Biodiversity climate change report card technical paper

5. Impacts of Climate Change on Terrestrial Habitats and Vegetation

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Summary

- Evidence [Medium] of the impacts of climate change from results of experiments and observations generally confirms earlier expert opinion of change to the vegetation and habitats of the UK [Agreement - High][Confidence – Medium]

- Most of the species of plants that form the matrix of vegetation communities in the UK have wide biogeographic amplitude [Agreement – High]. Almost all of the scenarios indicate the UK will have a climate that is within the limits of the Temperate zone until at least the 2080s. Observed spatial patterns and experimental evidence [Medium] is showing that at least some species have the ability to survive either because of small scale habitat heterogeneity and/or genetic variation leading to adaptation.[Confidence - Medium]

- Species from the Arctic Montane, Boreal Montane, and Boreal floristic elements of the British Flora have survived for centuries outside or at the margins of the climate where they are normally found [Agreement – High]. Observations show these species have been declining in recent decades and are likely to continue to do so. Species from the Southern Temperate and Mediterranean floristic element of the British Flora have been increasing.[Evidence – High][Confidence -High]

- UKCP09 scenarios give projections that are similar to earlier scenarios that were used to produce many models and experimental designs reviewed in this paper. The results from these earlier studies are therefore largely still valid. The exceptions are the UKCP09 projections resulting from the high carbon emissions scenarios for beyond the 2080s where the increase in temperature will give the UK a climate that is similar to a current day climate south of the Temperate biome. If these high carbon emissions scenarios are realised the vegetation of the UK is likely to change dramatically and sometimes in currently unpredictable ways.[Evidence – Low][Agreement – Medium] [Confidence - Medium]

- Correlative models have been developed that project the potential future distribution of some species, although the validity of these models is often questioned [Agreement – Low]. The rate at which species are lost from habitats is unclear but the rate at which new species will colonise is less clear as it depends on the population dynamics and dispersal rates of each individual species [Evidence Low][Agreement – High]. Evidence is beginning to show that many semi-natural plant communities are relatively resilient to climate change and especially temperature increase. Major stress on some plant communities will occur where summer precipitation decreases and temperature increases. Lowland Heath, Lowland Fen, some Lowland Calcareous Grassland communities and Lowland Beech and Yew Woodland are the most likely to be affected in the south and east of the UK.[Evidence – Medium][Agreement – Medium]. If precipitation becomes more seasonal e.g. wetter winters and drier summers this may have more impact on vegetation than if precipitation changes throughout the year in the same way[Evidence - Low] [Agreement – High]. [Overall: Evidence – Low, Agreement – High, Confidence – Medium]

- Changes to Mountain, Moor and Heath communities could be affected, especially by severe summer droughts even if annual precipitation increases. Atmospheric N deposition affects these communities detrimentally and the interplay between climate and pollution is important. Evidence suggests that under UKCP09 scenarios Blanket Bogs are likely to continue growing until the ratio between precipitation and temperature drops below a threshold value. However, the UKCP09 scenarios do not model cloudiness and fog sufficiently well to predict how often the ratio between precipitation and temperature will drop below the threshold nor which decade it will be a regular or permanent feature of the weather. Additionally, bogs may suffer surface drying in the summer, leading to fires and erosion by wind; [Evidence – High][Agreement – Low] [Confidence – Low]

- Montane/Arctic communities, already close to their climatic limits in the UK are particularly threatened by climate change and pollution. Although alpine and montane species are likely to decline it is unclear which species will replace them. [Evidence – High][Agreement – High] [Confidence - High]

- Although vegetation communities will change as different species decline or increase, Priority Habitats will not change identity frequently and Broad Habitats will change identity rarely. [Evidence – High][Agreement – High][Confidence -High]

Introduction

The impacts of the weather, climate and climate change on vegetation have been a topic of scientific debate since the 18th Century and probably before that. Models of projected climate for the UK in the 21st Century (Murphy *et al.*2009) indicate that many species within vegetation communities will be affected by climatic conditions that have not been encountered for many generations, if ever. Despite the longevity of debate and research into the determinants of distribution and abundance of species, evidence linking the performance of species to either the climate or weather patterns within it has seldom been obtained (see Jump & Woodward 2003 for discussion and examples). In this review experimental and observational evidence that exists will be used along with biogeographical and phytosociological knowledge gained from the observations of researchers and naturalists.

Here, habitats are defined by the Broad and Priority Habitat system introduced by the JNCC which form the means of national reporting (Jackson, 2000). Phytosociologists have devised various classifications of vegetation communities throughout Europe. In the UK, the National Vegetation Classification (NVC) (Rodwell1991a, 1991b, 1992, 1995, 2000) is the most widely accepted and is often used for reporting conservation status and condition. The NVC has critics but it is undoubtedly a useful framework for communicating in shorthand what species a plant community is likely to contain.

Making the assumption that the majority of plant species are ultimately limited in distribution by climate, the classification of the British Flora into biogeographic ‘floristic elements’ by Preston and Hill (1997) is a useful source of information. The work of Raunkiær (1907) in the early part of the 20th Century and his classification of vegetation into life-forms could become very helpful in predicting the types of vegetation that could appear in the UK in the next century, especially as there is now a European wide classification and mapping system based upon it (Bunce *et al.*2010).

It is the perceived wisdom that many habitats and the plant communities within them are resistant to changes in environmental conditions, especially those communities dominated by long lived individuals. The phrase 'natural inertia' has been coined to describe the response of established vegetation to climate change in the Alps (Theurillat & Guisan 2001) and this describes the situation well for many UK habitats too. This conjecture has been supported by Grime *et al.*(2000) who demonstrated that over 13 years of climate manipulation infertile long established, calcareous grassland has changed little, For most habitats, unless there is a major disturbance (e.g. fire or storms) the species that occupy an area are likely to remain because of a combination of population dynamics and the dispersal limitations of incoming species. Once disturbed, or soon after establishment habitats seem more susceptible to climate change. In contrast to the established calcareous grassland mentioned above, in a similar experiment in a recently established calcareous grassland (Grime, et al. (2000) showed it more vulnerable to change.

Evidence suggests that there are few non-native invasive species common in the UK countryside as a whole (Maskell et al.2006). In a study of vegetation plots in different vegetation zones of Europe, Chytry *et al.*(2008 YD) found universal patterns of invasion by alien species into Mediterranean-Sub Mediterranean, Subcontinental and Oceanic zones . None or few alien species were found in environmentally extreme and nutrient poor habitats e.g. mires, heathlands and high mountain grasslands, whereas many aliens were found in frequently disturbed habitats with fluctuating nutrient availability. Neophytes (species introduced post 1500) were often found in coastal, littoral and riverine habitats and also in habitats already occupied by archaeophytes (species introduced in the historic period). These authors predict that the number of archaeophytes in habitats will be a good predictor of alien invasion risk.

There are plant species in the UK that have continued to exist centuries after the conditions to which they are undoubtedly adapted have ceased to exist both nationally and locally. Most examples of such species are those that are typically found at high latitudes and/or altitude that reach their southern boundary in the UK. Predicting the impacts of climate change on habitats must take into account the time-lags caused by the resistance of plant communities to change. It follows that the component species of habitats are highly unlikely to change *en masse* (Keith et al.2009.) To begin with each community will retain its original 'mix' of species but their relative abundances will change and subsequently one or more species may disappear and may be replaced by others. For this reason, modelling the future state of the *individual species* that comprise each community type would appear to be more fruitful (Bittner *et al.*2011,Carey *et al*. 2015) .

