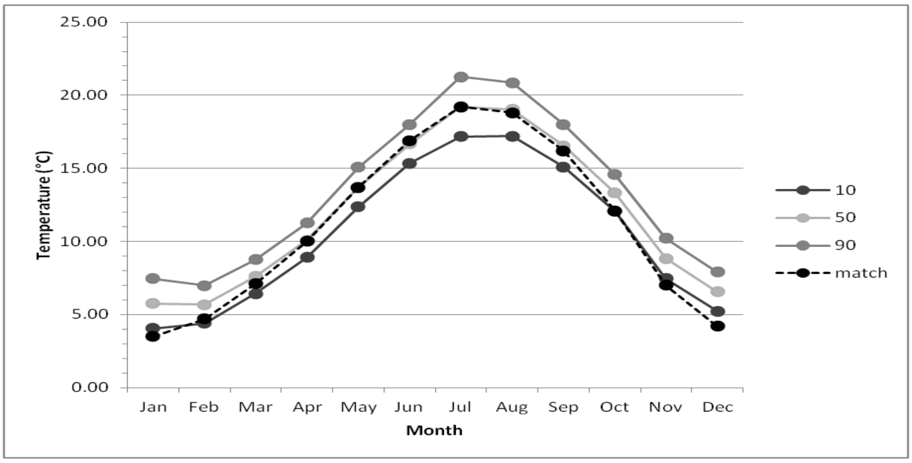
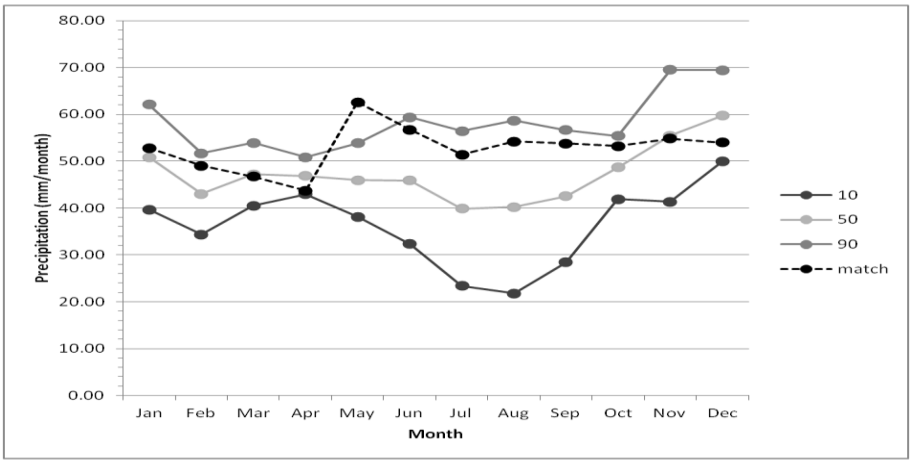


Figure 8.23 Climate comparison of existing conditions at square 4 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

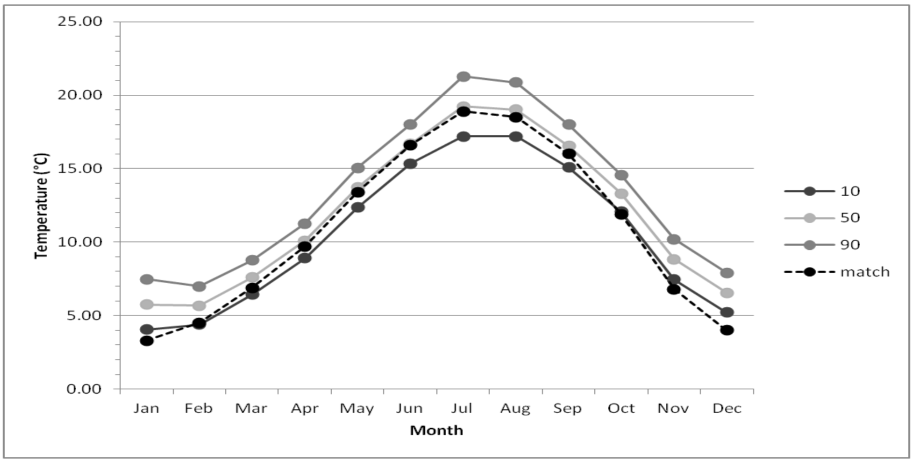
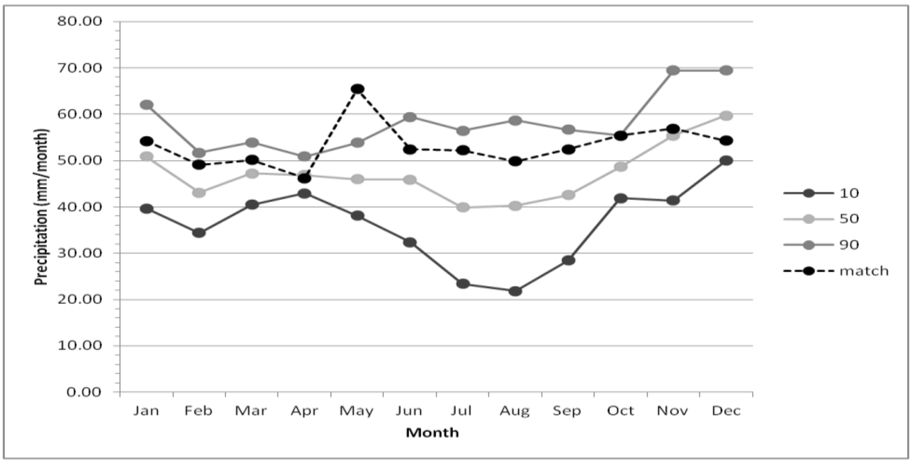


Figure 8.24 Climate comparison of existing conditions at square 5 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

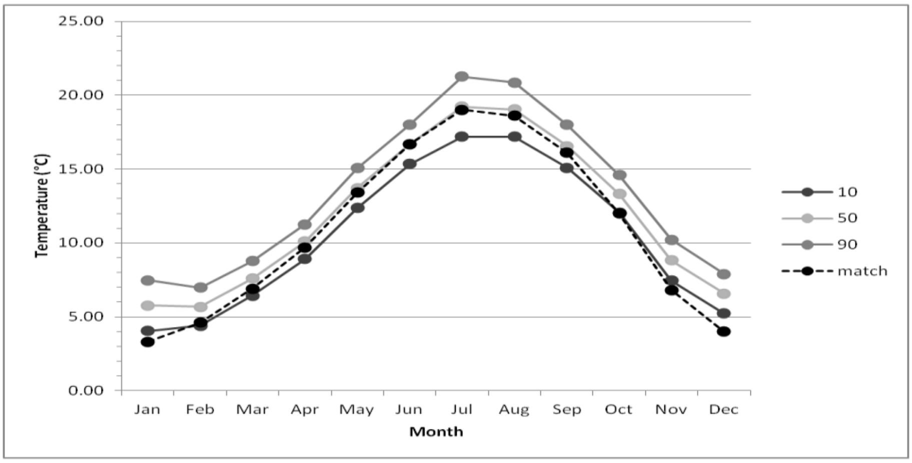
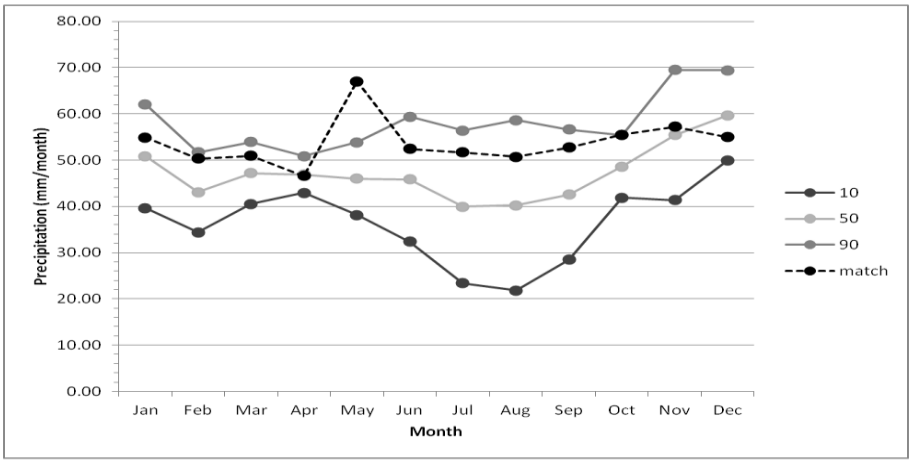


Figure 8.25 Climate comparison of existing conditions at square 6 and Brogborough Landfill projections.

(a) Temperature



(b) Precipitation

8.5 Minworth Sewage Works, Birmingham

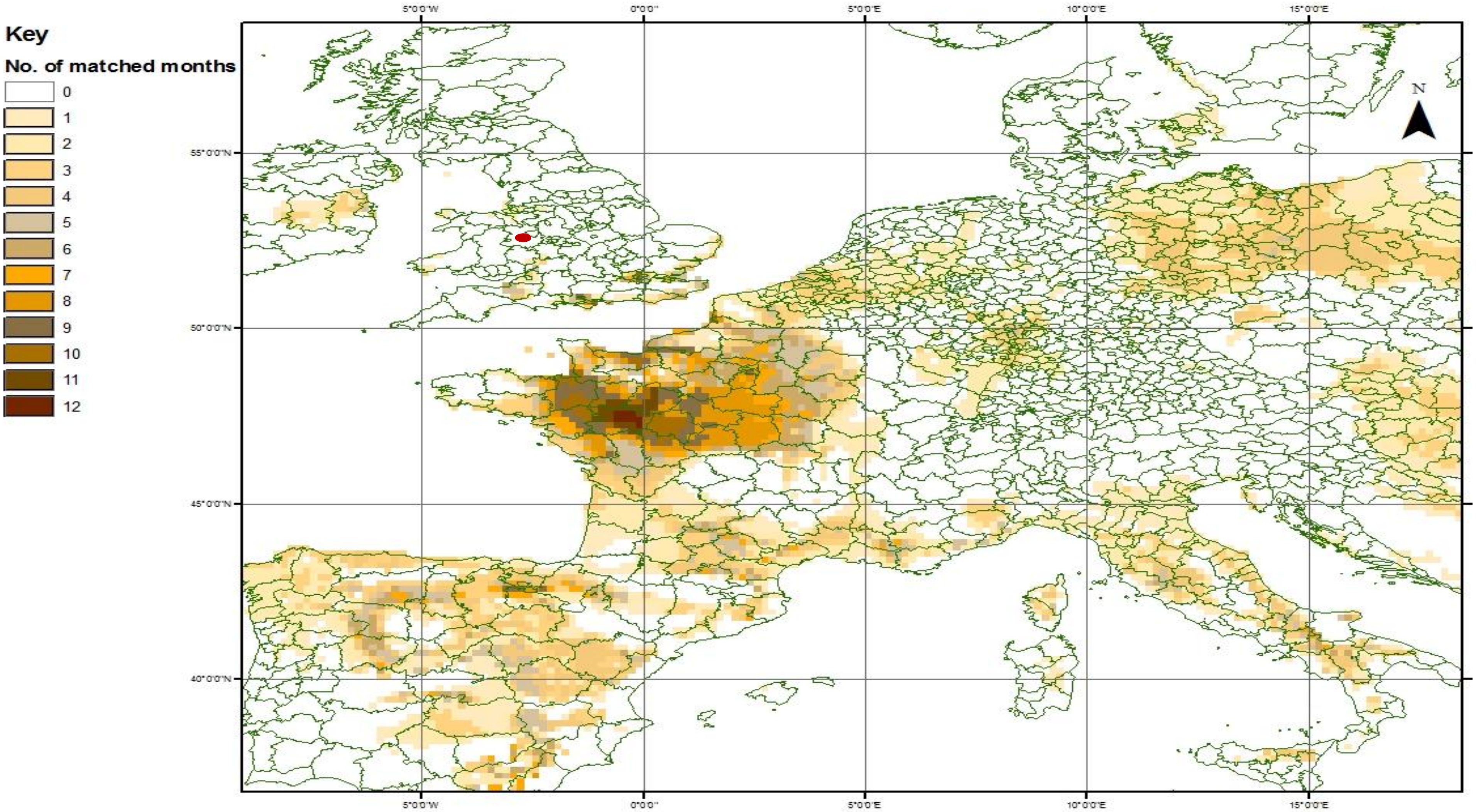
Minworth Sewage Works is located in grid square 1430, altitude 82m, and its projected mean monthly temperature and precipitation are shown in tables 8.14 and 8.15. Figure 8.26 shows the areas in Europe which have a climate, or part of a climate, that exists within these projections.

Table 8.14 Minworth sewage work's Temperature Projection range in 2050

		Temperature Change Projection °C			**Temperature Projection °C**		
		Probability Level			**Probability Level**		
Month	**Baseline Temp °C**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**
Jan	3.25	0.66	2.33	4.01	**3.91**	**5.58**	**7.26**
Feb	3.28	0.86	2.13	3.41	**4.14**	**5.41**	**6.69**
Mar	5.33	0.79	1.95	3.12	**6.12**	**7.28**	**8.45**
Apr	7.54	1.06	2.23	3.39	**8.60**	**9.77**	**10.93**
May	10.81	1.22	2.59	3.95	**12.03**	**13.40**	**14.76**
Jun	13.92	1.12	2.43	3.74	**15.04**	**16.35**	**17.66**
Jul	15.89	0.92	2.92	4.93	**16.81**	**18.81**	**20.82**
Aug	15.58	1.05	2.87	4.70	**16.63**	**18.45**	**20.28**
Sep	13.3	1.14	2.58	4.01	**14.44**	**15.88**	**17.31**
Oct	10.1	1.39	2.63	3.88	**11.49**	**12.73**	**13.98**
Nov	6	1.19	2.56	3.93	**7.19**	**8.56**	**9.93**
Dec	4.07	0.98	2.31	3.65	**5.05**	**6.38**	**7.72**

Table 8.15 Minworth's sewage works Precipitation Projection range in 2050

		Precipitation Projection Change			**Precipitation Projection mm/month**		
Month	**Baseline Precipitation (mm/month)**	**Probability Level**			**Probability Level**		
		10%	**50%**	**90%**	**10%**	**50%**	**90%**
Jan	58.9	-10.92%	19.28%	49.48%	**52.47**	**70.26**	**88.04**
Feb	47.6	-6.08%	18.55%	43.17%	**44.71**	**56.43**	**68.15**
Mar	52.08	-9.90%	8.28%	26.45%	**46.92**	**56.39**	**65.86**
Apr	49.8	-8.84%	1.31%	11.47%	**45.40**	**50.45**	**55.51**
May	54.87	-19.09%	-5.15%	8.79%	**44.39**	**52.04**	**59.69**
Jun	57.6	-39.42%	-13.48%	12.46%	**34.90**	**49.84**	**64.78**
Jul	49.6	-44.45%	-13.21%	18.03%	**27.55**	**43.05**	**58.54**
Aug	66.03	-61.16%	-28.01%	5.14%	**25.64**	**47.54**	**69.43**
Sep	54.3	-34.94%	-5.22%	24.50%	**35.33**	**51.47**	**67.60**
Oct	53.63	-13.50%	2.05%	17.60%	**46.39**	**54.73**	**63.07**
Nov	58.8	-15.89%	10.82%	37.53%	**49.46**	**65.16**	**80.87**
Dec	65.72	-5.50%	14.15%	33.79%	**62.11**	**75.02**	**87.93**



<u>Figure 8.26</u> Climate matched areas for Minworth sewage works (red dot)

Table 8.16 shows the number of European grid squares which match each category. There are 8 grid squares which match Minworth's climate projection for all 12 months, located in the Maine-et-Loire department in north-western France. The area surrounding this patch also spans out in a pattern to 11 month blocks, 10 month blocks and so on, extending as far north as the coast of Ille-et-Villaine, with 8 month matches stretching as far east as the Seine-et-Marne department near Paris. This illustrates that this area has a good agreement with Minworth's climate projection. The altitude over the best matched area (the 12 and 11 month cluster) ranges between 73m and 24m which would be comparative with the case studies elevation of 82m. There are a few 10, 9 and 8 month matches in the UK, on the south coast and in London, but as they are isolated patches, in comparison to the find in France, these are not considered further. It is however, worth noting that these climate matches in the south of the UK have only appeared with the northern case studies.

Table 8.16 The number of European grid squares matched to Minworth sewage work's climate

No of months matched	No of grid squares
1	7722
2	4622
3	1993
4	857
5	390
6	229
7	134
8	161
9	92
10	59
11	27
12	8

Figure 8.27 shows the large section which is climatically matched with Minworth, and the 8 grid squares which span the range and have been selected as examples for discussion. They are located in the Mayenne, Maine-et-Loire, Indre-et-Loire and Loiret departments of France. The average altitude across these areas varied from 41m in Angers to 114m in Orleans.

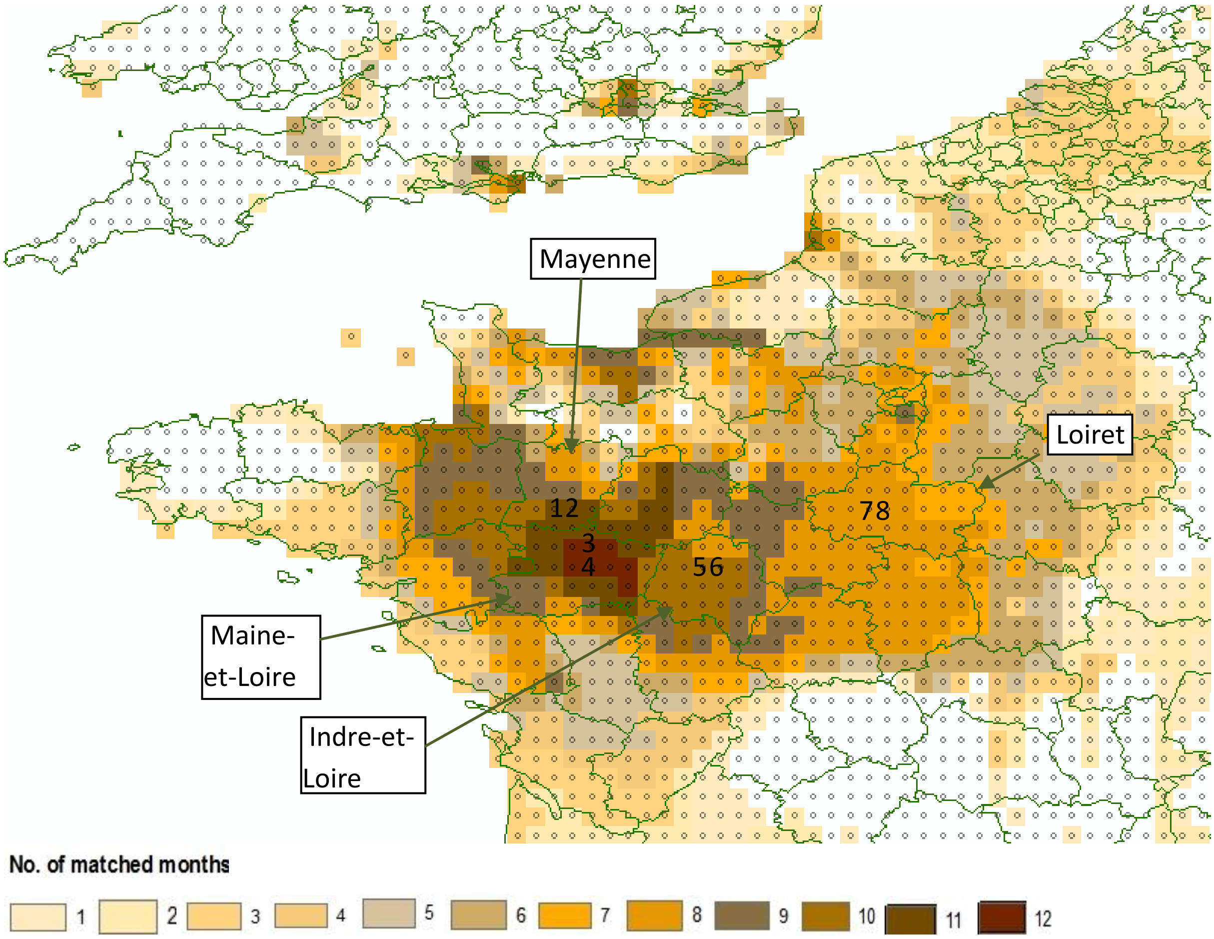


Figure 8.27 Suitable European Areas for Minworth sewage work's climate comparison

Table 8.17 shows the latitude/longitude and relevant figure to refer to in relation to the 8 grid squares numbered on figure 8.27.

Table 8.17 Minworth sewage work' matched squares for analysis

Square no.	Latitude/Longitude	No. Matched months	Figure No.
1	47.917, -0.75	11	8.28
2	47.917, -0.583	11	8.29
3	47.583, -0.417	12	8.30
4	47.417, -0.417	12	8.31
5	47.417, 0.583	10	8.32
6	47.417, 0.75	10	8.33
7	47.917, 1.917	8	8.34
8	47.917, 2.083	8	8.35

The temperature of the 12 month match grid squares are in very good agreement with Minworth's projected climate over the year, matching around the 50% probability projection for most of the year, with it veering near the 10% projection over the winter months as shown in figures 8.30a and 8.31a. The precipitation is also in good agreement with Maine-et-Loire experiencing slightly more rainfall in May, October and November, but they still fall within the range, as shown in figures 8.30b and 8.31b. The climate pattern is similar for the 11 month matches, but as shown in figures 8.28b and 8.29b it is the higher amount of precipitation in October which makes the match fall outside the range, e.g. by 4.23mm in figure 8.28b – across the range this is probably the maximum that it falls over by. Across the 11 month spread, sometimes it is the precipitation in May which falls higher than the range, a month which persistently has generally higher rainfall in comparison to April and June, throughout the Maine-et-Loire region. The temperature in December also in a few grid squares north east of Angers, has a temperature slightly lower than Minworth's projections.

The 10 month matches in the Indre-et-Loire department are overall in good agreement, apart from the winter temperatures being near the 10% projection. In December the temperature falls lower than the range by 0.35°C in figures 8.32a and 8.33a, which is not significant for the purposes of the research. The precipitation here is also in good agreement, apart from December when it is nearer the 10% projection, and in May when Indre-et-Loire experiences more rainfall than the range by 3.21mm, as shown in figure 8.32b. The other 10 month matches across the spread also experience higher rainfall in October, as well as in May, but this is not by significant amounts.

The 8 month matches in the far east of the matched area experience a similar temperature pattern, but the months of January, November and December have a lower temperature than Minworth's projected range falling under by 0.61°C, 0.39°C and 1.05°C respectively (figure 8.34a). The precipitation is a good match amongst most months, but the winter months and the start of spring have a rainfall in between the 10 and 50% projection range, with it falling out of the range by 8.21mm in December (figure 8.34b). Conversely the precipitation in May is higher than the range by 5.71mm in this same square. As mentioned before, with May being an important month for plants in the phenological calendar, this must be considered when making the plant selections.

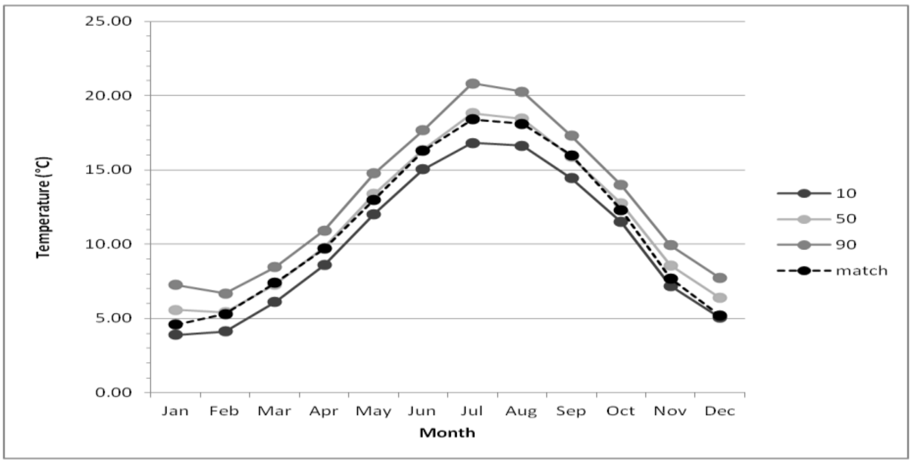
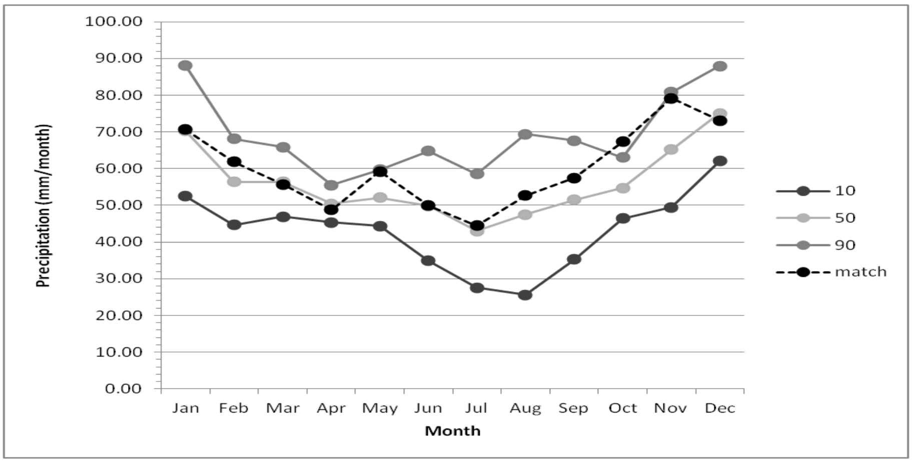


Figure 8.28 Climate comparison of existing conditions at square 1 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

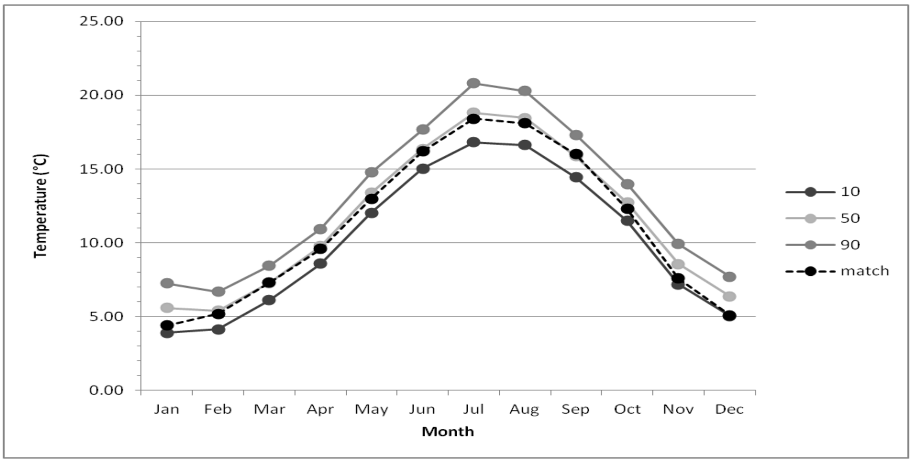
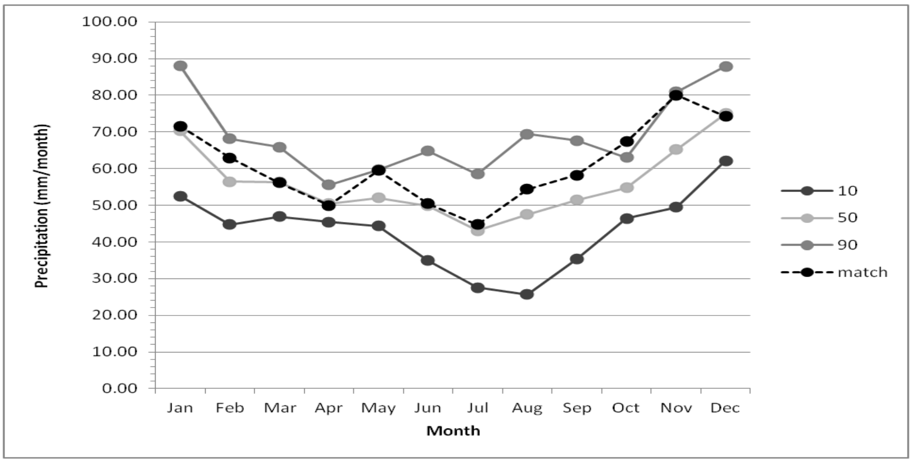


Figure 8.29 Climate comparison of existing conditions at square 2 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

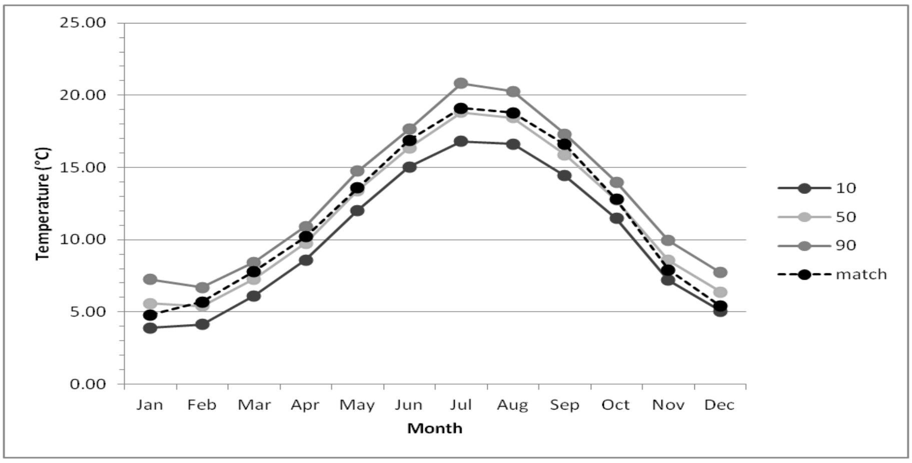
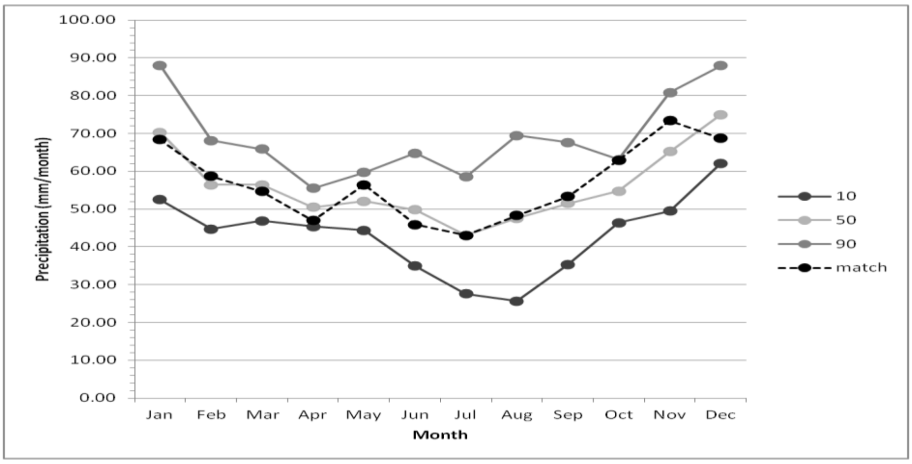


Figure 8.30 Climate comparison of existing conditions at square 3 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

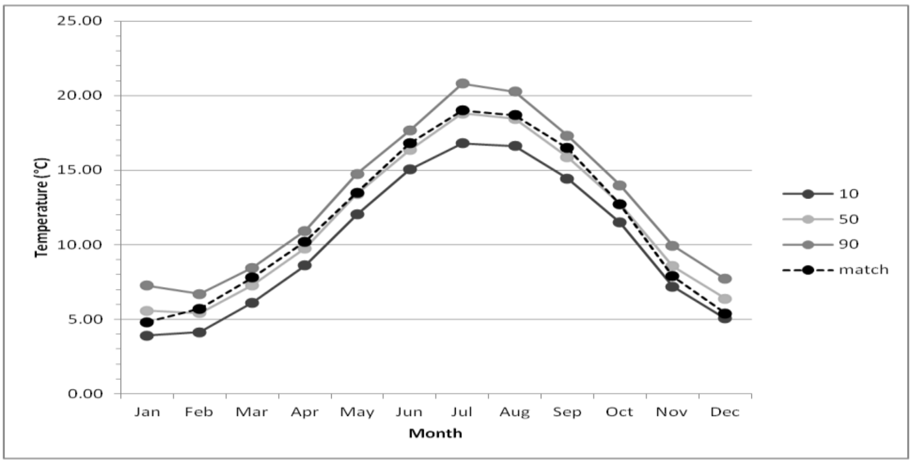
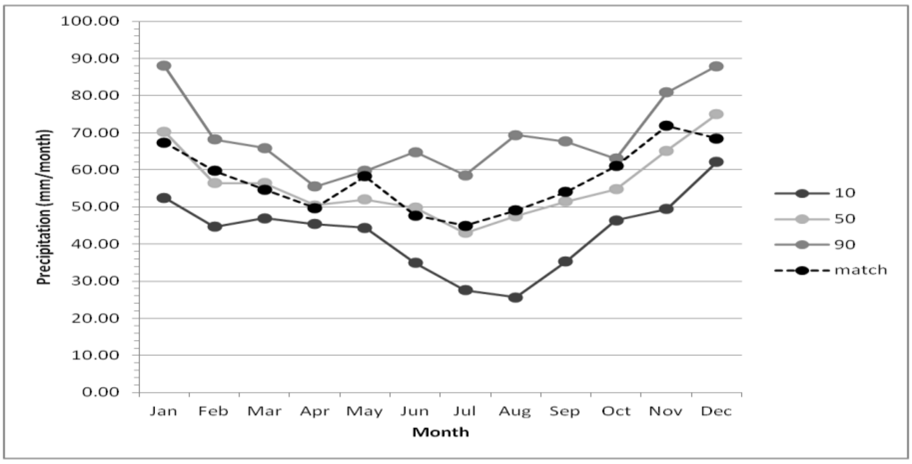


