Agriculture and Forestry Climate change report card technical paper

1. Climate change and land use systems

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1. Summary

- The land area of the UK is about 24.4 million hectares. Grass is the dominant land cover in the UK comprising 42% of the total area, followed by cropland (20%), woodlands (15%) and shrubland (10%), and artificial land (7%).
- The dominant primary land use in the UK is agriculture (65% of the area) followed by forestry (8%), residential use (5%), nature reserves (4%). About 8% cannot be classified into a land use category.
- Data shows that land use has changed historically. In the UK as a whole, the total agricultural land area has decreased from about 19.8 million ha in 1961 to about 17 million ha in 2005, and has been accompanied by an increase of capital intensive inputs such as fertiliser and machinery.
- Evidence suggests that agriculture will increase in Scotland, Wales, and Northern Ireland, and decrease in England.
- Elevated CO_2 levels should result in increased crop productivity. However, changes in land use capability are complex to model with results dependent on the extent to which different factors are taken into account.
- Climate change will have major impacts on agricultural land grades with increased droughtiness changing the relative proportions of both high and low land grades. This will inevitably influence crop mix and balance of rotations, although increased dependence on supplemental irrigation is expected particularly where high-value crops are grown on less well-suited soils.
- Flooding in coastal areas and around rivers will reduce the amount of land suitable for agriculture.
- But in most studies, it is suggested that in the UK, technology, policies and socio-economic factors will affect future agricultural land use patterns to a far greater degree than climate change
- Elevated CO_2 levels should increase tree productivity. However, productivity increases will also be affected by the droughtiness of land, pests, diseases, and wildfires.
- Tree productivity is likely to increase in Scotland, Wales and Northern Ireland, and decrease in England.
- The greatest increase in the productive range of forestry appears to be in Scotland.
- But competition for land from other land uses, such as agriculture, for carbon reduction policies particularly in peat rich areas, and for rural development policies will also affect the total area of forestry.
- The multifunctional importance of agricultural and forestry land needs to be more explicitly recognised in the future, not only by researchers or policy makers, but also by farmers, foresters, and other land managers.

The summary above has been developed from a review of literature. An attempt to evaluate the confidence associated with some of these statements, in terms of the level of agreement in the literature and the amount of evidence in the literature is provided in Appendix A.

1. Introduction

Many of the challenges facing UK agriculture and forestry can be linked to socio-economic, environmental and technological trends and issues – with climate change being an additive factor, rather than necessarily the main driving force of change at present. However, key challenges including food security (ensuring access to affordable, nutritious food), rising competition between sectors for natural resources including land and water, coupled with new environmental regulations are all exerting pressure on the UK land base. According to the latest Climate Change Risk Assessment 2012 (CCRA, 2012), increasing energy prices may also present a significant challenge, together with international pressures and market competition. A changing climate with greater uncertainty will exacerbate the situation and highlight the difficulties in reconciling the multifunctional nature and contributions from UK agricultural land use (See Appendix B for a summary of project climate change provided by the UK 2009 climate change projects).

Land in the UK can be classified according to cover and use. LUCAS offers a common European framework for describing land cover and use. Although the data can be presented in terms of primary land use, there are also options for looking at secondary, tertiary and other levels of land use. Any future increases in temperature in the UK would provide increased options for the planting of new annual and perennial species; a greater administrative (policy) and regulatory appreciation of the concept of multiple land use will thus be needed.

This technical review examines selected effects of climate change on land use systems in the UK and in particular the implications for arable, forestry and livestock systems. The introductory sections briefly discuss the concepts of UK land cover and land use from a historical perspective, and the consequences of climate change on land use for agricultural cropping, forestry, and livestock systems.

2.2 Land cover and land use

The land area of the UK is about 24.4 million hectares, about 0.16% of the land area for the planet. Descriptions of land use systems typically highlight the important difference between land cover and land use. Land cover has been defined as “the observed physical and biological cover of the Earth’s surface” (European Commission et al., 2012) and it includes vegetated, natural, and abiotic surfaces. Land use refers to the “arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it” (FAO, 2005). The LUCAS framework provides a standard European framework for describing land cover (Table 1) and land use (Table 2).

Grass is the dominant land cover in the UK comprising about 42% of the total area (Table 1). Cropland covers about 20% of the UK while about 15% and 10% is covered by woodlands and shrubland, respectively. Artificial land, defined as land that is associated with built up land, occupies about 7%.

The dominant primary land use in the UK is agriculture (cropping and grassland) representing about 65% of the area (Table 2). The practice of forestry occurs on about 8% of the area, and about 8% of the land (primarily to be found in Scotland) cannot be classified into any category as it has no visible use. Residential use accounts for about 5% of land use, and about 4% is held as nature reserves.

Table 1 Land cover in the UK, based on LUCAS 2009 data (after Hart et al., 2012).

Land cover type	Area (‘000 ha)	Proportion of area (%)
Grassland	10366	42.4
Cropland	4854	19.9
Woodland	3614	14.8
Shrubland	2502	10.2

Artificial land	1630	6.7
Water	578	2.4
Wetland	490	2.0
Bareland	408	1.7
Total	*24442*	

Table 2 Primary land use in the UK, based on LUCAS 2009 (derived from Hart et al., 2012).