There have been a number of projects already that have projected changes in the distribution of species. One notable methodology is based on the idea of climate envelopes (DoE Core Model, 1990-1993, TIGER IV 1994-1996, MONARCH 1999-2006). In general the climate envelopes work at the 10 x 10km scale for the UK or UTM grid cell for European studies, and relate species' distribution maps to climate variables. Typically, it has been found that a combination of winter cold, summer warmth and precipitation describes the distribution of most species of plant. The problem with climate envelope modelling is that it fails to distinguish between *fundamental* and *realised* niche; it relies only on climate variables and fails to take into account plant response to other environmental variables at a range of scales. A further problem with the climate-envelope approach, identified specifically by the

DoE Core Model project, is that the distribution of nearly all species is greater than the area of the UK. When modelled using climate at a UK scale the southern limits of the species are missing because they are much further south than the south coast of England. The conclusion from this work in the early 1990s was that the European distribution of species should be used to model species in the UK, which was adopted in the TIGER and MONARCH projects.

For many communities there will be a small number of species that cover a large proportion of the ground. These could be called 'matrix*' species* and these are typically essential for community functioning. The rest of the characteristic species of a community fill in gaps between the matrix species and, if missing, do not (as far as we know) fundamentally affect the function of the plant community. It follows that to understand how plant communities and habitats might change in the coming decades an understanding of what determines the abundance of the matrix species is vital.

As stated above climate and weather can cause stress to plants, but so can other factors; notably resource availability, especially nitrogen availability. Atmospheric nitrogen deposition will affect the balance of competitive species and stress tolerating species, with high levels of nitrogen favouring competitive species (RoTAP, 2012). However, the most important factor affecting habitats and widespread vegetation communities in the UK in the 21st Century, as it has been in the past, may not be the climate itself but the response of humanity to it, and the changes in land use that it imposes. Consequently the impacts of climate change on plant communities and habitats can be either direct (e.g. a severe storm event on sand dunes) or indirect (e.g. a change in the numbers of tourists visiting sand dunes because the weather is nicer which in turn causes a change in the habitats).

In this report the aim is to add to the evidence base on which previous reviews (e.g. IACCF 2010) were built, making a distinction between experimental or observational data and modelled data. In the text citations are followed by a two letter code. The first letter is either a 'Y' denoting a study based on experimental and/or observed evidence or a 'N' denoting a study not based on experimental or observed data, often a modelling exercise. The second letter is either a 'D' denoting a direct impact of climate change on vegetation or a 'I' denoting an indirect impact of climate change on vegetation. Experimental evidence provides information about the processes that affect plants, observational data provides information about how the weather and climate has affected plants and modelled data uses the information provided by experiments and observations to either explain past changes or project into the future.

The National Picture

The UKCP09 gives regional climate projections. From a biogeographic stand point the low, medium and high carbon emissions scenarios are not markedly different until the 2060s when the changes predicted by the high carbon emissions scenarios diverge. Should mean January temperature go above 10°C and mean July temperature go above about 22°C the southern limit of the temperate zone is passed and Mediterranean, xeric or sub-tropical vegetation becomes normal (depending on precipitation). Even with such large changes in the climate there are likely to be timelags before the vegetation changes.

Nearly all of the experimental and modelled studies that have been carried out have assumed changes in temperature of up to 3°C with or without precipitation change by 2100. They can give a good idea of the 'direction of travel' that the vegetation of the UK will encounter over the coming decades. The effects of extremes of the high carbon emissions scenarios for beyond the 2060s are more speculative .

Arctic and Boreal species have already been in decline in recent decades in the UK whilst widespread, Temperate and Mediterranean species have been increasing (Preston *et al*. 2002) and this is likely to continue. Some of the most obvious species in the British Flora are orchids and they tend to be very well recorded. Three species: *Ophrys* apifera (Bee Orchid), *Himantoglossum hircinum* (Lizard Orchid), and *Anacamptis pyramidalis* (Pyramidal Orchid) have shown increases in both distribution and abundance in recent decades. *O.apifera* formerly restricted to England is now regularly found in Scotland (Preston *et al.*2002 and Botanical Society of the British Isles database) and even as far north as the Shetland Isles. *H.hircinum* is one of the best studied plant species in the British isles and both the number of populations and their size are followed annually (Carey *et al.*2002 *et cit*. and www.bodseyecology.co.uk). In 1989 there were 10 populations and in 2011 there were 24. A population has recently been found in Yorkshire (an approximate northern expansion of 100km). *A.*pyramidalis has increased in both abundance and distribution in recent decades, it is now found 130km further north than it was in the 1970s (Botanical Society of the British Isles database and personal observations).As all three are wintergreen and do well when there are hot and dry conditions in the early summer they should have benefitted from the changing climate. There are no detailed population studies for *O.apifera* or *A.*pyramidalis that have looked at the link with weather although there are for *H.*hircinum (Carey 1998, 1999 and www.bodseyecology.co.uk).

There are key matrix species in the Arctic and Boreal species groups, and their continued decline and disappearance will alter the character of communities and their NVC classification. In some cases the change in communities is likely to extend to changes in Priority Habitats (Carey *et al.*2015) and very occasionally Broad Habitats. In almost all cases the affected communities are those of the mountains, moors and heaths (see section below). The UKCP09 scenarios have allowed regional and local differences in Priority Habitats to be modelled for the first time (Carey *et al.*2015). To date the Mediterranean flora of the UK is made up of species of disturbed, open habitats and these are not matrix species. The most likely habitats for Mediterranean matrix species to inhabit in the UK are probably Lowland Heath, Dry Acid Grassland, Lowland Calcareous Grassland and especially Maritime Cliffs and Heaths. These species would, in most cases, require introduction e.g. *Genista spp.* and

Cistus spp. The dominant species of woodland and grassland have wide biogeographic amplitude and are likely to remain within their range as the climate changes. Over the last 300 years the extinction of species regionally have been due to habitat loss and eutrophication rather than climate. The most likely species to have gone extinct were those with restricted distributions and were habitat specialists (Walker and Preston 2006 NI). It might be reasonable to assume therefore, that in future species that are both restricted in distribution and are habitat specialists could be more vulnerable than those species that are not. Drought is likely to be a major driver of vegetation change in most habitats (see sections below). For example, the UK Environmental Change Network has shown that climate/weather impacts have acted across the UK. Ruderal plant species have decreased at the same time precipitation increased which is what would be expected (Morecroft *et al.*2009 YD). Few studies have ever looked at the other climatic factors that change during drought. However, in Europe, De Boeck & Verbeek (2011 NI) have determined that typically during a period of drought, mean sunshine is 45% more than normal, mean temperature is 1.6°C higher, maximum temperature is 2.8°C higher and vapour pressure 51% higher. They modelled the impacts of these climatic effects on different vegetation types and discovered that carbon loss was greater in grassland than if lack of rainfall alone was in the model, whereas deciduous forests had increased carbon uptake. The authors attribute the difference to better access to water reserves in forest ecosystems. The conclusion of this is that water reserves are critical. The impacts of heatwaves have also been modelled (Teuling *et al.*2010 YD) showing that at the beginning of a heatwave air surface heating is twice as high above forests compared to grasslands, but as a heatwave continues this reverses. If prolonged heatwaves (like 2003) become more frequent, forests will be valuable in mitigating effects but for shorter heatwaves the reverse is true. Planning future land use around urban areas perhaps should consider a mixture of grassland and woodland to mitigate against both short and long heatwaves.