Figure 8.31 Climate comparison of existing conditions at square 4 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

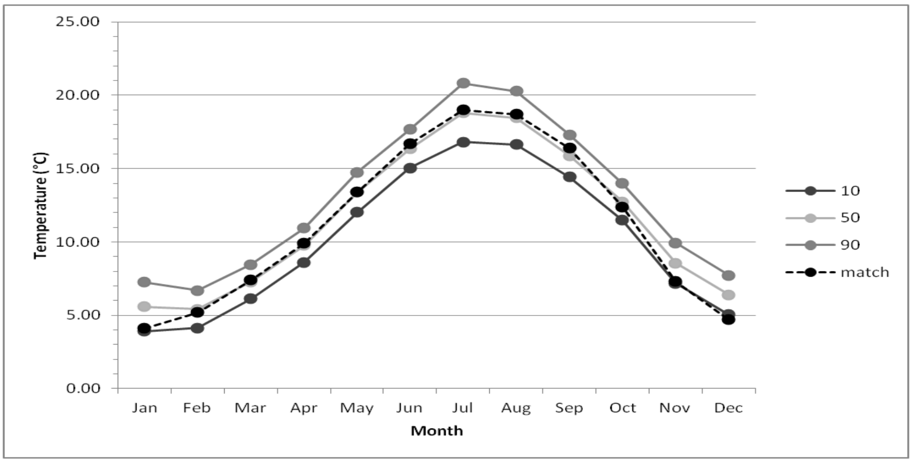
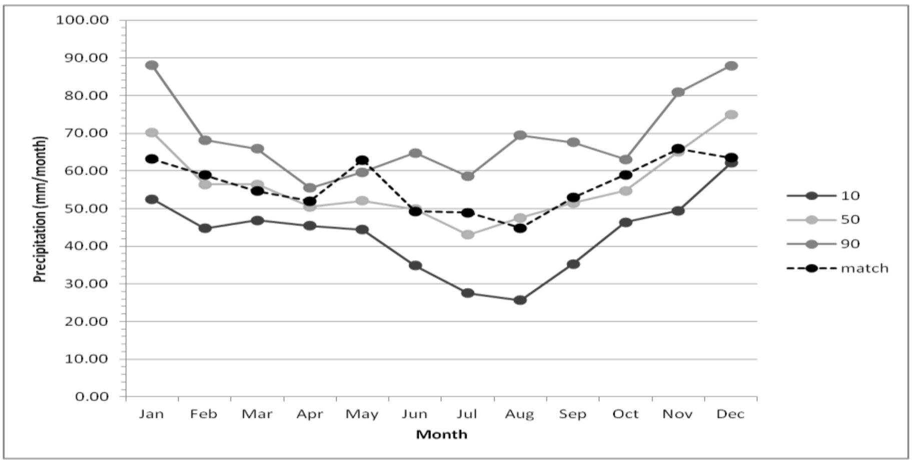


Figure 8.32 Climate comparison of existing conditions at square 5 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

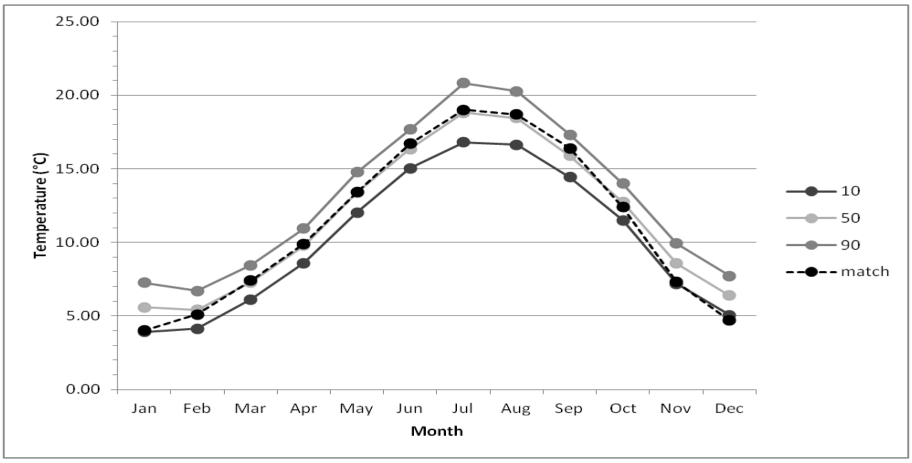
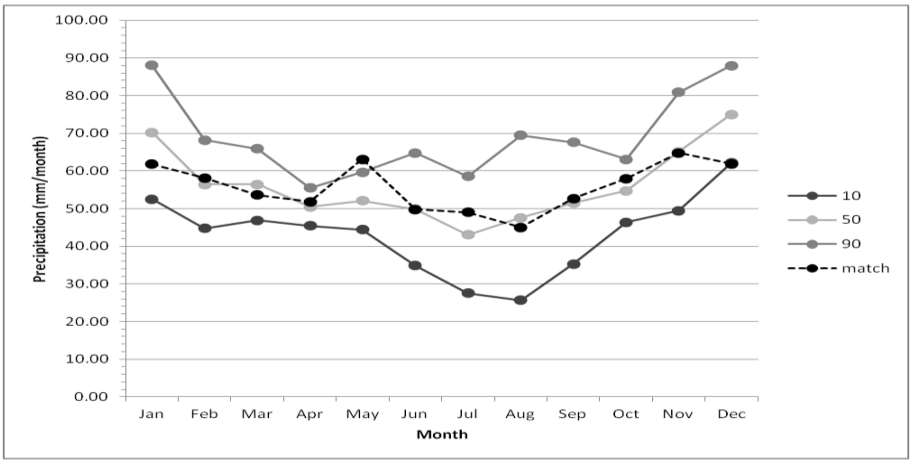


Figure 8.33 Climate comparison of existing conditions at square 4 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

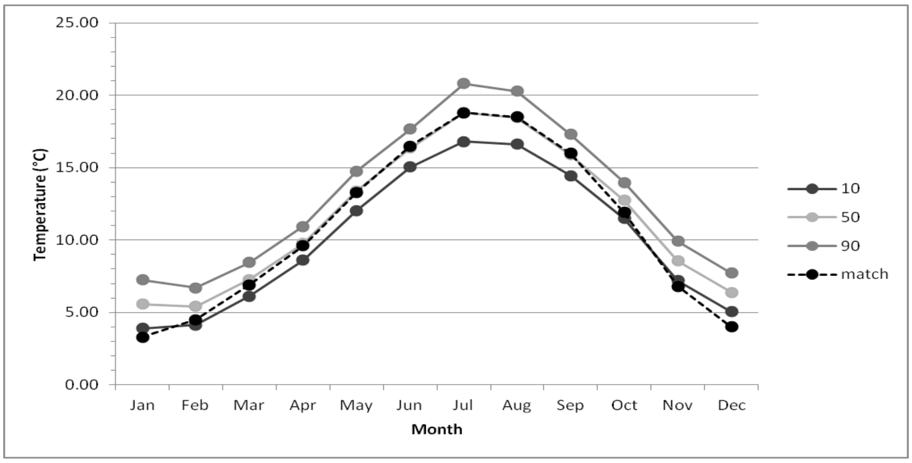
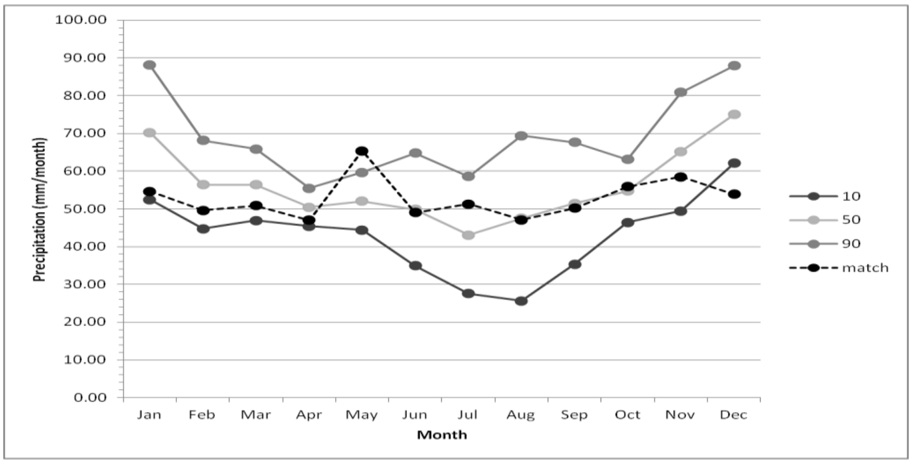


Figure 8.34 Climate comparison of existing conditions at square 7 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

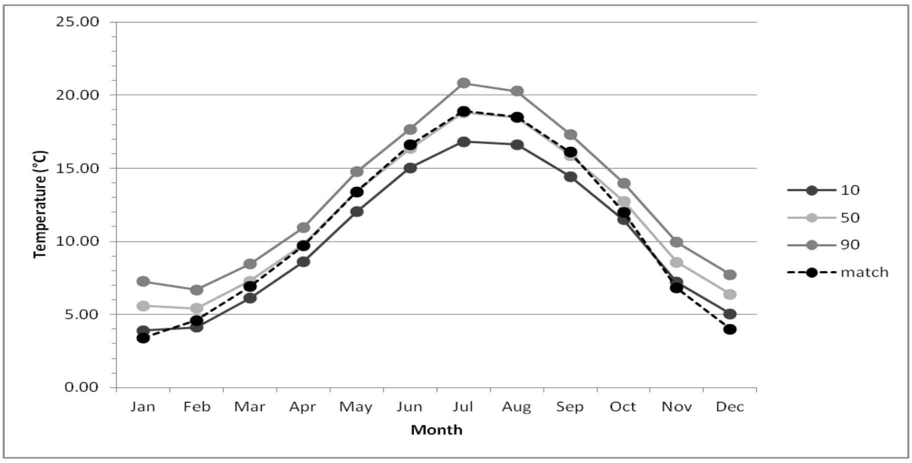
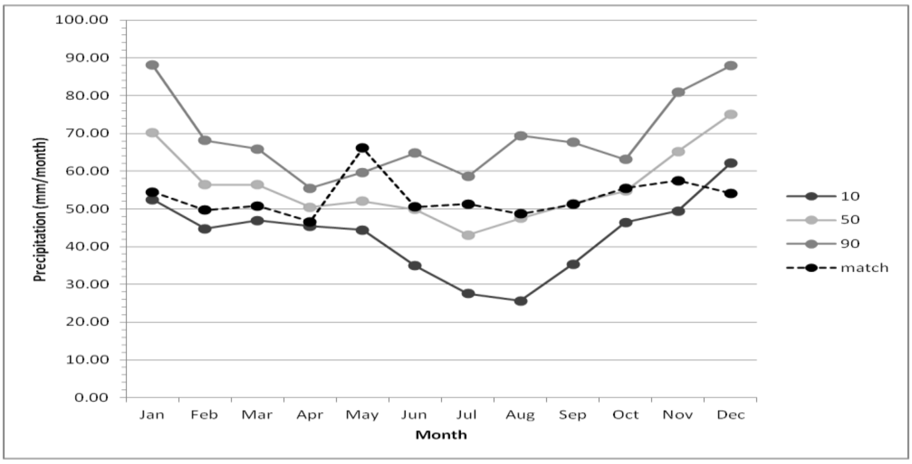


Figure 8.35 Climate comparison of existing conditions at square 8 and Minworth Sewage Work projections.

(a) Temperature



(b) Precipitation

8.6 Wheatley Hall Road, Doncaster

Wheatley Hall Road is located in grid square 1277, altitude 27m, and its projected mean monthly temperature and precipitation are shown in tables 8.18 and 8.19. Figure 8.36 shows the areas in Europe which have a climate, or part of a climate, that exists within these projections.

Table 8.18 Wheatley Hall Road's Temperature Projection range in 2050

		Temperature Change Projection °C			**Temperature Projection °C**		
		Probability Level			**Probability Level**		
Month	**Baseline Temp °C**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**
Jan	3.4	0.65	2.32	4.00	**4.05**	**5.72**	**7.40**
Feb	3.5	0.85	2.13	3.41	**4.35**	**5.63**	**6.91**
Mar	5.53	0.79	1.96	3.12	**6.32**	**7.49**	**8.65**
Apr	7.66	1.06	2.21	3.37	**8.72**	**9.87**	**11.03**
May	10.83	1.21	2.54	3.87	**12.04**	**13.37**	**14.70**
Jun	13.95	1.05	2.29	3.52	**15.00**	**16.24**	**17.47**
Jul	15.75	0.86	2.72	4.59	**16.61**	**18.47**	**20.34**
Aug	15.68	0.96	2.63	4.30	**16.64**	**18.31**	**19.98**
Sep	13.49	1.09	2.44	3.79	**14.58**	**15.93**	**17.28**
Oct	10.29	1.34	2.55	3.76	**11.63**	**12.84**	**14.05**
Nov	6.1	1.16	2.50	3.84	**7.26**	**8.60**	**9.94**
Dec	4.13	0.97	2.30	3.63	**5.10**	**6.43**	**7.76**

Table 8.19 Wheatley Hall Road's Precipitation Projection range in 2050

		Precipitation Projection Change			**Precipitation Projection mm/month**		
Month	**Baseline Precipitation (mm/month)**	**Probability Level**			**Probability Level**		
		10%	**50%**	**90%**	**10%**	**50%**	**90%**
Jan	46.19	-14.06%	11.10%	36.25%	**39.69**	**51.32**	**62.94**
Feb	35.84	-3.42%	15.52%	34.46%	**34.61**	**41.40**	**48.19**
Mar	45.57	-13.16%	4.00%	21.17%	**39.57**	**47.39**	**55.22**
Apr	47.1	-10.02%	2.01%	14.03%	**42.38**	**48.04**	**53.71**
May	49.29	-21.29%	-4.56%	12.18%	**38.79**	**47.04**	**55.29**
Jun	51.9	-33.98%	-11.33%	11.33%	**34.26**	**46.02**	**57.78**
Jul	50.53	-43.82%	-12.31%	19.21%	**28.39**	**44.31**	**60.23**
Aug	58.28	-54.06%	-24.10%	5.87%	**26.77**	**44.24**	**61.70**
Sep	48.6	-28.30%	-4.32%	19.66%	**34.85**	**46.50**	**58.16**
Oct	45.26	-15.25%	2.17%	19.58%	**38.36**	**46.24**	**54.12**
Nov	51.9	-16.15%	10.45%	37.04%	**43.52**	**57.32**	**71.12**
Dec	51.15	-5.11%	9.98%	25.06%	**48.54**	**56.25**	**63.97**

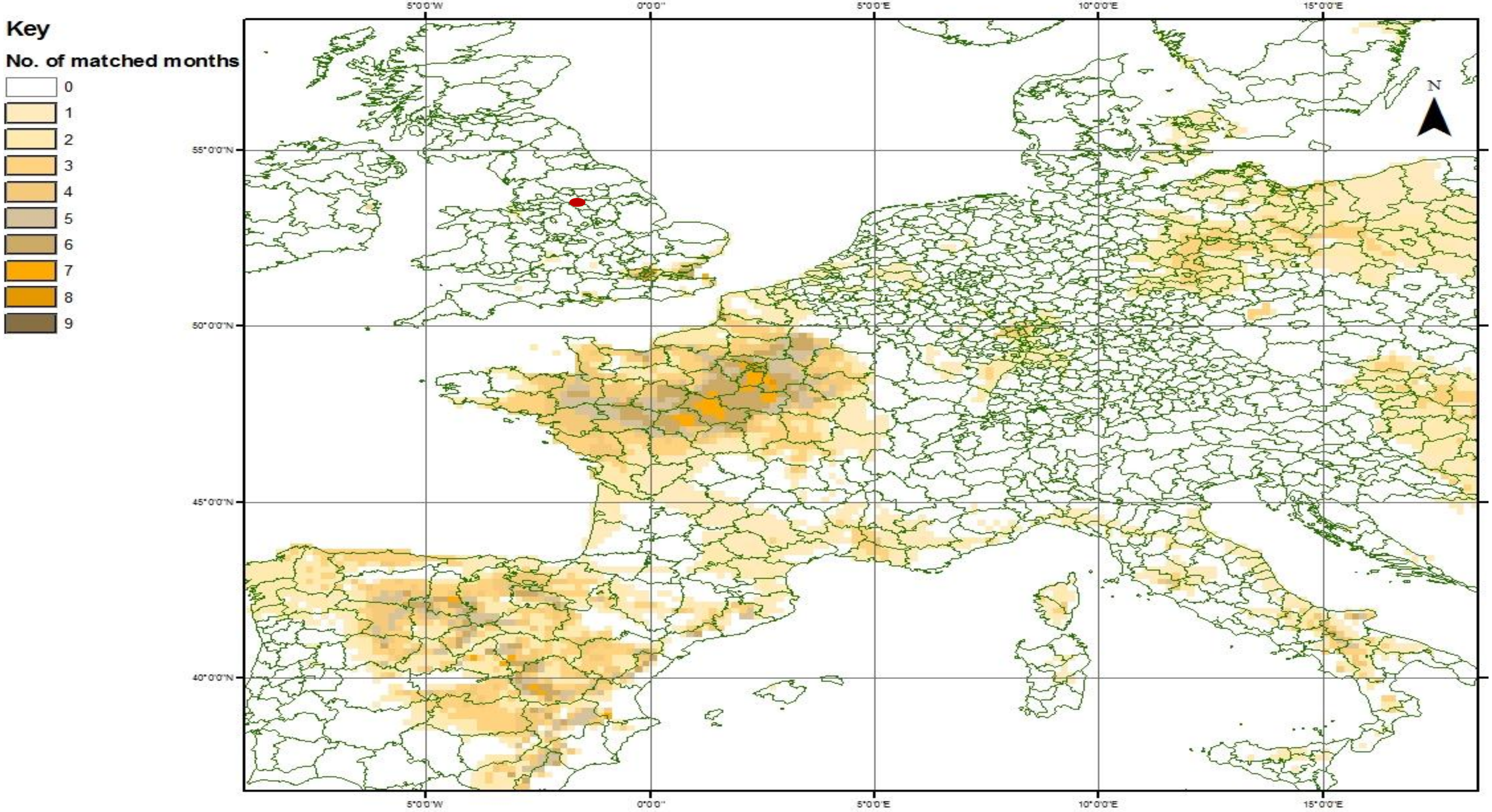


Figure 8.36 Climate matched areas for Wheatley Hall Road (red dot)

Table 8.20 shows the number of European grid squares which match each category. The best match is an area in North London (51.583, -0.083) with 9 months matching Wheatley Hall Road's 10 to 90% probability projection. The altitude is around 24m here and comparative with the case studies elevation of 27m. There are no grid squares which match the projections for 10, 11 and 12 months. As can be seen in figure 8.36 and up closer in figure 8.37 there are 2 areas in north-central France with a cluster of 7 and 8 month matches, and as the altitude is similar here to the case study site – the area surrounding Paris will be further investigated. The altitude varies here from 42m in Creteil to 79m in Fontainebleau.

Table 8.20 The number of European grid squares matched to Wheatley Hall Road's climate

No of months matched	**No of grid squares**
1	8269
2	3283
3	1351
4	510
5	252
6	208
7	42
8	4
9	1
10	0
11	0
12	0

Figure 8.37 shows the 6 grid squares which have been selected as examples for discussion. They are located in the Essonne, Seine-et-Marne and Loiret departments of France, and in London in the UK.

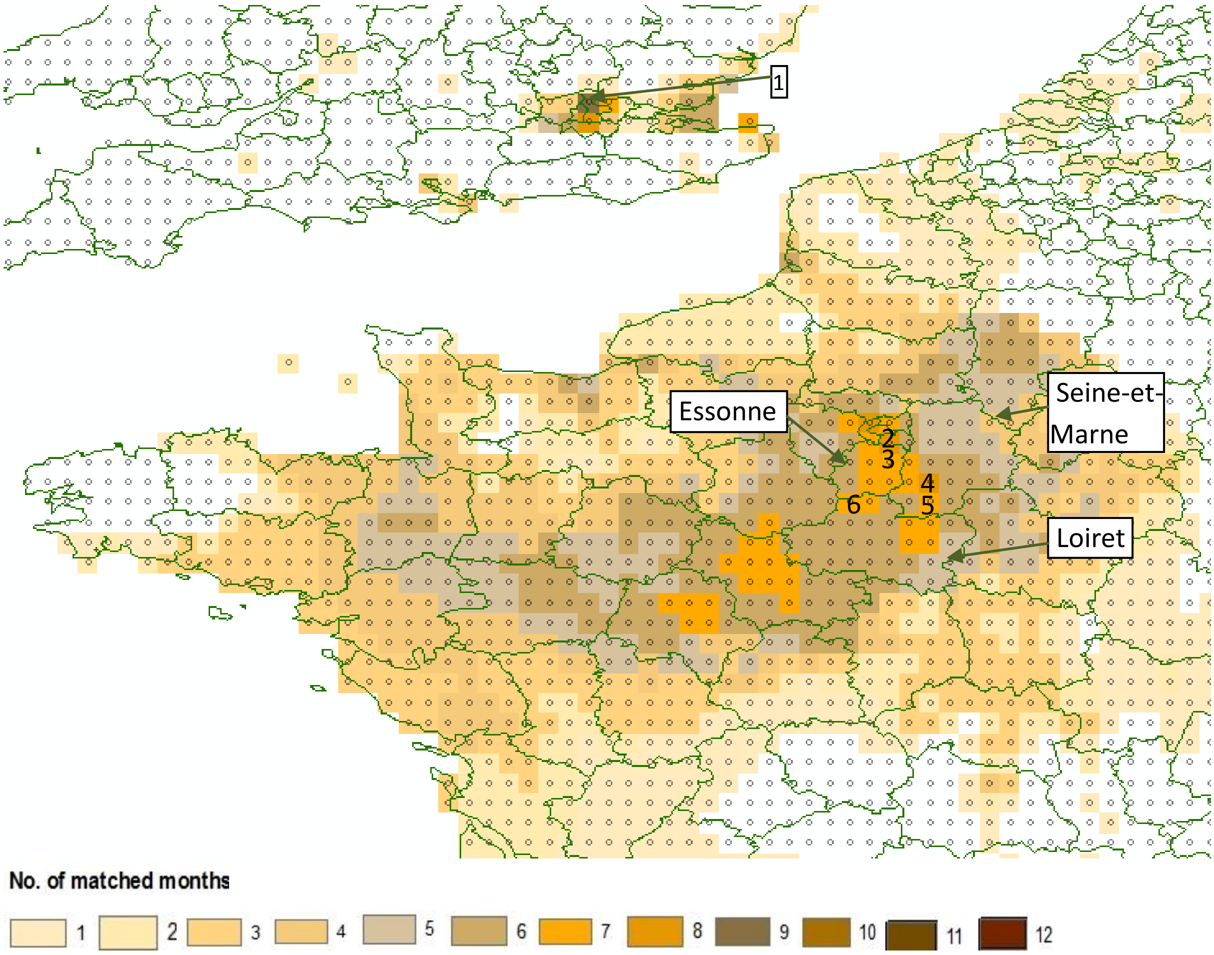


Figure 8.37 Suitable European Areas for Wheatley Hall Road's climate comparison

Table 8.21 shows the latitude/longitude and relevant figure to refer to in relation to the 6 grid squares numbered on figure 8.37.

Table 8.21 Wheatley Hall Road's matched squares for analysis

Square no.	Latitude/Longitude	No. Matched months	Figure No.
1	51.583, -0.083	9	8.38
2	48.75, 2.417	8	8.39
3	48.583, 2.417	7	8.40
4	48.417, 2.75	8	8.41
5	48.25, 2.75	7	8.42
6	48.25, 2.083	7	8.43

The UK match in figure 8.38a has a temperature which tends to fall nearer the 10% projection with April, October and November falling under the range by 0.02°C, 0.03°C and 0.06°C respectively. The precipitation generally is higher in this area of the UK in comparison to Wheatley Hall Road's 50% projection, but it is only greater than the range in October when it experiences 3.98mm more rainfall over the month (figure 8.38b).

The matches in France are better overall and similar to what is projected for Wheatley Hall Road in 2050. In figure 8.39a and 8.41a there is a relatively good match for temperature bar the winter months with the temperature in January and December falling out the range by 0.15°C and 0.4°C respectively (figure 8.39a). The precipitation generally tends to be higher than the 50% projection with higher rainfall than the 90% projection in May and November by, for example 3.91mm and 2.28mm respectively in figure 8.39b. Conversely the rainfall in April in this area of France is close to Wheatley Hall Road's 10% projection. The 7 months are matched less by one month in November when the temperature is 0.06°C lower than the range (figure 8.40a). Further south, the precipitation in February is higher than the range by 0.81mm (figure 4.42b), along with May. North of the Loiret department the climate pattern is similar as shown in figure 8.43a and b.

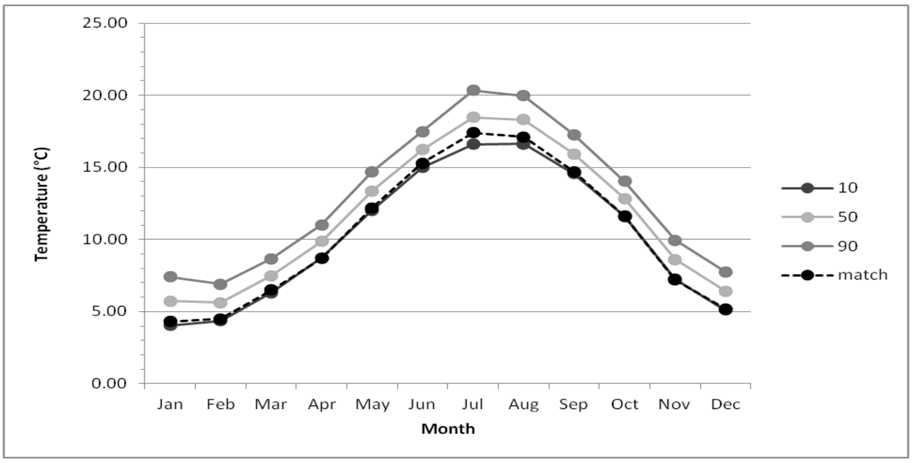
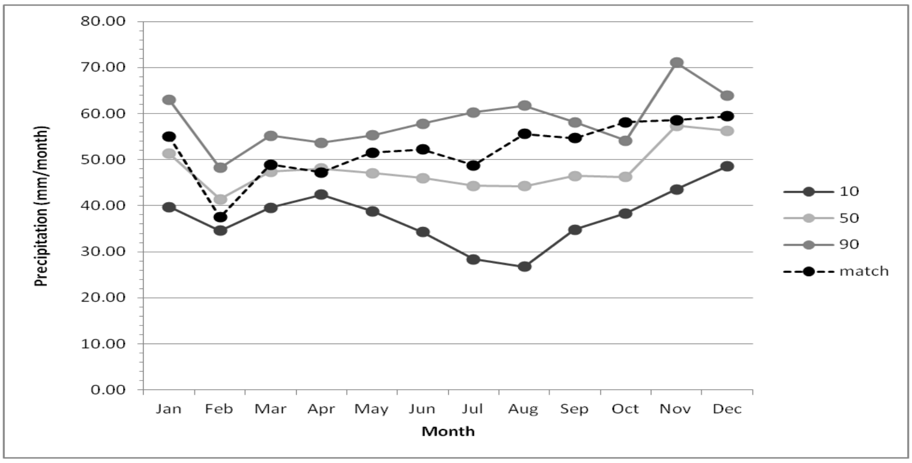


Figure 8.38 Climate comparison of existing conditions at square 1 and Wheatley Hall Road projections.

(a) Temperature



(b) Precipitation

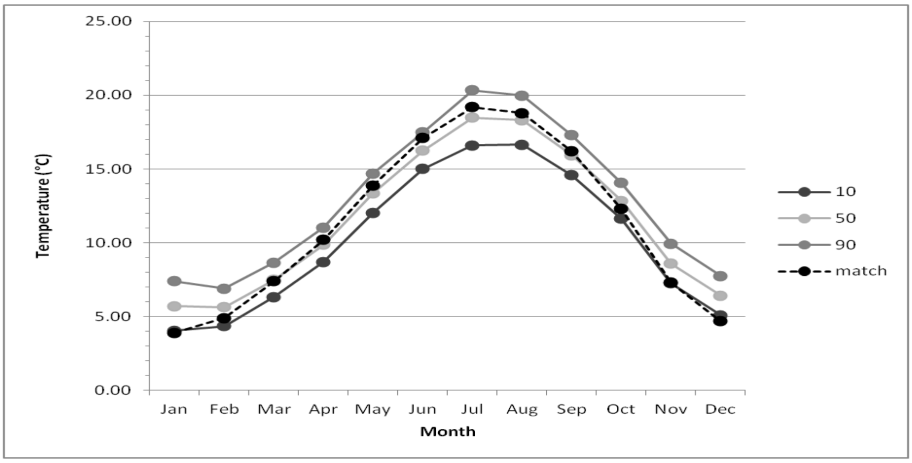
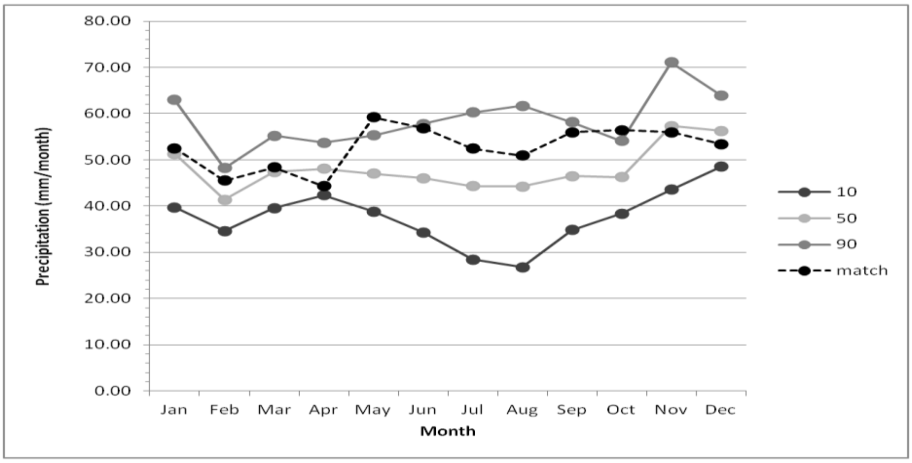
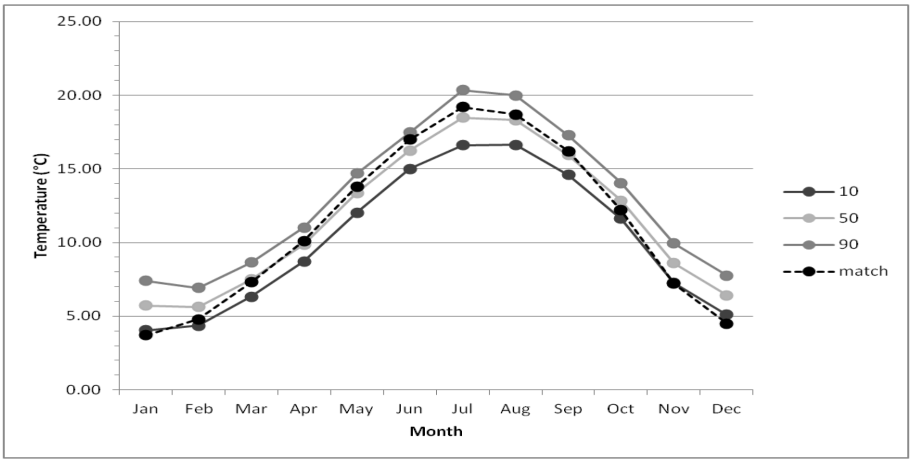


Figure 8.39 Climate comparison of existing conditions at square 2 and Wheatley Hall Road projections.