Primary land use	**Area ('000 ha)**	**Proportion of area (%)**
Agriculture	15902	65.1
Forestry	2083	8.5
Hunting and fishing	421	1.7
Mining and quarrying	96	0.4
Energy production	27	0.1
Industry and manufacturing	72	0.3
Water and waste water	89	0.4
Construction	28	0.1
Transport and communication networks	482	2.0
Commerce, finance and business	120	0.5
Community services	359	1.5
recreation, leisure and sport	662	2.7
Residential	1238	5.1
Natural reserves	930	3.8
No visible use	1932	7.9
Total	*24441*	*100*

2.3 Recent changes in land cover

There is a tendency to view land cover in the UK as being fixed. However, even over short periods there can be substantial changes. The area of developed land in the UK is steadily increasing (Table 3). The area of broadleaf woodland is also increasing, with some of this being due to the replanting of harvested coniferous woodland with broadleaf species. There can also be significant changes between agricultural land uses. In the period 1998 to 2007, when food prices and farming incomes were low, there was a tendency for the area of arable crops to decrease and the area of pastures to increase. By contrast, between 2010 and 2014, when food prices and farm incomes were higher, the area of arable crops increased and the area of permanent grassland decreased. Hence changes in food prices and farm profitability have a direct effect on the type of agricultural land cover, and on regional changes (e.g. livestock versus arable).

Table 3 Estimates of the land cover (thousand hectares) in the UK using the SEEA framework in 1998 and 2007 (Office of National Statistics, 2015).

Land cover category	1998	2007	Net change (x10^3 ha)	Proportion in 2007 (%)
Urban and associated developed areas	2,753	2,825	+71	11.6
Rainfed herbaceous crops	4,779	4,275	-503*	17.5
Permanent crops	114	52	-62	0.2
Pastures	5,069	5,363	295*	22.0
Semi-natural grassland	4,002	4,157	155	17.0
Broadleaved mixed and yew woodland	1,367	1,461	94*	6.0
Coniferous woodland	1,500	1,423	-77	5.8

Shrubland, bushland and heathland	1,293	1,312	19	5.4
Barrenland/sparsely vegetated areas	92	97	5	0.4
Open wetlands	2,812	2,800	-12	11.5
Inland water bodies	307	314	7	1.3
Coastal margins	150	153	3	0.6
Unknown	183	185	2	0.8
Total	24,419	24,417	-3	

***** Net change is significant at 5% level

2.4 Long-term and recent changes in land use

Between 1900 and 2008, the area of agricultural land in England has declined by about 12%, with 7% occurring since 1950 (MAFF, 1968; Defra 2008a). This equates to a total decline in area of 700,000 ha, equivalent to 6,500 ha per year. In the UK as a whole, the total agricultural land area has decreased from about 19.8 million ha in 1961 to about 17 million ha in 2005, and has been accompanied by an intensification of agriculture, in terms of capital inputs such as fertiliser and machinery per unit land area (Rounsevell and Reay, 2009). Khan and Powell (2011) used land use statistics from the Centre for Social and Economic Research on the Global Environment (CSERGE) to examine land use change in the UK (excluding Northern Ireland) between 2000 and 2010 (Table 4).

Their analysis suggested that the area of managed farmed land has increased, with a decrease in "non-farm" grassland and farmed rough grazing and an increase in farmed "permanent grass". Some of the increase in the grassland area since 2005 may be attributable to increased registration of smallholders under the EU Single Farm Payment Scheme. During this period of low food prices, many farmers also took advantage of incentives to increase farm woodland planting.

Table 4 Classifications of land use (ignoring inland waters) (thousand hectares) using the Centre for Social and Economic Research on the Global Environment (CSERGE) dataset for England, Scotland and Wales (Khan and Powell, 2011).

		2000		2010		% change
		Area ('000 ha)	(%)	Area ('000 ha)	(%)	
Farm	Crops and bare fallow[1]	4,623	19.9	4,560	19.6	-0.3
	Rough grazing (sole right)	4,211	18.1	3,914	16.8	-1.3
	Permanent grass (> 5 years)	4,754	20.4	5,259	22.6	2.2
	Temporary grassland (< 5 years)	1,061	4.6	1,108	4.8	0.2
	Farm woodland	493	2.1	764	3.3	1.2
	Other farmland	648	2.8	492	2.1	-0.7
		15,791	67.9	16,097	69.1	1.2
Non-farm	Urban and developed land	2,607	11.2	2,748	11.8	0.6
	Marine and coastal	352	1.5	383	1.7	0.2
	Freshwater	2,607	0.9	2,748	1.1	0.2
	Grass, mountains, moors and heath	2,609	11.2	2,147	9.2	-2.0
Total		23,282	100.0	23,282	100	

[1]: including horticulture

2. National and regional impacts of climate change on land capability and land use

Although UK agriculture accounts for a relatively small proportion of the national economy and employment, it occupies almost 75% of the total surface area (Angus *et al*., 2009). It is strategically important in the provision of food including both cropping (arable, horticulture) and livestock (beef, dairying, pigs, poultry) and provides over half of all food consumed in the UK (Defra, 2010a). As in many countries, UK agriculture has a multifunctional role, sitting at the interface between the natural environment and society, whilst also contributing to a range of environmental services including landscape enhancement, leisure and recreation, and the provision of non-food raw materials. As agriculture involves the manipulation of natural ecosystems, it is particularly vulnerable to climate change. But because of the interactions and feedbacks that exist between agriculture, the environment and society any climate risk assessments of agriculture are notoriously difficult. In the future, producing food sustainably in a changing and uncertain climate will clearly be a high priority (Defra, 2010b) but climate change is just one of a number of stresses on agriculture and responses to the threat of climate change need to be sensitive to ecosystems and the diversity of benefits that agriculture provides, and not just to food production.