To understand the likely impacts of climate change on the extent of different habitats it is best to have an understanding of the possible changes in land use. The UK is associated with Europe in terms of its land use in most recent modelling exercises. Rounsevell *et al.*(2006) produced scenarios where European agricultural land use declines with abandonment, urban areas increase (with varying patterns depending on the scenario used), forestry increases and there will be an expansion of bioenergy crops. The future of protected areas is included as a variable in the scenarios and protection status could act as a brake on land use change. A modelled analysis of Austrian habitats has indicated that more natural habitats were at greater risk from climate change than farmed habitats and that increasing the chances of species dispersal was vital (Renetzeder 2010 ND). This is a similar conclusion reached for England (Lawton *et al.*2010). Rounsevell & Reay (2009) give a projection for UK land use in the 21st Century based on the consistency of results from many modelled land-use, economic and climate scenarios. In summary, they show a decline in the area of agricultural land use for food production, but this may be replaced by bioenergy crops; increases in urban areas; an increase in forested land on former agricultural land; and a retreat in coastal land areas. An interpretation of the models of land use change is that there will be little impact on the extent of Priority Habitats within the UK with the exception of those at the coast (e.g. Coastal Sand Dunes, Saltmarsh and Coastal Floodplain and Grazing Marsh). Land use policy may change in ways that encourage climate change mitigation and adaptation strategies on agricultural land and forestry. The space required for renewable energy schemes may also be a factor (Foresight Land Use Futures Project, 2010).

Enclosed Farmland

The Broad Habitats Arable and Horticulture and Improved Grassland will be dealt with in a separate report card on the future of agriculture.

Here the only Priority Habitat that is found in the Improved Grassland Broad Habitat is considered. Coastal Floodplain and Grazing Marsh. Inundation by salt water would change the land use in these habitats, as livestock farming becomes largely unproductive (Rounsevell & Reay 2009). This land use change might not alter the identity of the Priority Habitat if grassland communities persist and in fact could become of greater wildlife value (inundation grasslands – NVC MG11, MG12). Possible changes could be to upper saltmarsh communities (NVC SM15-SM18, SM24,SM28) and scrub/woodlands associated with saline conditions (NVC SD14-SD16). The area of Coastal Floodplain and Grazing Marsh may also be reduced by managed realignment schemes (Berry *et al.* 2007, Richards *et al.* 2008 and see the technical paper in the series on Coastal Habitats).

Semi-Natural Grasslands

Extremely dry years can have an impact on species composition in UK grasslands. Following the hot and dry summer of 1995 the Environmental Change Network detected an increase in ruderal and biennial species that presumably colonised gaps left by the reduced size of perennial grass plants (Morecroft *et al.* 2002 YD). Most grassland species in the UK have broad biogeographical amplitude and should be able to withstand increasing temperature and occasional drought. The longer-term implications of drought will depend on the adaptive ability of the species concerned (e.g. Ravenscroft *et al.* 2014). Different ecotypes of common grass species grown in a common garden experiment have varying abilities to respond to climate change (Beierkuhnlein *et al.* 2011 YD), with drought tolerance greater in ecotypes from southern regions whilst the southern ecotypes did not do better than local ecotypes in an artificially warmed climate. This experiment is important for two reasons: 1) grasses seem to have a wide tolerance to a range of temperatures but not so much to drought; 2) enhancement of populations with ecotypes from southern regions may be required to acquire stronger resistance to drought. Studies in the EVENT 1 experimental garden in Bayreuth Germany (Jensch *et al.*2007 YD) show that species interactions can be facilitative or competitive following one off drought or extreme storm events but the effects vary from species to species and community composition (Grant *et al.*2014 YD). The unpredictability of one off extremes and also the response of grassland species makes current predictions of the impacts of climate change on grasslands difficult.

Grasslands could have an important role in enabling adaptation to high run-off and subsequent flooding where degraded permeable arable and grassland soils exist in the drier regions of the UK (Hess *et al.*2010 NI) thus providing an ecosystem service. This would involve land management ‘improvement’ assumed to mean improvement to prevent soil erosion and run-off and to create ways of holding back water in fields. In the past water meadows were a vital method of land use and the older ones are now considered extremely important from a landscape point of view and many are priority habitat. It is unclear from the work of Hess *et al.* (2010) whether this would have negative or positive impacts on the botanical diversity and extent of any Priority Habitats.

Neutral Grasslands

Neutral grassland communities (Mesotrophic Grasslands) include the most common grasslands found in the UK. The composition of common grassland communities (NVC-MG1, MG6, MG9) may change as the climate changes, becoming more open where precipitation decreases and more rank where it increases (especially if nitrogen deposition continues) but it is likely that in most cases any changes in community composition would not cause a change to the identity of the Broad Habitat at a site.

Priority Habitats found in the Neutral Grassland broad habitat are: Lowland Meadows; Upland Hay Meadow and Coastal Flood Plain and Grazing Marsh.

Lowland Meadows (NVC-MG4, MG5, MG8) are now very rare in the UK. Two of these communities (NVC-MG4 and MG8) are characteristic of meadows that are inundated in the winter and remain damp throughout the year (and these can also be Coastal Floodplain and Grazing Marsh priority habitat). Predictions of reduced summer rainfall and increased summer evaporation will put stress on wetland plant communities in late summer and autumn, and rainfed systems will be more affected than those dominated by river inflows (Acreman *et al.*2009 ND). Modelling the impacts of climate change on the Elmley marshes in north Kent (Thompson et al.2009 ND) showed that summer ditch water levels for potential evapotranspiration scenarios where only temperature varied are lower (0.01–0.21 m) and in dry winters they do not reach mean field level. Under potential evapotranspiration scenarios (PETtrws) where temperature, net radiation and wind speed varied summer and winter ditch water levels are lower on average by 0.21 m and 0.30 m respectively. Levels never reach the elevation of the marsh surface. Lower groundwater and ditch water levels result in declines in the magnitude and duration of surface inundation which is virtually eliminated with the PETtrws scenarios. Therefore, the remaining wet Lowland Meadows maybe in danger of disappearing if methods of maintaining water levels are not found. The likely trajectory of change is towards the more common neutral grassland communities. The matrix species of the NVC MG5 community have a wide biogeographical amplitude and these hay meadows should be resilient to climate change but the threats from changes in land management that caused the decline post 1945 remain.

Upland Hay Meadow priority habitat is defined as NVC MG3 grassland (and an unpublished form of upland NVC MG8 is included) characterised by the presence of *Geranium sylvaticum* and *Alchemilla glabra* and a suite of more common grassland species. Berry *et al.*(2005) identified that most of the matrix species will remain within their climatic envelope, and suggested that the Priority Habitat would not be affected too much. However, *Geranium sylvaticum* is in the European Boreal-montane floristic element (Preston and Hill 1997) and must be considered threatened, being one of the species that has survived in the UK beyond the time when the climate suitable to it has passed. *Alchemilla glabra* is in the European Boreo-temperate element which although not as threatened by climate change as *G.sylvaticum* is not likely to prosper. Without these two species, and notably the former, the Priority Habitat will cease to exist. The grassland that replaces MG3 could be diverse and of conservation value.

Calcareous Grasslands

Almost all calcareous grassland encountered in the UK will be either Lowland Calcareous Grassland or Upland Calcareous Grassland Priority Habitat. Experimental manipulations of temperature and drought at a site in Oxfordshire and another in Derbyshire demonstrated that a younger, less developed plant community (that in fact keyed out as a mesotrophic grassland type because it had not acquired enough calcareous grassland species) was more prone to increased temperature and drought than the established ancient sheep pasture (Grime *et al.*2000). Generally, examples of this Priority Habitat will have been established for a very long time and so will behave more like the ancient example in Derbyshire. The findings do have a bearing on the likely success of projects for reversion to calcareous grassland from arable land.