(a) Temperature

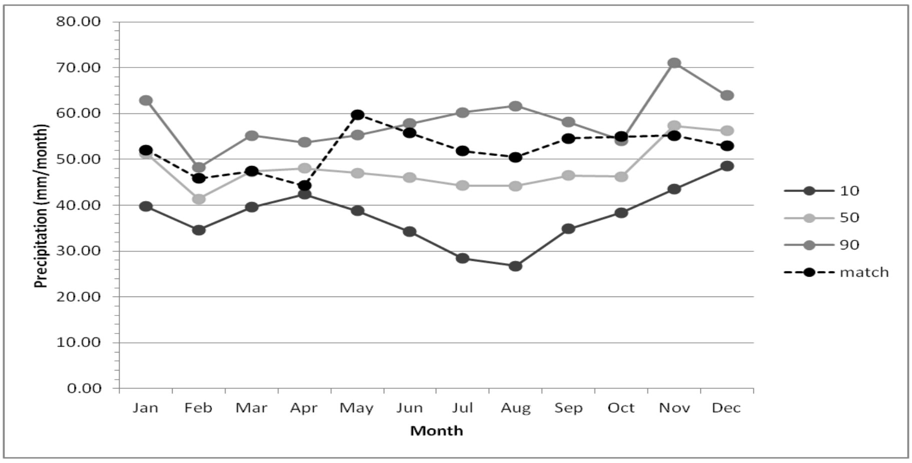


(b) Precipitation

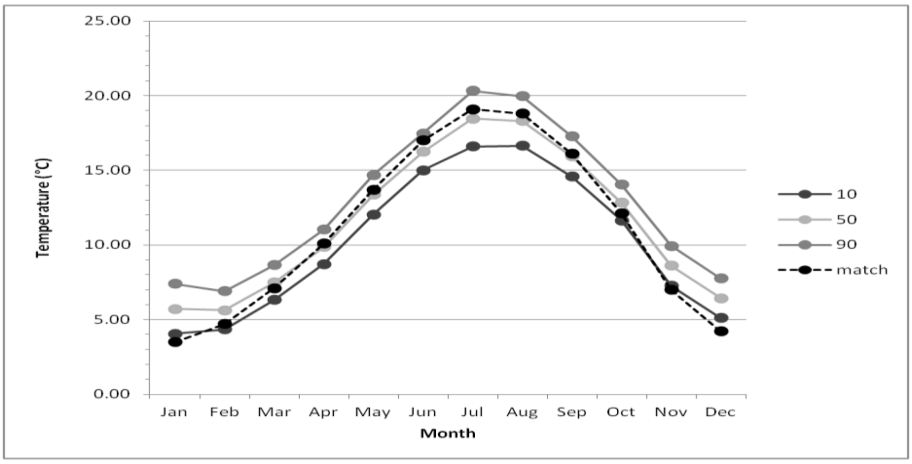


<u>Figure 8.40</u> Climate comparison of existing conditions at square 3 and Wheatley Hall Road projections.

(a) Temperature

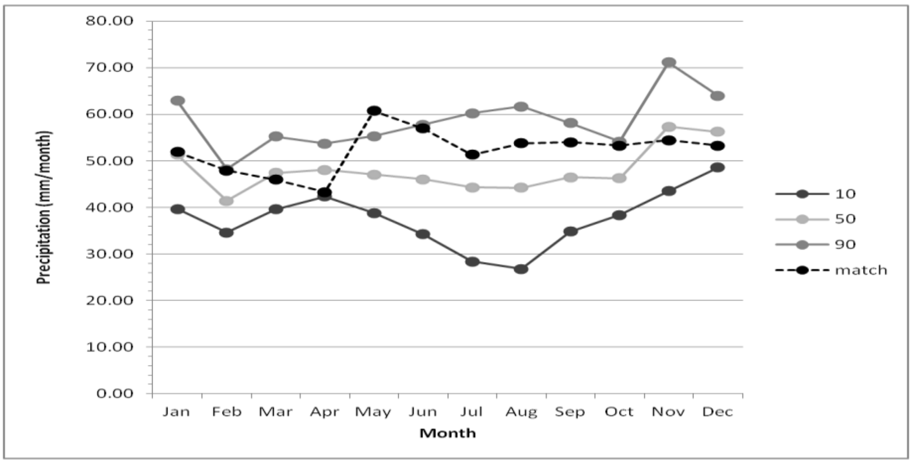


(b) Precipitation



<u>Figure 8.41</u> Climate comparison of existing conditions at square 4 and Wheatley Hall Road projections.

(a) Temperature



(b) Precipitation

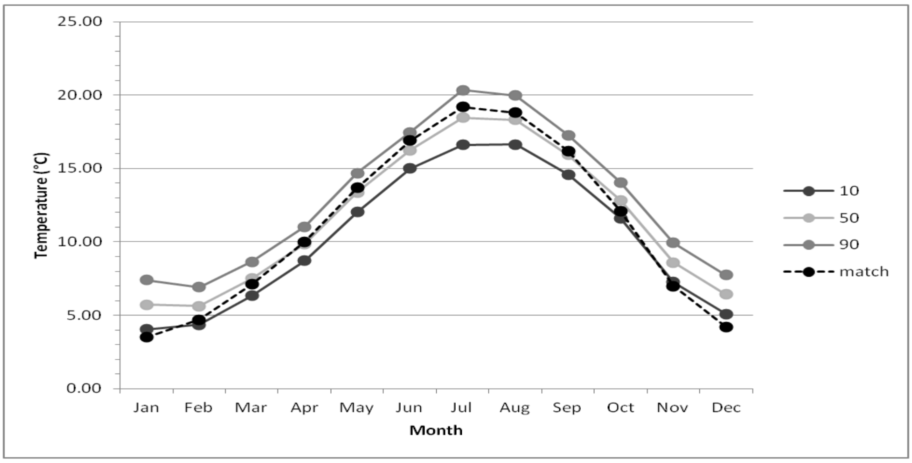
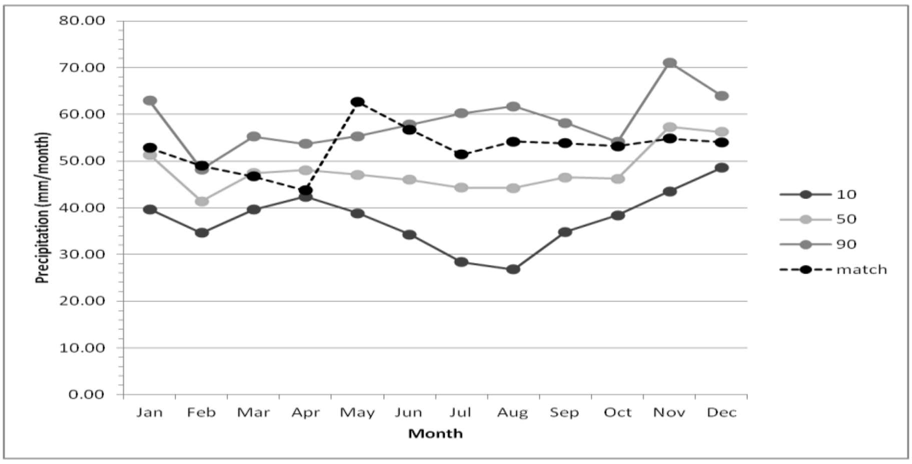


Figure 8.42 Climate comparison of existing conditions at square 5 and Wheatley Hall Road projections.

(a) Temperature



(b) Precipitation

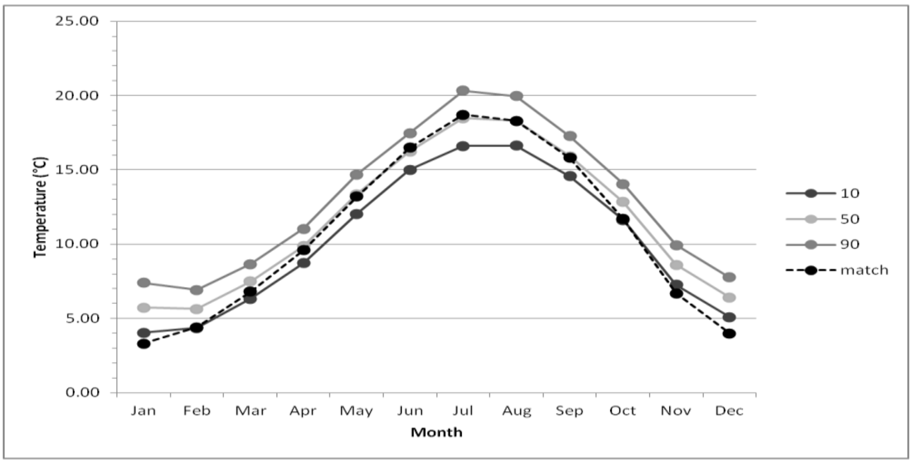
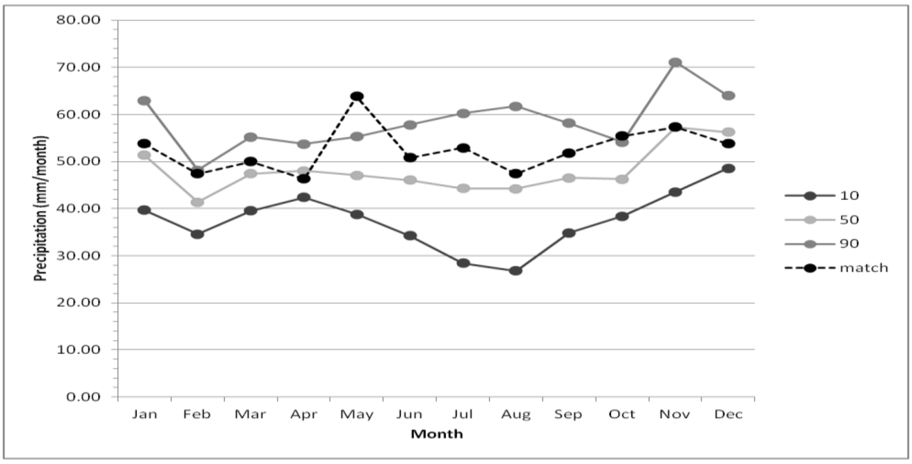


Figure 8.43 Climate comparison of existing conditions at square 6 and Wheatley Hall Road projections.

(a) Temperature



(b) Precipitation

8.7 Conclusion

The climate matching process, as described in this chapter, has enabled areas across Europe to be identified which are currently experiencing a similar climate to that expected by the case studies in 2050 across the UK. By further analysing these matches it is clear that overall those areas in better agreement with the case studies exist in north-western and north central France, particularly in the Pays de la Loire and the Ile-de-France regions of France.

A trend throughout has shown that often the precipitation in May at the matched locations is higher than the 90% projection range, which will need to be considered when investigating the vegetation in these areas – May is an important month in the growing cycle of plants. The temperature over the winter months in these areas of France tends to be lower than the projected ranges, but plants are often dormant during this period and so this is less of a concern. Overall there is a good agreement between the case study's projected climate and the climate in these areas of France.

The next chapter will explore the vegetation present in these matched areas and examine the suitability of this flora for incorporation into plant mixes in the UK, with the outcome being the creation of resilient planting assemblages capable of thriving under the projected climate change.

9. Vegetation Matching

The climate matching results of chapter 8 revealed that the cases studies have suitable matches in northern France. EQ in Kent, the Olympic Park in London and Minworth sewage works in Birmingham all have relatively strong matches in north-western France, particularly the Maine-et-Loire department. Conversely Brogborough Landfill in Central Bedfordshire and Wheatley Hall Road in Doncaster have good matches in north-central France, particularly the Essonne, Seine-et-Marne and Loiret departments, which are all just south of Paris.

Having identified suitable matched areas, the next step was to obtain species lists for the vegetation present at those locations. In order to obtain vegetation data for these locations, there were two ways of doing so, as discussed in chapter 5: 1) obtain field data by visiting the areas and identifying the vegetation; and 2) sourcing published data. Once suitable data has been obtained, plant species currently present at the matched locations can be investigated for their suitability for inclusion in planting schedules resilient to climate change, for the individual UK development sites.

The UK predominantly use the National Vegetation Classification (NVC), phase one habitat classification or the broad habitat classification to classify vegetation communities, whereas the French have their "Cahiers d'Habitats" – which are four habitat books for the communities found in France. As matched sites could occur anywhere in Europe, and there is no standard vegetation classification system, with each country typically employing their own method, a case study approach was adopted for obtaining the species lists. The object of this was to develop guiding principles that could be applied no matter where the analogous climate location occurred for any UK development site. EQ was consequently selected as the pilot study for this research.

9.1 Site Visits

Areas of ecological interest in EQs' matched areas (see figure 8.4), including Natura 2000 sites, were sought through online searching and studying Google Maps, which highlight natural parks etc. Ideally habitats typically created on development sites (e.g. woodland, wildflower meadow) were sought, and since this would require local knowledge, the help of botanists was sought who could recommend locations that would be suitable to visit. Consequently, several French botanical societies were contacted – the European base of Society of Ecological Restoration (SER), the Society of French Ecology (SFE), the Botanical Society of France, the National Botanical Conservatoire for the Parisian Basin and Tela Botanica. Correspondence was sent both in English and French to attract a greater interest. The emails generated some response, mainly from people interested in the outcomes of this research and those who had useful information. One of the societies also advertised this research in their weekly newsletter. A student botanist from Paris, Jonathan Locqueville, responded and was interested and able to assist, and an Associate Professor in Botany from Angers (Maine-et-Loire department), Valéry Malécot, offered to provide knowledge and assistance.

The botanist in Angers created an inventory of suitable locations within and around Angers, as this area had an overall good agreement with EQ's climate. The four sites visited for data collection included (see table 9.1 for site details):

- Chandelais Forest (broadleaved woodland),
- Longuenee Forest (broadleaved woodland),
- Etang St Nicolas (heathland),
- Jarze (Meadow).

The field work was carried out in mid June to coincide with the flowering season. In identifying the flora, Helen Miller, an experienced ecologist assisted, along with Valéry. Due to the size of the areas surveyed and time constraints a procedure of random quadrat sampling was adopted to obtain vegetation data. Given the array of different vegetation types, the method involved an initial walk-over of the site to delimitate stands of homogenous vegetation (i.e. stands of uniform structure and species), followed by quadrat sampling. The JNCC guidelines (JNCC, 2006) for choosing the size of samples state the following:

- 2x2 m for short, herbaceous vegetation, dwarf-shrub heaths;
- 4x4 m for short woodland field layers, tall herbaceous vegetation, heaths, open vegetation;
- 10x10 m for dense scrub, tall woodland field layers and species poor herbaceous vegetation;
- 50x50 m for woodland canopy and shrub layers and sparse scrub.

The sample sizes used were appropriate to the habitats being sampled, but they were not always square in shape. Representative samples of the selected stands were taken, with the percentage cover of species present within the quadrat recorded. Five samples were taken from different positions within the habitat of each vegetation type - five being a customary number (JNCC, 2006). Soil moisture was also recorded, along with an estimation of soil pH and soil type. Due to time and financial constraints, only limited field work was possible, but it provided an insight into, and appreciation of, the types of habitat and flora present in the analogous climate location, as well as what was required to obtain a sensible list of species.

9.2 Analysing field data with MAVIS

Modular Analysis of Vegetation Information System (MAVIS) is an analytical computer programme which determines National Vegetation Classification (NVC) communities based on the data input into the system (CEH, 2000). The possibility of using this programme was explored as it was initially thought that it could be employed to identify the NVC communities that were present in France and to see if there was a change in community as a result of the differing climates.

Difficulties were encountered, however, as several species were not recognised by the system, and it was discovered that unless extensive data is collected, MAVIS may give results that are misleading and inconclusive. The NVC, and thus MAVIS, are very UK centric and were developed for natural communities across the breadth of the UK. The NVC is, thus, unlikely to be applicable when incorporating non-native species. On testing the system, it was found that there were some similarities, but given the uncertainties surrounding the validity of the outcomes, the NVC was discounted as a viable tool to aid in species selection. Having rejected the NVC, no alternative analytical tool could be found that incorporated both UK and European vegetation data.

9.3 Online Data

As time and money were limited, the field data collected was not adequate enough on its own and other measures for developing species lists for the French sites were sought. As discussed in section 5.5.3 data from online resources pertaining to the biodiversity aspects of the area of interest are often reliable and important sources of data. The French habitat books mentioned would require translation and someone familiar with the community types if they were to be utilised in the study, it was therefore decided against this type of published material.

9.3.1 CORINE Online Data

Co-ordination of Information on the Environment (CORINE) biotopes data for Europe (EEA, 2003) were investigated as a possible avenue for online species data collection. CORINE biotopes are a habitat classification system developed to describe sites of nature conservation importance across Europe, with a biotope defined as 'an area of land or a body of water which forms an ecological unit of community significance for nature conservation, regardless of whether this area is formally protected by legislation or not (Commission of the European Communities, 1994). When querying the Access dataset by entering the latitude and longitude of the Maine-et-Loire department, results were generated for 13 habitats. However, on further inspection only one of the sites had plant data associated with it, and this comprised only 3 species. The other sites were found not to be important for plants, but for other taxa/species of interest like amphibians and invertebrates. The CORINE biotopes have now been superseded by the Palaearctic habitat classification and European Nature Information System (EUNIS) Habitat classification (EEA, No date), which on investigation also gave the same outcome. These however, should be considered for other development sites with matches across Europe, as relevant data may be present for other sites.

9.3.2 France's National Museum of Natural History

The Inventaire National da Patrimoine Naturel (INPN) website (National Museum of Natural History, 2013) is France's national inventory of natural heritage and is an extensive nature inventory programme, integrating all the data on species, natural habitats, protected areas and geological heritage present on French territory. The National Heritage Service (NPS), part of the national museum of natural history in France, organises the management, validation and dissemination of this data. Government, scientists, local authorities, naturalists and conservation associations make this inventory of France's natural heritage possible, with data voluntarily uploaded for public access. Given the size of some of the sites, and the relatively small number of botanists, however, it is possible that not all the species for an area will be collected and thus it will not appear in the database (Locqueville, 2012).

9.3.3 ZNIEFFs

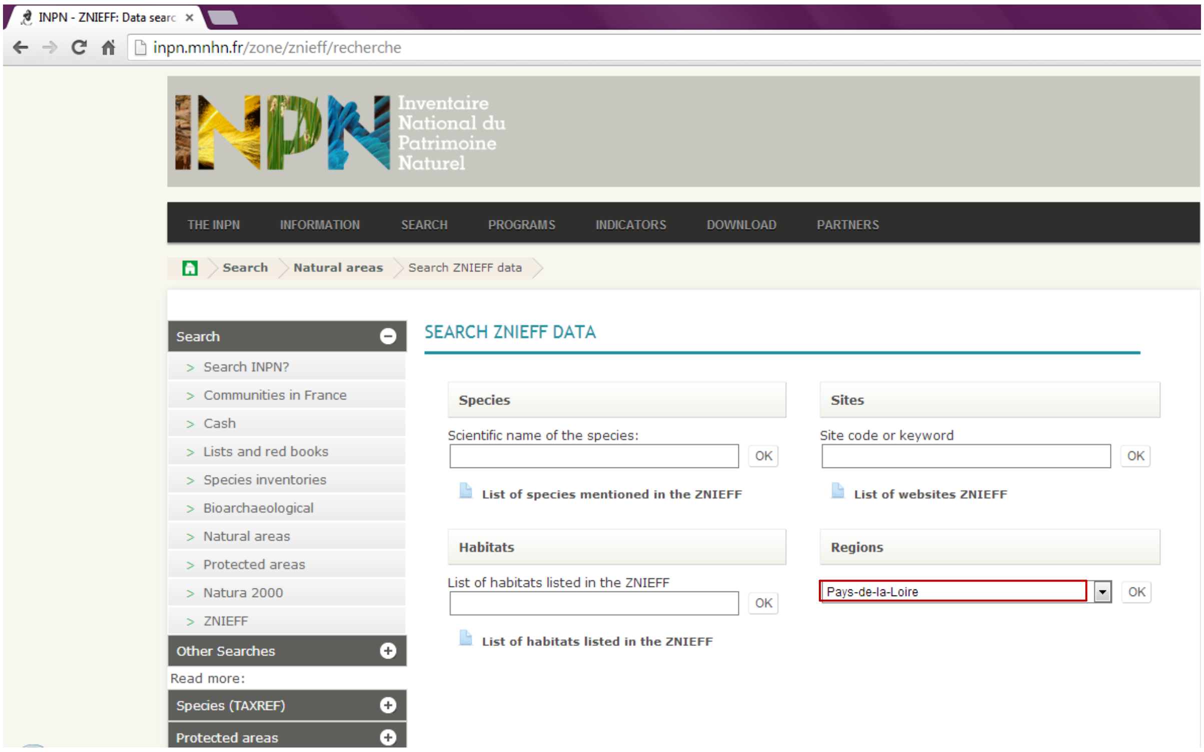
Online inventories can be searched on the INPN website, which for natural areas includes their designated Natural Areas of Ecological Fauna and Flora (ZNIEFFs), Natura 2000 sites (European-wide preservation sites) and protected areas which included national parks, reserves, Ramsar sites etc. One is also able to search for species present or otherwise in regions, departments and communes, but this generates impractically large species lists. Following detailed investigation of the INPN website, for the purposes of this research the ZNIEFFs present in France were further investigated, as these provided adequate species lists (at a more manageable level) for all taxa, including plants.

The ZNIEFF inventory was launched in 1982 with the aim to identify and describe areas with strong biological capabilities and a good state of conservation. They are classified into two types:

- ZNIEFF type I: areas of great biological or ecological interest;
- ZNIEFF type II: large, rich natural assemblages which have been little modified, offering important biological potential.

There are nearly 15,000 zones across the whole of the French territory (12915 type I and 1921 type II), and the inventory is now a major consideration in nature protection policies and must be consulted in spatial planning projects (National Museum of Natural History, 2013).

With so many ZNIEFFS across France, the search for relevant data was narrowed by looking at those locations present within the Pays de la Loire region (see figure 9.1 for screenshot). By translating the search page into English, key words in the title of the ZNIEFFs could be searched for, including woods, forest, meadow, heathland, grassland etc. The resulting ZNIEFFs, based on the latitude/longitude provided, were investigated to see whether they were suitable for further study. If there were no plant species data available then those sites were rejected, but otherwise the ZNIEFFs relevant plant species data was downloaded - this included a list of key species.



<u>Figure 9.1</u> Screenshot of INPN website and ZNIEFF search

After exploring the ZNIEFFs, sites were accepted only if they were situated within or near the cluster of grid squares which had a climate match of 7 or 8 months. Three of the four sites visited in Angers (section 9.1) were actually part of ZNIEFFs themselves, and so the relevant data was downloaded. The details and location of all the sites for which data had been collected (including data from those visited and online data) can be seen in table 9.1, and figure 9.2 shows an enlarged image of the grid squares in France and the locations of the ZNIEFFs and the one non-ZNIEFF site.

The species present in the ZNIEFFs which are already included in the planting lists at EQ will be adapted to the future climate and hence appropriate for planting, whereas those that are not matched will require further assessment regarding their suitability.

Table 9.1 Details and location of the sites with data collection

ZNIEFF (type)	**Latitude/ Longitude**	**Altitude (min – max)**	**No. of months matched**
Longuenee Forest (II)* ▲	47.56°, -0.75°	72-103m	8
Chandelais Forest (II)* ■	47.51°, -0.03°	65-101m	6
Small Meadow (I) ●	47.35°, -0.54°	70-73m	8
Wood, Moors & Peat Bogs of Chaumont-D'Anjou (II)* ◆	47.54°, -0.29°	36-80m	7
Wood and heathland between Gennes and Cunault (II) ▼	47.31°, -0.22°	58-91m	6
Non-ZNIEFF			
Etang St.Nicolas* ✦	47.48, -0.59	41	8

*parts of these habitats were visited during the site visits

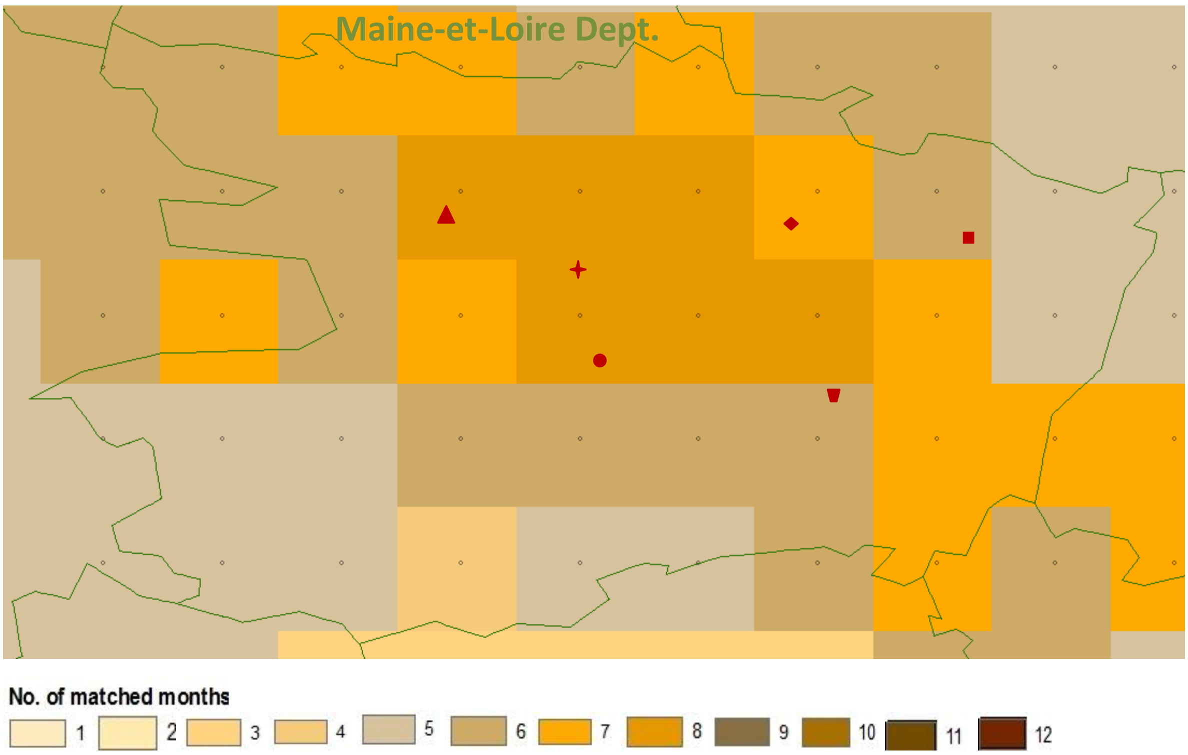


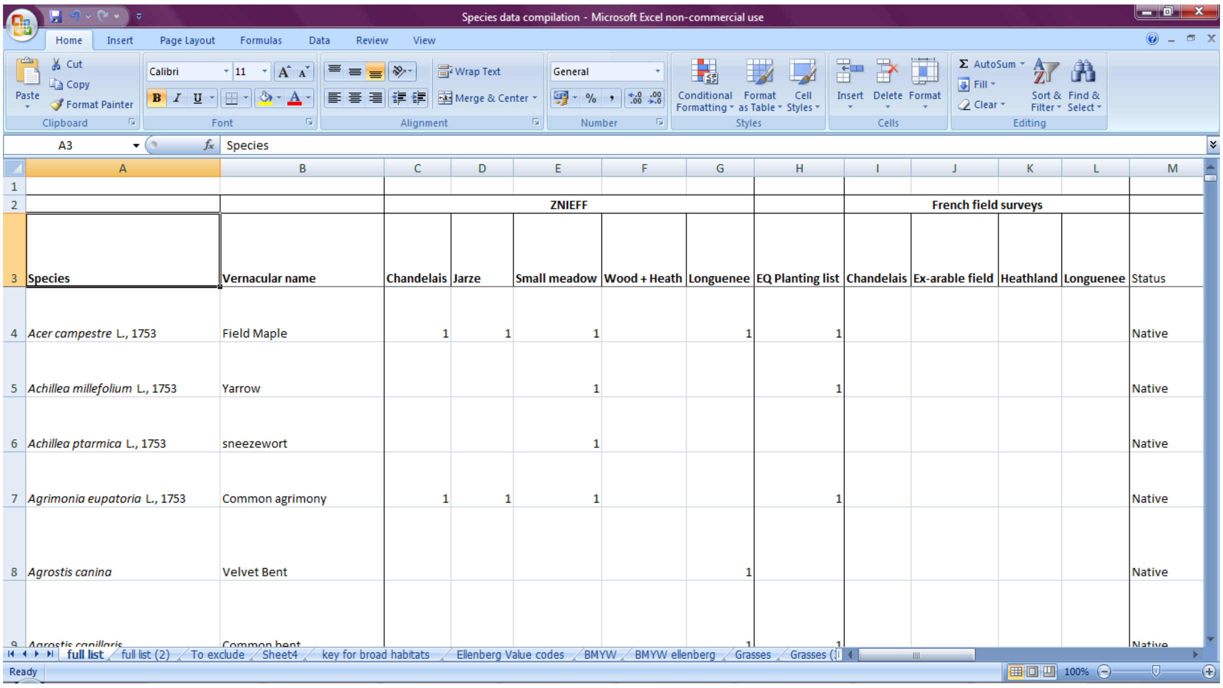
Figure 9.2 The locations of the 6 sites in the Maine-et-Loire where species data (from both site visit and online) was collected from (see table 9.1 for red symbol key)

9.4 Ecological Characteristics of EQ Species

The ecological characteristics of the species listed for planting at EQ were input into an Excel spreadsheet as a way of classifying the data and for assessing the species' traits. The range of characteristics input included: status; world distribution; northern limit in Britain; broad habitat class; Ellenberg values for light, moisture, nitrogen, reaction; January and July mean temperatures; annual precipitation; count of 10km squares in Great Britain, response to frost, both seedlings and non-woody tissue; response to drought; aspect and conservation status. These characteristics were accessed from various sources, including the Ecological Flora of the British Isles database (Fitter and Peat 1994), which is funded by the British Ecological Society (BES) and NERC, the Online Atlas of the British Flora (BSBI, 2013), whose contributions include BSBI and JNCC, and the vascular plant red data list (Dines *et al.*, 2005). However, not all the characteristics listed above were available for every plant species.

9.5 Data Compilation

The data gathered from the field work, the online resources and the EQ planting list were subsequently compiled into one spreadsheet and sorted alphabetically. Columns included the various locations and a '1' was used to identify if a particular species was present in that location, as shown in figure 9.3. Once duplicate species were removed, 498 species remained. The status of the species was also recorded to see if the French species are native in the British Isles, as well as their conservation status, if any. Species which are present in France, but on the WCA schedule 9 (e.g. Canadian waterweed), noxious weeds on the Weeds Act 1959 listing (e.g. Common Ragwort), and invasive species like Japanese Knotweed etc., were also noted on the spreadsheet, as the French genotype of the species may share similar characteristics. Species also in decline, on the red data waiting lists, or species with a particular habitat niche were also flagged up, as these may not be suitable for development site planting or be unlikely to establish.



Species	Vernacular name	ZNIEFF						French field surveys				
		Chandelais	Jarze	Small meadow	Wood + Heath	Longuenee	EQ Planting list	Chandelais	Ex-arable field	Heathland	Longuenee	Status
Acer campestre L., 1753	Field Maple	1	1	1		1	1					Native
Achillea millefolium L., 1753	Yarrow			1			1					Native
Achillea ptarmica L., 1753	sneezewort			1								Native
Agrimonia eupatoria L., 1753	Common agrimony	1	1	1			1					Native
Agrostis canina	Velvet Bent					1						Native
Agrostis capillaris	Common bent					1	1					Native

Figure 9.3 Screenshot of data compilation from all sites

9.6 Data Sort

The INPN use the CORINE biotopes classification system to describe the communities present within the ZNIEFFs, even though they have now been superseded. For a particular ZNIEFF the main biotopes or 'critical environments' are listed, along with other environments, with there typically being more than one community type within a ZNIEFF. The percentage cover of these biotopes is given, but the plant species listed are not differentiated into the communities they fall within. On further investigation of these classified habitats types on the CORINE biotopes database, it was found that characteristic species are seldom listed in their description. The species lists could therefore not separated into their relevant communities.

As a form of classifying the species into habitat types, the JNCC terrestrial and freshwater biodiversity Broad Habitat Classifications were used, of which there were 20 relating to the species data set. These classifications were developed by the UK Biodiversity Group in 1998. In creating the priority habitats and species as part the UK's commitment to biodiversity, they needed to be set within the context of the UK's land surface and marine environments, and thus the broad habitats, defined in report 307 (Jackson, 2000), were produced. The report contains correspondence tables between the broad habitats and the EC Habitats Directive Annex I habitat types, and in most cases several EC classified habitats fall under one JNCC broad habitat, which indicates how broad these classifications are. Although the JNCC classification system is for UK species, as the classifications are broad, it has been assumed that French species would be allocated similar appropriate habitat classifications.