3.1 Crops

The biophysical limitations imposed on land use by spatial and temporal changes in climate, soils, topography and hydrology can be described through the use of land capability classification systems (Brown et al., 2011). Typically, these have been used to help quantify the potential that land might have for different uses, particularly agricultural crop production, by identifying the potential limitations that land might have on productivity (yield) and management (trafficability, access). Land classes used in the UK range from Grade 1 with few limiting factors for a wide range of crops to Grade 7 where limitations are extremely severe and the land is of very limited agricultural value. Brown et al. (2008) predicted that prime agricultural land in Scotland might in fact increase significantly under a projected future climate, but the study excluded climate-soil interactions such as droughtiness, wetness and erosion risk. A more recent assessment (Brown et al., 2011) concluded that drought risk was likely to have a much greater effect on land use, and that in effect, this would reduce land capability, particularly in the south of Scotland, reducing the area of prime land.

At a European level, the effects of climate change on agriculture, including for example, extended cropping seasons and elevated CO_2 levels should result in increased crop productivity (Alcamo et al., 2010; Rounsevell et al., 2009). However, it is expected that technology, prices, populations, and changing patterns of supply and demand are likely to affect agricultural land use patterns in the future to a much greater degree than climate change (Audsley et al., 2008; 2015; Rounsevell et al., 2009; Almaco et al., 2010). Yield increases ranging from 37% to 101% have been predicted by Ewert et al (2005) and Rounsevell (2005) who argue that such yield increases coupled with stabilising demand may in fact result in a decrease in the agricultural land area of Europe. However, the effects of climate change are expected to affect different parts of Europe differently, with northern Europe experiencing the greatest potential increase in yields (Table 5).

Table 5 Potential changes in crop productivity in Europe (Source: Alcamo et al., 2010).

	By 2020	By 2050	By 2080	References
Northern Europe				
Wheat	+2% to +9%	+8 to +25%	+10 to +30%	Alexandrov et al., 2002; Ewert et al., 2005; Audsley et al., 2006; Olesen et al., 2007

Sugar beet	+14 to +20%	Richter and Semenov, 2005
Southern Europe		
Legumes	-30% to + 5%	Olesen and Bindi, 2002; Alcamo et al., 2005;
Sunflower	-12 to +3%	Maracchi et al., 2005
Tuber crops	-14 to +7%	

Within the UK, it might be argued that, if all things remained equal, land requirements for agriculture could in fact decline. However, loss of productivity in other parts of the world and the increasing demand for food as a result of rapidly growing populations in Asia, Latin America and Africa, as well as increasing incomes and changing diets in those areas, seems likely to increase the demand for food and fodder crops (Rounsevell and Reay, 2009; ASC, 2013; Strengers et al., 2004). Pressure may also arise from an increase in demand for bioenergy crops (Rounsevell et al., 2009) driven in part by policy objectives which aim to reduce carbon emissions (ref). Given the relative climatic advantage that the UK seems likely to have under future climate change, when compared to southern European countries, this may increase the importance of the UK as a food producing nation (ASC, 2013).

Whilst some studies have concluded that pressure on land will increase because of such drivers (e.g. Busch, 2006) a number of other studies (e.g. Knox et al., 2012; Rounsevell and Reay, 2009; Almaco et al., 2007; Audsley et al., 2006; Rounsevell et al., 2006; Schröter et al., 2005; van Meijl et al., 2006) have concluded that the growing international demand for food is unlikely to outstrip productivity increases due to improved technologies and management practices, resulting in a reduction in agricultural land use. The land released might then be put under forestry or bioenergy crops, helping to sequester carbon and reduce emissions. However, it should be noted that decarbonisation policies and strategies for green infrastructure development are likely to play an important role in such land use conversion. Such land use change would be more likely to occur on agricultural land of lower land capability, whilst production would be likely to become more intense on prime agricultural land.

Whilst the increase in CO_2 might increase the yield of certain crops, such as wheat and potatoes in the UK, longer growing seasons associated with climate change might also make it possible for new more “continental” crops, such as grape vines and sunflowers to be grown, especially in southern England, and grass productivity might increase in upland areas (Daccache et al., 2012; Rounsevell et al., 2009; ASC 2013; CCRA, 2012; NFU, 2005). However, the absolute changes in area will depend on the relative economic competitiveness of the new crops in comparison with existing crops. Sunflower for example may still remain less profitable than alternative oilseed crops (Audsley et al., 2008) making it less economically attractive to farmers.

The area of forage maize quadrupled in the 1990’s compared with the area in the 1980’s. However, this increase was not driven directly by a change in land use suitability for maize caused by climate change, but rather by a combination of factors in the form of the development of varieties of maize that were better adapted for the UK, the perception that climate was changing, the introduction of an arable payment scheme under the Common Agricultural Policy (Defra 2003), the establishment of anaerobic digesters (AD), and bioenergy policies. Maize whilst more productive under higher temperatures, can also suffer reduced yields from high soil moisture deficits. Since it is a low margin crop, it is generally not currently irrigated. However, on droughty soils in dry summers farmers would be expected to irrigate maize, particularly given the large areas now being grown to support AD plants. Further expansion of maize in the future may occur in western and northern parts of the UK, which receive higher rainfall but are too cool at present for maize production (Defra 2003).

Within the UK, a broad northward shift of some crops such as potatoes and sugar beet from southeast England seems likely, given projected decreases of summer precipitation (Rounsevell et al., 2009). An increase in both crop and livestock diseases seems likely (ASC, 2014) and rising sea levels will not only destroy coastal habitats with implications for biodiversity, people and property, but will also lead to a reduction in the land available for agriculture. Almost 60% of grade 1 agricultural land in the UK lies less than 5m above sea level. This area is likely to be increasingly at risk from flooding, erosion and saline intrusion (Harrison et al., 2008) and these impacts are likely to most affect southern and eastern England. The process of roll-back in which new salt marsh and flood plain areas are created is likely to consume some prime agricultural land, adding pressure on agricultural or forestry land in other area, as displaced populations relocate inland.