Lowland Calcareous Grassland (NVC CG1-CG10) is often associated with drought prone soils on chalk and other lime rich soils and most of the species in these communities have a degree of drought tolerance as well as broad biogeographic amplitude in regard to temperature. Mitchell *et al.*(2007) suggest that Lowland Calcareous Grassland will become more sparse with an increase in forb/grass ratio. This seems plausible although it should be noted that NVC CG7 grassland already exists on mesic sites in East Anglia and more severe drought threatens them (Rodwell *et al.*2007). These CG7 stands could become much more like Mediterranean calcareous grasslands in nature, although (without introductions) not species composition. The predicted increase in overall summer/winter precipitation for the south west of England under the UKCP09 would probably ensure that the threat to NVC CG1 and CG9a of severe drought identified by Rodwell *et al.*(2007) will not occur. More is known about the impacts of climate change on this Priority Habitat than any other because of the work at Buxton, Derbyshire (this plant community which is found in a marginal upland situation arguably still falls within the Lowland Calcareous Grassland Priority Habitat because of its NVC classification). Factorial treatments at Buxton of: increased temperature; control and reduced summer rainfall; increased summer rainfall; and a control have shown that the plant community there has proved resistant to climate change (Grime *et al.*2008). The bryophyte flora responds to the treatments in varying ways but not dramatically. One of the reasons why the results may have been less than clear was the importance of dewfall which maybe an important source of moisture for the bryophytes in the grassland (Bates *et al.*2005 YD). Species have shifted their position along a gradient of soil depth at Buxton indicating that the impacts of climate change may be buffered by soil heterogeneity (Fridley *et al.*2011 YD). At least one species *Plantago lanceolata* shifts growth from vegetative growth to reproductive growth as an avoidance strategy after a prolonged series of summer droughts (Ravenscroft *et al.*2014). This heterogeneity in growth strategies could enable at least some of the species within calcareous grassland to adapt to changes in precipitation and the resulting droughts.

A greater threat than direct climate change effects to Lowland Calcareous Grasslands may be the combination of increased temperature accompanied by increased nutrients from N deposition, especially where drought is not expected. The likely impact is increased grass productivity and lower forb:grass ratio and a move towards the least diverse of the calcareous grassland communites e.g. NVC CG4. This change although undesirable from a nature conservation perspective does not affect the extent of the Priority Habitat.

Upland Calcareous Grassland is not common and is described by the NVC communities (CG9-CG14). *Sesleria caerulea* is the key determinant species for CG8 and CG9 and is in the European Boreo-temperate element and may become less competitive in respect of the other matrix species. If this does occur then the community will cease to exist in its current definition and will become Lowland Calcareous Grassland instead. The montane forms , especially the *Dryas octopetala*communities (CG13 and CG14) are likely to lose their Arctic-Alpine species and graminoids will increase (see Mountain Moor and Heath section below). It is likely that all of the NVC communities of upland calcareous grasslands will change so much by the end of the century that the habitats currently defined will cease to exist.

Acid Grasslands

Acid grasslands are mostly associated with the uplands and west of the UK. The only Priority Habitat in the Broad Habitat is Lowland Dry Acid Grassland (which curiously contains calcareous dry grassland too).

Acid grasslands tend to be species poor and the dominant land use is (extensive) livestock grazing. In a study of acid grasslands along a transect of the Atlantic biogeographic zone of Europe, Stevens *et al.*(2011 YD) showed that climate and geography explained most of the variation in species composition, but that deposition of Nitrogen and Sulphur compounds could be detected in them also. Changes in an acid grassland community in the Welsh uplands between 1968 and 2008 were attributed to acid deposition but impacts due to land use change or climate were not detected (McGovern *et al.*2011 YI). These two pieces of work suggest that, although in the long-term acid grassland species composition has been driven by the climate, in the short-term these grasslands are going to be resistant to the UKCP09 scenarios, especially as precipitation is predicted to increase in the west of the UK. However, the timing of precipitation seasonally could be critical for lighter acid soils with low water-holding capacities.

Dry Acid Grasslands are found in xeric conditions on typically acid sandy soils. The NVC communities U1-U4 are used for the definition, but a Breckland grassland not included in the NVC that includes *Vulpia ciliata* ssp *ambigua* on calcareous soils is also included in the Priority Habitat. These grasslands are likely to increase in extent if conditions become too hot and dry for dwarf shrubs such as *Calluna vulgaris* and *Erica cinerea*. Such conditions are predicted for the south east of England under the UKCP09 scenario high carbon emissions scenario by 2050 onwards, mainly because these two dwarf shrub matrix species belong to the European Boreo-temperate element and Oceanic Temperate respectively. Dry Acid Grassland may replace permanently Lowland Heathland following fires in the future.

The added nutrients available from N deposition may move the plant communities to more widespread acid grassland communities and species poor mesotrophic grasslands (in a similar way to the Lowland Heathland described below), but much will depend on the level of precipitation and its seasonal variability.

Boundary and Linear features

This Broad Habitat consists entirely of man-made features and most effects of climate change will be indirect. These features are important for future landscape planning (Lawton *et al.*2010)

Hedgerows (Woody Linear Features)

Hedgerows are seen as key to maintaining links for the movement of certain animals in the future.

Most of the woody species of hedgerows have broad biogeographical amplitude and are unlikely to be much affected by the direct effects of climate change. Climate scenarios suggest that precipitation will increase so that the characteristic *Fagus sylvatica* (Beech) hedgerows of the south west of England may not be affected by drought. However, this depends on there not being seasonal extremes in precipitation. Much will depend on the future management of hedgerows. Countryside Survey 2007 (Carey *et al.*2008) showed that hedgerows are less managed than previously. Although not proven this could aid the spread of southern species from gardens. Examples already seen are *Aquilegia vulgaris* (garden hybrids) and *Helleborus foetidus* which have been observed progressively colonising along Cambridgeshire hedgerows in the last 15 years and *Echium pinanana* is becoming quite common on hedge banks in the south west of England and South Wales.

Road verges

Road verge management may require that vegetation is cut more frequently if fire risk becomes too great in the south east of England, which would lead to a permanent ruderal community. An increase in temperature, precipitation, nutrients and lack of management could further the move towards species communities dominated by tall herbs as observed over the period 1978-2007 (Carey *et al.*2008).

Walls

The structure of walls is unlikely to be affected by climate change, but the plant species that grow on them might be. Increased temperature, sunshine and lack of moisture is likely to burn off many plant species and bryophytes currently associated with walls but these may be replaced by Mediterranean species escaping from gardens.

Woodland

Woodland and Forestry will be covered in detail in a separate report card. A brief note on woodlands is included here, focussing on the UK Priority Habitat types.

There is little doubt that woodland and forests could play an important role as a method of carbon sequestration, providing sustainable fuel sources and also by affecting local climates (Broadmeadow *et al.*2009).

Broadleaved Woodland

In the temperate Oceanic Zone (ie the UK) increased CO_2 and increased nutrient availability are likely to promote the growth of woodland trees in the coming decades although on a regional scale the impacts of violent storms and insect outbreaks could cause temporary slowing of this (Campioli *et al.*2012 ND). The same authors state that in Belgium extreme events have had the largest effects on woodland growth in the past decades, especially for Poplar and Beech. In France, Piedallu *et al.*(2009 ND) predict a decrease in the suitable area for Beech of between 80 and 93% and for Sessile Oak to be between 43 and 83% by 2071-2100. Berry *et al.*(2012 ND) model the climate envelopes for all of the main canopy trees of UK woodlands and show that in almost all cases there is little change when climate scenarios are applied up to the 2080s.

Kirby *et al.*2005 found that the distribution and abundance of species within fixed plots in 103 British woodlands changed between 1971 and 2001. Fifty one species showed responses to spring temperature, only four of these were negative correlations. The authors predict further changes in the coming decades. Reported changes in the ground flora of Wytham Woods have been attributed to changing canopy dynamics, nitrogen deposition and deer numbers (Corney *et al.*2008 YI). The method used by these authors could be used to interpret the impacts of climate change but as yet this has not been done.