To narrow the species set to contain only species which are found in habitats typically created on development sites, and in this case at EQ, four category habitats were created – woodland, grassland, hedgerows and aquatic. Table 9.2 shows the broad habitats which have been assigned to these four categories and consequently applied to the species data set. Some species belong to more than type of habitat type and will therefore appear in multiple lists.

Table 9.2 The allocation of Broad Habitats into habitat categories

Habitat category	**Broad Habitat**
Woodland	Broadleaved, mixed and yew woodland (BMYW)
Grassland	Acid grassland (AG) Calcareous grassland (CG) Neutral grassland (NG)
Hedgerows (linear features)	Boundary and linear features (BLF)
Aquatic and marginal	Fen, marsh and swamp (FMS) Standing water and canals (SWC)

9.6.1 Ellenberg Values

To further narrow the species set to create potential species assemblages for EQ, it was decided to use the Ellenberg indicator values to enable the organisation of the data into relevant species groups. Ellenberg (Ellenberg *et al.*, 1991) in classifying the ecological requirements and grouping of species, derived 7 indicator values (see Table 9.3) for nearly 2000 vascular plants across Central Europe. In the Ellenberg system, each species is assigned a value for each factor representing their ideal position along an environmental gradient, based on where it is most abundant, i.e. its realised ecological niche. For most of the factors, the values are over a 9 point scale where for each factor '1' signifies a low value and '9' a very high value (See table 9.3). A study by Hill and Carey (1997) comparing experimental treatments of annual yield with Ellenberg Nitrogen values (N) (i.e. for productivity), found them to be well correlated and that the use of such values was acceptable.

Most species can tolerate a wide range of conditions, but Ellenberg lists provide a species ideal. Different factors are more important for different species/communities, for example *Melampyrum pratense* is able to tolerate both acidic and limestone soils (R) as long as other factors, in this instance light availability (L), are high, and that the habitat is sparsely occupied (Ellenberg, 1988). The presence of competitors does however play a deciding role in the composition of the community, particularly in woodlands and meadows.

Table 9.3 Ellenberg indicator values and their gradient (Ellenberg, 1988; Hill and Carey, 1997)

Factor	Gradient
Light value (L)	Occurrence in relation to the relative light intensity = R.L 1 = plant in deep shade 9 = plant in full light, found mostly in full sun
Temperature (T)	Occurrence in the temperature gradients from the Mediterranean to the Arctic and from lowland to alpine levels 1 = Cold indicator plants, found only in high mountains or in the boreal-arctic regions 9= Indicate extreme warm conditions, spreading only into the warmest sites in Central Europe from the Mediterranean.
Continentality (K)	Occurrence in the gradient from the Atlantic coast to the inner parts of Eurasia 1 = Extreme oceanic, only in a few outposts of Central Europe 9 = Extreme continental
Moisture value (F)	Occurrence in the gradient from dry shallow-soil rocky slopes to marshy ground; also from shallow to deep water 1 = indicator of extreme dryness, restricted to soils that often dry out for some time 12 = submerged plant, permanently or almost constantly under water
Reaction value (R)	Occurrence in the gradient of soil acidity and lime content 1 = indicator of extreme acidity, never found on weakly acid or basic soils 9 = indicator of basic reaction, always found on calcareous or other high pH soils
Nitrogen value (N)	Occurrence in the gradient of available nitrogen during the growing period 1 = indicator of extremely infertile soils (low in available mineral nitrogen NH_4 and NO_3) 9 = indicator of extremely fertile situations
Salt tolerance (S)	0 = absent from saline sites 9 = species of extremely saline conditions

Of the available sources for understanding the ecological requirements of plants, Ellenbergs are known to be one of the most useful (Firbank *et al.*, 2000) and have been used across central Europe as well as outside the defined region for which they were developed (Thimonier *et al.*, 1994; Diekmann, 1995), although some have argued their inappropriateness when used in these instances (Hill *et al.*, 2000). They have been utilised in many studies from monitoring change in British vegetation (Firbank *et al.*, 2000), to assessing the needs of a vegetation class or species group (Hill and Carey, 1997). With there being numerous species in common across north-western Europe, and the 'relatively similar latitudinal distribution' there use across Europe, to some extent has been justified (Godefroid and Dana, 2007). However, in some cases the values have been recalibrated to reflect the situation in different countries, as has been done for the British Isles (Hill *et al.,* 2000) and France (Julve, 2013). Hill *et al*. (2000) states that:

"several species have differing ecological requirements across their range, so that some degree of alteration of the central European values to take account of local preferences is inevitable".

The French Ellenberg values have been used in this research to classify the French species, and were accessed through the Base Floristic (Baseflor) online database (Julve, 2013). There are obviously discrepancies between the requirements of plants in the different countries, but with the aim to create habitats from analogous climate locations, i.e. France, it was decided that the French values would be the most appropriate as the species currently exist in that particular climate and environment. Four of the seven indicator values were deemed relevant and used in the research – moisture (F), reaction (acidity) (R), nitrogen (N) and relative light intensity (L). These values are particularly important for plant growth, for reasons discussed in section 9.6.2, but temperature (T) and continentality (K) are not suitable for an oceanic climate like that of Britain (Hill *et al.*, 2004) they are more geographical qualities than climatic, and were therefore not used. Given that EQ and the sites in France are generally not affected by salt intrusion, the Ellenberg salinity values were also not considered.

9.6.2 Factors important for plant growth

As already discussed, different species and communities have different requirements, so the habitat categories in the spreadsheet were filtered on the Ellenberg values to produce species lists. The 3 soil variables – moisture (F), reaction (acidity) (R) and nitrogen (fertility) (N) are important factors for plant growth and are interlinked to some extent. A plant can obtain nutrients from the weathering of the parent material, or deposited from another source, or by plant decay, decomposition and bacterial action (Money, 1972). Climatic conditions affect the moisture of the soil and the weathering processes. The acidity of the soil influences the availability of certain nutrients, and the attenuation properties of the soil dictate the availability of water for plants; good soil moisture improves nutrient uptake (Ashman and Puri, 2002). Ellenberg (1988) also states that fertility is 'more or less correlated with the acidity'.

The Ellenberg values for the four factors considered (F, N, R, and L) have been categorised into the groups shown in Table 9.4, and the species sorted accordingly. The value ranges specified have been used to allow for natural tolerances and variations in niche. For each habitat category the species have been sorted depending on the habitat's requirements, using Ellenberg values, as discussed in the next four sections.

Table 9.4 Ellenberg value groups based on a likely tolerance range

Ellenberg values	**Value tolerance range**
Moisture (F)	Dry (1-3), Moist (4-6), Damp (7-9), Wet (10-12)
Nitrogen (N)	Infertile (1-3), Intermediate fertility (4-6), Fertile (7-9)
Reaction (R)	Acid (1-3), Neutral (4-6), Alkaline (7-9)
Light (L)	Shade (1-3), Semi-shade (4-6), Partial shade – full sun (7-9)

9.6.3 Grassland

Ellenberg values for moisture will be the first filter to sort the grassland habitat species. Meadow species typically like full sun light and thus they are well suited for south facing aspects, the moisture regime consequently would be dry-moist dependant on the overall climatic conditions. If wet meadows are to be created, which often depends on the site's drainage, groundwater level and locality to water sources, then the respective species can be targeted. Here it is important to consider the moisture regime for the site as future climate change will bring less precipitation over the summer for most areas.

Calcareous grasslands and acidic grasslands are BAP habitats, and are often selected for creation. Although some species can tolerate a wide range of conditions, there are specific calcicolous and calcifugous species; the meadow habitat species were therefore filtered, at the second tier, for Acidity (R). Species rich grasslands are often found on soils which are infertile (i.e. low in nutrients), as highly competitive species are unable to grow and out-compete the other plants. Therefore lists were also broken down to this level – N, to observe the ideal species for such communities.

9.6.4 Woodland

The growth and yield of trees is determined primarily by the soil conditions, in particular their moisture and fertility (Ellenberg, 1988). In competing for nutrients and water, trees which are able to reach heights are more successful as their canopy casts shade on the surrounding area. The tree component of the woodland will therefore be classified firstly by moisture (F) and then by fertility (N), but the acidity preferences (R) of trees will also be taken into account. Large shrubs (small trees) will also be included with the trees.

Trees live in an environment different from that of the understory (Ellenberg, 1988), but again water and nutrients have a deciding role in the overall composition of the latter, and therefore will be filtered accordingly. Light (L) will also be a filter as this affects the small scale distribution on the woodland floor. Ellenberg (1988) states that "there are no real woodland shrubs, that is species which flourish better in the shade than in the open. Some species however can tolerate shade quite well and are found more often in woods than in full sunlight". It may be more appropriate to plant the understory once the canopy has established, but species will naturally colonise the area.

9.6.5 Hedgerows (linear features)

Species characteristic of woodlands are also characteristic of hedgerows, and therefore this habitat type will be filtered by moisture (F), fertility (N) and then acidity (R).

9.6.6 Aquatic and Marginal

The species under this habitat type were filtered first on their moisture value (F) due to the varying gradient of moisture preferred by these plants; some plants prefer shallow water and some submerged. Fertility (N) was the next filter, based on the wetland communities typically created considering this factor e.g. mesotrophic. Acidity (R) will also be considered at the third tier.

9.7 Vegetation Results

For the grassland habitat, table 9.5 shows the species list created, including the comprehensive list, as well as the breakdown of the list based on appropriate Ellenberg values. This process has been carried out for the other 3 habitats – woodland, aquatic and marginal, and hedgerows and can be seen in appendix 3. The species lists include the variety of habitats and environmental preferences that would be appropriate for a development site. Selection of those relevant to the area would be through identifying the factor relevant to what habitat trying to achieve, e.g. calcareous search for alkaline under reaction (R).

The species lists created currently contain all the species that were in the Maine-et-Loire, including invasive species like Japanese knotweed and Canadian waterweed, they are thus not recommended for species lists. Consult CD 9.1 - on the excel sheets these species are clearly shown in red writing. Species labelled with a * or + are either a UK BAP species, Kent BAP species or have a conservation status attached to them, as can also be found in the excel sheet. With planting design guided by the BAP the non-native form of them may be appropriate to the area, but this would depend on the ecologist's expert opinion. Ash and Elm species are also on the lists, and with Ash currently banned from being imported, these species would be excluded.

Table 9.5 Grassland Species List

Complete List	**Moisture (F)**	**Reaction (R)**	**Nitrogen (N)**
	Dry	**Acid**	**Low fertility**
Agrostis vinealis	*Agrostis vinealis*	*Agrostis vinealis*	*Agrostis vinealis*
Hippocrepis comosa	*Hippocrepis comosa*	**Alkaline**	**Low fertility**
Euphorbia cyparissias	*Euphorbia cyparissias*	*Hippocrepis comosa*	*Hippocrepis comosa*
Galium verum	*Galium verum*	*Euphorbia cyparissias*	*Euphorbia cyparissias*
Helianthemum nummularium	*Helianthemum nummularium*	*Galium verum*	*Galium verum*
Rumex acetosella		*Helianthemum nummularium*	*Helianthemum nummularium*
Jasione Montana			
Luzula campestris			
Campanula rotundifolia	**Moist**	**Acid**	**Low fertility**
Hieracium pilosella,	*Rumex acetosella*	*Rumex acetosella*	*Rumex acetosella*
(*Pilosella officinarum*)	*Jasione Montana*	*Jasione Montana*	*Jasione Montana*
Myosotis discolour	*Luzula campestris*	*Luzula campestris*	*Luzula campestris*
Hypochaeris radicata	*Campanula rotundifolia*	**Neutral**	**Low fertility**
*Potentilla argentea**	*Hieracium pilosella* (*Pilosella officinarum*)	*Campanula rotundifolia*	*Campanula rotundifolia*
Juniperis communis+	*Myosotis discolor*	*Hieracium pilosella* (*Pilosella officinarum*)	*Hieracium pilosella* (*Pilosella officinarum*)
Polygala serpyllifolia	*Hypochaeris radicata*	*Myosotis discolor*	*Myosotis discolor*
Deschampsia flexuosa	*Potentilla argentea**	*Hypochaeris radicata*	*Hypochaeris radicata*
Galium saxatile	*Juniperis communis+*	*Potentilla argentea**	*Potentilla argentea**
Danthonia decumbens	*Polygala serpyllifolia*	*Juniperis communis+*	*Juniperis communis+*
Lathyrus linifolius var. Montanus	*Deschampsia flexuosa*	*Polygala serpyllifolia*	*Polygala serpyllifolia*
Carex pilulifera	*Galium saxatile*		
Veronica officinalis			

Euphrasia nemorosa *Potentilla erecta* *Luzula multiflora* *Peucedanum gallicum* *Stachys officinalis* *Echium vulgare* *Orobanche minor* *Crepis capillaris* *Asphodelus albus* subsp.*Albus* *Digitalis purpurea* *Agrostis capillaries* *Anthoxanthum odoratum* *Chamaemelum nobile**+ *Stellaria graminea* *Viola riviniana* *Conopodium majus* *Festuca rubra* *Linaria repens* *Vicia hirsuta* *Holcus lanatus* *Achillea millefolium* *Malva moschata* *Cynosurus cristatus* *Phleum pratense* *Veronica chamaedrys* *Bellis perennis* *Gaudinia fragilis* *Odontites vernus* subsp.*vernus* *Plantago lanceolata* *Rumex acetosa* *Trifolium repens* *Vicia sativa* subsp *Nigra* *Leontodon saxatilis* subsp.*saxatalis*	*Danthonia decumbens* *Lathyrus linifolius var. montanus* *Carex pilulifera* *Veronica officinalis* *Euphrasia nemorosa* *Potentilla erecta* *Luzula multiflora* *Peucedanum gallicum* *Stachys officinalis* *Echium vulgare* *Orobanche minor* *Crepis capillaris* *Asphodelus albus* subsp.*Albus* *Digitalis purpurea* *Agrostis capillaris* *Anthoxanthum odoratum* *Chamaemelum nobile**+ *Stellaria graminea* *Viola riviniana* *Conopodium majus* *Festuca rubra* *Linaria repens* *Vicia hirsuta* *Holcus lanatus* *Achillea millefolium* *Malva moschata* *Cynosurus cristatus* *Phleum pratense* *Veronica chamaedrys* *Bellis perennis* *Gaudinia fragilis* *Odontites vernus* subsp.*vernus* *Plantago lanceolata*	*Deschampsia flexuosa* *Galium saxatile* *Danthonia decumbens* *Lathyrus linifolius var. montanus* *Carex pilulifera* *Veronica officinalis* *Euphrasia nemorosa* *Potentilla erecta* *Luzula multiflora* *Peucedanum gallicum* *Stachys officinalis* *Echium vulgare* *Orobanche minor* *Crepis capillaris* *Asphodelus albus* subsp.*Albus* *Digitalis purpurea* *Agrostis capillaris* *Anthoxanthum odoratum* *Chamaemelum nobile**+ *Stellaria graminea* *Viola riviniana* *Conopodium majus* *Festuca rubra* *Linaria repens* *Vicia hirsuta* *Holcus lanatus* *Achillea millefolium* *Malva moschata* *Cynosurus cristatus* *Phleum pratense* *Veronica chamaedrys* *Bellis perennis* *Gaudinia fragilis* *Odontites vernus*	*Deschampsia flexuosa* *Galium saxatile* *Danthonia decumbens* *Lathyrus linifolius var. montanus* *Carex pilulifera* *Veronica officinalis* *Euphrasia nemorosa* *Potentilla erecta* *Luzula multiflora* *Peucedanum gallicum* *Stachys officinalis* **Medium fertility** *Echium vulgare* *Orobanche minor* *Crepis capillaris* *Asphodelus albus* subsp.*Albus* *Digitalis purpurea* *Agrostis capillaris* *Anthoxanthum odoratum* *Chamaemelum nobile**+ *Stellaria graminea* *Viola riviniana* *Conopodium majus* *Festuca rubra* *Linaria repens* *Vicia hirsuta* *Holcus lanatus* *Achillea millefolium* *Malva moschata* *Cynosurus cristatus* *Phleum pratense* *Veronica chamaedrys* *Bellis perennis*

Hypericum perforatum *Leucanthemum vulgare* *Trifolium dubium* *Daucus carota* *Lolium perenne* *Prunella vulgaris* *Ranunculus acris* *Trifolium pratense* *Vicia sepium* *Ranunculus paludosus* *Scorzonera humilis** *Plantago coronopus* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Cirsium arvense* *Dactylis glomerata* *Senecio sylvaticus* *Heracleum sphondylium* *Poa annua* *Vicia sativa* *Sanguisorba minor* *Filipendula vulgaris* *Geranium sanguineum* *Agrimonia eupatoria* *Bromus hordeaceus* *Linaria vulgaris* *Pastinaca sativa* *Origanum vulgare* *Brachypodium pinnatum* *Fragaria vesca* *Lathyrus pratensis* *Orchis mascula* *Galium mollugo* *Tragopogon pratensis* *Lithospermum*	*Rumex acetosa* *Trifolium repens* *Vicia sativa* subsp *Nigra* *Leontodon saxatilis* subsp.*saxatalis* *Hypericum perforatum* St.John's Wort *Leucanthemum vulgare* *Trifolium dubium* *Daucus carota* *Lolium perenne* *Prunella vulgaris* *Ranunculus acris* *Trifolium pratense* *Vicia sepium* *Ranunculus paludosus* *Scorzonera humilis** *Plantago coronopus* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Cirsium arvense* *Dactylis glomerata* *Senecio sylvaticus* *Heracleum sphondylium* *Poa annua* *Vicia sativa* *Sanguisorba minor* *Filipendula vulgaris* *Geranium sanguineum* *Agrimonia eupatoria* *Bromus hordeaceus* *Linaria vulgaris* *Pastinaca sativa* *Origanum vulgare* *Brachypodium pinnatum*	subsp.*vernus* *Plantago lanceolata* *Rumex acetosa* *Trifolium repens* *Vicia sativa* subsp *Nigra* *Leontodon saxatilis* subsp.*saxatalis* *Hypericum perforatum* St.John's Wort *Leucanthemum vulgare* *Trifolium dubium* *Daucus carota* *Lolium perenne* *Prunella vulgaris* *Ranunculus acris* *Trifolium pratense* *Vicia sepium* *Ranunculus paludosus* *Scorzonera humilis** *Plantago coronopus* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Cirsium arvense* *Dactylis glomerata* *Senecio sylvaticus* *Heracleum sphondylium* *Poa annua* *Vicia sativa* **Alkaline** *Sanguisorba minor* *Filipendula vulgaris* *Geranium sanguineum* *Agrimonia eupatoria*	*Gaudinia fragilis* *Odontites vernus* subsp.*vernus* *Plantago lanceolata* *Rumex acetosa* *Trifolium repens* *Vicia sativa* subsp *Nigra* *Leontodon saxatilis* subsp.*saxatalis* *Hypericum perforatum* St.John's Wort *Leucanthemum vulgare* *Trifolium dubium* *Daucus carota* *Lolium perenne* *Prunella vulgaris* *Ranunculus acris* *Trifolium pratense* *Vicia sepium* *Ranunculus paludosus* *Scorzonera humilis** *Plantago coronopus* **High fertility** *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Cirsium arvense* *Dactylis glomerata* *Senecio sylvaticus* *Heracleum sphondylium* *Poa annua* *Vicia sativa* **Low fertility** *Sanguisorba minor* *Filipendula vulgaris* *Geranium sanguineum*

officinale _Cardamine pratensis_ _Potentilla reptans_ _Arrhenatherum elatius_ _Cruciata laevipes_ _Cirsium vulgare_ _Viola odorata_ _Carex hirta_ _Lobelia urens_ _Gentiana pneumonanthe_ _Succisa pratensis_ _Juncus effusus_ _Bromus racemosus_ _Deschampsia cespitosa_ _Lysimachia nummularia_ _Blackstonia perfoliata_ _Ranunculus repens_ _Rumex crispus_ _Alopecurus pratensis_ _Poa trivialis_ _Silaum silaus_ _Equisetum ramosissimum_ _Anacamptis laxiflora_ _Fritillaria meleagris_* _Festuca arundinacea_ _Oenanthe silaifolia_* _Pulicaria dysenterica_ _Agrostis stolonifera_ _Alopecurus geniculatus_ _Potentilla anserine_ _Mentha pulegium_*+ _Ranunculus sardous_	_Fragaria vesca_ _Lathyrus pratensis_ _Orchis mascula_ _Galium mollugo_ _Tragopogon pratensis_ _Lithospermum officinale_ _Cardamine pratensis_ _Potentilla reptans_ _Arrhenatherum elatius_ _Cruciata laevipes_ _Cirsium vulgare_ _Viola odorata_ _Carex hirta_ **Damp** _Lobelia urens_ _Gentiana pneumonanthe_ _Succisa pratensis_ _Juncus effuses_ _Bromus racemosus_ _Deschampsia cespitosa_ _Lysimachia nummularia_ _Blackstonia perfoliata_ _Ranunculus repens_ _Rumex crispus_	_Bromus hordeaceus_ _Linaria vulgaris_ _Pastinaca sativa_ _Origanum vulgare_ _Brachypodium pinnatum_ _Fragaria vesca_ _Lathyrus pratensis_ _Orchis mascula_ _Galium mollugo_ _Tragopogon pratensis_ _Lithospermum officinale_ _Cardamine pratensis_ _Potentilla reptans_ _Arrhenatherum elatius_ _Cruciata laevipes_ _Cirsium vulgare_ _Viola odorata_ _Carex hirta_ **Acid** _Lobelia urens_ **Neutral** _Gentiana pneumonanthe_ _Succisa pratensis_ _Juncus effuses_ _Bromus racemosus_ _Deschampsia cespitosa_ _Lysimachia nummularia_ _Blackstonia perfoliata_	**Medium fertility** _Agrimonia eupatoria_ _Bromus hordeaceus_ _Linaria vulgaris_ _Pastinaca sativa_ _Origanum vulgare_ _Brachypodium pinnatum_ _Fragaria vesca_ _Lathyrus pratensis_ _Orchis mascula_ _Galium mollugo_ _Tragopogon pratensis_ _Lithospermum officinale_ _Cardamine pratensis_ _Potentilla reptans_ **High fertility** _Arrhenatherum elatius_ _Cruciata laevipes_ _Cirsium vulgare_ _Viola odorata_ _Carex hirta_ **Low fertility** _Lobelia urens_ **Low fertility** _Gentiana pneumonanthe_ _Succisa pratensis_ **Medium fertility** _Juncus effuses_ _Bromus racemosus_ _Deschampsia cespitosa_ _Lysimachia_

	Alopecurus pratensis *Poa trivialis* *Silaum silaus* *Equisetum ramosissimum* *Anacamptis laxiflora* *Fritillaria meleagris** *Festuca arundinacea* *Oenanthe silaifolia** *Pulicaria dysenterica* *Agrostis stolonifera* *Alopecurus geniculatus* *Potentilla anserina* *Mentha pulegium**+ *Ranunculus sardous*	*Ranunculus repens* *Rumex crispus* *Alopecurus pratensis* *Poa trivialis* --- **Alkaline** *Silaum silaus* *Equisetum ramosissimum* *Anacamptis laxiflora* *Fritillaria meleagris** *Festuca arundinacea* *Oenanthe silaifolia** *Pulicaria dysenterica* *Agrostis stolonifera* *Alopecurus geniculatus* *Potentilla anserina* *Mentha pulegium**+ *Ranunculus sardous*	*nummularia* *Blackstonia perfoliata* --- **High fertility** *Ranunculus repens* *Rumex crispus* *Alopecurus pratensis* *Poa trivialis* --- **Low fertility** *Silaum silaus* --- **Medium fertility** *Equisetum ramosissimum* *Anacamptis laxiflora* *Fritillaria meleagris** *Festuca arundinacea* *Oenanthe silaifolia** *Pulicaria dysenterica* *Agrostis stolonifera* *Alopecurus geniculatus* --- **High fertility** *Potentilla anserina* *Mentha pulegium**+ *Ranunculus sardous*

There are 25 species without Ellenberg values, listed next, and these would be shown to the ecologist for inspection for suitability

No Ellenberg Values:

Aira praecox

Aphanes australis

Bromus hordeaceus subsp. *hordeaceus*

Cardamine pratensis L. subsp. *pratensis*

Cerastium fontanum

Dactylorhiza fuchsii

Daucus carota L.subsp. carota

Erodium cicutarium

Geranium columbinum

Herniaria glabra

Leontodon hispidus

Lotus corniculatus L. subsp*. corniculatus*

Lotus corniculatus

Luzula multiflora (Ehrh.) Lej. subsp. multiflora

Medicago lupulina

Ornithopus perpusillus

Primula veris

Ranunculus bulbosus

Saxifraga granulata

Taraxacum campylodes

Taraxacum erythrospermum

*Teesdalia nudicaulis**

Trifolium arvense

Trifolium subterraneum

Vicia sativa subsp*. Sativa*

Table 9.6 summarises the vegetation data across the 4 habitats, including a column for those native species in the UK, currently recommended for EQ, that respond to drought. See CD 9.1 and the excel sheets within the workbooks to identify which species are referred to in table 9.6. If a species has a conservation status this can also be observed. A blank square indicates no data was available, in relation to Ellenberg and native status.

Table 9.6 Vegetation data summary for the habitats recommended

Habitat	Sort criteria	No. species found	Native to GB	No. new species	Currently recommended for EQ	EQ species response to drought
Woodland (Trees)	1st F 2nd N 3rd R	31	23	4	16	2 resist, 1 wilts and recovers
Woodland (Under-storey)	1st F 2nd N 3rd R 4th L	78	72	4	8	1 wilts and recovers, 1 wilts
Grassland	1st F 2nd R 3rd N	144	131	5	22	4 resist, 1 wilts & recovers, 1 wilts & dies
Hedgerows	1st F 2nd N 3rd R	138	100	4	16	1 resists, 1 wilts and recovers
Aquatic and marginal	1st F 2nd N 3rd R	139	119	7	17	1 resists

Discussion

Many of the species currently growing in the Maine-et-Loire department are also native to Great Britain. However, their genotype may not be able to adapt or survive in the likely future climate, and thus species of a French provenance will be more appropriate. Apart from the new species and the native species, the rest of the species exist in the UK either as neophytes, archaeophytes or they are naturalised. The number of completely new species is relatively small, but in theory all the species are new as they are of a non-native provenance and will provide robustness to climate change.

The non-native species which are currently recommended for EQ, albeit in their native form (to GB), indicate 2 things: 1) if the species share similar characteristics then they may be able to survive future climate change, but this would all depend on the plants genes; 2) as these species were originally recommended for EQ, then it means that the visual effect wanted from the plants can still be achieved by using the non-native species, but there is the added benefit of resilience to climate change. However, those native plants which have been recorded as resistant to drought, or could recover from drought (an event which will likely become more common under climate change with drier summers as seen in the 2003 heat wave (Jolly *et al.*, 2005)), then they should ultimately be recommended for planting as they are more likely to survive than those natives which are vulnerable.

With the habitat species lists created, an experienced ecologist would be required to refine the lists and ensure the most suitable species are selected for inclusion in the final planting list. Developers normally recruit ecology consultants to take care of the biodiversity aspects of the site and advise accordingly. At this point the ecologist would select the appropriate species to be used from the analogous climate locations. This may be in combination with native species as a mosaic of species, as often this leads to increased species diversity and a greater resilience to climate change.

9.8 Conclusion

The vegetation matching process discussed, albeit novel, aims to provide resilience to species list, which may be achievable with current native species recommendations.

As there is no habitat classification system or one that details the associated plant species across Europe, an alternative approach has been devised, which, although requires little plant knowledge, considers the environmental preferences of the species. An expert ecologist is essential to ensure the planting lists created are appropriate to the environment, based on their extensive field knowledge.

In terms of the case study approach, the Ellenberg values have been recalibrated for several European countries, but this has not been done for Spain. In determining if the Ellenberg calibrations for Italy and Greece could be used in other Mediterranean regions, Godefroid and Dana (2007) believe that this would not be ideal. If Spain turned out to be a suitable match for a development site's climate projections, then an alternative method would need to be employed. An expert ecologist would also be consulted for advice on the best course of action. A case-by-case approach is therefore the best way to deal with the likely variation in vegetation matching that would be encountered across the continent.

10. Discussion

Through the use of published climate change model output data, the future climate at specific UK development sites was predicted. Subsequently, through the use of a GIS, the predicted rainfall and temperature were matched to locations in Europe, which currently experience similar meteorological conditions. Theoretically, the vegetation present at these locations would be suitable for compiling a planting list for development sites that would be resilient to climate change. This premise was explored through considering the EQ case study.

10.1 Introduction

The vegetation selected for the case study site at EQ, as discussed in chapter 9, has created a list of species which considers both the climatic and environmental preferences in anticipation that the species population will survive and flourish at the development site, increasing resilience to climate change. This chapter will identify the implications of the research within its field, as well as the limitations of the research outcomes.

10.2 Issues Surrounding the Research

10.2.1 Non-native Species

Advocating certain non-native species to be used in development site planting lists, would essentially be assisted colonisation, which goes against conventional conservation practices. When it occurs, the introduction of non-natives is typically only carried out for rare or threatened species on the edge of extinction. However, in the face of climate change such limited practices may result in biodiversity loss of a much wider range of species, i.e. more than those rare/threatened, particularly if climate projections surpass 3°C (Hoegh-Guldberg *et al.*, 2008). The use of non-natives outside their native range does bring with it the added risks, for example of invasion, as species may lose their natural enemies, such as pests, predators and diseases, typically found in their native environment (Defra, 2003; Hulme, 2009b).

Not all non-native species manage to establish when they are introduced, and many do not become invasive; only a minority have a significant negative effect, and this tends to be at the local scale in Britain as oppose to the landscape scale (Carey *et al.*, 2008). There are many long-established non-native species which provide substantial social and economic benefits, including the use of species in agricultural, horticultural and forestry activities, amongst other sectors (Defra, 2003). Many are valued by society and now exist as part of the native scenery. The majority of established non-native species in GB are higher plants (1,377 out of 1,875) (Roy *et al.*, 2012), which is not surprising when over 70,000 different types of non-native plants are grown in Britain, many of which can be purchased in garden centres (Plantlife, 2010).

A species potential for invasion can be assessed using a decision framework; it would highlight those species of a high risk and those which are safe, through the assessment of various traits. Where factors which make up such a framework include experimental trials, they have been questioned (Ruesink *et al.*, 1995), as this would be costly and time consuming given the vast numbers of species introduced or imported annually. Assuming all non-natives are invasive, i.e. guilty till proven innocent, would affect a range of global markets and is impractical. Other frameworks developed to assess risk have looked at the available data on a species including the species characteristics (Ruesink *et al.*, 1995), since a good predictor of a species capability for invasion is if it has successfully invaded other parts of the world (Williamson, 1999).

The horticultural trade contributes greatly to plant invasions through the number of species which escape cultivation. Dehnen Schmutz (2011) has therefore proposed a 'green list' for ornamental species, i.e. species which are less likely to escape cultivation, with the aim to target large scale planting and landscaping projects. The list would detail species that have undergone a risk assessment based on four factors – residence time, propagule pressure, no previous invasion elsewhere, and hardiness. The IUCN guidelines (2012) for planned introductions also recommend assessing the likelihood of the species reaching numbers that may pose a threat to the environment, and the probability of invasion into other habitats. In relation to this research, it is recommended that the species selected for new planting schedules resilient to climate change, be subject to some form of risk assessment. This would screen out any likelihood of invasiveness and re-assure developers, planners etc that the plants have been screened and are unlikely to cause damage to the surrounding environment.

Plantlife (2010), a wild plant conservation charity, have also devised a rapid risk assessment screening process for quickly assigning a broad level of invasive threat to a non-native plant. This process has been applied to nearly 600 plants that are grown or sold in the UK or are present at the moment but not yet widespread in the wild. The system is based on the internationally well-received tool for invasive threat detection - the Australian Weed Risk Assessment. Those identified under the risk assessment system as critical or urgent, i.e. on the brink of becoming invasive, are flagged for further investigation. Plantlife states that that these plants are 'likely to become a major established pest in the coming decades...becoming a major nuisance in years to come'. In their list of 'ones to watch' there are species which are currently on planting lists for development sites in the UK, including Tree of Heaven (*Ailanthus altissma*), and clearly the use of such species needs to be avoided and planting lists rethought.

Potentially invasive species present in the assemblages created during this research could include purple loosestrife which although non-invasive in the UK, is invasive in the US (Ruesink *et al.*, 1995) and there are certain families (e.g. the Poaceae and Asteraceae in plants) and genera (e.g. Bromus, Cirsium, Poa) that contain many species which are problematic globally (Mack, 1996). Wild Oat (*Avena fatua*), which was present in the French habitats, is also one of the five species to which a third of the costs for dealing with established invasive non-natives is targeted (Hulme, 2013). These species would need to be risk assessed prior to their introduction.