In some cases, as in lowland peats, global warming might exacerbate and accelerate changing crop patterns. In the Fens for example, Graves et al. (2013) proposed that as peats degraded, exposing the underlying soils, land use would change from a more root-based rotation to a cereal-based rotation. Such changes are already evident. Greater rates of global warming were associated with greater rates of peat degradation, and would therefore accelerate the change in cropping patterns (see Box 1).

More broadly, studies suggest that the bioclimatic envelope suitable for blanket peatland in the UK will contract. Using UKCIP02 projects, Gallego Sala et al (2010) concluded that blanket peatland would gradually retreat to the north and the west of Great Britain as the bioclimatic envelope contract by between 53% and 84% (low and high emissions scenarios respectively) by 2080 against the baseline emissions scenario (1961-1990). Clarke (2010) concluded that findings were in part dependent on whether models were temperature sensitive, in which case bioclimatic envelope retreated to higher altitudes, or whether they were more sensitive to precipitation than temperature, in which case bioclimatic enveloped retreated to the north and west. However, the Joint Nature Conservation Committee (JNCC) concluded that the area of blanket peatland might not necessarily shrink in direct association with the reduction in the bioclimatic envelope, since bog mosses can tolerate wide climatic variations, but noted that the best adaptive response to climate change was to secure favourable management, in particular to retain water (JNCC, 2011).

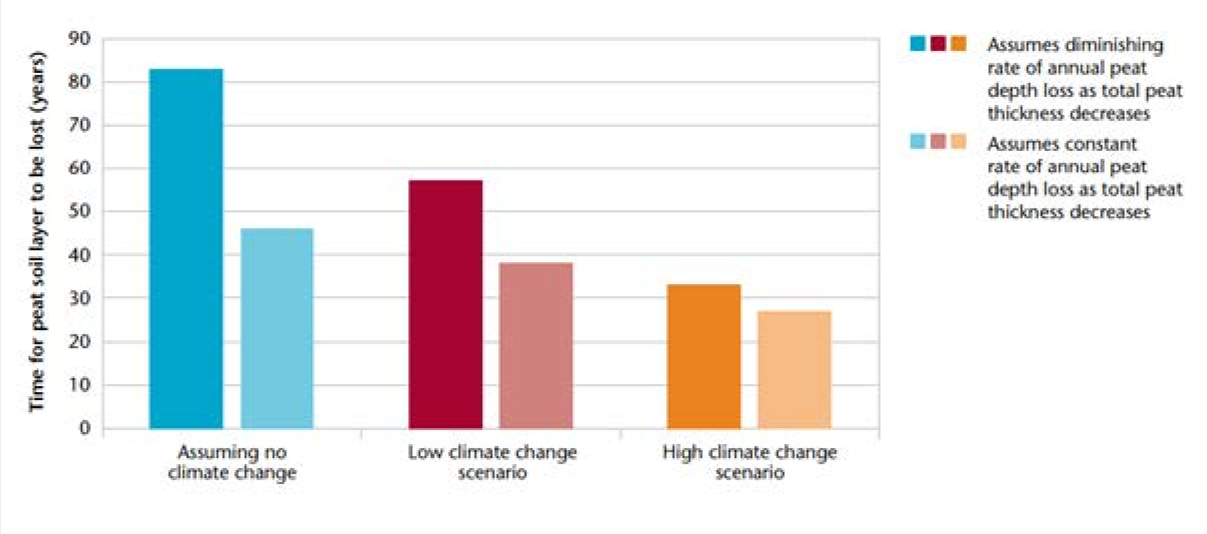
A SPICe briefing paper (2012) notes that historically, peatlands in Scotland have been viewed as an unproductive resource and that much damage to peatlands has been done in trying to make it productive, either by draining it for agricultural or forestry activities or cutting it for physical removal. Thus, whilst climate change may damage peatlands, for example, because higher temperatures may lead to greater drying, cracking, erosion, and wildfires, it has been noted that land management is likely to play a much greater role in peat degradation than climate change (Smith et al., 2007, 2009).

The carbon storage value of peat is likely to become more important under Scotland's carbon abatement targets under the Climate Change (Scotland) Act of 2009. The net potential abatement benefit from peatland restoration in Scottish peatlands is between 0.6 and 8.3 t ha-1 CO2e per hear (Artz et al, 2012). But other productive benefits can require peat drainage (agriculture and forestry), cause reductions in peat water levels (windfarms) or require actual physical cutting and removal of the peat (compost) (SPICe briefing paper (2012). Thus, in the end, the key changes in land use and management are likely to by driven by the outcome of competing policy and socio-economic interests regarding the appropriate use of peat, rather than climate change. Strong policy is need now and into the future to ensure that peats continue to perform effectively as carbon sinks.

Box 1: Case study: Restoration of Fenland Peat under climate change

Degradation of England lowland peatlands due to intensive farming is associated with carbon loss that has potential to contribute to global warming. Simultaneously, climate change can induce more rapid deterioration of remaining peats. As peat soils degrade, their comparative advantage for intensive farming declines.

These challenges are evident in the 133,000 ha of remaining peat soils within the East Anglian Fens (see Graves et al., 2013). In this context, the potential degradation of peatlands and associated loss of soil carbon were estimated for different land use scenarios (continued intensive arable, degraded arable, conservation grassland, and peatland restoration) and climate change scenarios (P10 low, P90 high). Annual peat loss per year (mm) and associated CO_2e emissions were estimated as a function of starting and remaining depth, type of land use and climate change signal. It was shown that intensively farmed soils could lose all of their peat topsoil in 50-80 years under current land management practices. With climate change, the rate of degradation could increase, resulting in complete loss in 30-60 years.