There are several Priority Habitats within the Broadleaved Woodland Broad Habitat: Lowland Beech and Yew Woodland; Lowland Mixed Deciduous Woodland; Upland Birchwoods; Upland Mixed Ashwoods; Upland Oakwood; Wet Woodland; and Wood-Pasture and Parkland.

Most concern has been so far been centred on the future of Lowland Beech and Yew Woodland because Beech trees (*Fagus sylvatica*) are likely to be impacted by drought in the summer that causes xylem embolism whilst water-logging in spring could negatively affect nutrient uptake and growth (Gessler *et al.*2007 ND). As a result of these impacts the competitive capacity of Beech may be reduced at the expense of other species notably oak, and results from Lady Park Wood following the drought of 1976 do indeed show this (Peterken and Mountford, 1996, Cavin *et al.*2013 YD). It is interesting to note that by 2012 the landscape impacts of 1976 on Lady Park Wood are certainly not obvious to younger observers. Recent dendrochronological work (A. Hacket-Pain *pers comm.*) on Beech across its entire European distribution shows that there is a negative relationship between growth and summer drought. In particular there is a cluster of sites in the south of England that show this response. In an interesting study in Germany drought stress in Beech stands was shown to be similar on both northeast and southwest facing slopes (Holst *et al.*2010 YD) and so the impacts of a future climate will be shown equally on north facing slopes like the South Downs as well as south facing slopes such as the North Downs. Despite the studies suggesting that Beech is prone to drought it seems that the species has high adaptive potential to environmental change because of its initial genetic diversity, pollen dispersal distance and heritability of selected phenotypic traits (Kramer *et al.*2008 YD). If the UK population of Beech has the variability within it to adapt to drought then the outlook might not be as bleak as previously thought but evidence is mounting that the growth of Beech will at least be restricted by drought.

The dominant canopy species of Lowland Mixed Deciduous Woodland all have wide biogeographic amplitude for both temperature and precipitation, and combined with their long life-span, suggests that major changes in the canopy structure of this Priority Habitat is unlikely in the coming decades. However, the ground flora may change especially due to phenological changes in spring temperatures and subsequent leafing of the canopy (Kirby *et al.*2005). As Oliver Rackham emphasised shortly before his death in 2015, the appearance of Chalara fraxinea in the UK population of *Fraxinus excelsior* and Phytophthora ramorum in *Quercus* species is likely to have a much greater impact than climate change in the coming decades.

Upland Birchwoods are found in the north of Scotland on acidic poorly drained soils. The habitat description states that it occurs where climatic conditions are too cold for oak or ash to thrive. It follows that if the temperature increases then oak and ash could invade these areas. The process is likely to take a very long time because of the generation time of trees and the ability of trees to disperse naturally into the areas that become suitable (notably the northern isles).It would be surprising to see the effects in the 21st Century.

Upland Mixed Ashwoods occur on base rich slopes in the northwest of the UK. The canopy trees have the biogeographic amplitude for both temperature and precipitation to allow them to persist. Some of the ground flora and the lichens and ferns growing on the trees may be affected by increased temperature. However, the flora is characterised by a need for moisture and the UKCP09 projections (Low, Medium and High carbon emissions scenarios 50% probability) suggest that the increase in precipitation should mediate the increase in temperature (unless precipitation becomes extremely seasonal). There are similar woodlands in the north of the Iberian peninsula with a very rich flora where the climate is similar to that predicted for Scotland.

Upland Oakwoods occur in similar areas to Upland Mixed Ashwoods, but on acidic to neutral soils. The implications of the UKCP09 projections are similar to those for Upland Mixed Ashwoods.

Wet Woodlands in the south east of the UK could be threatened because UKCP09 projections indicate a reduction of precipitation and an increase in temperature in the coming decades. Most Wet Woodland occurs where there are hollows that accumulate rainwater or where there are springs. Much will depend on how often the hollows become inundated in the future. Over a period of decades if the hollows dry out regularly trees such as *Alnus glutinosa* and *Betula* will be replaced by *Quercus*, *Fraxinus* and *Corylus*. The ground flora will change more quickly as the wetland species (e.g. *Molinia caerulea*) are likely to be replaced by species that are more competitive in drier conditions (e.g. *Deschampsia cespitosa, Dactylis glomerata)*. The identity of the incoming species will depend on neighbouring plant communities and also the nutrient status of the soil. Wet Woodland in the north and west of the UK may remain little changed as precipitation is predicted to increase under the UKCP09 projections (Low, Medium and High carbon emissions scenarios 50% probability).

Wood Pasture and Parkland is a man-made habitat that is likely to be managed such that it is maintained. The veteran trees could be more prone to stress from drought due to their age and they are certainly susceptible to storm damage and lightning strikes which are both predicted to increase. The grassland, grazed or mown, may become sparser if droughts become more common, and the landscape effect of brown grassland in summer is likely to be more important than the ecological effect.

Coniferous Woodland

Coniferous woodland will be covered in a separate report card on forestry.

The only Priority Habitat in this Broad Habitat is Native Pinewoods which are found in a few places in Scotland. *Pinus sylvestris* is in the Eurasian Boreal Montane element and under the UKCP09 projections (Low, Medium and High carbon emission scenarios, 50% probability) the area with suitable climate for this species disappears (Carey *et al.*2015). Invasion of the heathlands and forests by species, such as *Betula* (Birch), is certainly a possibility, especially as much of the current Priority Habitat has very sparse tree cover.

Mountain Moor and Heath

A recent review of climate change in the British Uplands has been undertaken (House *et al.*2010) and many of the papers from that review are cited here.

Under the previous UKCIP02 projections the climate indices that describe the current upland habitat extent of Scotland decreased 13-51% (depending on the index) for the low emissions scenario and 24-84% for the high emissions scenario between 2071 and 2100 (Clark *et al.*2010 NI). Therefore, if upland vegetation is described merely by climate variables the area suitable for it will decrease. One argument against climate envelope modelling is that it takes no account of anthropogenic influences (ie land use). Yeo & Blackstock (2002 YD) demonstrated that vegetation communities were described well by climatic factors which were accentuated by anthropogenic influences, suggesting that climate envelopes for upland vegetation in southern Britain maybe more robust than previously expected. Not only does land use affect vegetation but changes in vegetation communities can affect land use decisions. A model that investigates the interdependence of vegetation and land use management decisions has been produced for the Peak District. Simulations with warmer temperatures indicate invasion of the uplands by *Pteridium aquilinum* (Bracken) (Chapman *et al.*2009 NI), unless there is rigorous control.

One of the difficulties of determining the impacts of climate change on upland systems is that there has always been an argument that the regional climate models do not adequately include the variation found in these areas because 10km grid cells can include huge changes in topography meaning mean values for the grid cells do not include the true variations in climate to which species are responsive. This is especially important as many of the key plant communities are sensitive to temperature, shading and snow lie, for example. A recent model may help future modelling exercises of impacts by using station data from the Scottish Highlands (Coll *et al.*2010). Further, the impact of small scale variation in topography has been demonstrated for the mountain flora of Europe (Engler *et al.* 2011 ND). Having assessed 2632 species from relevées these authors predict that the mountain areas of Scotland will be less affected than the mountains of central and southern Europe, because although temperature is predicted to rise, so is precipitation.