A further potential problem with the importation of non-native species is the potential for the introduction of diseases, currently not present in the UK. Dutch Elm disease was introduced from imported timber. Its second outbreak in the UK, of which was in the 1970s, created a major problem and highlighted the need for tighter regulations on imported tree stock (Everett, 2012). However, the most recent pest outbreak in 2012 has been that of Ash dieback, a disease caused by the fungal pathogen *Chalara fraxinea* affecting native Ash in recently planted woodlands across GB, nursery stock and established woodlands in southern and eastern Britain. As a result, Environment Secretary Owen Paterson, in October 2012, prohibited the movement of Ash planting material (seeds, plants and trees) into and within GB. Ash, in parts of continental Europe, has been plagued with the disease since as early as the 1990s and it is believed to have originated from the nursery trade, highlighting failures in monitoring imported material. Other pests include the Oak Processionary moth and Red Band Needle Blight. New in 2013 was the requirement for statutory notifications for imports of Ash, Sweet Chestnut, London Plane and Oak.

The examples given above illustrate the ecological threats associated with imported non-native species. Consequently, in relation to this research, imported plant material of French provenance recommended for resilient planting assemblages in the UK should be inspected to ensure they comply with regulations, with assurance from the supplier that they are free from potential pests, and should be subject to risk assessments to ensure they do not become invasive.

10.2.2 Climate Change and Non-Natives

Climate change is driving species' range extensions, and new species have already been observed to date. For the measures in place to deal with non-native species that develop invasive characteristics, i.e. the Invasive Non-native Species Framework Strategy for GB (INNS) framework strategy, they state that there will need to be more deliberation on the topic of non-natives arriving due to a changing climate, both on the policy front as well as the science one (Defra, 2012).

Several researchers are against the idea of assisted colonisation (Davidson and Simkanin, 2008; Alyokhin, 2011) and some organisations promote a strictly native only policy in their conservation work, e.g. the RSPB, whilst others have a more flexible approach to the topic. The Woodland Trust (2008) are not opposed to non-natives, their main concern is whether the species have a detrimental impact on the environment and/or surrounding species, additional to that from climate change, a similar viewpoint is also reiterated by Davis *et al.* (2011). Good practice guidelines are available for introducing species, like that of the IUCN (2012), illustrating that such customs are acceptable.

Professor Hitchmough (2011), horticulturalist for the Olympic gardens, believes that there is a conceptual idea that we do not want to change the native flora, yet biodiversity can be maximised if a diverse range of species, including non-natives are included. He sees there is a need to challenge current conventions and believes there are benefits associated with the introduction of non-invasive non-natives. The benefits being that they flower and thus produce nectar later in the year, providing better provisions for invertebrates than most natives. Hitchmough (2011) comments that native invertebrates are not fussed whether the plant is exotic or native, and that gardens which are full of non-natives are rich in invertebrates.

The need for change and a more flexible approach in conservation management practices to allow communities to respond to climate change has been recognised by some organisations. CEH (2008), for example, remark that previous approaches for promoting diversity may not be applicable in the future and a more dynamic view will be necessary for conservation objectives. With regards to assisted migration, a case by case evaluation is recommended and should only proceed if barriers prevent a species from naturally migrating there. The spatial project, BRANCH, (discussed in section 4.12.6) made it clear that adaption measures to climate change need to be put in place to prevent species loss, given the highly fragmented landscape across north-western Europe hindering species tracking their climate space. Species from neighbouring countries would spread naturally into GB under predicted warming given that there was not a sea obstructing their path. The need for more flexibility in the Birds and Habitats Directive was also highlighted in BRANCH as conservation objectives for certain species may not be necessary if species distribution encroach on designated land.

Species from a lower latitude, as suggested for the case study development sites, are adapted to the predicted climate conditions in 2050 in the UK, and given the geographical barrier between the UK and mainland Europe which exacerbates species migration ability, assisted colonisation appears to be a feasible option, particularly for the south of England, where the impacts of climate change will likely be of a greater magnitude. As long as the habitat is suitable and matches the species' requirements, facilitation of a specie's distribution should be a success. Hoegh-Guldberg *et al.* (2008) argues that we need to 'move beyond the preservation or restoration of species and ecosystems in situ' and apply assisted colonisation given it is a low risk situation.

With the outcome of this research being resilient planting assemblages for climate change, it fulfils the requirements of various planning objectives, including adapting biodiversity for climate change (an NPPF objective), and the need to consider links between biodiversity and its response to climate change under the biodiversity duty. If local authority ecologists are involved with habitat creation for development sites, then utilisation of the lists would be seen as fulfilling part of their duty. In many instances the landscape architect develops the planting lists, so they would need to be aware of these recommendations. It was determined in the questionnaire, however, that the majority of ecologists are allowed to have an influence on the architects' selections. The utilisation of the planting assemblages however requires the acceptance of non-natives in habitat creation. Depending on the region and the authority in charge, non-natives are commonly planted on development sites, but the research aims to ensure that the species selected are appropriate and suitable to the future climate.

Calow (2009) suggested local BAP reviews should consider climate change when selecting species, as some may become vulnerable under climate change whilst others become more suitable. Drayson and Thompson (2012) in analysing 42 EIA reports, found that the majority (95%) did not consider or even mention climate change impacts in their assessments on site biodiversity, even though this is a topic discussed greatly in many publications including *England's Biodiversity Strategy*. They recommend that drought tolerant species in habitat creations could be a measure to lessen the impact. Along with the point raised here, this analysis highlights that researchers believe climate change adaption measures should be incorporated into EIAs as a way of considering biodiversity and protecting its future. Overall there are mixed attitudes to the use of non-native species, with some accepting the need for change in response to climate change, whilst others resist the idea. Current attitudes are therefore a barrier to implementing planting regimes resilient to climate change.

10.2.3 The Need to Adapt Now

The importance to consider and implement adaptive action to climate change now, has been highlighted in the forestry sector (Broadmeadow and Ray, 2005). The long time frame associated with tree life cycles, typically maturation times of 50-200 years, indicates that due thought needs to be applied to the planting decisions of today. Research has been carried out on the use of non-natives, through provenance trials, to assess the suitability of non-native provenances to the UK, primarily in relation to advising silvicultural practice, i.e. for timber production, but would also benefit woodland management for recreational purposes etc.

Although native species are recommended in forestry, as well as by many conservation bodies, non-native provenances from warmer climates may be considered, given that they are able to perform under the future climate predicted for the UK, as well as the current climate (Hubert and Cottrell, 2007). Many of the guidelines which recommend the use of local stock were created before the scale and implications of climate change were fully understood. Speculation is, however, that non-natives are likely to be maladapted to local conditions. More southerly European provenances may be susceptible to frost damage if they burst bud early (Hubert and Cundall, 2006), or as experienced in 2012 such provenances may not be able to cope with the occasional extreme precipitation patterns in the UK (Pilbeam, 2012).

10.2.3.1 Non-native genotypes

The conservation of genetic material within woodland may not equip the local population to adapt to climate change, and as the local environment changes with time the question is raised of whether local (provenance) is still best (Hubert and Cottrell, 2007). There needs to be the appropriate genetic variation within populations, as non-natives of a southerly provenance will be better adapted to the future climate and thus genetic diversification could be positive for survival of the species. It is feared however that there could be a loss of biodiversity through changes in the gene pool if related non-native and native species hybridize (Manchester and Bullock, 2000) and that stock may be less suited to the British environment or affect the species palatability to native insects (Defra, 2012). The stress caused to trees, however, as a result of climate change may make native species more susceptible to pests and diseases (Broadmeadow, 2002).

As the majority of British tree populations have migrated from glacial refugia in southern Europe, when the UK was part of mainland Europe (Hubert and Cottrell, 2007), it may mean that there are better suited genotypes unable to migrate and add to the adaptive genetic variation (increase resilience to climate change). It was also found by Petit *et al.* (2002) that UK and French stands of oak had the same chloroplast DNA haplotypes and originated from the same glacial refugium. Woodlands in the south of England may decline in diversity, as new material is prevented from migrating there, due to the English Channel, and assisted migration may be a suitable option to overcome this, increasing the chances that the woodland will prosper under impending change. As Hubert and Cottrell (2005) state:

"There is a general need to accept that there is no single answer and that the situation is a dynamic one which requires potentially different approaches through time".

The best option for a site will differ dependant on the objective. For example, if the objective was to extend or restore ancient woodland, then in comparison to planting for timber production, the use of non-native provenances would not normally be acceptable (Blakesley and Buckley, 2010).

In relation to this research the objective is to create habitats resilient to climate change on development sites, whereby practices for planting selection are less strict and often contain non-native species. Hubert and Cundall (2006) also state that it is feasible to use non-local provenances in the creation of an ecologically functional woodland. The research undertaken by the forestry sector is obviously only on trees, but these observations may be applicable to other flora as well, which would be beneficial to the aims of this research.

10.2.3.2 Provenance Trials

In trying to identify the correct provenance of tree species that would be suited to the growing conditions of the UK, and help adapt forests for climate change, trials have been carried out by numerous researchers. Where species of French provenance have performed well or poorly, this has been noted. Worrell (1992) observed only a small difference in height growth between UK and continental sessile oak provenances, in trails in the UK, and it appeared that French provenances from northwest France had slightly better form and out-performed the GB provenance. In contrast Cundall *et al.* (1993) reported that in their trials sessile oak of French seed had below average performance. Four of the five Ash trials of the same provenance conversely demonstrated good early vigour. Cundall *et al.* (1993) therefore stated:

"such inter-specific differences in patterns of genetic variation demonstrate the importance of field testing before making recommendations on the choice of provenances for forest use"

This statement has more pertinence to the forestry sector, given the economic cost associated with their trade, but trials would be recommended for the research species to test suitability of provenance selection.

Trials on pedunculate and sessile oak assessed for height at years 6-8 and 10-13 (Hubert, 2005) found that British selected seed had a consistent good measurement on most of the sites in England and Wales, near continental sources were average in performance, in contrast to the Danish and eastern European provenances which demonstrated poor performance and would consequently not be recommended. Hubert and Cundall (2006) stated that seed from northern France would be acceptable in the southern half of Britain.

Recent analysis (Pilbeam, 2012) of 3 year old saplings at a site in Kent, with different provenances of Ash, Oak, Cherry and Sweet Chestnut, as selected from the climate matching technique discussed in section 5.5, found good survival and growth across species of French provenance from predicted 2050 climates. Material from Italian provenance for predicted 2080 UK climates, however, showed poor adaption to current conditions in the UK. Pilbeam (2012) consequently recommends the French provenance material as suitable for 'buffering against climate change'. The Italian provenance material for all species except cherry had the earliest budburst date, which is typical given that certain phenotypic traits vary on a scale with latitude (Broadmeadow, 2002). The outcomes from Pilbeam's study were similar to that of Worrell's (1992) who concluded provenances greater than 4° south of the planting site demonstrated poor performance. In relation to latitude variation, the distance covered to achieve this kind of latitude difference is relatively small; Edinburgh to London represents this latitudinal extent. Plant selections for climate adaption would thus be within a small latitudinal range based on this conclusion. Overall, the analysis by Pilbeam (2012) is inconclusive given the young age of trees, and as Hubert and Cottrell (2007) remark, caution should be shown when considering provenance trials which have covered little time, as only a small part of a much larger life cycle has occurred.

Consideration of the geographical proximity of a proposed non-native species is not always priority, as if the provenance displays good phenotypic quality (Hubert, 2005), and the site conditions are matched (Hubert and Cottrell, 2007), then the likelihood of success is high.

In view of the above discussions, trials would be recommended for the species selected in the research to ensure their suitability in the UK, as the above studies only apply to trees. These experiences, however, illustrate that non-native provenance can fair well to the climate of the UK, which is essential for survival.

10.3 Evaluation of the Research

Given that certain elements of the research are highly topical subjects (e.g.: climate change modelling), there is a mass of published research available, with often advanced knowledge associated with them. There are other areas, however, where understanding is much less well developed (e.g.: vegetation migration in response to climate changes). The most current knowledge therefore, was employed at the time each aspect of this research was undertaken, and as a consequence it is recognised that there are limitations within it.

10.3.1 The Climate Data

The Baseline

The UKCP09 climate change projections relative to the 1961-1990 baseline period were employed as this was recommended by a UKCP09 user panel. For the 25km gridded data, only this baseline selection was available. With 23 years having elapsed since the end of this time frame, a certain degree of climate change has already occurred, and so the projections given may not be as accurate if they had been made relative to a more recent time frame. The degree of change in the projections should also not be referred to as from today's climate. If a linear trend is assumed then it would be possible to calculate the rate of change since the baseline period and subtract this from the projections, but this technique would add more uncertainty to the projections. It was therefore decided to use the 1961-1990 baseline.

The CRU data for the current day European values were also the average of the same time period 1961-1990, and thus do not reflect the current situation. However, by using this baseline there is consistency between the UK and European current values, and although there is a data set for the time period ending more recently 1950-2000, as discussed in the next section, the CRU data set has been used in recent studies (Doxford and Freckleton, 2012) adding to its credibility.

After carrying out this research it was discovered that there was a higher resolution data set of climate surfaces for 1950 to 2000 by Hijmans *et al.* (2005) that could have been used for the European current day climate values (the GIS layer). This data set had a resolution of approximately 1km (30 arc-seconds spatial resolution) in comparison to New *et al*.s (2002) of approximately 18km (10 arc-minutes). The comparison Hijmans *et al.* (2005) did between their data and New *et al.'*s (2002) data showed 'overall agreement, but with significant variation in some regions'. A higher resolution would be more beneficial in mountainous and other areas with steep climate gradients (Hijmans *et al.*, 2005).

Hijman *et al.'*s (2005) methods for creating global climate surfaces were similar to New *et al.* (2002), but they incorporated more climate station records with improved elevation data. Locations with few recording stations were where the main differences emerged (Hijmans *et al.*, 2005), but as station density for Europe does not appear to be low, e.g. see figure 5.4, it can be assumed that the use of Hijman *et al*.'s (2005) data in this research, based on the differences between these two data sets, would not have greatly affected the outcomes. Figure 10.1 shows that that the climate is in general similar in most regions, but there are some clear large variations. The area of interest for the research – Europe, had maximum differences in precipitation of -50 to -500mm. This should be taken into consideration when using the outcomes of this research.

Although Hijmans *et al.* (2005) data is at a higher resolution, other studies utilising surface climate over global land areas, e.g. (Thuiller *et al.*, 2005; Doxford and Freckleton, 2012), also use New *et al.*'s (2002) CRU 10' resolution data.

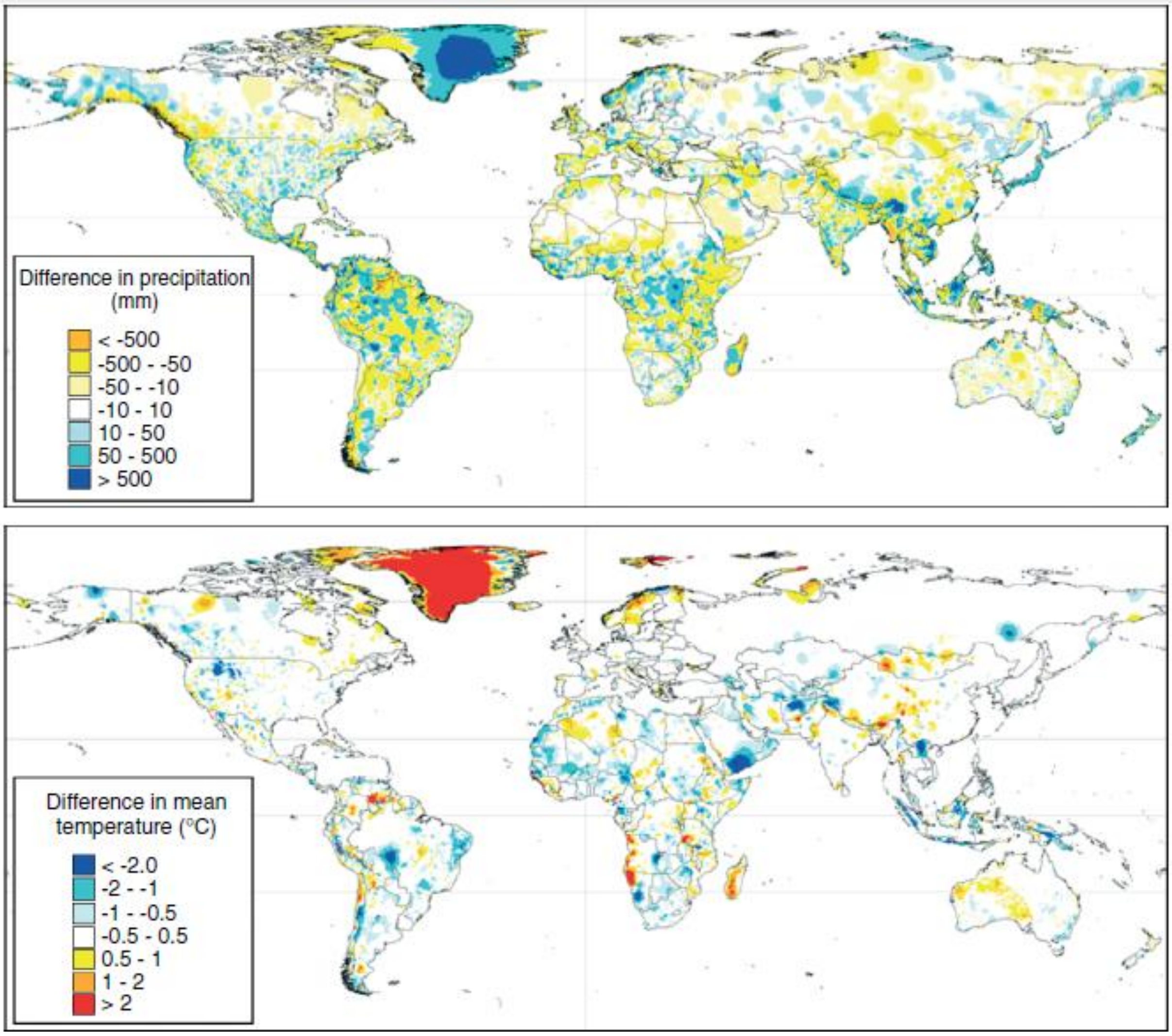


Figure 10.1 Difference between Hijmans et al. (2005) climate surfaces and those of New et al. (2002) for mean annual temperature and annual precipitation (Hijmans *et al*., 2005)

Scale

The climate projection values are at the 25km grid level which is considerably larger than the case study sites. Furthermore, given that the elevation over an area will affect the local climate, the climate projections given may not accurately reflect the future micro-climate at the case study, since the values used are an average of readings from across the 25km square. Due to the large scale inaccuracy of the climate models however, as discussed in chapter 2, there will be inherent uncertainty with the climate values, but this was the best available option at the present time.

Emission Scenario Selection

The decision to use the medium emission scenario for the climate projections was made in early 2010. However, there is now speculation that the high emission scenario pathway may be more likely, reasons for which are discussed below.

The increase rate of CO_2 emissions was 1.1% per year between 1990-1999, but this elevated to greater than 3% per year between 2000-2004 (Raupach *et al.*, 2007), a rate at which sustained would put us on an emission pathway higher than those produced in the SRES. In a study by Peters *et al.* (2012), it was found that observed emission trends are on track with SRES A1F1, A1B and A2 pathways (A1B being the scenario used in this research), but that greater mitigation efforts would be needed to curb the temperature increase within the 2°C limit and prevent even higher emission rates happening. Anderson and Bows (2008) and New *et al.* (2011) have also deduced similar findings based on global emission reduction policies.

The 400ppm atmospheric CO_2 level was recorded at the Mauna Loa Observatory in Hawaii in 2013, with a 2ppm rise in concentrations occurring every year for the last few decades (New Scientist, 2013). The pre-industrial levels were 280ppm, and in the early 20^{th} century levels were around 300ppm, rising to 350ppm in the late 1980s. This continual rise illustrates the effect man is having on the concentration of ghg in the atmosphere, and that action needs to be taken to keep these levels within reasonable limits to prevent 'dangerous' climate change and the higher emission scenarios being reached.

The US Energy Information Administration Data published in the Guardian (Guardian, 2012b), reveals that since the first Rio summit of 1992, based on 2010 figures, the world now discharges 48% more CO_2 from the consumption of energy. In 2012 the total global figure was 35.6billion tonnes.

The growth of emissions from Asia and Africa is apparent in the data; their continued consumption of fossil fuels means that non-renewables will remain to dominate the global energy mix (IEA, 2012), whilst Europe's emissions have plateaued. China's CO_2 emissions have rocketed by 240% since 1992, emitting 8.3bn tonnes of CO_2 in 2010, and producing 48% more CO_2 than the USA, who it overtook in the league charts in 2006. China is responsible for a quarter of the worlds' emissions, partly because they are one of the main consumers of coal. After a drop in emissions when the recession hit, US emissions have now resumed upward path (Peters *et al.*, 2012), illustrating the positive relationship between pollution and 'economic success' (Guardian, 2012b).

By 2035 the IEA (2012) believe renewables will become globally the main source for power generation. This will only happen, however, if enough subsidies contribute to their investment and deployment, which during the recession, declined in the UK (IEA, 2012). Interest in the future of nuclear power has been somewhat dampened since the Fukushima Daiichi catastrophe of 2011, but its role in the energy mix is still projected to increase, led by China, Korea, India and Russia. Analysis carried out by the IEA showed that unless the potential for a conversion towards global energy efficiency is realised 'two thirds of the economically viable potential to improve energy efficiency will remain unrealised through to 2035'. Energy efficiency measures are required if the lower-medium emission scenario pathways are to be realised.

The recent increase of 'fracking' in the US, the process of blasting dense rocks apart to release the fossil fuels stored within them, has raised concerns. Although this secures some of the US's energy independence, fossil fuels are being exploited to an extent which will prevent the global climate change target from being reached (Guardian, 2012a).

The thawing of permafrost in the Arctic and the release of methane trapped within it (BBC, 2013) is an example of a natural event which will also have an effect on the future climate. Even though methane has a shorter life cycle than CO_2, it is a more powerful greenhouse gas, the release from frozen tundra could therefore bring forward the imminent 2°C warming increase.

Global climate negotiations are one of the main mechanisms for emission mitigation measures. At the UN climate deal talks at the end of 2012, where nearly 200 countries gathered in Doha, Qatar, the key outcomes were (UN, 2012):

- To reach a legally binding global climate change agreement by 2015;

- To extend the Kyoto protocol which was due to end 31 December 2012; this is the only current and binding agreement under which developed countries pledge to cut ghg;
- For developed countries to continue their commitment to long-term climate funding support to developing nations, as well as provision of infrastructure.

Although the US and China refused to sign the Kyoto agreement, they have agreed, along with other big producers of CO_2 like India, Brazil and South Africa, to negotiate on a global treaty by 2015 (Telegraph, 2012). This exemplifies that the need to tackle climate change has been recognised by those most responsible, but due to the inertia of the climate system the globe is already committed to a certain degree of climate change.

Given the current situation emissions appear to be on a par with that of the high scenario, rather than the medium scenario employed in this research. The UKCP09 high emission scenario (SRES A1F1) climate projections were consequently entered into the GIS to see what difference this would have on the climate matching for the EQ case study. It was found (Fig 10.2) that the areas identified as good matches before, i.e. north-western France, northern Spain and south-eastern Italy (see Fig 8.4), increased in size, i.e. larger areas with a well correlated climate were matched. This was particularly evident in the Mediterranean regions, where more grid squares had a better agreement with EQs' projections for 2050. The conclusion from this is that as temperatures increase, under a higher emission scenario, the climate is likely to become more similar to that of southern Europe, with greater consequences for biodiversity.

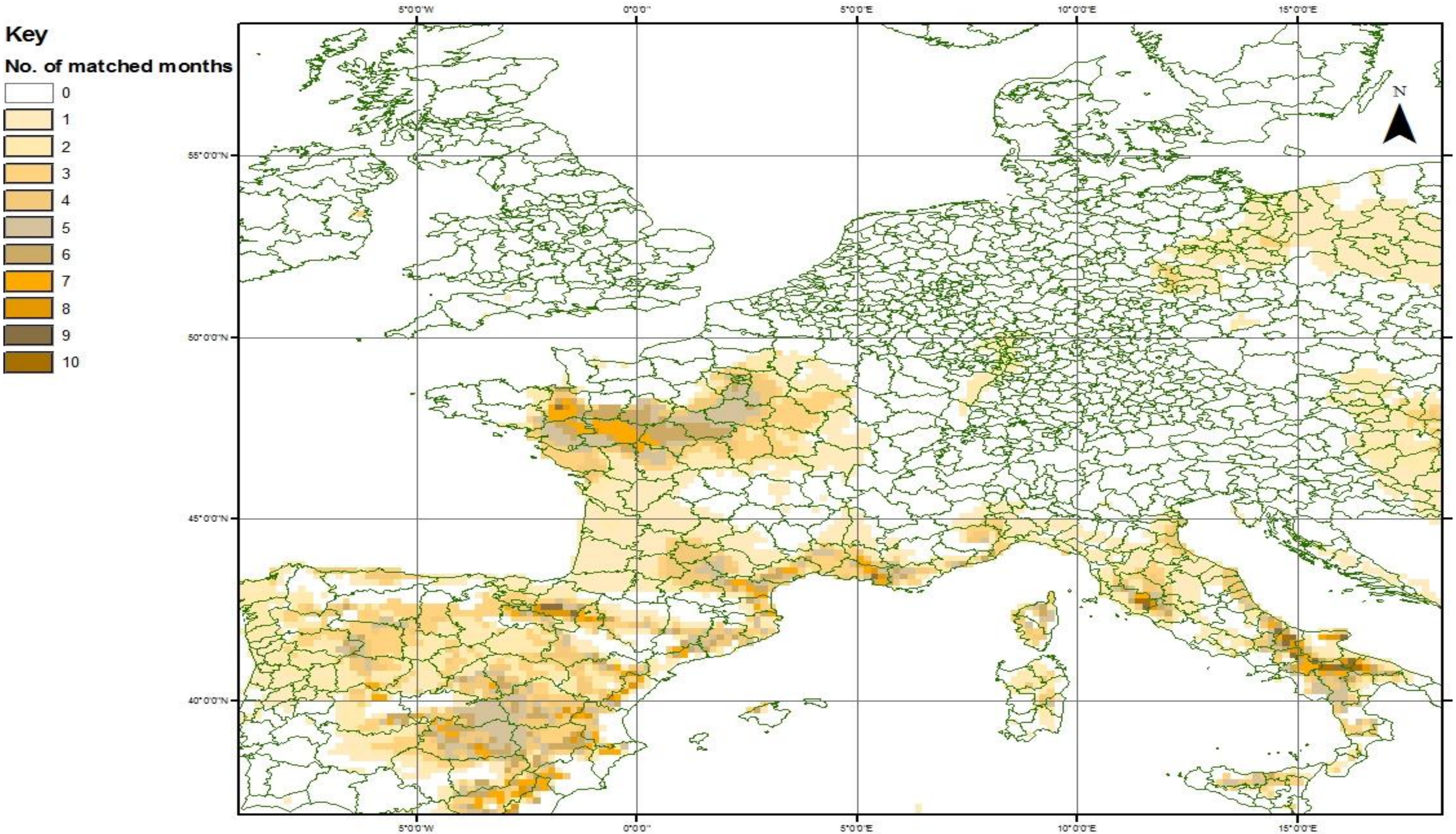


Figure 10.2 EQ's climate matches under a high emission scenario

The 2013 IPCC Climate Scenarios

In the latter half of 2013 the IPCC published the draft for their fifth assessment report on the physical science basis (IPCC, 2013). It reconfirmed the impacts that climate change is having on the atmosphere, the oceans, sea level and the cyrosphere, but they now state that it is *extremely likely* that human influence has been the dominant cause of the global warming since the 1950s, as opposed to the phrase *very likely* used in the AR4. A new set of four scenarios for the climate model simulations have also been developed, the Representative Concentration Pathways (RCPs), which replace the SRES used in the TAR and AR4.

These four scenarios are different from the SRES, in that they cover a range of climate intervention policies spanning the 21st century, and they are defined by the radiative forcing which they will exert in 2100. RCP2.6 is the lowest forcing level due to it being a mitigation scenario, whereas RCP4.6 and RCP6 are stabilisation scenarios. RCP8.5 represents the largest radiative forcing by 2100 due to the very high emissions of greenhouse gases associated with this scenario. The climate models produced in the new report have improved on the last report with temperature patterns and trends over many decades being accurately reproduced, thereby adding confidence to the models and their associated projections.

Although this research project uses the SRES scenarios for the climate projections, the framework created is still valid and the new scenarios could replace the ones employed once probabilistic projections by the likes of UKCP09 have been developed.

Climate Model Confidence

There is of course uncertainty in the climate projections themselves, owing to the complex climate system and the interactions which are considered in order to create them. Recent analysis of the climate change over the past 15 years has, however, discovered that forecasts of rising global temperatures were very closely matched to recent observations (Allen *et al.*, 2013). This instils confidence in the climate model predictions and the scientific basis behind them, which have been subject to a lot of speculation and doubt previously.

10.3.2 Climate Variables Limitation

The use of only two climate variables – temperature and precipitation, has potentially limited the accuracy of the climate matching. Although these two variables are important for describing the general climate of an area and for plant growth, other variables are important for plant growth including minimum/mean temperature of the coldest month (explains distribution of the different types of woody plants based on their lower growth limits and requirement for chilling to ensure bud burst in the spring), and growing degree days (>5°C) is also important (Thuiller *et al.*, 2005). Although UKCP09 provides the minimum daily temperature, the CRU data for the current European values, however, do not have the corresponding data.

Potential evapotranspiration (PET) was not considered in the climate matching of this research, yet it is a good indicator of the available soil moisture, a variable which affects plant growth. Potential evapotranspiration is how much evapotranspiration could occur if sufficient soil moisture was available to avoid plant stress. As it is an important factor, the difference between the PET at the case study site of EQ and its analogous climate location in the Maine-et-Loire has been examined.

Evapotranspiration is the combination of the amount of water (vapour) lost from the soil surface (evaporation) as well as the uptake of water by vegetation and the consequent loss of it through stomata (transpiration) (Allen *et al.*, 1998). The amount lost depends mainly on four climatological variables:

- Solar radiation
- Ambient air temperature
- Vapour pressure (Air humidity)
- Wind speed (at 2m above ground)

Solar radiation is determined by latitude and season, and so the higher the latitude of the location the less radiation there is reaching per unit area of land surface and the lower the evapotranspiration rate will be, as shown in figure 10.3 For vegetated land surfaces, evapotranspiration will vary dependant on the vegetation characteristics, but typically in the earlier stages of growth water is predominantly lost by soil evaporation, which continues until the vegetation occupies more soil area with time, and then transpiration will have a larger effect on the overall rate (Allen *et al.,* 1998).

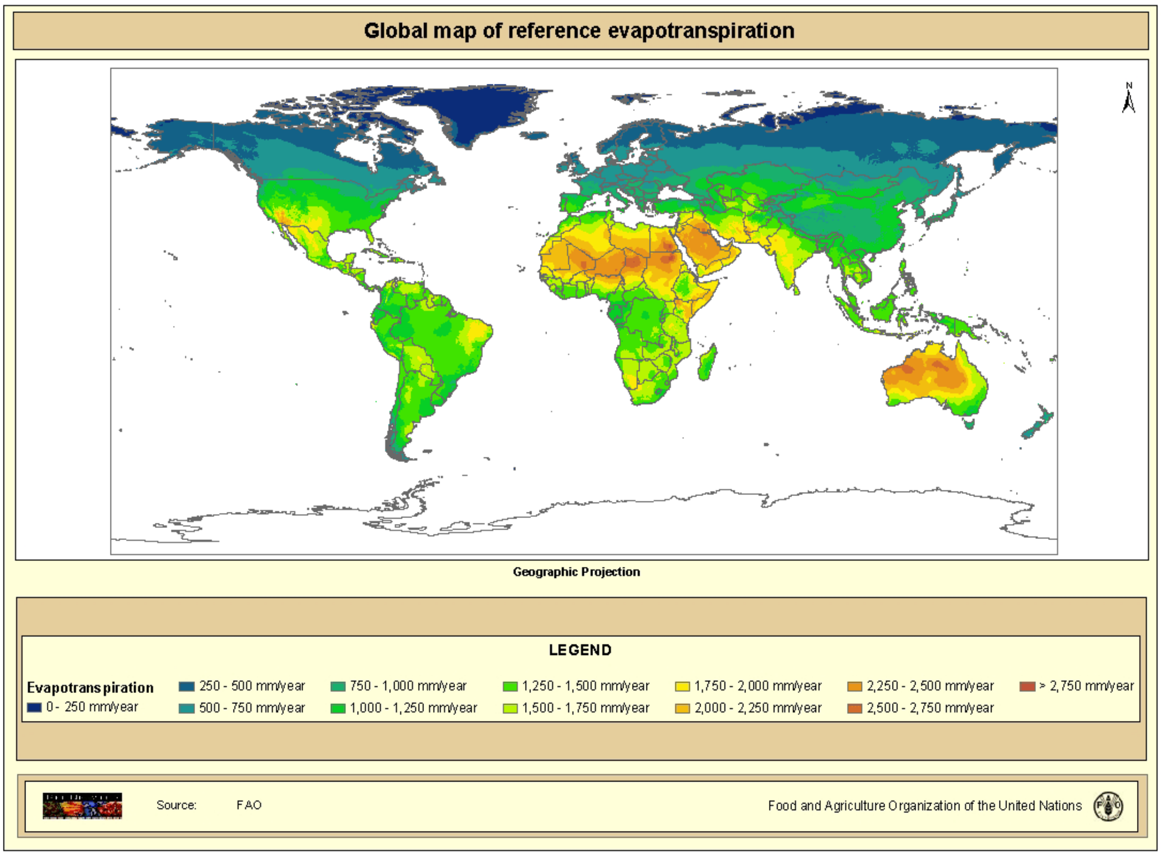


Figure 10.3 Global map of reference evapotranspiration (FAO-UN, 2004)

The FAO-UN (FAO-UN, 2004) have developed a dataset and associated maps showing the global monthly reference evapotranspiration at a spatial resolution of 10 arc-minutes. It provides the mean monthly values for global land areas, for the period 1961-1990. The Penman-Monteith method has been used in calculating the dataset with input data from the CRU. The reference crop evapotranspiration (ET_0) represents the evapotranspiration from a standardised vegetated surface – it is the 'climatic parameter expressing the evaporation power of the atmosphere' (Allen *et al*., 1998) and is calculated independently of crop characteristics and management practices. ET_0 provides the evapotranspiration rate from a reference surface which is a hypothetical grass reference crop with specific characteristics, the soil of which has sufficient moisture. The values from different locations can be compared as they use the same reference surface. On inspection of the monthly maps produced, the values for the areas of interest have been noted and are shown in table 10.1. The bold values highlight where the differences lie between EQ and the Maine-et-Loire, both in their current climate conditions.