Source: Graves and Morris (2013) for the Adaptation Sub-Committee.
Notes: The analysis assumes an average peat topsoil depth of 86 cm in 2012. The darker shaded bars assume a diminishing rate of loss as total peat thickness decreases to 8 cm by 2080. The lightly shaded bars assume a constant loss rate of 2 cm each year. The effects of climate change on degradation rates are based on two scenarios of climate change: low climate scenario = low emissions (B1), 10% probability level from UKCP09; and high climate scenario = high emissions (A1FI), 90% probability level from UKCP09. The analysis is based on evidence that under normal conditions, emissions increase by 30% for each degree increase in temperature.

Figure B.1 Estimated degradation times (years from present) of peat soils in the east Anglian Region (Source: Adaptation Sub-Committee, 2013: P36).

The economic implications of peat degradation under different scenarios were considered in terms of the value of agricultural production and the cost of carbon emissions due to peat degradation. Assuming climate change scenarios through to 2080, the estimated annual net margins (in $£_{2012}$ prices) from agriculture reduced significantly due to degraded soils and more or less broke even under conservation grassland. Peatland restoration involved small annual net costs for maintenance. Conversely, the costs of carbon emissions from peat soils, valued at policy prices ($£\ t^{-1}\ CO_2e$), varied considerably between intensive arable (high) and conservation grassland (low). Peatland restoration gave a small net gain associated with soil formation and carbon sequestration. Combining agricultural income effects and the value of carbon emissions within a cost benefit analysis model over the period 2012 to 2080 suggested that switching from intensive arable to peatland restoration gives an overall net benefit of restoration under both climate change scenario. Under a high climate change scenario, a switch to conservation grassland appeared beneficial.

Extending the environmental effects of different peatland land uses to include allowance for land system costs (such as GHG and acidification emissions from agricultural production) as well as cultural services provided by different landscape and habitat types, further increases the relative advantage of peatland restoration and conservation land use scenarios.

The study identified about 20,500 ha of remaining deep Fenland peat soils where restoration could offer an economically viable option. This probably accounts for around 1.5% of each of the total national areas of sugar beet area, potatoes and field vegetables. It is feasible that this could be substituted by high-value cropping elsewhere without impacts on national food supply. Climate change also increases the economic viability of measures to arrest carbon loss on the other 100,000 ha of degraded arable peats in the Fens.

Readers interested in further details on this project are referred to:

Graves, A.R. and Morris, J. 2013. Restoration of Fenland Peatland under Climate Change**.** Report to the Adaptation Sub-Committee of the Committee on Climate Change. Cranfield University, Bedford. Available from: https://www.theccc.org.uk/wp-content/uploads/2013/07/report-for-asc-project_final-9-july.pdf

Also see the Adaptation Sub-Committee's 2013 progress report:

Adaptation Sub-Committee (2013) Managing-the-land-in-a-changing-climate. Progress report 2013. 137pp. https://www.theccc.org.uk/publication/managing-the-land-in-a-changing-climate/

UK agriculture could be significantly affected by climate change. Rising temperatures and changing rainfall patterns, changes in sunshine levels and in concentrations of atmospheric carbon dioxide (CO_2), and increasing frequency of weather events currently considered extreme would all have an impact on operations, productivity and the range of products offered by the sector. Accommodating change and uncertainty is a familiar feature of running an agricultural business. However, the potential impacts of climate change on UK agriculture may be intensified due to the strong interdependencies with other sectors. In particular, key issues facing the water sector (e.g. water availability and demand) are also of primary importance to UK agriculture (Watts et al., 2015; Knox et al., 2010; Weatherhead and Knox, 2015; CCRA, 2012).

Warmer temperatures and higher concentrations of CO_2 in the atmosphere may lead to higher yields of many crops currently grown in the UK. These benefits will not materialise, however, if rising temperatures coupled with lower summer rainfall result in increased heat stress to crops and significant decreases in soil moisture availability. In some cases, faster growth rates may reduce crop quality. Overall, yields of crops such as winter wheat and sugar beet are projected to rise. Grass yields may also increase, although in some parts of England and Wales dry conditions may constrain yield. In Scotland and Northern Ireland, where water stress may be less of a problem, there may be more significant increases in grass yields, which may prove beneficial for livestock and dairy producers. There could also be opportunities to expand existing crops that are currently only grown in small quantities and introduce new crops, especially in the south, including, for example, blueberries and grain maize, as well as new industrial, energy and pharmaceutical crops. However, increases in rainfall intensity or the frequency of intense storms could increase the risk of soil erosion throughout the UK, although the implications for crop yields are unclear (CCRA, 2012). Although many of the impacts on the agriculture sector may be negative, potentially valuable new opportunities may also arise that can benefit existing agricultural activities and encourage farm diversification (CCRA, 2012).

3.1.1 Changes in land suitability

The viability of commercial agricultural production is strongly influenced by spatial and temporal variability in soils and agroclimate, and the availability of water resources where supplemental irrigation is required. Soil characteristics and agroclimatic conditions thus greatly influence crop choice, agronomic husbandry practices, and the economics of production (see Box 2).

Box 2: Case study: climate change and land suitability for potato production

Using the latest (UKCP09) scenarios of climate change for the UK, Daccache et al. (2012) developed a methodology using pedo-climatic functions and a GIS to model and map current and future land suitability for potato production in England and Wales. The outputs from that study identified regions where rainfed production was likely to become limiting and where future irrigated production would be constrained due to shortages in water availability. Their analyses suggested that by the 2050s, the area of land that is currently well or moderately suited for rainfed production would decline by 74 and 95% under the "most likely" climate projections for the low and high emissions scenario respectively, owing to increased droughtiness. In many areas, rainfed production would become increasingly risky. However, with supplemental irrigation, around 85% of the total arable land in central and eastern England would remain suitable for production, although most of this is in catchments where water resources are already over-licensed and/or over-abstracted; the expansion of irrigated cropping is thus likely to be constrained by water availability. An unexpected side effect arising from the predicted impacts of climate change on potato land suitability was that the future increase in volumetric water demand due to the switch from rainfed to irrigated potato cropping was likely to be much greater than the incremental increase in water demand solely on irrigated potatoes (Daccache et al., 2012).