It has long been thought that a warming of the climate will lead to an upward altitudinal shift of treelines in mountainous areas. The treeline in Switzerland has seen a shift upwards in recent decades with much of the increase being infill of the 300m below the modelled treeline limit, indicating land use changes as the cause, with only 4% being upward shifts of the treeline that could be attributed to climate change (Gehrig-Fasel *et al.*2007 YD). Conversely, Dullinger *et al.*(2003 YD) suggest that abandoned grasslands that contain vigorous species are less liable to invasion than the grassland above the current treeline which typically contain less vigorous stress tolerating species. It follows that in UK upland situations if land abandonment occurs it is likely to be above the moorland line where there are less vigorous stress tolerating species. Only mountains above 700m in the UK potentially have a natural treeline that reflects where temperature limits the growth of trees. The treelines in the UK are imposed by grazing and in a few cases extreme exposure and a lack of soil. If trees spread upwards in the UK it will primarily be because of changes in land use not climate change.

Observations by naturalists across the UK suggest, and results from Countryside Survey (Carey *et al.* 2008) show, that many habitats are becoming less diverse, especially those (previously) diverse communities.There is documented evidence that plant communities (Dwarf Shrub Heath, upland grasslands, Blanket Bog and montane habitats) have changed over the last few decades in the north western Scottish Highlands. There are indications that there has been a general homogenisation of the communities found there over the last 50 years or so (Ross *et al.*2012). Species that prefer warmer, drier and more acidic conditions have increased in abundance and generalist species have increased at the expense of specialist species..

Bracken

An increase in the extent of Bracken is considered undesirable for agriculture, in the uplands especially, and tends to lead to a loss of botanic diversity. An increase in the competitive ability of this species because of climate change could be problematic. Experiments in Upper Teesdale have shown that increased temperatures will allow earlier growth and later senescence of *Pteridium aquilinum* (Bracken) which increases its competitive ability against *Calluna vulgaris* (Heather) (Werkman *et al.*1996). In a controlled experiment, drought was shown to be an important factor in competitive trials between Bracken and Heather, with the former being affected detrimentally by early drought and the latter by later drought (Gordon *et al.*1999). Drought caused more damage to Heather when nutrients were added than not. Warmer temperatures are predicted which will allow Bracken to invade areas of moorland where there is bare peat associated with reduced burning combined with an increase in degenerative heather (Fraser *et al.* 2009 NI).

The increased competitive ability of Bracken may mean that to maintain it at its current levels of abundance will require more resources to control it.

Dwarf Shrub Heath

Two Priority Habitats form this Broad Habitat: Lowland Heath; and Upland Heathland.

The interplay between conservation management and climate change could affect the proportions of the Broad Habitats Acid Grassland, Bracken and Dwarf Shrub Heath in ways that make the outcomes for either Dwarf Shrub Heath Priority Habitat difficult to predict.

In addition to the experiments in the section on Bracken (Werkman *et al.*1996, Gordon *et al.*1999), field manipulation experiments in the Netherlands and Denmark that warmed dry lowland heathlands showed increased nutrient supply and a subsequent encroachment by grasses, but sometimes this was slowed by drought (Wessel *et al.*2004 YD). In Upland Heathland in the UK the same warming experiment increased productivity. This could lead to increased grazing densities, which in turn would lead to greater nutrient input, affecting the interactions between dwarf shrub species and grass (Wessel *et al.*2004 YD). The results of a long-term experiment to show the impacts of nitrogen deposition on Lowland Heath in England showed that added nitrogen exacerbated the damage to *Calluna* caused by drought (Southon *et al.*2012 YI). As most Lowland Heath is now affected by atmospheric nitrogen deposition this must be considered as an additional burden on top of the impacts of reduced precipitation in future bioclimatic models. Heather is not the only matrix species of Dwarf Shrub Heath although it is the most studied. For other species: increased drought in the growing season of *Vaccinium myrtillus* could increase physiological stress, whilst increased temperature in the spring will have the opposite effect (Llorens *et al.*2002 YD); increased fire risk will be a particular issue for heathland dominated by *Ulex gallii* and/or *U.minor* (NB *U.europaeus* is part of the Broadleaved Woodland Broad Habitat); *Erica tetralix* as a species of Lowland Heath in southern England is threatened because of its need for (permanently) moist conditions; and *Empetrum nigrum* is already in decline (Preston *et al.*2002) and this decline is likely to continue.

The importance of heathland as protection for carbon-rich soils in the uplands has been recognised. Any change in the climate that affects soil carbon will therefore be important. Drought has been shown to cause an increase in the respiration of both mesic and hydric heathland soils (Sowerby *et al.*2008 YI). The mesic sites recovered during the winter, whereas the hydric site did not, and consecutive years of drought caused much higher respiration in the hydric site. This is an important result as it suggests northern hydric heathland sites will act as a major CO2 source if drying and drought becomes a consistent feature of the climate whilst mesic sites will not contribute so much CO2. There is nothing in the study that suggests how vegetation communities may change as a result. Note that these results also apply to dwarf shrub heath found on Blanket Bogs.

The Lowland Heath of southeastern England is extremely threatened by the climatic conditions in the UKCP09 projections (Low, Medium and High carbon emissions scenarios, 50% probability). Reduced precipitation will see remnants of wet heath containing *Sphagnum* and *Erica tetralix* largely disappear, although the *E.tetralix* may be replaced by other *Erica* species. After the 2050s most Lowland Heath in the south east could be replaced by another Priority Habitat, Dry Acid Grassland, unless added nutrients from N deposition allow more competitive grasses to invade (Britton *et al.*2001) leading to species poor acid grassland or mesotrophic grassland. Lowland Heath could theoretically be maintained in the south east of England by the introduction of dwarf shrub species with a more Mediterranean affinity (e.g. *Genista* and/or *Cistus*), although the acceptability of this would no doubt be debated. In the other areas of the UK, increased precipitation may lessen the impact of increased temperature on Lowland Heath (assuming that precipitation does not become extremely seasonal). Lowland Heath may increase in extent by moving uphill into Upland Heathland, especially in the hills of the south west. In particular, *Agrostis curtisii* communities (NVC H3 and H4), which are already seen at higher altitudes on Exmoor than they were 20 years ago are likely to carry on spreading uphill.

Apart from encroachment by Bracken and/or Lowland Heath most Upland Heathland is in areas where UKCP09 predicts both increased precipitation and temperature and with correct management major changes are unlikely to occur in the coming decades.

Fen Marsh and Swamp

Obviously this Broad Habitat is dominated by the presence of enough water to cause inundation. The Priority Habitats in this Broad Habitat are: Lowland Fens; Purple Moor Grass and Rush Pastures; Reedbeds; and Upland Flushes, Fens and Swamps.

The maintenance of the few remaining Lowland Fens is already a constant battle to get enough water, and this is likely to become worse under the UKCP09 projections . These Fens are very threatened.

Purple Moor Grass and Rush Pastures have been well studied (Wheeler *et al.*2004) and are known to be sensitive to seasonal rainfall. Wet winters and dry summers would probably see alterations in the plant communities that would lead to a change in the identity of the Priority Habitat to Acid Grassland (Mitchell *et al.*2007) .

Reedbeds are likely to remain, as long as open water and the correct management is continued, because *Phragmites australis* has a very wide biogeographical amplitude.

Upland Flushes, Fens and Swamps may be resilient to increases in temperature as long as precipitation increases enough to prevent drying out in rainfed areas and/or periods of summer drought are not too severe (see Bog section below). UKCP09 projections seem favourable.