Table 10.1 The ET_0 differences between EQ and Maine-et-Loire

Month	**EQ (mm/month)**	**Maine-et-Loire (mm/month)**
January	0 - 25	0 - 25
February	0 - 25	0 - 25
March	25 - 50	25 - 50
April	50 - 100	50 - 100
May	50 - 100	50 - 100
June	**50 - 100**	**100 - 150**
July	100 - 150	100 - 150
August	**50 - 100**	**100 - 150**
September	50 - 100	50 - 100
October	25 - 50	25 - 50
November	0 - 25	0 - 25
December	0 - 25	0 - 25
Year	**500 - 750 mm/year**	**750 – 1000 mm/year**

The ET_0 values are similar between the two areas, which was expected with the UK and north-western France being of the same biogeographical region (the Atlantic). As the value for the year shows, it is slightly higher in Maine-et-Loire, which may be due to it being at lower latitude than EQ. PET indirectly affects soil moisture; if this was different in France then species selected for EQ may not be able to establish due to differing conditions. As the PET is similar though, the vegetation should be able to grow in the UK conditions.

Given that GB and north-western France are part of the same biogeographical region then it is expected differences in some variables would not be large. It is only when species of a Mediterranean origin are considered that larger differences would start to emerge. If a development site was paired with a more southerly climate, and the altitude was similar, then more consideration should be given to PET, with projections calculated to observe the comparison that exists between the UK site and the matched site.

A quote of pertinence to the research project from Doxford and Freckleton's (2012) study is:

"A change of several degrees in temperature may not result in distribution change if it is within a species tolerance limits; however, a small temperature change in another instance may reach a biotic threshold forcing a response to climate through distribution change".

Optimal physiological temperature data is rarely available for species and this makes decisions harder when trying to see which plants are closer to reaching their climatic tolerances, and thus more vulnerable to climate change than others. A potential flaw may be that the climate is not limiting species distribution, as discussed in chapter 4. Although the climate preferences of the species are considered, other important factors, for example, the abiotic factors or its biotic interactions with other species which have led to a particular species being able to survive in a particular environment, have not wholly been considered. The species selected may therefore not be able to survive/establish at a given site. To cater for a species' environmental preferences, the Ellenberg indicator values have been used to classify the species accordingly, but this will not take into account a species complete interaction with the surrounding environment.

10.3.3 Similar Methods

The climate matching technique used by Forest Research, as discussed in section 4.13, uses the least squares method to identify locations which have the smallest difference overall for the year between a specific set of future projections for a site with current conditions at a matched location. This structured statistical approach seems a legitimate, accurate way to carry out the climate matching, and by narrowing their range they can increase the accuracy of their agreements. The underlying principles of the climate matching technique used by Forest Research and that presented in this research are the same, but a visual inspection is involved to observe the overall climatology of the matched locations in this research. In this way the months that are more important for plants can be inspected for closeness to fit. A greater number of matched locations were identified in this research, because a wide range (10-90% probability range) of climate projections are considered for each monthly climate variable, as it is deemed best not to be too specific given the uncertainty provided with the climate change projections.

Altitude was not considered for seed collection in the FR trials, which may yield unsuitable provenances due to differing conditions. The reasons for considering altitude are discussed in section 8.1.3. In both this research and that of Forest Research, however, the fact that energy balances change with latitude needs to be a major consideration when selecting seed material to use from areas of lower latitudes, as suitability may be questionable.

10.3.4 Soil Limitations

Soils are a fundamental part of the overall ecosystem and provide many services. In relation to this research, generally restored soils are employed on development sites to support plant growth; they provide the medium through which plants can establish and contribute to biodiversity improvement on site. Their importance is also recognised in international policies like the 2010 Aichi Targets (as discussed in chapter 4). With the online data used for vegetation matching, the website did not state the soils on site, which inevitably has implications for the habitat creation proposals for the case study development site. The use of manufactured soils, however, as in the case with the Olympic Park, is a common approach that is employed on development sites for increasing the quality of the soil and reducing the requirement for natural soils, which are a scarce resource. When development sites are built on contaminated land, the protocol is to cap the soil to isolate the contamination, as observed in some of the case studies. The subsoil/topsoil, or the extra capacity required, is then either taken from uncontaminated areas of the site, from stockpiles/overburden, or if needed the soils are imported. Manufactured soils offer a sustainable alternative.

Manufactured soils are typically a mixture of organic substrates like green waste compost and a mineral fraction like sand, with the ratio of these two substrates depending on the planting requirements of the site, (Stanley, 2011). Sufficient organic substrate can improve the physical, chemical and biological properties of the soil and allows for the soils to adapt to the surrounding vegetation. The mineral component is normally taken from overburden waste from sand and gravel quarries which tend to have a good proportion of sand, silt and clay (Landscape Institute UK, 2012). If drainage is required the soil is made more permeable, but if drainage is not required then more clay like soils are used. The soils can be altered accordingly over the years if required, so that plants have an opportunity to successfully establish (Stanley, 2011).

Publicly Available Specification (PAS) 100 green compost waste and paper mill crumb (PMC) were two substrates used in the manufacture of subsoils for the restoration of Lambton Coke Works in County Durham (Palmer and Davies, 2008), as there was a shortage of subsoils on site. The study undertaken there found that both a 50:50 and 80:20 ratio of compost to PMC both resulted in successful establishment of trees, and the importance of loose-tipping was also demonstrated. In relation to soil food webs and plant communities de Vries *et al.* (2012) studied fungal-based food webs and found that they increase the resilience of soil to drought by reducing the loss of nitrogen from the soil and thus facilitating a better recovery. With droughts more likely under future predicted climate conditions, this knowledge and its application may better prepare soils, and indirectly plant communities, for climate change.

The manufacture of soils has become increasingly popular on development sites as they (Stanley, 2011; Boulden, 2012):

- Reduce use of, and disruption of native topsoil which is scarce;
- Reduce the amount of unsuitable soils to be exported off site to landfill, so both a sustainable best practice and an economic cost issue;

- Involves the recycling of materials;
- Comply with British Standards for Topsoils;
- Are of a consistent quality.

In relation to EQ, the soils are not contaminated, but with climate change the soil quality may worsen, whereas manufactured soils would allow for sustained conditions and a well functioning soil ecosystem. Through using these soils the below-ground biodiversity is enhanced allowing for more successful above ground interactions; such objectives are key priorities for development sites and reclaimed land (Boulden, 2012). As certain plant species prefer particular soil characteristics, this is taken into consideration through matching of the manufactured soil to the relevant Ellenberg indicator values – the soils are essentially tailor made to the plants preferences. The underlying geology of the site should also be taken into consideration as this will affect soil conditions, particularly acidity, but as shown through the case studies, development sites with contamination problems often cap the soil to separate the contamination from the proposed development plans and thus the soil is not influenced by the geology.

10.3.5 Vegetation Decisions

A comprehensive species list for Maine-et-Loire the area was not available. The species list produced from the field and online data was not extensive; there will be other species present in the area which have not been accounted for, but would be suited to the climate at EQ in 2050. The data, however, is manageable and allowed a list for varying habitat and soil conditions to be compiled, giving an example of how the framework can be used to create resilience in planting lists for UK development sites.

The vegetation matching method is novel and requires a broad sense of perspective. Classification of the vegetation data was not straight forward owing to:

- there being no habitat classification standard across Europe, or at least none with sufficient plant data available;
- the online plant data for the ZNIEFFs were not categorised into appropriate habitats;
- differing definitions between EU and UK habitats.

The UK broad habitat classification was applied to the plant species and then subsequently the species were filtered based on their French Ellenberg values, as discussed in section 9.6.1, to create communities of similar preferences. There were limitations of using Ellenberg as some of the species were not assigned values for every indicator, resulting in these species being removed from consideration and limiting the size of the list. The approach was also mechanical, and thus the lists do not fully take into account species tolerances (albeit a range of 3, for example for F - dry (1-3)), given that some species can tolerate a wider range of conditions than others. The lists produced are thus the species ideal, but this aims to achieve habitats that will successfully establish on the development site as their preferences are matched.

At a smaller scale the inclusion of additional environmental data, like aspect and slope for the vegetation data would have been ideal as this affects the micro-distribution of species on a site. This, however, can be decided upon by an ecologist or on further investigation of the plants' requirements. Given the limitations of the methodology, it would be advisable to consult an appropriate ecologist with expert botany knowledge to refine the created lists. In examining the species lists, they would be able to select species which thrive together in the habitat, i.e. unlikely to compete with each other for resources.

A lack of time prevented the method from being tested on more than just the EQ case study. The principles, nonetheless, would be the same regardless of the site under consideration and the method created could perhaps be further refined, with, for example, inclusion of more characteristics. It is debateable, though, whether this would be worthwhile given the current uncertainty surrounding the climate projections, and what is actually known about plant interactions and their ability to respond to climate change.

The approach employed to create the species lists using Ellenberg characteristics is mechanical and only requires a limited knowledge of plant botany to apply. As discussed above, it is restricted to those species where the Ellenberg parameters have been published. An alternative approach would be to employ an expert ecologist to use their specialist knowledge to create planting lists directly from the comprehensive species list. This would have the advantages of an expert who has knowledge from the field and would select plants that thrive together and would be unlikely to compete.

10.4 The Framework

Despite the limitations of this research, a methodology has been developed that aims to future-proof species selection for development sites given the impending climate change. Albeit novel, it is a proactive adaption approach to ensure the long term robustness of the biodiversity element of development sites, and considers the plant species climatic and environmental preferences. Figure 10.4 provides a diagrammatic representation of the methodology created. Given a development site, to apply the process, one must first ascertain:

- the predicted future climate at the site;
- Site and soil conditions;
- What is guiding species selection in the area – i.e. BAPs, NCAs - and hence the habitats to be created.

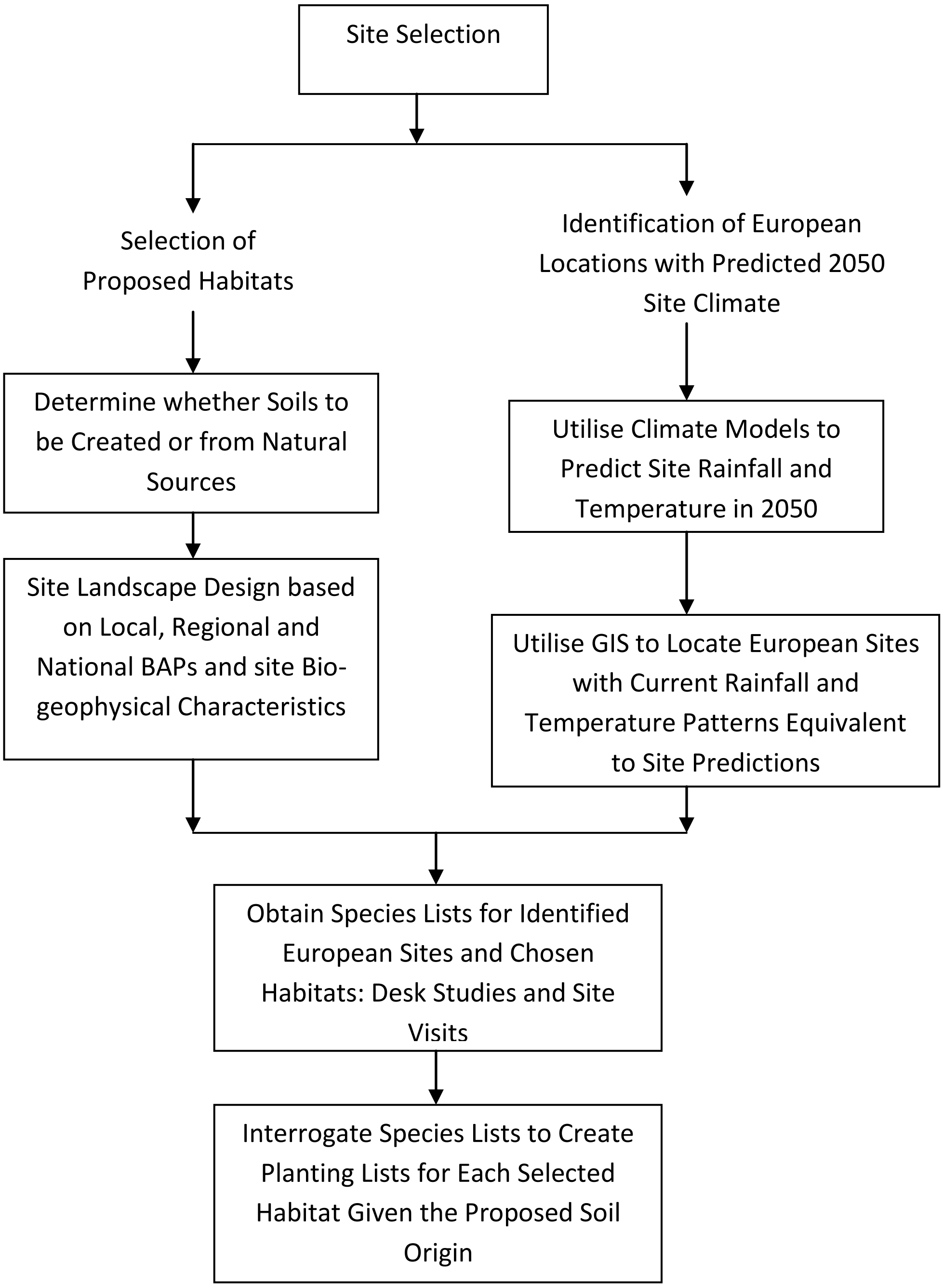
The future climate predictions for the development site are dictated by climate models which give projections for temperature and precipitation in 2050. Climatically matched areas in Europe, which currently experience this future climate are then identified through the use of a GIS. A suitable match location is then found through a closer inspection of these areas' climatology and altitude. Vegetation species data from the selected location can then be acquired through either site visits or online published data, and compiled into a database for ease of management.

Natural soils can be used, which will influence the species selected, or the soils can be created, in which case the soils are tailor made to the plant/habitat preferences. Dependant on the habitat proposals for the site, or the schemes guiding the biodiversity decisions (e.g. BAP/NCA recommendations), the species database can be searched for the relevant plants to create the desired planting lists. At this point either an expert ecologist can select species from the comprehensive list, or alternatively they can refine the list once it has been filtered using broad habitat classifications and Ellenberg values for moisture, acidity, fertility and light. A plant list is then generated for each of the habitats proposed for the given development site.

Brownfield Site development

Vegetation Planting for 2050

Proposed Methodology



(continued…)

Species List Selection

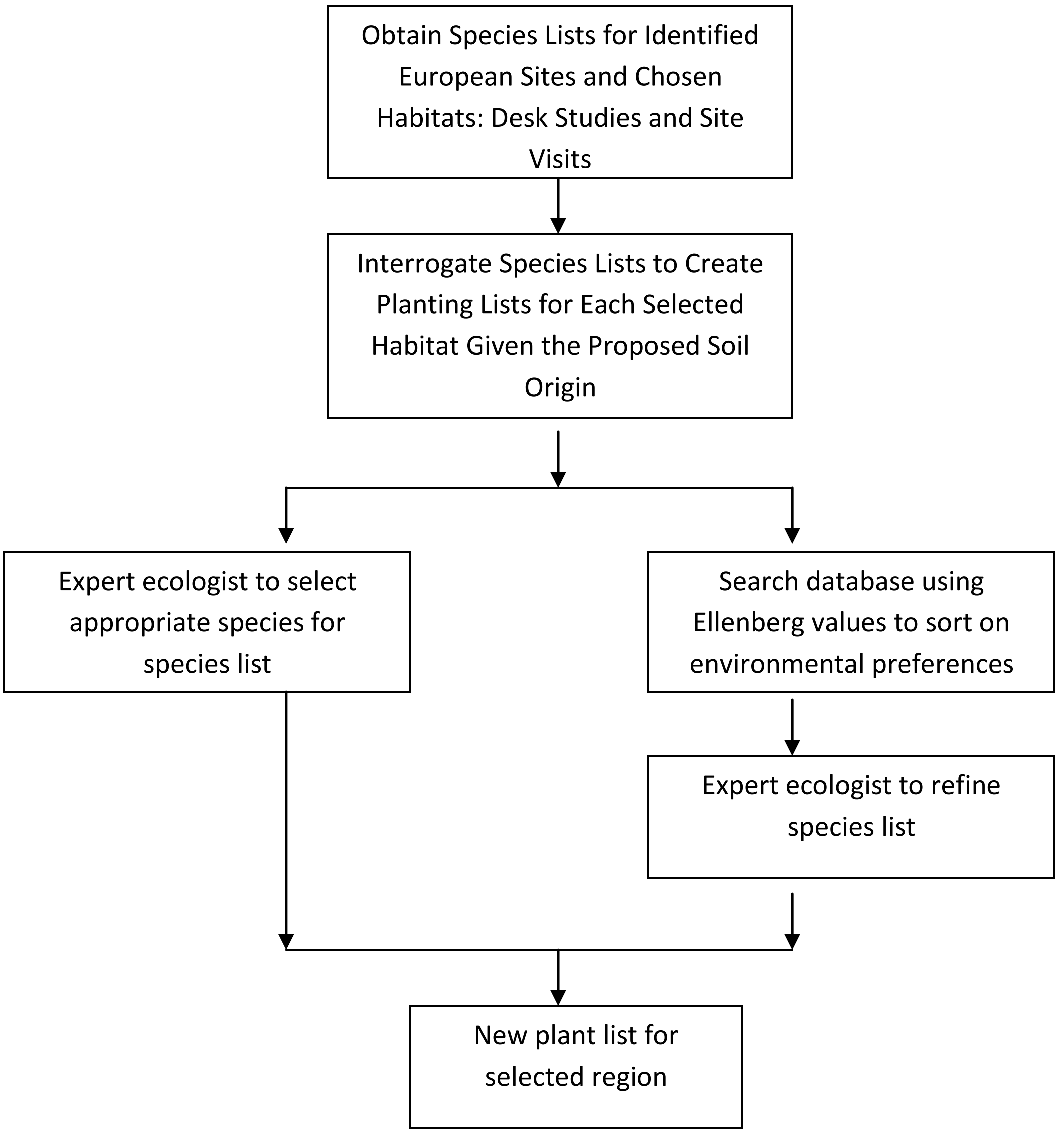


Figure 10.4 Proposed methodology for planting lists resilient to climate change

10.5 Conclusion

In conclusion, this research has produced a methodology which offers biodiversity elements of development sites resilience to climate change, through the selection of species from southerly latitudes which match the future climate of the UK. There are barriers to its implementation, particularly as some organisations and authorities enforce strictly native policies for landscaping. However, given the rate and likely magnitude of climate change action needs to be taken now to ensure plant species and communities can survive. There needs to be recognition of the need for change in conservation practices, and that species would naturally migrate to parts of the UK, if there were not geographical barriers preventing this. Certain non-native species offer great benefits, including longer flowering seasons, and there are many established non-natives which people already accept as part of the natural scenery.

Inevitably there are limitations to this research method, but the decisions taken to reach the outcomes are deemed acceptable and credible given the surrounding literature and the context within which and when the decisions were made. As only climate variables have been used to identify the flora likely to survive the future meteorological conditions of the UK, it has thus been assumed that the climate is limiting the distribution of the species selected. However, there may be other abiotic factors or interactions which have not been considered in the climate matching technique, which would prevent a species surviving in the UK. As areas in north-western Europe fall under the same biogeographic region as the UK, the conditions are relatively similar, but if the species were from a more Mediterranean origin, then greater attention should be paid to a wider range of climate variables and how good the match is.

All in all the method aims to inform the biodiversity requirements of a development site, with recommendations for planners and developers, ensuring the site's sustainability for years to come, with the creation of resilient planting assemblages for the impending climate change.

11. Conclusions and Future Recommendations

In concluding this research, there is a discussion on how the aims and objectives were met, and on the process developed to enable planners and developers to select plant species for sites subject to climate change. Recommendations for further research to enhance the procedure will also be discussed.

11.1 Project Aim

The aim of the project was...

> "to develop a process to enable the production of species lists for the habitat creation and planting design associated with large scale development sites subject to climate change."

In adopting a case study approach, the project aim was successfully met and a methodology developed which, for a given development site in the UK, would recommend appropriate species for planting design that would be robust to future climate change.

11.1.1 Origin of the Problem

The original idea for this research was proposed by Middlemarch Environmental Ltd, who are often appointed ecological consultants for a number of large scale brownfield development sites. In order to provide the most appropriate environmental and financial solutions, given the long term objectives for such sites, Middlemarch saw a need for habitat proposals and planting design to be re-considered given their likely susceptibility to climate change. The plant species often recommended for development site planting include designated BAP species, or species characteristic of the surrounding area, but these species are suited to the current climate and may not be appropriate or survive the climate expected over the course of the 21st century. Species better suited to the future climate would be a sustainable investment for developers and ensure biodiversity can survive and flourish on the site.

11.1.2 Meeting the Aim through the Objectives

The aim of the research was met through the undertaking the objectives detailed in section 1.3.2, which will be further discussed here.

The literature review (Objective i) revealed that it is evident in the climate records that the climate is changing at an unprecedented rate (EEA, 2004) and that anthropogenic agents are partly responsible for such events given the drastic increase in CO_2 emissions since the industrial revolution began. CO_2 is one of the greenhouse gases which absorbs heat radiating from the earth, thus raising the global temperature (Hulme, 2009a). Global circulation models, which mimic the complex interactions of the climate system, simulate the future climate based on a range of likely emission scenarios over the 21st century (Randall *et al*., 2007). Although the degree of change varies between models, dependant on the methods employed, many models predict a climate warming.

Without the necessary global action required to curb greenhouse gas emissions, there will be disastrous consequences for biodiversity, as well as for economies, and therefore the need to take action is pivotal. Although there are international agreements in place to implement mitigation measures (Hulme, 2009a), the earth is already committed to a certain degree of climate change and it has been estimated that at the current emissions rate, the earth may be exposed to the higher emission scenarios propounded in IPCC's Fourth Assessment Report (New *et al*., 2011). The Fifth Assessment report, to be published next year, will place more onus on anthropogenic forcings contributing to the climate change.

Regarding objective iii, the literature provides many examples of the effect climate change is having on biodiversity, both historically, and recently, with species typically migrating polewards to follow their suitable climate space (Thomas *et al*., 2004). Species were able to migrate at the end of the last glacial over 10,000 years ago, but there are uncertainties as to the dispersal rate at which this occurred (McLachlan *et al*., 2005; Clark *et a*l., 1998). The rate of climate change today is of a greater magnitude, and given the poor permeability of the landscape to allow species to migrate, the rate of habitat loss (predominantly due to human activity) and the uncertainty surrounding species ability to disperse long distances, biodiversity may consequently be lost. As well as species expanding their northern ranges to follow their suitable climate space, other observed phenology changes include earlier flowering dates, which coincide with an earlier onset of spring (Sparks and Smithers, 2002). Species models have incorporated the distribution of species and their climate tolerances to identify future climate spaces across a range of taxa. For many, the necessary future climate space exists, but their ability to reach such destinations is questioned (Pearson and Dawson, 2003). Areas which will be affected the most include the Mediterranean and Euro-Siberian landscapes (Thuiller *et al*., 2005), with Europe likely to incur many plant extinctions. These climate models are, however, limited in their recommendations given that a species may not be limited in distribution by climate, and other factors may dictate its existence in a particular community. They also expect vegetation to snap to these new suitable environments, when in reality their dispersal limits this notion.

Recognition of the importance of the environment did not really occur until post WW2 when regulations imposed limits on development (Bell and McGillivray, 2008). The designation of sites worthy of protection occurred in the 1980s, and for those ratified to the UNFCCC agreement there was a requirement for conservation and sustainable use of biological diversity, as stipulated by the Convention on Biological Diversity (CBD). The important services provided by biodiversity also gained more attention, and the recent NPPF now requires the environment to be given equal consideration as economic and social factors to ensure sustainable development (DCLG, 2012). Developers are also required to consider the biodiversity of a site when carrying out an EIA; they must mitigate accordingly for any damage and implement compensation measures. It is also at the discretion of the local authority to ensure they have regard for biodiversity and act accordingly when making decisions on planning proposals. Some developers, however, proactively want to enhance the biodiversity of a site and make it a principle feature of the development, which is encouraging and allows green space for both aesthetic purposes, but also to facilitate the surrounding species and provide connection between areas. This, however, is not always the case as ascertained by the questionnaire (chapter 6), with ecologists responding that most developers do not willingly want to maximise the biodiversity on their sites.

Local government ecologists were consulted to determine their views on this research (objective v), their attitudes towards non-natives, as well as general information on the practices they employ for planting selections. In furthering the observations of recent changes to biodiversity in the literature, many ecologists have also observed changes in species' distributions relative to their local area, exemplifying that species are expanding their ranges at a local scale. For those involved with the planting selections, the majority recommend species for planting in accordance with BAP habitats, but as mentioned, such species may be unlikely to survive the future climate change. Species need to be selected that can withstand the likely climate pattern of the future.

To develop the framework for suitable species selection, a case study approach was adopted (objective iv). Suitable brownfield sites from across the UK were sought, all with a requirement for biodiversity and a planting schedule available. The methodology could then be applied to each site for the acquisition of species which will be better suited to the future climate at that given site. For the case study of Eastern Quarry, a chalk quarry in North Kent, the climate change expected in 2050 for the UK was required in accordance with objective ii. The most recent climate projections by UKCP09 were therefore employed to predict the climate variables temperature and precipitation under a medium emission scenario for the time period 2050 (2040-2069). The Met Office baseline was then combined with the projection data at the 10, 50 and 90% probability levels and the probabilistic range of future climate values for each grid square of the UK was calculated.

To meet the requirements of objective iv, the current mean European rainfall and temperature values were uploaded into a GIS. Subsequently, by inputting the projected climate range for EQ, and using an appropriate query, areas were identified in Europe which currently experience this expected climate. The GIS allowed for a visual display of the analogous climate locations across Europe, and those which had the best match, i.e. a greater number of months in agreement, could then be further investigated to ensure suitability. Areas in north-western France, northern Spain and southern Italy were well matched for the case study of EQ, but on further investigation of the climate match, by considering other factors such as altitude, north-western France was identified as the better match overall.

Species lists were obtained from the respective areas in the selected location through site visits and by sourcing online published data (objectives vii and viii). National natural history museums are important resources for a wide range of species, and published data from the likes of these are validated by the extensive records they hold (Graham *et al.*, 2004). In classifying the species into manageable, understandable lists, they were classified according to the broad habitats that they reside within, based on those typically created on development sites, e.g. woodland, meadows, aquatics and marginal. To cater for species environmental preferences the lists were further sorted using the French Ellenberg values for moisture, fertility, acidity and light, to create habitat lists which would be appropriate for a given development site's criteria (i.e. calcareous grassland, wet meadow), dependant on the original habitat proposals and/or the surrounding areas characteristics. A limitation here was that the Ellenberg values were not available for all plants. The final step would be for an ecologist to use their specialist knowledge to further refine the selection (objective ix). The outcome would then be relevant species lists for planners and developers who are seeking to maintain the biodiversity longevity of their site. Time, however, did not permit for this objective to be successfully met, and the list created would need refining before recommendation to planners. An ecologist, nonetheless, did advise on the selection process and assisted during site visits.

It was found that many of the species on the new lists created, i.e. native to France, were also native to the UK, but the UK provenance may not be suitable for the expected climate change of the future.

The acceptance of non-native species in conservation practices is varied, with some bodies operating a strictly native only approach. Others, however, recognise that species will naturally migrate and appear in new environments. Efforts to conserve the native flora may be wasted by focusing on current native species, and consequently there needs to be worthwhile investment into suitable resilient planting practices, otherwise biodiversity may be lost. From the questionnaire distributed to local government ecologists, it was found that nearly half of the respondents were against the introduction of non-natives to new planting lists for development sites, with most of the remaining respondents being undecided on the matter. This limits the implementation of this research, as ultimately they have an influence on planting lists. There perhaps needs to be awareness that not all non-native species are invasive, that many provide benefits and some are already accepted as part of natural scenery. When introducing non-native species, there is a possibility that they may become invasive as they lose their natural enemies associated with their native community, but ideally the species selected would undergo a risk assessment to identify any potential invasive species prior to their use.

The methodology produced for development site planting creates a species selection resilient to climate change, as summarised in Fig 10.4. It is recognised that there are limitations associated with this research methodology, but given the period of time this study was undertaken, and the time constraints of a study of such breadth, a suitable framework has been developed. Species lists need to be created which, for a given development site, are able to survive and provide resilience to future climate change, the possibility of which has been shown through a case study approach. This research has previously not been undertaken, and the proposed methodology is a new process for creating resilience on development sites, an issue given little attention to date. The outcomes, if utilised, would provide a sustainable investment for the long term biodiversity objectives of a given development site, buffering them against climate change.

11.2 Future Recommendations

To further develop the methodology for the creation of species list suitable for development sites subject to climate change, it is recommended that the underlying principles are updated as and when they become available. This applies to the climate projections, in terms of new emission scenarios and climate projections developed by the IPCC, given that information published to date relating to the IPCC's Fifth Assessment Report indicates that the earth may be committed to much higher emission levels than originally thought, unless serious reduction measures are implemented.

It would be ideal to determine whether temperature is limiting the species distribution or whether other factors are involved, given that only temperature and precipitation have been utilised in this research. An experimental approach is therefore recommended for the non-native species identified by the methodology developed, to ascertain factors controlling their distribution. Assessment of the suitability of the provenance to the UK of the range of species selected for planting would also be recommended through trials, such as those being undertaken by the forestry commission for trees.

It would be interesting to establish the distribution range of the species in France (i.e. for the species identified, if they are at their northern or southern margin), as this may have implications for their ability to survive in the UK. Data on their distribution can be accessed through online resources, including the INPN website utilised in this research to identify the ZNIEFFs. The distribution range of species in southern England would also reveal the factors controlling their distribution and the potential future shape of the landscape under a changing climate.

These recommendations would further enhance the framework proposed in this research, resulting in the creation of more refined resilient biodiversity plantings for infrastructure developments.

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<u>**Appendix 1 Questionnaire**</u>

Biodiversity and Climate Change

Aston University
Birmingham

About You

Your Work and Climate Change

1. What is your professional job title?

- ◯ General Ecologist
- ◯ Biodiversity Officer
- ◯ Specialist Planning Ecologist
- ◯ Team Leader Ecologist
- ◯ Other *(please specify)*:

2. What area of ecology is your work focused on? *(select all that apply)*

- ☐ Marine and Freshwater
- ☐ Terrestrial
- ☐ Plants
- ☐ Reptiles
- ☐ Birds
- ☐ Mammals
- ☐ Invertebrates
- ☐ Amphibians
- ☐ Other *(please specify)*:

3. Which region of the UK is your work based in?

Select an answer

4. How long have you been working in a ecology related field?

Select an answer

5. Have you noticed any significant biodiversity changes, attributed to climate change, during this time?

- ◯ Yes
- ◯ No

If Yes, what changes have you noticed?