Readers interested in further details on this project are referred to:

Daccache, A., Keay, C., Jones, R.J.A., Weatherhead, E.K, Stalham, M.A., and Knox, J.W (2012). Climate change and land suitability for potato production in England and Wales: impacts and adaptation. *Journal of Agricultural Science* 150: (2): 161-177.

There is also an information booklet available from: http://www.potato.org.uk/sites/default/files/publication_upload/CC%20impacts%20potatoes_Final_20Sept2011.pdf

More recently, Keay et al. (2014) assessed how future changes in climate might affect agricultural land use in England and Wales based on the well-established Agricultural Land Classification (ALC) system. Future changes were modelled relative to a 1961-90 baseline using 12 UKCP09 climate change scenario, for selected time periods (2020s to 2080s). Keay et al. (2014) reported that the main climate limitation in ALC is built on the premise that warmer and drier climate conditions would lead to improvements in land grade. Although the average annual rainfall was assumed to remain constant under future scenario there were assumed projected increases in accumulated temperature. This resulted in an improvement in ALC grades with the proportion of England and Wales potentially in Grade 1 (based only on that criterion) increasing from 58% (baseline) to over 90% by the 2080s. Soil wetness (based on the duration of field capacity and drainage status) was shown to be largely unaffected because although the start and end dates of field capacity are likely to change, their duration remained constant. In order to consider potential changes in seasonality the calculation of field capacity duration was also varied to use the average summer and winter rainfalls rather than just average annual rainfall. This showed a drying of soils resulting in fewer sites being downgraded by being too wet with the proportion of England and Wales potentially in Grade 1 (based only on that criterion) increasing from 24% (baseline) to over 30% by the 2080s.

The potential impacts of climate change were found to be significant when droughtiness was considered. Keay et al (2014) used two crops (wheat and potatoes) as indicators of average drought risk, although they noted that grassland would also be impacted as it has characteristics (e.g. shallow rooting) which make it prone to drought over a wide range of conditions. Low grass yields would affect grazing, increasing the need for supplementary feed or reduced stocking rates. The ALC method for classifying drought risk resulted in the amount of Grade 1 (based only on that criterion) land being downgraded from 37% (baseline) to 7% by the 2080s (high emission scenario). Conversely, the amount of land in Grade 4 was estimated to increase from 2% to 66%.

Areas vulnerable to inundation or flooding based on UKCP09 projections of sea level change were also mapped. The number of NSI sites affected by flooding, for which the ALC had been calculated were assessed. Assuming no defence against any marine incursion existed or was planned, 13 of the current 96 Grade 1 sites were identified as ‘at risk’ from sea inundation. By the 2080s, it was estimated that there would be only 9 NSI sites remaining in Grade 1 of which 3 could potentially be lost to flooding.

Despite potentially significant impacts on agricultural land classification, the net impact of climate change on cropping outcomes in the UK remains unclear, since positive effects related to warmer temperatures and increased CO_2 concentrations could be off-set by negative impacts due to increased water stress and droughtiness. There is thus great potential for adaptation within the agricultural sector. This will be either planned as part of policy changes, or autonomous as individual farmers respond to changing local soil and agroclimate conditions. If aridity zones shift northwards (as projected by aridity indices), then there could be a geographical shift in the range of crops grown, including the introduction of crops not currently grown (and not represented in the ALC classification). Long-term climate projections (2050s and 2080) show areas of the UK likely to experience similar climatic conditions to those currently experienced in parts of mainland Europe. For example by the 2050s, grain maize, which is currently grown extensively in western France, could become an important crop in the UK. By the 2080s, agricultural areas which currently grow wheat and potatoes may experience a more Mediterranean type climate able to support crops such as maize, olives and vines. Of course, the agronomic and economic viability of such crops will also depend on water availability for supplemental irrigation.

Finally, changes in climatic conditions could also lead to changes in farming conditions in both lowland and upland areas. As yields increase the viability of farming marginal land could increase, leading to increases in the area of land used for agriculture and changes to the type of farming in some areas. For example, grassland productivity in upland areas could increase, prompting a shift from rough grazing to improved grassland in some areas. Some upland areas may become more suited to arable crops. This increase in the intensity of farming in upland areas could lead to adverse consequences including an increase in soil erosion (Smith et al., 2011) and damage to biodiversity. Other factors such as concerns regarding methane emissions could also affect upland based production systems which could affect the amount of upland grazing (Keay et al., 2015; CCRA, 2012; Smith et al., 2011).

3.1.2 Impacts of regional changes in agroclimate on land use

Future agricultural land use will also be strongly influenced by changes in agroclimate. Knox et al (2010) modelled and mapped the spatial changes in agroclimate from the 1961-90 baseline for selected future UKCIP02 scenarios using maximum potential soil moisture deficit ($PSMD_{max}$) as an aridity indicator (Figure 2). Nine zones were used to represent ranges of $PSMD_{max}$ values (where Zone 1 was the lowest and Zone 9 was the highest). The baseline map shows the long term average PSMD between 1961 and 1990. The zones where aridity is greatest include parts of Suffolk, Kent, areas in West Midlands, Nottinghamshire, and the south coast. Climate change will have a direct impact on PSMD and the need for supplemental irrigation. Crops that are currently irrigated in the UK would need increased application depths to cope with higher ET rates, and many crops previously rain-fed might need irrigation to maintain crop yield and quality, particularly in south east England. Scotland, Wales and Northern Ireland would be much less affected. Projections for average $PSMD_{max}$ for the 2030s and 2050s are shown in Figure 2. Drier zones generally increase in area and magnitude spreading from the south and east towards the north and west.