Bog

All bogs in the UK depend on the growth of *Sphagnum* species to be functionally active. *Sphagnum* requires almost constant wet or humid conditions to survive and grow. The relatively cool and wet areas of the western, northern and upland areas of the UK currently provide these conditions. Bogs that have been degraded by drainage or peat cutting cease to be active as they have higher proportions of vascular plants and less of the bryophytes that form peat. Palaeoecological studies of peat show variations in the rate that it formed in the past and those variations were caused by climatic shifts. Peat formation was thought to be greatest in cool wet periods and least in warmer and drier periods (Barber *et al.*2000 YD) but recent models on a large number of cores worldwide has shown that peat accumulates most in warmer periods (Charman *et al.*2013). Bogs survived the drier periods when growth was minimal or non-existent and began growing again when the hydrological conditions were more amenable. This recent work suggests that Sphagnum will grow more as the temperature rises as long as there is enough moisture. In can be assumed that bogs would respond to a drier period in the coming decades or centuries by ceasing to grow. The ability of bogs to recover from a modern dry period is not a certainty because in the past bogs have not had the added large scale disturbance resulting from anthropogenic practices such as peat-cutting, drainage and variable grazing intensity.

A recent bioclimatic model suggests that there will be a large decrease in the area suitable for blanket bogs globally (Gallego-Sala and Prentice 2013 ND) with most of the UK falling out of the bioclimatic space. The Gallego-Sala and Prentice model has a cut-off mean July temperature of 15°C for Sphagnum survival which may be overly conservative as it can certainly grow at higher temperatures than this. A UK based study is less pessimistic and predicted a long-term decline in actively growing peat bogs with eastern blanket bogs being more vulnerable than western bogs under the UKCIP02 scenarios (Clark *et al.*2010 NI). A key factor determining the future of bogs is the amount of moisture that is available from clouds or fog and dew, knowns as occult precipitation. This source of moisture has been shown to be approximately equal to an increase in precipitation of 300mm in the summer months for bogs in Newfoundland (Price, 1992), but we have no figures for the UK. The UKCP09 scenarios do not model cloudiness and fog for the summer months in a way that can be used to predict the impacts of climate change on occult precipitation. If occult precipitation continues through the summer months in the future then bogs could continue to grow but without measurements or climate scenarios for fog and low cloud it is impossible to say how much. It should be stated that most scenarios suggest surface desiccation of peat soils is likely to increase as periods of summer drought become more frequent, this will be especially true if there are long periods of sunny weather and a lack of humidity. This is likely to be a key factor. *Sphagnum* growing as hummocks are vital for the development of a diverse bog. The species of *Sphagnum* that form the hummocks are more dependent on capillary action to remain moist than *Sphagnum* growing on flat areas. As a result hummocks are more at risk of desiccation even in short hot dry spells than *Sphagnum* species growing on flat plains or lawns. Hummocks of *Sphagnum* were considered to be irreversibly damaged by the hot dry conditions of the summer of 2003 in Italy (Bragazza 2008 YD), with one side of the hummock dying, the consequence of which would be the collapse of the structure. Observations of, Sphagnum hummocks in the UK suggest that this will not be true as a hard crust of liverworts and *Racomitrium* forms on the dry side that prevents collapse (R.Lindsay pers comm.).

Bragazza (2008) demonstrated that there is a threshold in the ratio of precipitation to temperature over the months when the moss is actively growing (May to September in the Italian Alps) below which the damage is permanent (6.5), and above which recovery can take place (6.5 to 8.5) once the drought/heatwave is over. The simple ratio used by Bragazza (2008) can be replaced by measurements that include evapotranspiration and soil moisture but the principle will remain the same; if it becomes too hot or dry for even one summer a proportion of the moss in the bogs will be permanently damaged or killed. It should be noted that different species of Sphagnum will have different tolerances to drought. Clymo and Hayward (1982) found that *S.imbricatum,* a hummock forming species, had 100% survival after desiccation for 16 days whereas a proportion of the other species tested died. If bogs in the UK are likely to be affected by drought and heatwaves in the same way as the Italian example in 2003 then the hot and dry summers of 1975 and 1976 might be expected to have had an impact on Sphagnum in the north of the UK. This was not the case (R.Lindsay pers comm.). Neither 1975 nor 1976 in the UK were as hot as 2003 in the Alps. A future climate that produces heatwaves like that in 2003 are predicted to occur more regularly in the future and so could produce an impact. Hummocks are a small component of most bogs, although most would argue that they are a functionally important proportion of the system as they provide microtopographical variation that increases biodiversity. Looking at the carbon budget rather than biodiversity, Swanson (2007) argues that the microtopography caused by hummock forming mosses has a negative impact and that dry periods are positive because they prevent the microtopographic features from forming. Here there is an obvious disconnect between the ecosystem service for carbon sequestration and the maintenance of biodiversity.

One way to counter the impacts of dry periods is to retain as much water as possible, e.g. by drain blocking. Wilson *et al.*(2011 YI) demonstrate that drain blocking leads to higher more stable water tables that can resist drought and Bellamy *et al.*(2012 YI) have shown that species characteristic of degraded, drained bogs soon die-back once drains are blocked and there was some evidence that moisture loving plants were increasing. There will be a lag between drains being blocked and *Sphagnum* mats and hummocks forming, which could be decades or longer. Reintroduction could increase the rate of the recovery and experiments with *Sphagnum* are underway in the Peak District. The results of these experiments are not yet published. Of course, *Sphagnum* is not the only component of Blanket Bog and Fraser *et al.*(2009 NI) address the problem of a lack of dwarf shrub heath recovery on bogs and develop a framework to address it, which comprises a spatially-explicit vegetation model that incorporates management decisions. They suggest that increasing temperature will lead to an increase in Bracken and also prevent the revegetation of bare peat. From results so far, it is unclear what the state of the peat and the bog vegetation will be during the recovery phase will be. It is possible that there will be a period where quality declines until a functioning bog surface is restored. There is no evidence available on the trajectories towards known vegetation communities. It is unlikely that northern species will return to these bog restoration sites unless introduced and maintained by artificial management. If bog vegetation does establish theory suggests that species with a more southern affinity will form the basis of the vegetation communities (see paragraphs in the Introduction and National Picture above).

There are other consequences of drought or the general drying of bogs. One such consequence is increased erosion due to wind (Foulds and Warburton 2007 YI) and another is increased fire risk. For the Peak District, models have shown that the incidence of fire is not likely to change much until about 2070 when the frequency of fires will increase (Albertson *et al.*2010 NI). In the model that produced this result temperature increase has a non-linear effect, with the incidence of wildfires increasing disproportionately to temperature increase. It is possible that major changes in species composition could follow fires in the future. However, during the last 5000 years, pre-fire communities of bogs consisted of dry *Sphagnum* hummocks with *Calluna vulgaris*. Only the most severe fires caused change to these communities which in any case were restored over time. This study of historic communities showed there was no link in species composition to the long-term effects of regional climate (Silasoo *et al.*2011 YD). It should be reiterated that historically the bogs were not degraded by human activities.The impacts of climate change and nitrogen N and sulphur S deposition are predicted to have only a small direct impact on the cover of *Sphagnum* (<1% in an average 4m^2 unit area) between 2020 and 2050 (Smart *et al.*2010 ND).

Decomposition rates in peatlands as a result of climate change are a concern. The rate of decomposition of litter has been shown to be dependent on the evenness of species abundance and also on species identity (Ward *et al.*2010 YD). Decomposition of litter was greatest in communities dominated by *Calluna vulgaris* and least where *Pleurozium schreberi* was dominant. Summer warming studies of peat bogs and the microbial activity within them have shown that organic N dynamics may be much more important than previously thought, and because many plant species in bogs are capable of organic N uptake this may have important consequences in the future (Weedon *et al.*2012 YI). The impacts of summer warming of bogs also vary between wet bogs (fen) and dry bogs (open bog) with peat water and water-extractable organic matter decreasing in the former (Delarue *et al.*2011 YD).