6. Are your individual thoughts towards adapting to climate change allowed to influence your work?

◯ Always ◯ Sometimes ◯ Rarely ◯ Never ◯ N/A

Continue >

Survey testing only
Check Answers & Continue >

Biodiversity and Climate Change

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Development Sites and Planning Involvement

Brownfield Sites

7. Have you noticed developers willingly wanting to maximise the biodiversity of a brownfield site, if so, in how many of your cases?

○ None ○ 1-20% ○ 21-40% ○ 41-60% ○ 61-80% ○ 81-99% ○ All ○ N/A

8. At what stage are you typically questioned on ecological/biodiversity aspects of a site?
(select all that apply)

- ☐ Pre-application
- ☐ During application process
- ☐ Design phase
- ☐ Construction phase
- ☐ Operational phase
- ☐ N/A

9. How do you feel about introducing species of a non-native provenance into new planting schedules for brownfield sites?

○ For it ○ Against it ○ Undecided

Action To Take

10. Which of the following actions do you feel should be taken to tackle the impacts of climate change on biodiversity?
(select all that apply)

- ☐ No action, business as usual
- ☐ Strict conservation practices (native at all costs)
- ☐ Ecological corridors, stepping stones
- ☐ Intervention - translocation of both native and non-native species
- ☐ Intervention - translocation of only native species
- ☐ Other *(please specify)*: ____________

Continue >

Survey testing only
Check Answers & Continue >

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Biodiversity and Climate Change

Planting Selections

Planting Decisions

11. Are you involved in selecting planting regimes for brownfield sites?

- ◯ Yes
- ◯ No

a. In making these choices which factors/documents do you consider? *(select all that apply)*

- ☐ BAP habitat/species recommendations
- ☐ Landscape Character Assessments (LCAs)
- ☐ Schedule 9 of the Wildlife & Countryside Act
- ☐ National Vegetation Classification (NVC) lists
- ☐ Soil characteristics
- ☐ Aspect of the site
- ☐ Other *(please specify)*:

b. Are you able to have an influence over the landscape architect's planting selections?

◯ Always ◯ Sometimes ◯ Rarely ◯ Never ◯ Depends on the architect ◯ N/A

c. On brownfield sites, what do you think are the most important factors to consider when selecting planting regimes? *(Optional)*

Continue >

Survey testing only
Check Answers & Continue >

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Biodiversity and Climate Change

Biodiversity and Climate Change

Your Opinion

12. In response to climate change, in order to achieve no net loss of biodiversity (EU target), do you think we should 'gain' biodiversity by translocation and intervention, in order to compensate for those species that will become vulnerable?

◯ Yes ◯ No ◯ Undecided

13. Do you agree a resilient landscape is the best way to tackle climate change when considering biodiversity? **More Info**

◯ Strongly agree ◯ Agree ◯ Neither Agree/Disagree ◯ Disagree ◯ Strongly Disagree

14. What do you think will create a landscape resilient to climate change? *(Optional)*

Continue >

Survey testing only
Check Answers & Continue >

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Biodiversity and Climate Change

Comments

15. Do you have any comments or thoughts with regards to my research? *(Optional)*

Contact Details

16. Please leave your contact details if you do not mind being contacted to discuss your thoughts further, or would like a copy of the survey results. *(Optional)*
(select all that apply)

- ☐ Do not mind being contacted
- ☐ Copy of the survey results

17. Name: *(Optional)*

18. Email Address: *(Optional)*

Continue >

Survey testing only
Check Answers & Continue >

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Biodiversity and Climate Change

Final Page

Thank You for your time in completing this survey.

Jennifer Allen

Appendix 2: EQ Planting scheme

Northern Boundary Planting list

Trees	
Species	Common name
Acer campestre	Field maple
Alnus glutinosa	Alder
Betula pendula	Silver birch
Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Pinus sylvestris	Scots pine
Populus tremula	Aspen
Prunus avium	Gean/wild cherry
Quercus robur	English oak
Screen planting	
Trees 40%	
Alnus glutinosa	Alder
Betula pendula	Silver birch
Carpinus betulus	Hornbeam
Quercus robur	English oak
Shrubs 60%	
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crategus monogyna	Hawthorn
Ilex aquifolium	Holly
Sambuca nigra	Elder
Virburnum lantana	Wayfaring tree
Native Shrub planting	
Clematis vitalba	Wild clematis
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crategus monogyna	Hawthorn
Ligustrum vulgare	Wild privet
Prunus spinosa	Blackthorn
Rosa canina	Dog rose
Sambuca nigra	Elder
Aquatic planting	
Juncus effusus	Soft rush
Mentha aquatica	Watermint
Typha angustifolia	Lesser bulrush
Lythrum salicaria	Purple loosestrife
Iris pseudacorus	Yellow flag
Emergent perennials	

Alisma plantago aquatica	Water plantain
Butomus umbellatus	Flowering rush

Floating aqautic

Polygonum amphibium	Amphibious bistort

Open water with submerged oxygenators over 10% of area

Ceratophyllum demersum	Hornwort
Myriophyllum spicatum	Water milfoil
Callitriche stagnalis	Water starwort

Dry perennial wildflower meadow

Native grasses 80%

Cynosurus cristatus	Crested dogs-tail
Festuca rubra ss rubra	Slender red fescue
Festuca ovina	Sheeps fescue
commutata	Chewings fescue
Anthoxanthum odoratum	Sweet vernal grass
Agrostis capillaris	Common bent
Deschampsia flexuosa	Wavy hairgrass

Native wildflowers 20%

Achillea millefolium	Yarrow
Centauria nigra	Common knapweed
Daucus carota	Wild carrot
Echium vulgare	Vipers bugloss
Leucanthenum vulgare	Ox-eye daisy
Lotus corniculatus	Birdsfoot Trefoil
Malva moschata	Musk mallow
Plantago lanceolata	Ribwort plantain
Primula veris	Cowslip
Ranunculus acris	Meadow buttercup
Silene vulgaris	Bladder campion
Silene alba	White campion
Agrostemma githago	Corncockle*
Centaura cyanus	Cornflower*

Sow at 5g per m2

* = annuals

Hedgerow

Shrubs

Betula pendula	Silver birch

Perennial mass planting

Grasses 30%

Deschampsia cespitosa	Tussock grass

Molinia caerulea	Purple moorgrass
Schizachyrium scoparium	Little blue stem
Flowers 70%	
Verbena bonariensis	Verbena
Salvia x superba	Ornamental sage
Sanguisorba officinalis	Great burnet
Tanacetum vulgare	Tansy
Rudbackis subfomentosa	Coneflower
Echinacea purpurea	Purple cone flower
Monarda fistulosa	Wild bergamot
Monarda didyma	Bergamot
Solidago rigida	Rigid golden rod
Persicaria amplexicaulis	Mountain fleece flower
Helianthus mollis	Ashy sunflower
Silphium perfoliatum	Cup plant
Silphium laciniatum	Compass flower
Silphium integrifolium	Rosin weed
Sow at 5g per m2	

<u>Weldon Interim Landscape</u>

Planting Plan no.1

Tree and Shrub block planting

Species

Betula pendula

Salix alba subsp vitellina Britzensis

Salix viminalis

Perennial planting

Species

Crop strip 1

Grasses

Avena fatua

Deschampsia cespitosa

Flowers

Gaura lindheimeri

Papaver rhoeas

Verbena bonariensis

Sow at 5g/m2

Crop strip 2 Purple mix

Grasses

Deschampsia cespitosa

Molinia caerulea

Schizachyrium scoparium

Flowers

Achillea millefolium
Echinacea purpurea
Salvia x superba
Sanguisorba officinalis
Verbena bonariensis
Sow at 5g/m2

Crop strip 3 yellow spring/purple summer
Brassica nepus
Lathyrus odoratus
Sow at 2g/m2

Crop strip 4 - Yellow mix
Grasses
Deschampsia cespitosa
Molinia caerulea
Schizachyrium scoparium
Flowers
Achillea 'cerise'
Helianthus mollis
Rudbeckia subtomentosa
Solidago rigida
Tanacetum vulgare
Sow at 5g/m2

Crop strip 5 - Yellow spring/blue-purple summer
Lotus corniculatus
Lupinus polyphyllus
Sow at 2g/m2

Ornamental grass strip Type A
Calamagrostis x acutiflora 'Karl Foerster'
Ornamental grass strip Type B
Miscanthus sinensis Zebrinus

Wildflower meadow planting
DRY
Grasses
Cynosurus cristatus
Festuca ovina
Festuca rubra
Flowers
Achillea millefolium
Centauria nigra
Centaurea scabiosa
Daucus caroto
Knautia arvensis
Leucanthemum vulgare

Linum catharticum
Myosotis arvensis
Papaver rhoeas
Ranunculus acris
Sow at 5g/m2

Wet wildflower meadow mix (swales)
Grasses
Cynosurus cristatus
Festuca rubra ss rubra
Flowers
Digitalis purpurea
Geranium pratense
Lychnis flos cuculi
Lythrum salicaria
Ranunculus acris
Sow at 5g/m2

Amenity grassland
Perenial ryegrass
Rhizomatous tall fescue
Tufted tail fescue
Sow at 50g/m2

Planting Plan no.2

Orchard
Prunus avium cullivers transplanted from East Mailing research centre.
OR
Prunus avium 'Plena'

Main Street Tree planting
Platanus x hispanica
Tilia cordata 'Greenspire'
Liquidambar styraciflua
Fraxinus excelsor 'Westhof's Glorie'

Central Swale Planting mix

Tree and shrub planting
Screen planting - Native trees and shrubs

Species	**Common name**
Trees	
Alnus glutinosa	Alder
Betula pendula	Silver birch
Carpinus betulus	Hornbeam

Fraxinus excelsior	Ash
Prunus avium	Gean/Wild cherry
Quercus robur	English oak
Sorbus aucuparia	Rowan
Shrubs	
Corylus avellana	Hazel
Crategus monogyna	Hawthorn
Virburnum opulus	Guelder rose

Screen planting at 1.5cm centres random single species in groups of 16.25

Trees in Grassland	
Alnus glutinosa	Alder
Betula pendula	Silver birch
Betula utilis 'Jacquemontii'	Himalyan birch
Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Populus tremula	Aspen
Prunus avium 'Plena'	Wild cherry cultivar
Quercus robur	English oak
Varieties of apples from Kent	
Malus domestica 'George Neal'	Apple 'George Neal'

Aquatic planting	
Native marginal perennials	
Carex pendula	Pendulous sedge
Caltha palustris	Marsh marigold
Digitalis purpurea	Foxglove
Iris pseudacorus	Yellow flag iris
Juncus effusus	Soft rush
Lythrum salicaria	Purple loosestrife

Native emergent perennials	
Butomus umbellatus	Flowering rush
Schoenoplectus lacustris	Common club rush

Submerged oxygenators	
Callitriche stagnalis	Water starwort
Ceratophyllum demersum	Hornwort
Myriophyllum spicatum	Water milfoil

Weighted bunches in unplanted areas of pools up to 1.0m depth

Grasslands and Meadows	
Amenity grassland	
Barenbrug Bar 10 RTF	
Seed Barlennium	Perennial ryegrass
Seed RTF	Rhizomatous tall fescue
Seed Barlexas II	Tufted tall fescue

Sow at 50g per m2

Dry perennial wildflower meadow

Native grasses 80%

Agrostis capillaris	Common bent
Anthoxanthum odoratum	Sweet vernal grass
Cynosurus cristatus	Crested dog's-tail
Deschampsia flexuosa	Wavy hairgrass
Festuca ovina	Sheeps fescue
Festuca rubra ss commutata	Chewings fescue
Festuca rubra ss rubra	Slender red fescue
Native wildflowers 20%	
Achillea millefolium	Yarrow
Agrostemma githago	Corncockle*
Centaurea cyanus	Cornflower*
Centauria nigra	Common knapweed
Daucus carota	Wild carrot
Echium vulgare	Viper's bugloss
Leucanthenum vulgare	Ox-eye daisy
Lotus corniculatus	Birdsfoot trefoil
Malva moschata	Musk mallow
Plantago lanceolata	Ribwort plantain
Primula veris	Cowslip
Ranunculus acris	Meadow buttercup
Silene alba	White campion
Silene vulgaris	Bladder campion

Sow at 5g/m2 *=annuals

Wet perennial wildflower meadow

Native grasses 80%

Cynosurus cristatus	Crested dogs-tail
Festuca rubra ss rubra	Slender red fescue
Native wildflowers 20%	
Ajuga reptans	Bugle
Anthriscus sylvestris	Cow parsley
Filipendula ulmaria	Meadowsweet
Lychnis flos cuculi	Ragged robbin
Lythrum salicaria	Purple loosestrife
Ranunculus acris	Meadow buttercup
Silene dioca	Red campion
Succisa sylvatica	Devil's-bit-scabious

Sow at 5g/m2

<u>Eastern Batter</u>

Native tree and shrub planting

Native trees

Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Sorbus aucuparia	Rowan

Native shrubs	
Clematis vitalba	Wild clematis
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Ligustrum vulgare	Wild privet
Prunus spinosa	Blackthorn
Rosa canina	Dog rose
Sambuca nigra	Elder

Native trees	
Betula pendula	Silver birch
Sorbus aucuparia	Rowan
Native shrubs	
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Rosa canina	Dog rose
Salix caprea	Goat willow

East Swale

Tree and Shrub planting

Native trees in grassland

Species	**Common name**
Betula pendula	*Silver Birch*

Aquatic planting

Native marginal perennials	
Carex pendula	Pendulous sedge
Caltha palustris	Marsh marigold
Iris pseudacorus	Yellow flag iris
Juncus effusus	Soft rush
Lythrum salicaria	Purple loosestrife
Sparganium erectum	Branched bur reed

Native emergent perennials

Eleocharis palustris	Spike-rush

Native floating aquatic (rooted)	
Polygonum amphibium	Amphibious bistort

Native submerged oxygenators

Potamogeton crispus	Curfed pondweed
Ceratophyllum demersum	Hornwort
Myriophyllum spicatum	Water milfoil

Weighted bunches in unplanted areas of 0.1-1.0 below WL

Wildflower meadows
Dry perennial wildflower meadow

Native grasses 80%

Agrostis capillaris	Common bent
Anthoxanthum odoratum	Sweet vernal grass
Cynosurus cristatus	Crested dog's-tail
Deschampsia flexuosa	Wavy hairgrass
Festuca ovina	Sheeps fescue
Festuca rubra ss commutata	Chewings fescue
Festuca rubra ss rubra	Slender red fescue

Native wildflowers 20%

Achillea millefolium	Yarrow
Agrostemma githago	Corncockle*
Centaurea cyanus	Cornflower*
Centauria nigra	Common knapweed
Daucus carota	Wild carrot
Echium vulgare	Viper's bugloss
Leucanthenum vulgare	Ox-eye daisy
Lotus corniculatus	Birdsfoot trefoil
Malva moschata	Musk mallow
Plantago lanceolata	Ribwort plantain
Primula veris	Cowslip
Ranunculus acris	Meadow buttercup
Silene alba	White campion
Silene vulgaris	Bladder campion

Sow at 5g/m2 *=annuals

Plan 2
Tree and Shrub planting
Native trees in grassland

Betula pendula	Silver Birch
Betula pubescens	Downy birch
Salix alba	White willow

Native wetland shrubs

Crategus monogyna	Hawthorn
Salix alba var vitellina 'Britzensis'	Osier willow
Sambuca nigra	Elder
Virburnum opulus	Guelder rose

Bark mulch applied to shrub areas to a depth of 50mm

Observatory Bluff

Tree and shrub planting
Orchard trees

Species Common name

Malus domestica 'Beauty of Bath'	Apple 'Beauty of Bath'
Malus domestica 'Discovery'	Apple 'Discovery'
Malus domestica 'Ellison's orange'	Apple 'Ellison's orange'
Malus domestica 'Egremont Russet'	*Apple 'Egremont Russet'*

Prunus avium

Prunus avium	*Gean/Wild cherry*

Structure planting - Native trees and shrubs

Trees

Acer campestre	Field maple
Alnus glutinosa	Alder
Carpinus betulus	Hornbeam
Fagus sylvatica	Beech
Fraxinus excelsior	Ash
Ilex aquifolium	Holly
Malus sylvestris	Crab apple
Populus tremula	Aspen
Prunus avium	Gean/Wild cherry
Quercus robur	English oak
Sorbus aucuparia	Rowan
Sorbus torminalis	Wild service tree

Shrubs

Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Prunus spinosa	Blackthorn
Sambucus nigra	Elder
Virburnum lantana	Wayfaring tree
Virburnum opulus	Guelder rose

Structure planting - Native trees - specimens

Betula pendula	*Silver birch*
Betula pendula	*Silver birch*

Native Hedgerow

Acer campestre	Field maple
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Ilex aquifolium	Holly
Ligustrum vulgare	Wild privet
Malus sylvestris	Crab apple
Prunus spinosa	Blackthorn
Rosa canina	Dog rose
Virburnum opulus	Guelder rose

Wildflower meadows

Native grasses 70%	
Agrostis capillaris	Common bent
Anthoxanthum odoratum	Sweet vernal grass
Cynosurus cristatus	Crested dog's-tail
Deschampsia flexuosa	Wavy hairgrass
Festuca rubra ss rubra	Slender red fescue
Native wildflowers 30%	
Achillea millefolium	Yarrow
Agrostemma githago	Corncockle
Anthriscus sylvestris	Cow parsley
Centaurea cyanus	Cornflower
Centauria nigra	Common knapweed
Daucus carota	Wild carrot
Digitalis purpurea	Foxglove
Leucanthenum vulgare	Ox-eye daisy
Lotus corniculatus	Birdsfoot trefoil
Plantago lanceolata	Ribwort plantain
Ranunculus acris	Meadow buttercup
Silene dioca	Red campion
Sow at 5g per m2	

Perennial wildflowers (with annuals) 100% wildflowers	
Native wildflowers 100%	
Agrostemma githago	Corncockle
Centaurea cyanus	Cornflower
Centauria nigra	Common knapweed
Daucus carota	Wild carrot
Digitalis purpurea	Foxglove
Knautia arvensis	Field scabious
Leucanthenum vulgare	Ox-eye daisy
Lychnis flos-cuculi	Ragged robin
Silene dioca	Red campion
Verbascum thapsus	Great mullein
Sow at 1g per m2	

Willow spilling

Willow poles	
Salix caprea, Salix fragilis, Salix alba, or similarly approved willow	Goat willow, Crack willow, White willow
Willow rods	
Salix alba x fragilis 'Flanders red', Salix viminalis, or similarly approved willow	White willow and Crack willow cross, Common osier

Plan 2
Tree and shrub planting

Orchard trees

Prunus avium cultivars transplanted from East Malling reseacrh centre	Cherry cultivars
OR	
Prunus avium 'Plena'	Cultivar of Gean/Wild cherry

Ornamental Hedgerow

Shrubs	
Cornus sericea 'Flaviramea'	Golden twig dogwood
Cornus sanguinea 'Midwinter Fire'	Midwinter fire dogwood

Ornamental Grass planting

Ornamental grass strip

Calamagrostis x acutiflora 'Karl Forester'	Feathered reed grass 'Karl Forester'

<u>**North East Local Park**</u>

Woodland and Playground

Semi mature trees

Species	Common name
Betula utilis 'Jacquemontii'	Himalayan birch
Fagus sylvatica	Beech
Fraxinus angustifolia 'Raywood'	Ash
Quercus robur	English oak
Prunus avium	Wild cherry
Pyrus calleryana 'Chanticlear'	Ornamental pear

Trees in Screen and Woodland Planting

Betula pendula	Birch
Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Malus sylvestris	Crab apple
Prunus avium	Gean/Wild cherry
Sorbus aucuparia	Rowan

Screen Planting

Trees 50%	
Acer campestre	Field maple
Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Quercus robur	English oak
Shrubs 50%	
Acer campestre	Field maple
Cornus sanguinea	Dogwood

Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Ilex aquifolium	Holly
Virburnum lantana	Wayfaring tree

Woodland planting

Trees 35%	
Acer campestre	Field maple
Betula pendula	Birch
Carpinus betulus	Hornbeam
Fraxinus excelsior	Ash
Shrubs 65%	
Cornus sanguinea	Dogwood
Corylus avellana	Hazel
Crataegus monogyna	Hawthorn
Prunus spinosa	Blackthorn
Virburnum lantana	Wayfaring tree
Virburnum opulus	Guelder rose

Ornamental shrub planting	Childrens playground
Hedge	
Fagus sylvatica	Beech hedge
Large shrubs	
Amelanchier lamarckii	June berry
Cornus alba 'Sibirica'	Dogwood
Philadelphus coronarius	Mock orange
Medium-small shrubs	
Hypericum x moseriznum	Rose of Sharon
Rosa pimpinellifolia	Scotch rose
Hebaceous & Groundcover	
Geranium x catabrigiense 'Blokovo'	Geranium
Vinca major	Large periwinkle

Amenity grass

Barenbrug Bar 10 RTF	
Seed Barlennium	Perennial ryegrass
Seed RTF	Rhizomatous tall fescue
Seed Barlexas II	Tufted tall fescue
Sow at 50g per m2	

Wildflower mix

Grasses 70%	
Cynosurus cristatus	Crested dogstail
Festuca ovina	Sheep's fescue
Festuca rubra	Slender creeping red

	fescue
Wildflowers 30%	
Achillea millefolium	Yarrow
Centauria nigra	Common knapweed
Centaurea scabiosa	Greater knapweed
Daucus carota	Wild carrot
Knautia arvensis	Field scabious
Leucanthenum vulgare	Ox-eye daisy
Linum catharium	Fairy flax
Myosotis arvensis	Forget me not flower
Papaver rhoeas	Poppies
Ranunculus acris	Meadow buttercup
Sow at 5g per m2. No topsoil	

Shady meadow mix (for woodland glades)

Grasses 80%	
Cynosurus cristatus	Crested dogstail
Festuca rubra	Slender creeping red fescue
Wildflowers 20%	
Agrimonia eupatoria	Common agrimony
Alliaria petiolata	Hedge garlic
Anthriscus sylvestris	Cow parsley
Centaura nigra	Lesser knapweed
Digitalis purpurea	Foxglove
Filipendula ulmaria	Meadowsweet
Gallium mollugo	Hedge bedstraw
Geum urbanum	Wood avens
Hyancinthoides non-scripta	Bluebell
Hypericum perforatum	St.John's Wort
Leucanthenum vulgare	Ox-eye daisy
Silene dioca	Red campion

Plan 2

Semi-mature trees

Fraxinus excelsior	Ash
Quercus robur	English Oak
Prunus avium	Wild cherry
Prunus avium'Plena'	Cherry cultivar
Prunus x yedoensis	Tokyo cherry

Ornamental shrub planting	Teenage playground
Large shrubs	
Philadephus coronarius	Mock orange
Medium-small shrubs	
Rosa pimpinellifolia	Scotch rose

Herbaceous and ground cover	
Vinca major	Large periwinkle

Appendix 3: Planting Lists for Habitat Design

Woodland – Trees

Complete List	Moisture (F)	Nitrogen (N)	Reaction (R)
Pinus pinaster	**Moist**	**Low fertility**	**Neutral**
Mespilus germanica	*Pinus pinaster*	*Pinus pinaster*	*Pinus pinaster*
Betula pendula	*Mespilus germanica*	*Mespilus germanica*	*Mespilus germanica*
Pinus nigra	*Betula pendula*	*Betula pendula*	*Betula pendula*
Ilex aquifolium	*Pinus nigra*	*Pinus nigra*	
Castanea sativa	*Ilex aquifolium* *Castanea sativa*		**Alkaline**
Quercus pubescens			*Pinus nigra*
Viburnum lantana	*Quercus pubescens*		
Quercus pyrenaica	*Viburnum lantana*	**Medium fertility**	**Acid**
Sorbus torminalis	*Quercus pyrenaica*	*Ilex aquifolium* *Castanea sativa*	*Ilex aquifolium*
Quercus petraea	*Sorbus torminalis*		
Pyrus pyraster	*Quercus petraea*	*Quercus pubescens*	**Neutral**
Fagus sylvatica	*Pyrus pyraster*	*Viburnum lantana*	*Castanea sativa*
Carpinus betulus	*Fagus sylvatica*	*Quercus pyrenaica*	*Quercus pubescens*
Prunus avium	*Carpinus betulus*	*Sorbus torminalis*	*Viburnum lantana*
Quercus robur	*Prunus avium*	*Quercus petraea*	*Quercus pyrenaica*
Tilia cordata	*Quercus robur*	*Pyrus pyraster*	*Sorbus torminalis*
Crataegus monogyna	*Tilia cordata*	*Fagus sylvatica*	*Quercus petraea*
Corylus avellana	*Crataegus monogyna*	*Carpinus betulus*	*Pyrus pyraster*
Cornus sanguine	*Corylus avellana*	*Prunus avium*	*Fagus sylvatica*
Euonymus europaeus	*Cornus sanguine*	*Quercus robur*	*Carpinus betulus*
Taxus baccata	*Euonymus europaeus*	*Tilia cordata*	*Prunus avium*
Acer campestre	*Taxus baccata*	*Crataegus monogyna*	*Quercus robur*
Ulmus minor subsp. *procera*	*Acer campestre*	*Corylus avellana*	*Tilia cordata*
Ulmus minor	*Ulmus minor* subsp. *procera*	*Cornus sanguine*	*Crataegus monogyna*
		Euonymus europaeus	*Corylus avellana*
Salix atrocinerea	*Ulmus minor*	*Taxus baccata*	
Frangula dodonei subsp.*dodonei*	*Salix atrocinerea*	*Acer campestre*	**Alkaline**
			Cornus sanguine
Betula pubescens			*Euonymus europaeus*
Alnus glutinosa			*Taxus baccata*
Fraxinus excelsior			*Acer campestre*
		High fertility	**Akaline**

	Damp *Frangula dodonei* subsp.*dodonei* *Betula pubescens* *Alnus glutinosa* *Fraxinus excelsior*	*Ulmus minor* subsp. *procera* *Ulmus minor* *Salix atrocinerea* **Low fertility** *Frangula dodonei* subsp.*dodonei* *Betula pubescens* **Medium fertility** *Alnus glutinosa* *Fraxinus excelsior*	*Ulmus minor* subsp. *procera* *Ulmus minor* *Salix atrocinerea* **Neutral** *Frangula dodonei* subsp.*dodonei* *Betula pubescens* **Neutral** *Alnus glutinosa* **Alkaline** *Fraxinus excelsior*

No Ellenberg:

Populus tremula

Woodland – Ground flora list

Complete list	Moisture (F)	Nitrogen (N)	Reaction (R)	Light (L)
Agrostis vinealis *Hylotelephium telephium* (*Sedum telephium*) *Melampyrum pratense* *Rubus fruticosus* *Blechnum spicant* *Holcus mollis* *Luzula forsteri* *Rubia peregrina* *Geum urbanum* *Glechoma hederacea Peucedanum gallicum* *Ranunculus auricomus* *Geranium robertianum* *Pteridium aquilinum* *Ceratocapnos claviculata* *Dryopteris affinis* subsp. *affinis* *Dryopteris affinis* subsp. *borreri* *Dryopteris carthusiana* *Dryopteris dilatata* *Polystichum setiferum* *Dryopteris filix-mas* *Hedera helix* *Sanicula europaea* *Ruscus aculeatus*	**Dry** *Agrostis vinealis* *Hylotelephium telephium* (*Sedum telephium*) **Moist** *Melampyrum pratense* *Rubus fruticosus* *Blechnum spicant* *Holcus mollis* *Luzula forsteri* *Rubia peregrina* *Geum urbanum* *Glechoma hederacea Peucedanum gallicum* *Ranunculus auricomus* *Geranium robertianum* *Pteridium aquilinum* *Ceratocapnos claviculata* *Dryopteris affinis* subsp. *affinis* *Dryopteris affinis* subsp. *borreri* *Dryopteris carthusiana* *Dryopteris dilatata* *Polystichum setiferum*	**Low fertility** *Agrostis vinealis* *Hylotelephium telephium* (*Sedum telephium*) **Low fertility** *Melampyrum pratense* *Rubus fruticosus* *Blechnum spicant* *Holcus mollis* *Luzula forsteri* *Rubia peregrina* *Geum urbanum* *Glechoma hederacea Peucedanum gallicum* *Ranunculus auricomus* *Geranium robertianum* **Medium fertility** *Pteridium aquilinum* *Ceratocapnos claviculata* *Dryopteris affinis* subsp. *affinis* *Dryopteris affinis*	**Acid** *Agrostis vinealis* **Neutral** *Hylotelephium telephium* (*Sedum telephium*) **Acid** *Melampyrum pratense* *Rubus fruticosus* *Blechnum spicant* *Holcus mollis* **Neutral** *Luzula forsteri* *Rubia peregrina* *Geum urbanum* *Glechoma hederacea Peucedanum gallicum* **Alkaline** *Ranunculus auricomus* *Geranium robertianum* **Acid** *Pteridium aquilinum* *Ceratocapnos claviculata* **Neutral** *Dryopteris affinis*	**Partial shade-full sun** *Agrostis vinealis* **Partial shade-full sun** *Hylotelephium telephium* **Semi-shade** *Melampyrum pratense* *Rubus fruticosus* *Blechnum spicant* *Holcus mollis* **Semi-shade** *Luzula forsteri* *Rubia peregrina* *Geum urbanum* *Glechoma hederacea Peucedanum gallicum* **Semi-shade** *Ranunculus auricomus* *Geranium robertianum* **Semi-shade** *Pteridium aquilinum* *Ceratocapnos claviculata* **Shade** *Dryopteris affinis*

Luzula sylvatica *Lonicera periclymenum* *Teucrium scorodonia* *Viola riviniana* *Stellaria holostea* *Conopodium majus* *Pulmonaria longifolia* *Anemone nemorosa* *Hyacinthoides non-scripta* *Melica uniflora* *Polygonatum multiflorum* *Carex sylvatica* *Euphorbia amygdaloides* *Primula vulgaris subsp. vulgaris* *Narcissus pseudonarcissus* *Veronica chamaedrys* *Potentilla sterilis* *Juncus tenuis* *Ajuga reptans* *Moehringia trinervia* *Arum italicum** *Scrophularia nodosa* *Hypericum androsaemum* *Ranunculus ficaria* Geranium robertianum subsp. purpureum	*Dryopteris filix-mas* *Hedera helix* *Sanicula europaea* *Ruscus aculeatus* *Luzula sylvatica* *Lonicera periclymenum* *Teucrium scorodonia* *Viola riviniana* *Stellaria holostea* *Conopodium majus* *Pulmonaria longifolia* *Anemone nemorosa* *Hyacinthoides non-scripta* *Melica uniflora* *Polygonatum multiflorum* *Carex sylvatica* *Euphorbia amygdaloides* *Primula vulgaris subsp. vulgaris* *Narcissus pseudonarcissus* *Veronica chamaedrys* *Potentilla sterilis* *Juncus tenuis* *Ajuga reptans* *Moehringia trinervia* *Arum italicum** *Scrophularia nodosa* *Hypericum*	subsp. *borreri* *Dryopteris carthusiana* *Dryopteris dilatata* *Polystichum setiferum* *Dryopteris filix-mas* *Hedera helix* *Sanicula europaea* *Ruscus aculeatus* *Luzula sylvatica* *Lonicera periclymenum* *Teucrium scorodonia* *Viola riviniana* *Stellaria holostea* *Conopodium majus* *Pulmonaria longifolia* *Anemone nemorosa* *Hyacinthoides non-scripta* *Melica uniflora* *Polygonatum multiflorum* *Carex sylvatica* *Euphorbia amygdaloides* *Primula vulgaris subsp. vulgaris* *Narcissus pseudonarcissus* *Veronica chamaedrys* *Potentilla sterilis* *Juncus tenuis*	subsp. *affinis* *Dryopteris affinis* subsp. *borreri* *Dryopteris carthusiana* *Dryopteris dilatata* *Polystichum setiferum* *Dryopteris filix-mas* *Hedera helix* *Sanicula europaea* *Ruscus aculeatus* *Luzula sylvatica* *Lonicera periclymenum* *Teucrium scorodonia* *Viola riviniana* *Stellaria holostea* *Conopodium majus* *Pulmonaria longifolia* *Anemone nemorosa* *Hyacinthoides non-scripta* *Melica uniflora* *Polygonatum multiflorum* *Carex sylvatica* *Euphorbia amygdaloides* *Primula vulgaris subsp. vulgaris* *Narcissus pseudonarcissus* *Veronica chamaedrys* *Potentilla sterilis*	subsp. *affinis* *Dryopteris affinis* subsp. *borreri* *Dryopteris carthusiana* *Dryopteris dilatata* *Polystichum setiferum* *Dryopteris filix-mas* *Hedera helix* *Sanicula europaea* **Semi-shade** *Ruscus aculeatus* *Luzula sylvatica* *Lonicera periclymenum* *Teucrium scorodonia* *Viola riviniana* *Stellaria holostea* *Conopodium majus* *Pulmonaria longifolia* *Anemone nemorosa* *Hyacinthoides non-scripta* *Melica uniflora* *Polygonatum multiflorum* *Carex sylvatica* *Euphorbia amygdaloides* *Primula vulgaris subsp. vulgaris* *Narcissus pseudonarcissus* *Veronica*