Changes in agroclimate and hence land suitability would also impact on the sustainability of existing cropping (eg Daccache et al, 2012; see Box 2) and opportunities for new crops. For example, in Scotland, Brown *et al.* (2009) demonstrated the importance of soil moisture on land-use options, and how shifts in land-use potential have implications for both strategic resource planning and for adaptation actions. Their assessment highlighted not only potential changes in agriculture and other productive land uses, but also repercussions for biodiversity and terrestrial carbon stocks.

3.1.3 Flood risks to agriculture

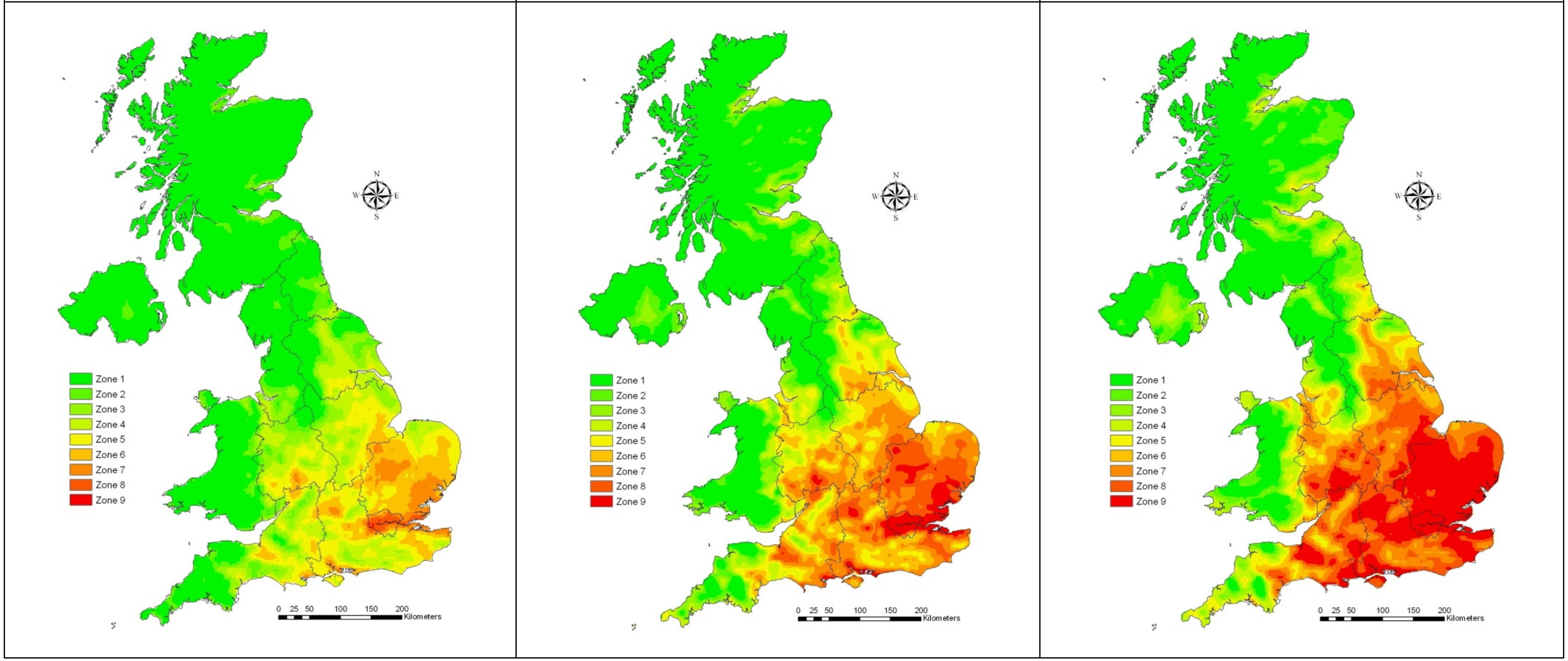
Significant areas of agricultural land are at risk from flooding from rivers, coasts and estuaries and groundwater. In the CCRA (2012) response functions for agricultural land at risk of frequent tidal and river flooding were based on GIS analysis of flood risk areas combined with spatial assessments of land suitability using the Agricultural Land Classification (ALC) to estimate the areas of agricultural land flooded from the sea with return periods of less than 1 in 3 years, 3-5 years and 5-10 years, and for ALC grades 1 to 3 (horticulture/arable) and 4 and 5 (grassland/grazing) for selected 2020s, 2050s and 2080s scenario.

In the near term (2020s) there were small projected increases in the area at risk of tidal flooding at frequencies of 1 in 10 years on average or more frequent. The largest increase in flood risk is a more than two-fold increase in the area affected for arable and horticultural land in the 3 to 5 year class. This means that that there is a large area of good quality land (ca. 14000 ha) that currently floods occasionally (less frequently than once in 5 years on average) but would flood more frequently (between 1 in 3 and 1 in 5 years) by the 2020s.

In the longer term (2050s, 2080s) the CCRA (2012) projected large increases in the areas of agricultural land that would be flooded from the sea on a regular basis (once in 3 years on average or more frequent). Under the highest rates of relative sea level rise for the 2080s (of 57 cm under the high emissions scenario) an almost tenfold increase is projected in the amount of good quality agricultural land that could be flooded regularly from the sea, making it untenable for normal agricultural use. There are also potentially large increases in the amount of grassland and rough grazing that could be flooded regularly from the sea, although some of this land may still be used for grazing.