As more studies are carried out the complex interactions between peat, decomposition of organic matter and the vegetation dynamics with the climate is becoming clearer. Currently, evidence suggests that under UKCP09 projections (Low, Medium and High carbon emissions scenarios at 50% probability) Blanket Bogs may stop being active if the ratio between precipitation and temperature in the growth period drops below a threshold value. They may suffer surface drying in the summer, leading to fires and erosion by wind; release more carbon; but vegetation may change subtly and in unpredictable ways.

Montane

The vast majority of montane habitats of the UK are in Scotland and research and modelling has been centred there. Many montane communities are dependent on snowbeds and snow cover. A model for one mountain, Ben Lawers, shows that snow cover is predicted to reduced by 100% at 130masl , 68% at 600masl and 32% at 1060masl by the 2050s using HadRM3 model (Trivedi *et al.*2007). This will have the effect of reducing the size of the snow bed communities dramatically. Other Scottish mountains are likely to be similarly affected.

Climate envelope modelling has shown that many species of Scottish montane communities are sensitive to temperature rise (Trivedi *et al.*2008 ND). This study suggests that by the 2080s a potential shift uphill of the climate space for many plant species and communities. The arctic alpine communities such as *Raccomitrium-Carex* moss heath becoming severely short of space. An analysis MODIS satellite data showed that Scottish high montane vegetation had a longer growing season in warmer years between 2000 and 2011. It follows that predicted climate change will lead to longer growing seasons (Chapman 2013 ND). It is unclear whether this will allow existing species to survive or species from lower altitudes to invade. As yet there is no evidence of how montane communities will be invaded and by what species although in the northwestern highlands graminoid species have increased in the last 50 years (Ross *et al.*2012) at the expense of dwarf shrubs, forbs and lichens. Should this change in vegetation become a trend then the Mountain Heaths and Willow Scrub priority habitat will morph into acid grassland and upland calcareous grasslands, especially the *Dryas octopetala* communities will decline or disappear. The effects of increased nitrogen from N deposition have been shown to cause degredation of montane communities (Armitage *et al.*2012 YD) and it is unclear whether climatic change will be more or less important than pollution.

In a study of *Festuca vivipara* in the Arctic, root decomposition increased in low-Arctic plots when a 2°C increase in soil temperature was applied (equivalent to a 4°C increase in air temperature)(Robinson *et al.*1997 YD). The effects of community composition on biogeochemical systems in the Arctic are discussed by Callaghan *et al.*(2004). It might be reasonable to think that in high montane systems in Scotland similar phenomena would occur, with higher carbon and element turnover, and long-term changes in species composition.

Coastal Land

The habitats found around the coast are covered in a separate report.

Developed Land

On a European scale areas with high concentrations of species are often associated with increased human activity. Storylines have been developed by modelling land uses and species distributions for future land use and conservation strategies (Araujo *et al.*2008 NI). They conclude there is no one size fits all development strategy across Europe and there are likely to be trade-offs between one strategy and another.

The impacts of climate change on the vegetation on infrastructure slopes needs to be understood to help protect them from failure in the future (Loveridge *et al.*2010 NI).

The concept of plant communities and habitats does not fit well within the developed environment. The many and varied plants that people grow in their gardens are likely to become a source of invasion for species with more southern biogeographic affinities. There is ample evidence of this occurring already e.g. *Opuntia phaeacantha* appearing in Kent in 2013 (Gay *et al.*2014 YD).

Evidence Needs

Despite the many decades of theoretical research the number of species for which we know the true climatic or weather dependencies is incredibly small and can probably be counted on two hands. If we are to understand how habitats are going to change in the future there is a critical need to understand how species will react to changes in temperature and precipitation. Future results from the Environmental Change Network, the Buxton facility and the EVENT 1 group may make things clearer and support for these facilities is vital.

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Method of Review

In 2007 produced “The England Biodiversity Strategy: Towards adaptation to Climate Change” (Mitchell *et al.*2007). That review summarised the knowledge of how the Broad Habitats in England might respond to the climate changes predicted by UKCIP02 scenarios and was based on available evidence and expert opinion. Since then Natural England have made slight alterations to the findings to the tables presented in Mitchell *et al.*(2007). Scottish Natural Heritage produced a Handbook of Climate Change Impacts Across Scotland (SNIFFER 2006).This report is intended to be used as a follow on from the work of Mitchell *et al.*2007 and SNIFFER and not to replace them. All citations in those reports should be considered alongside those in this report.

A full systematic review using the methods proposed by Pullin and Stewart (2006) was not possible here because of limited time and resources. A mini review has been carried out to find literature published since 2006 not included in the Mitchell *et al.*2007 review and to widen the search to European studies. In particular, the search was to find experimental evidence to support the theories, models and observations that have been widely reported. The citation database Web of Science was searched using combinations of the following keywords :

Impact*; Climate; Change; vegetat*; crop*; grass*; upland*; bog*; woodland*; forest*; habitat*; temperature; precipitation; UK; Europe*.

No date of publication limit was imposed so that papers and reports that might have been missed in the earlier reviews were not excluded. The first sift removed papers dealing with: subjects other than the study of plants: climate change from ancient history; hydrological modelling of rivers and streams (not covered by this review); socio-economic studies (e.g.

many titles including “grass-roots”); and those from outside Europe except those that dealt with vegetation also found in Europe. This sift was based on the titles of the papers only.

The abstracts were read to answer two questions 1) is there experimental evidence that climate (weather,temperature and/or precipitation) has an impact on vegetation? 2) are the causes of the impacts direct or indirect?

Google scholar was searched using the same keywords and the first 100 reports were scanned to identify any reports not identified in Web of Science or not known from the earlier reviews.

Results of Review

Following the review of Web of Science abstracts resulting from the searches undertaken, 82 papers were considered to have information pertinent to this review. The results can be portrayed in a 2x2 matrix (Table 1). Most of the papers (57%) provided results and opinions that were not based on experiments or field survey whilst the remaining 43% provide useful information based on experimental evidence and field observations. The high proportion of studies (55%) that address factors that will indirectly affect vegetation came largely from arable and forestry research and also predicted land use change. In these cases it was assumed that changing cropping patterns and growth of crops and trees will affect the vegetation communities associated with them indirectly. It can be quite difficult to disentangle what is a crop from a habitat in the case of forestry. In the UK this is only has to be considered for Broadleaved Woodland because, with the exception of the small area of Native Pinewoods in Scotland, all coniferous woodland is a crop.

Table 1. Matrix of papers found in the review of Web of Science answering the questions:1) were the results based on experimental or observed field data? and 2) do the results show a direct or indirect impact of climate on vegetation?

	Experimental Evidence or Field Survey	No Experimental Evidence
Direct Effects of Climate on Vegetation	23 (28%)	14 (17%)
Indirect Effects of Climate on Vegetation	12 (15%)	33 (40%)

Fifty nine of the 82 papers listed date from 2007 or later and therefore post date the Mitchell *et al.*2007 report. The papers are listed in a separate section of the reference list and each is labelled: YD (Yes for experimental evidence and/or field survey and climate Directly affecting vegetation); YI (Yes for experimental evidence and/or field survey and climate Indirectly affecting vegetation); ND (No for experimental evidence and/or field survey and climate

Directly affecting vegetation) ; and NI(No for experimental evidence and/or field survey and climate Indirectly affecting vegetation . Each of the 82 references were cited in the text in 2012. The same review was repeated in 2015 and a few more references found. The scope of this report card was tightened in 2015 and the sections on arable and forestry largely removed. As a result several papers were removed from the report. These are given an asterisk in the reference list. They have been left in the list as they still have relevance for anybody who will read the agriculture and forestry report cards.