Rosa canina Crataegus monogyna Neottia nidus-avis* Daphne laureola Dioscorea communis Fragaria vesca Orchis mascula Rhamnus cathartica Stellaria neglecta Ligustrum vulgare Lithospermum officinale Listera ovata Scirpus sylvaticus Athyrium filix-femina Deschampsia cespitosa Ribes rubrum Osmunda regalis Carex pendula Thelypteris palustris Juncus tenageia Circaea lutetiana Poa trivialis Rumex sanguineus Cucubalus baccifer Allium ursinum	androsaemum Ranunculus ficaria Geranium robertianum subsp. purpureum Rosa canina Crataegus monogyna Neottia nidus-avis* Daphne laureola Dioscorea communis Fragaria vesca Orchis mascula Rhamnus cathartica Stellaria neglecta Ligustrum vulgare Lithospermum officinale Listera ovate	Ajuga reptans Moehringia trinervia Arum italicum* Scrophularia nodosa Hypericum androsaemum Ranunculus ficaria Geranium robertianum subsp. purpureum Rosa canina Crataegus monogyna Neottia nidus-avis* Daphne laureola Dioscorea communis Fragaria vesca Orchis mascula Rhamnus cathartica Stellaria neglecta Ligustrum vulgare Lithospermum officinale	Juncus tenuis Ajuga reptans Moehringia trinervia Arum italicum* Scrophularia nodosa Hypericum androsaemum Ranunculus ficaria Geranium robertianum subsp. purpureum Rosa canina Crataegus monogyna --- **Alkaline** Neottia nidus-avis* Daphne laureola Dioscorea communis Fragaria vesca Orchis mascula Rhamnus cathartica Stellaria neglecta Ligustrum vulgare Lithospermum officinale	chamaedrys Potentilla sterilis Juncus tenuis Ajuga reptans Moehringia trinervia Arum italicum* Scrophularia nodosa Hypericum androsaemum Ranunculus ficaria --- **Partial shade-full sun** Geranium robertianum subsp. purpureum Rosa canina Crataegus monogyna --- **Shade** Neottia nidus-avis* --- **Semi-shade** Daphne laureola Dioscorea communis Fragaria vesca Orchis mascula Rhamnus cathartica Stellaria neglecta --- **Partial shade-full sun** Ligustrum vulgare Lithospermum officinale

	Damp *Scirpus sylvaticus* *Athyrium filix-femina* *Deschampsia cespitosa* *Ribes rubrum* *Osmunda regalis* *Carex pendula* *Thelypteris palustris* *Juncus tenageia* *Circaea lutetiana* *Poa trivialis* *Rumex sanguineus* *Cucubalus baccifer* *Allium ursinum*	**High fertility** *Listera ovata* **Medium fertility** *Scirpus sylvaticus* *Athyrium filix-femina* *Deschampsia cespitosa* *Ribes rubrum* *Osmunda regalis* *Carex pendula* *Thelypteris palustris* *Juncus tenageia* **High fertility** *Circaea lutetiana* *Poa trivialis* *Rumex sanguineus* *Cucubalus baccifer* *Allium ursinum*	**Alkaline** *Listera ovata* **Acid** *Scirpus sylvaticus* **Neutral** *Athyrium filix-femina* *Deschampsia cespitosa* *Ribes rubrum* *Osmunda regalis* *Carex pendula* *Thelypteris palustris* *Juncus tenageia* **Neutral** *Circaea lutetiana* *Poa trivialis* **Alkaline** *Rumex sanguineus* *Cucubalus baccifer* *Allium ursinum*	**Shade** *Listera ovata* **Semi-shade** *Scirpus sylvaticus* **Shade** *Athyrium filix-femina* **Semi-shade** *Deschampsia cespitosa* *Ribes rubrum* *Osmunda regalis* *Carex pendula* *Thelypteris palustris* **Partial shade-full sun** *Juncus tenageia* **Semi-shade** *Circaea lutetiana* *Poa trivialis* **Semi-shade** *Rumex sanguineus* *Allium ursinum* **Partial shade-full sun** *Cucubalus baccifer*

No Ellenberg:

Brahypodium sylvaticum

Polypodium interjectum

Polypodium vulgare

Potentilla montana

Hedgerow list

Complete List	**Moisture (F)**	**Reaction (R)**	**Nitrogen (N)**
Euphorbia cyparissias Hylotelephium telephium (Sedum telephium) Helminthotheca echioides Rubus fruticosus Carex ovalis Holcus mollis Potentilla argentea* Mespilus germanica Melampyrum cristatum*+ Epilobium lanceolatum Cytisus scoparius Arrhenatherum elatius subsp. bulbosum Pyrus cordata* Ruscus aculeatus Equisetum arvense Linaria repens Pulmonaria longifolia Vicia hirsuta Phleum pratense Prunus spinosa Quercus robur Rosa canina Veronica chamaedrys Veronica serpyllifolia Apera spica-venti* Matricaria recutita Corylus avellana Gaudinia fragilis Hedera helix Juncus tenuis	**Dry** Euphorbia cyparissias Hylotelephium telephium (Sedum telephium) Helminthotheca echioides **Moist** Rubus fruticosus Carex ovalis Holcus mollis Potentilla argentea* Mespilus germanica Melampyrum cristatum*+ Epilobium lanceolatum Cytisus scoparius Arrhenatherum elatius subsp. bulbosum Pyrus cordata* Ruscus aculeatus Equisetum arvense Linaria repens Pulmonaria longifolia Vicia hirsuta Phleum pratense Prunus spinosa Quercus robur Rosa canina Veronica chamaedrys Veronica serpyllifolia	**Low fertility** Euphorbia cyparissias **Medium fertility** Hylotelephium telephium (Sedum telephium) **High fertility** Helminthotheca echioides **Low fertility** Rubus fruticosus Carex ovalis Holcus mollis Potentilla argentea* Mespilus germanica Melampyrum cristatum*+ **Medium fertility** Epilobium lanceolatum Cytisus scoparius Arrhenatherum elatius subsp. bulbosum Pyrus cordata* Ruscus aculeatus Equisetum arvense Linaria repens Pulmonaria longifolia Vicia hirsuta Phleum pratense	**Alkaline** Euphorbia cyparissias **Neutral** Hylotelephium telephium (Sedum telephium) **Alkaline** Helminthotheca echioides **Acid** Rubus fruticosus Carex ovalis Holcus mollis **Neutral** Potentilla argentea* Mespilus germanica **Alkaline** Melampyrum cristatum*+ **Acid** Epilobium lanceolatum Cytisus scoparius **Neutral** Arrhenatherum elatius subsp. bulbosum Pyrus cordata* Ruscus aculeatus Equisetum arvense Linaria repens Pulmonaria longifolia

Myosotis arvensis Plantago major Arum italicum* Crepis biennis Geranium molle Lolium perenne Scrophularia nodosa Vicia sepium Plantago coronopus Salix atrocinerea Vicia cracca Cerastium glomeratum Hypericum androsaemum Ranunculus ficaria Campanula rapunculus* Viburnum lantana Dioscorea communis Viscum album Ligustrum vulgare Melampyrum arvense Crepis setosa Geranium Rotundifolium Lactuca serriola Linaria vulgaris Muscari comosum Pastinaca sativa Reseda luteola Silene dichotoma Lithospermum officinale Acer campestre Brachypodium pinnatum Cornus sanguine Rhamnus cathartica	Apera spica-venti* Matricaria recutita Corylus avellana Gaudinia fragilis Hedera helix Juncus tenuis Myosotis arvensis Plantago major Arum italicum* Crepis biennis Geranium molle Lolium perenne Scrophularia nodosa Vicia sepium Plantago coronopus Salix atrocinerea Vicia cracca Cerastium glomeratum Hypericum androsaemum Ranunculus ficaria Campanula rapunculus* Viburnum lantana Dioscorea communis Viscum album Ligustrum vulgare Melampyrum arvense Crepis setosa Geranium Rotundifolium Lactuca serriola Linaria vulgaris Muscari comosum Pastinaca sativa Reseda luteola Silene dichotoma Lithospermum	Prunus spinosa Quercus robur Rosa canina Veronica chamaedrys Veronica serpyllifolia Apera spica-venti* Matricaria recutita Corylus avellana Gaudinia fragilis Hedera helix Juncus tenuis Myosotis arvensis Plantago major Arum italicum* Crepis biennis Geranium molle Lolium perenne Scrophularia nodosa Vicia sepium Plantago coronopus Salix atrocinerea Vicia cracca Cerastium glomeratum Hypericum androsaemum Ranunculus ficaria Campanula rapunculus* Viburnum lantana Dioscorea communis Viscum album Ligustrum vulgare Melampyrum arvense Crepis setosa Geranium Rotundifolium Lactuca serriola Linaria vulgaris	Vicia hirsuta Phleum pratense Prunus spinosa Quercus robur Rosa canina Veronica chamaedrys Veronica serpyllifolia Apera spica-venti* Matricaria recutita Corylus avellana Gaudinia fragilis Hedera helix Juncus tenuis Myosotis arvensis Plantago major Arum italicum* Crepis biennis Geranium molle Lolium perenne Scrophularia nodosa Vicia sepium Plantago coronopus Salix atrocinerea Vicia cracca Cerastium glomeratum Hypericum androsaemum Ranunculus ficaria **Alkaline** Campanula rapunculus* Viburnum lantana Dioscorea communis Viscum album Ligustrum vulgare Melampyrum arvense Crepis setosa

Geranium lucidum *Papaver rhoeas* *Stellaria neglecta* *Cichorium intybus* *Geranium dissectum* *Medicago arabica* *Rubus caesius* *Epilobium tetragonum* *Cymbalaria muralis* *Silene alba (Silene latifolia)* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Bromus sterilis* *Epilobium angustifolium* (*Chamerion angustifolium*) *Cirsium arvense* *Elytrigia repens* subsp.*repens* *Glechoma hederacea* *Heracleum sphondylium* *Poa annua* *Robinia pseudoacacia* *Anthriscus sylvestris* *Matricaria discoidea* *Rumex obtusifolius* *Stellaria media* *Urtica dioica* *Reynoutria japonica* *Convolvulus arvensis* *Sison amomum* *Hordeum murinum* *Malva sylvestris* *Arrhenatherum elatius* *Avena sativa* subsp.*fatua*	*officinale* *Acer campestre* *Brachypodium pinnatum* *Cornus sanguine* *Rhamnus cathartica* *Geranium lucidum* *Papaver rhoeas* *Stellaria neglecta* *Cichorium intybus* *Geranium dissectum* *Medicago arabica* *Rubus caesius* *Epilobium tetragonum* *Cymbalaria muralis* *Silene alba (Silene latifolia)* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Bromus sterilis* *Epilobium angustifolium* (*Chamerion angustifolium*) *Cirsium arvense* *Elytrigia repens* subsp.*repens* *Glechoma hederacea* *Heracleum sphondylium* *Poa annua* *Robinia pseudoacacia* *Anthriscus sylvestris* *Matricaria discoidea* *Rumex obtusifolius* *Stellaria media* *Urtica dioica* *Reynoutria japonica* *Convolvulus arvensis* *Sison amomum*	*Muscari comosum* *Pastinaca sativa* *Reseda luteola* *Silene dichotoma* *Lithospermum officinale* *Acer campestre* *Brachypodium pinnatum* *Cornus sanguine* *Rhamnus cathartica* *Geranium lucidum* *Papaver rhoeas* *Stellaria neglecta* *Cichorium intybus* *Geranium dissectum* *Medicago arabica* *Rubus caesius* *Epilobium tetragonum* *Cymbalaria muralis* **High fertility** *Silene alba (Silene latifolia)* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Bromus sterilis* *Epilobium angustifolium* (*Chamerion angustifolium*) *Cirsium arvense* *Elytrigia repens* subsp.*repens* *Glechoma hederacea*	*Geranium Rotundifolium* *Lactuca serriola* *Linaria vulgaris* *Muscari comosum* *Pastinaca sativa* *Reseda luteola* *Silene dichotoma* *Lithospermum officinale* *Acer campestre* *Brachypodium pinnatum* *Cornus sanguine* *Rhamnus cathartica* *Geranium lucidum* *Papaver rhoeas* *Stellaria neglecta* *Cichorium intybus* *Geranium dissectum* *Medicago arabica* *Rubus caesius* *Epilobium tetragonum* *Cymbalaria muralis* **Neutral** *Silene alba (Silene latifolia)* *Jacobaea vulgaris* (Syn. Of *Senecio jacobaea*) *Bromus sterilis* *Epilobium angustifolium* (*Chamerion angustifolium*) *Cirsium arvense* *Elytrigia repens* subsp.*repens* *Glechoma hederacea* *Heracleum*

Clematis vitalba *Laspana communis* *Sonchus asper* *Verbena officinalis* Vervain *Veronica persica* *Valerianella carinata* *Alliaria petiolata* *Chaerophyllum temulum* *Cirsium vulgare* *Lamium purpureum* *Sambucus nigra* *Galium aparine* *Senecio vulgaris* Groundsel *Sonchus oleraceus* *Dipsacus fullonum* *Hypericum humifusum* *Athyrium filix-femina* *Bromus racemosus* *Mentha suaveolens* *Parentucellia viscosa* *Equisetum x litorale Kuhlew. ex Rupr* *Ranunculus repens* *Poa trivialis* *Rumex crispus* *Solanum dulcamara* *Cucubalus baccifer* *Stachys sylvatica* *Bryonia cretica subsp. dioica* *Ranunculus sardous* *Persicaria maculosa*	*Hordeum murinum* *Malva sylvestris* *Arrhenatherum elatius* *Avena sativa* subsp.*fatua* *Clematis vitalba* *Laspana communis* *Sonchus asper* *Verbena officinalis* Vervain *Veronica persica* *Valerianella carinata* *Alliaria petiolata* *Chaerophyllum temulum* *Cirsium vulgare* *Lamium purpureum* *Sambucus nigra* *Galium aparine* *Senecio vulgaris* Groundsel *Sonchus oleraceus* *Dipsacus fullonum* --- **Damp** *Hypericum humifusum*	*Heracleum sphondylium* *Poa annua* *Robinia pseudoacacia* *Anthriscus sylvestris* *Matricaria discoidea* *Rumex obtusifolius* *Stellaria media* *Urtica dioica* *Reynoutria japonica* *Convolvulus arvensis* *Sison amomum* *Hordeum murinum* *Malva sylvestris* *Arrhenatherum elatius* *Avena sativa* subsp.*fatua* *Clematis vitalba* *Laspana communis* *Sonchus asper* *Verbena officinalis* Vervain *Veronica persica* *Valerianella carinata* *Alliaria petiolata* *Chaerophyllum temulum* *Cirsium vulgare* *Lamium purpureum* *Sambucus nigra* *Galium aparine* *Senecio vulgaris* Groundsel *Sonchus oleraceus* *Dipsacus fullonum* --- **Low fertility**	*sphondylium* *Poa annua* *Robinia pseudoacacia* *Anthriscus sylvestris* *Matricaria discoidea* *Rumex obtusifolius* *Stellaria media* *Urtica dioica* *Reynoutria japonica* --- **Alkaline** *Convolvulus arvensis* *Sison amomum* *Hordeum murinum* *Malva sylvestris* *Arrhenatherum elatius* *Avena sativa* subsp.*fatua* *Clematis vitalba* *Laspana communis* *Sonchus asper* *Verbena officinalis* Vervain *Veronica persica* *Valerianella carinata* *Alliaria petiolata* *Chaerophyllum temulum* *Cirsium vulgare* *Lamium purpureum* *Sambucus nigra* *Galium aparine* *Senecio vulgaris* Groundsel *Sonchus oleraceus* *Dipsacus fullonum* --- **Neutral** *Hypericum humifusum*

	Athyrium filix-femina *Bromus racemosus* *Mentha suaveolens* *Parentucellia viscosa* *Equisetum x litorale Kuhlew. ex Rupr* *Ranunculus repens* *Poa trivialis* *Rumex crispus* *Solanum dulcamara* *Cucubalus baccifer* *Stachys sylvatica* *Bryonia cretica subsp. dioica* *Ranunculus sardous* *Persicaria maculosa*	*Hypericum humifusum* **Medium fertility** *Athyrium filix-femina* *Bromus racemosus* *Mentha suaveolens* *Parentucellia viscosa* *Equisetum x litorale Kuhlew. ex Rupr* **High fertility** *Ranunculus repens* *Poa trivialis* *Rumex crispus* *Solanum dulcamara* *Cucubalus baccifer* *Stachys sylvatica* *Bryonia cretica subsp. dioica* *Ranunculus sardous* *Persicaria maculosa*	**Neutral** *Athyrium filix-femina* *Bromus racemosus* *Mentha suaveolens* *Parentucellia viscosa* *Equisetum x litorale Kuhlew. ex Rupr* **Neutral** *Ranunculus repens* *Poa trivialis* *Rumex crispus* *Solanum dulcamara* **Alkaline** *Cucubalus baccifer* *Stachys sylvatica* *Bryonia cretica subsp. dioica* *Ranunculus sardous* *Persicaria maculosa*

No Ellenberg:

Conyza canadensis

Crassula tillaea

Crepis sancta

Dianthus armeria+*

Dianthus armeria L. subsp. armeria

*Filago vulgaris**

Geranium columbinum

Lapsana communis L. subsp. communis

Stellaria media. subsp. media

Trifolium campestre

Umbilicus rupestris

Veronica arvensis

Vulpia myuros

Vulpia myuros subsp..sciuroides (syn of Vulpia Bromoides)

Aquatic and marginal list

Complete list	**Moisture (F)**	**Nitrogen (N)**	**Reaction (R)**
Veronica serpyllifolia	**Moist**	**Medium fertility**	**Neutral**
Juncus tenuis	*Veronica serpyllifolia*	*Veronica serpyllifolia*	*Veronica serpyllifolia*
Salix atrocinerea	*Juncus tenuis*	*Juncus tenuis*	*Juncus tenuis*
Vicia cracca	*Salix atrocinerea*	*Salix atrocinerea*	*Salix atrocinerea*
Cardamine pratensis	*Vicia cracca*	*Vicia cracca*	*Vicia cracca*
Listera ovata	*Cardamine pratensis*	*Cardamine pratensis*	**Alkaline**
Dipsacus fullonum	*Listera ovata*	**High fertility**	*Cardamine pratensis*
Pinguicula lusitanica	*Dipsacus fullonum*	*Listera ovata*	**Alkaline**
Agrostis canina	**Damp**	*Dipsacus fullonum*	*Listera ovata*
Veronica scutellata	*Pinguicula lusitanica*	**Low fertility**	*Dipsacus fullonum*
Scutellaria minor	*Agrostis canina*	*Pinguicula lusitanica*	**Acid**
Galium palustre subsp.*debile*	*Veronica scutellata*	*Agrostis canina*	*Pinguicula lusitanica*
Isolepis fluitans	*Scutellaria minor*	*Veronica scutellata*	*Agrostis canina*
Cyperus flavescens	*Galium palustre* subsp.*debile*	*Scutellaria minor*	*Veronica scutellata*
Juncus conglomeratus	*Isolepis fluitans*	*Galium palustre* subsp.*debile*	*Scutellaria minor*
Lysimachia tenella	*Cyperus flavescens*	*Isolepis fluitans*	*Galium palustre* subsp.*debile*
Carex viridula subsp.*oedocarpa*	*Juncus conglomeratus*	*Cyperus flavescens*	*Isolepis fluitans*
Carum verticillatum	*Lysimachia tenella*	*Juncus conglomeratus*	**Neutral**
Juncus acutifloris	*Carex viridula* subsp.*oedocarpa*	*Lysimachia tenella*	*Cyperus flavescens*
Cirsium dissectum	*Carum verticillatum*	*Carex viridula* subsp.*oedocarpa*	*Juncus conglomeratus*
Carex panicea	*Juncus acutifloris*	*Carum verticillatum*	*Lysimachia tenella*
Ranunculus flammula	*Cirsium dissectum*	*Juncus acutifloris*	*Carex viridula* subsp.*oedocarpa*
Hydrocotyle vulgaris	*Carex panicea*	*Cirsium dissectum*	*Carum verticillatum*
Littorella uniflora	*Ranunculus flammula*	*Carex panicea*	*Juncus acutifloris*
Eleocharis multicaulis	*Hydrocotyle vulgaris*	*Ranunculus flammula*	*Cirsium dissectum*
Juncus heterophyllus	*Littorella uniflora*	*Hydrocotyle vulgaris*	*Carex panicea*
*Baldellia ranunculoides**	*Eleocharis multicaulis*	*Littorella uniflora*	*Ranunculus flammula*
Carex viridula var.*viridula*	*Juncus heterophyllus*	*Eleocharis multicaulis*	*Hydrocotyle vulgaris*
Dactylorhiza elata var. *sesquidpedalis*	*Baldellia*	*Juncus heterophyllus*	*Littorella uniflora*
Dactylorhiza incarnata		*Baldellia*	*Eleocharis multicaulis*
Epipactis palustris			

*Liparis loeselii** *Spiranthes aestivalis** *Triglochin palustris* *Juncus anceps* *Scirpus sylvaticus* *Cirsium palustre* *Achillea ptarmica* *Juncus effusus* *Equisetum palustre* *Gnaphalium uliginosum* *Lychnis flos-cuculi* (*Silene flos-cuculi*) *Oenanthe crocata* *Angelica sylvestris* *Eleocharis uniglumis* *Jacobaea aquatica* (syn. of *Senecio aquaticus*) *Juncus bufonius* *Lythrum portula* *Filipendula ulmaria* *Lysimachia nummularia* *Cyperus esculentus* *Lythrum salicaria* *Trifolium patens* *Elatine hexandra* *Lotus pedunculatus* *Osmunda regalis* *Galium palustre* *Carex disticha* *Cyperus fuscus** *Eleocharis palustris* *Juncus articulatus* *Oenanthe fistulosa**+ *Equisetum x litorale Kuhlew* *Myosotis laxa*	*ranunculoides** *Carex viridula* var.*viridula* *Dactylorhiza elata* var. *sesquidpedalis* *Dactylorhiza incarnata* *Epipactis palustris* *Liparis loeselii** *Spiranthes aestivalis** *Triglochin palustris* *Juncus anceps* *Scirpus sylvaticus* *Cirsium palustre* *Achillea ptarmica* *Juncus effusus* *Equisetum palustre* *Gnaphalium uliginosum* *Lychnis flos-cuculi* (*Silene flos-cuculi*) *Oenanthe crocata* *Angelica sylvestris* *Eleocharis uniglumis* *Jacobaea aquatica* (syn. of *Senecio aquaticus*) *Juncus bufonius* *Lythrum portula* *Filipendula ulmaria* *Lysimachia nummularia* *Cyperus esculentus* *Lythrum salicaria* *Trifolium patens* *Elatine hexandra* *Lotus pedunculatus* *Osmunda regalis* *Galium palustre* *Carex disticha*	*ranunculoides** *Carex viridula* var.*viridula* *Dactylorhiza elata* var. *sesquidpedalis* *Dactylorhiza incarnata* *Epipactis palustris* *Liparis loeselii** *Spiranthes aestivalis** *Triglochin palustris* *Juncus anceps* --- **Medium fertility** *Scirpus sylvaticus* *Cirsium palustre* *Achillea ptarmica* *Juncus effusus* *Equisetum palustre* *Gnaphalium uliginosum* *Lychnis flos-cuculi* (*Silene flos-cuculi*) *Oenanthe crocata* *Angelica sylvestris* *Eleocharis uniglumis* *Jacobaea aquatica* (syn. of *Senecio aquaticus*) *Juncus bufonius* *Lythrum portula* *Filipendula ulmaria* *Lysimachia nummularia* *Cyperus esculentus* *Lythrum salicaria* *Trifolium patens*	*Juncus heterophyllus* *Baldellia ranunculoides** --- **Alkaline** *Carex viridula* var.*viridula* *Dactylorhiza elata* var. *sesquidpedalis* *Dactylorhiza incarnata* *Epipactis palustris* *Liparis loeselii** *Spiranthes aestivalis** *Triglochin palustris* *Juncus anceps* --- **Acid** *Scirpus sylvaticus* *Cirsium palustre* --- **Neutral** *Achillea ptarmica* *Juncus effusus* *Equisetum palustre* *Gnaphalium uliginosum* *Lychnis flos-cuculi* (*Silene flos-cuculi*) *Oenanthe crocata* *Angelica sylvestris* *Eleocharis uniglumis* *Jacobaea aquatica* (syn. of *Senecio aquaticus*) *Juncus bufonius* *Lythrum portula* *Filipendula ulmaria* *Lysimachia nummularia* *Cyperus esculentus*

subsp.cespitosa Caltha palustris Mentha aquatica Carex cuprina var. cuprina Scutellaria galericulata Glyceria fluitans Thelypteris palustris Carex acutiformis Carex vesicaria Glyceria notata Rorippa amphibia Lycopus europaeus Althaea officinalis Epilobium parviflorum Mentha arvensis Equisetum telmateia Pulicaria dysenterica Myosotis scorpioides Salix viminalis Cladium mariscus Samolus valerandi Carex pseudocyperus Carex elata Carex riparia Lysimachia vulgaris Ranunculus ophioglossifolius* Solanum dulcamara Phragmites australis Eupatorium cannabinum Bidens cernua Epilobium hirsutum Calystegia sepium Bidens frondosa Glyceria declinata Mentha pulegium *+	Cyperus fuscus* Eleocharis palustris Juncus articulatus Oenanthe fistulosa*+ Equisetum x litorale Kuhlew Myosotis laxa subsp.cespitosa Caltha palustris Mentha aquatica Carex cuprina var. cuprina Scutellaria galericulata Glyceria fluitans Thelypteris palustris Carex acutiformis Carex vesicaria Glyceria notata Rorippa amphibia Lycopus europaeus Althaea officinalis Epilobium parviflorum Mentha arvensis Equisetum telmateia Pulicaria dysenterica Myosotis scorpioides Salix viminalis Cladium mariscus Samolus valerandi Carex pseudocyperus Carex elata Carex riparia Lysimachia vulgaris Ranunculus ophioglossifolius* Solanum dulcamara Phragmites australis Eupatorium	Elatine hexandra Lotus pedunculatus Osmunda regalis Galium palustre Carex disticha Cyperus fuscus* Eleocharis palustris Juncus articulatus Oenanthe fistulosa*+ Equisetum x litorale Kuhlew Myosotis laxa subsp.cespitosa Caltha palustris Mentha aquatica Carex cuprina var. cuprina Scutellaria galericulata Glyceria fluitans Thelypteris palustris Carex acutiformis Carex vesicaria Glyceria notata Rorippa amphibia Lycopus europaeus Althaea officinalis Epilobium parviflorum Mentha arvensis Equisetum telmateia Pulicaria dysenterica Myosotis scorpioides Salix viminalis Cladium mariscus Samolus valerandi Carex pseudocyperus Carex elata Carex riparia Lysimachia vulgaris	Lythrum salicaria Trifolium patens Elatine hexandra Lotus pedunculatus Osmunda regalis Galium palustre Carex disticha Cyperus fuscus* Eleocharis palustris Juncus articulatus Oenanthe fistulosa*+ Equisetum x litorale Kuhlew Myosotis laxa subsp.cespitosa Caltha palustris Mentha aquatica Carex cuprina var. cuprina Scutellaria galericulata Glyceria fluitans Thelypteris palustris Carex acutiformis Carex vesicaria Glyceria notata Rorippa amphibia Lycopus europaeus **Alkaline** Althaea officinalis Epilobium parviflorum Mentha arvensis Equisetum telmateia Pulicaria dysenterica Myosotis scorpioides Salix viminalis Cladium mariscus Samolus valerandi

Phalaris arundinacea *Ranunculus sardous* *Chenopodium rubrum* *Alisma plantago-aquatica* *Iris pseudacorus* *Rumex hydrolapathum* *Sparganium erectum* *Rumex maritimus* *Rumex palustris* *Typha latifolia* *Luronium Eleocharis acicularis natans* *Hypericum elodes* *Myriophyllum alterniflorum* *Utricularia australis* *Utricularia vulgaris* *Equisetum fluviatile* *Schoenoplectus lacustris* *Callitriche brutia* var. *hamulata* Intermediate *Lemna minor* *Potamogeton natans* *Potamogeton gramineus* *Potamogeton trichoid* *Callitriche stagnalis* *Alisma lanceolatum* *Typha angustifolia* *Nymphaea alba* *Nuphar lutea* *Potamogeton pectinatus* *Elodea canadensis* *Potamogeton crispus* *Potamogeton lucens* *Myriophyllum*	*cannabinum* *Bidens cernua* *Epilobium hirsutum* *Calystegia sepium* *Bidens frondosa* *Glyceria declinata* *Mentha pulegium* *+ *Phalaris arundinacea* *Ranunculus sardous* *Chenopodium rubrum* *Alisma plantago-aquatica* *Iris pseudacorus* *Rumex hydrolapathum* *Sparganium erectum* *Rumex maritimus* *Rumex palustris* *Typha latifolia* --- **Wet** *Luronium Eleocharis acicularis natans* *Hypericum elodes* *Myriophyllum alterniflorum* *Utricularia australis* *Utricularia vulgaris*	--- **High fertility** *Ranunculus ophioglossifolius** *Solanum dulcamara* *Phragmites australis* *Eupatorium cannabinum* *Bidens cernua* *Epilobium hirsutum* *Calystegia sepium* *Bidens frondosa* *Glyceria declinata* *Mentha pulegium* *+ *Phalaris arundinacea* *Ranunculus sardous* *Chenopodium rubrum* *Alisma plantago-aquatica* *Iris pseudacorus* *Rumex hydrolapathum* *Sparganium erectum* *Rumex maritimus* *Rumex palustris* *Typha latifolia* --- **Low fertility** *Luronium Eleocharis acicularis natans* *Hypericum elodes* *Myriophyllum alterniflorum* *Utricularia australis* *Utricularia vulgaris*	*Carex pseudocyperus* *Carex elata* *Carex riparia* *Lysimachia vulgaris* --- **Neutral** *Ranunculus ophioglossifolius** *Solanum dulcamara* *Phragmites australis* --- **Alkaline** *Eupatorium cannabinum* *Bidens cernua* *Epilobium hirsutum* *Calystegia sepium* *Bidens frondosa* *Glyceria declinata* *Mentha pulegium* *+ *Phalaris arundinacea* *Ranunculus sardous* *Chenopodium rubrum* *Alisma plantago-aquatica* *Iris pseudacorus* *Rumex hydrolapathum* *Sparganium erectum* *Rumex maritimus* *Rumex palustris* *Typha latifolia* --- **Acid** *Luronium Eleocharis acicularis natans* --- **Neutral** *Hypericum elodes* *Myriophyllum alterniflorum*

spicatum	*Equisetum fluviatile* *Schoenoplectus lacustris* *Callitriche brutia* var. *hamulata* Intermediate *Lemna minor* *Potamogeton natans* *Potamogeton gramineus* *Potamogeton trichoid* *Callitriche stagnalis* *Alisma lanceolatum* *Typha angustifolia* *Nymphaea alba* *Nuphar lutea* *Potamogeton pectinatus* *Elodea canadensis* *Potamogeton crispus* *Potamogeton lucens* *Myriophyllum spicatum*	 **Medium fertility** *Equisetum fluviatile* *Schoenoplectus lacustris* *Callitriche brutia* var. *hamulata* Intermediate *Lemna minor* *Potamogeton natans* *Potamogeton gramineus* *Potamogeton trichoid* *Callitriche stagnalis* *Alisma lanceolatum* *Typha angustifolia* *Nymphaea alba* *Nuphar lutea* **High fertility** *Potamogeton pectinatus* *Elodea canadensis* *Potamogeton crispus* *Potamogeton lucens* *Myriophyllum spicatum*	*Utricularia australis* *Utricularia vulgaris* **Neutral** *Equisetum fluviatile* *Schoenoplectus lacustris* *Callitriche brutia* var. *hamulata* Intermediate *Lemna minor* *Potamogeton natans* *Potamogeton gramineus* *Potamogeton trichoid* *Callitriche stagnalis* **Alkaline** *Alisma lanceolatum* *Typha angustifolia* *Nymphaea alba* *Nuphar lutea* **Neutral** *Potamogeton pectinatus* *Elodea canadensis* **Alkaline** *Potamogeton crispus* *Potamogeton lucens* *Myriophyllum spicatum*

No Ellenberg:

*Baldellia ranunculoides (L.) Parl. subsp. Ranunculoides**

Baldellia ranunculoides subsp..repens

Cardamine pratensis L. subsp. pratensis

Dactylorhiza fuchsii

Galium palustre L. subsp. palustre

Juncus bufonius L. subsp. bufonius

Juncus bulbosus L. subsp. bulbosus

Persicaria amphibia (Polygonum amphibium)