Figure 1 Project changes in spatial variability in agroclimate (using $PSMD_{max}$ as an aridity index) from the long-term average (baseline, 1961-90) for selected UKCP09 emissions scenario and time periods (2030s and 2050s).

Baseline (1961-90)	UKCP09 2030 High emissions	UKCP09 2050 High emissions



Flooding of agricultural land from rivers with a frequency of 1 in 10 years on average or more frequent was projected to increase from a 1961-90 baseline of about 280,000 ha to about 400,000 ha by the 2020s (central estimate). The CCRA (2012) projected figure for the 2080s was between 350,000 and 840,000 ha. The central estimate of 560,000 ha is about twice the 1961-90 baseline.

The area of land at risk of very frequent river flooding (frequency of once in 3 years on average or more frequent) is projected to increase from a 1961-90 baseline of about 50,000 ha to about 70,000 ha in the 2020s. The range of projections by the 2080s for the climate scenarios assessed is 60,000 to 400,000 ha.

The results from these CCRA analyses for present day areas at risk of flooding were reported to differ from results reported in Defra FD2634. However, based on a qualitative assessment, the evidence available on the climate risks related to flooding of agricultural land was considered at the time (2012) to be 'strong'. An example case study of the effects of flooding on agriculture is shown in Box 3.

Box 3. Climate change, flooding and agriculture: impacts and adaptation

Climate change, with wetter winters and more extreme rainfall events, is likely to increase the vulnerability of farm land to flooding, including areas previously drained and protected from flooding. The probability of spring and summer flooding is likely to increase. The floods in June and July 2007 in England on 42,000 ha of farmland in the West Midlands, Oxfordshire and Yorkshire are indicative of the type of floods that might occur more frequently with climate change. Summer floods can cause extensive damage at a time when agriculture is most vulnerable to flooding.

A survey of over 80 farmers affected by the summer 2007 floods (Posthumus et al., 2009) showed that agricultural flood damage costs varied significantly ($P< 0.05$) between crops -types, the duration of flooding and between regions. High value crops such as potatoes and horticultural produce were completely destroyed. Cereals yields were reduced by about 60% - 80% in flooded areas, and grass yields were about 40% of normal annual production due to loss of hay/silage. Overall average costs were about £1,200 ha^{-1} (in $£_{2007}$), ranging from about £380 ha^{-1} on grass to over £4,000 ha^{-1} on potatoes. Significant differences in flood costs (£ ha^{-1}) were apparent between farm types (Table B3.1) reflecting the relative intensity of farming as well as the vulnerability to seasonal flooding. The impact of summer flooding was exacerbated by continued wetness of soils during 2007 that delayed the establishment of subsequent crops.

Spring and early summer floods can also affect grassland farming that is generally more tolerant to flooding. Flooding in excess of four weeks in April and May 2012 on the Somerset Moors and Levels caused extensive damage (Morris and Brewin, 2013), resulting in loss of grass for feed production, of 'grazing days', of livestock produce and the need to reseed damaged pastures. Damage costs in the most severely affected areas approached £900 ha^{-1} ($£_{2012}$), rising to over £1,100 ha^{-1} when the knock-on effects into 2013 were considered. Impacts were greatest on 'improved' agricultural grassland irreversibly damaged by long duration flooding. Recovery was set back by the long duration 12 weeks that subsequently occurred in the winter of 2013/14.

Table B3.1 Average damages (£ ha^{-1}) by farm type due to summer flooding in England 2007.

	Horticulture	General cropping	Cereals	Mixed	Dairy	Grazing livestock	Pigs	All farms
	(n = 4)	(n = 20)	(n = 22)	(n = 11)	(n = 9)	(n = 9)	(n = 3)	(n = 78)
Arable production	6,592	1,760	530	223	163	7	715	828
Grass production	0	64	73	143	464	371	68	156
Livestock production	0	5	12	–3	328	152	4	58
Other	287	199	236	49	104	81	162	163
Total cost	**6,879**	**2,028**	**850**	**411**	**1,058**	**612**	**948**	**1,207**

Notes: Mean values are significantly different between farm types at P<0.01; General cropping included potatoes and field vegetables; Mixed farming combines arable and grassland.

Source: Posthumus *et al*, 2009

The recent flood events in Somerset revealed the vulnerability of 'improved' agricultural grasslands relative to semi natural grasslands that showed greater resilience to flooding. In response to recent extreme flood events in Somerset, some farmers have reduced livestock numbers and made changes to forage management in order to reduce their exposure to future flooding. It is apparent that the viability of existing relatively intensive crop and grassland farming systems will be challenged by the increased probability of flooding under climate change. While climate change is likely to increase the probability of serious but occasional floods, sustained exposure to flooding (and associated decline in standards of agricultural drainage) could lead to abandonment of agricultural land in the most severe cases, or a permanent reduction in the intensity of agricultural land use as a means of adapting to new conditions (Penning-Rowsell et al., 2013).

3.2 Livestock

A comprehensive assessment of the impacts of climate change on the UK livestock sector has previously been undertaken by Sugden et al (2008). Selected livestock risks were then evaluated as part of the CCRA (2012) and reported by Knox et al (2012). The key elements from these studies are briefly summarised below.

In terms of seasonal changes to land use, given the significant variation in soil types and sward composition on farms, the effects of climate change will vary spatially. Longer growing seasons will result in grass growth starting earlier in the spring and continuing later into the autumn, with potentially higher yields, although these will be dependent on nitrogen use and possibly the need for supplemental irrigation in future dry summers. Higher levels of CO_2 will impact on grass growth rates, development and yield. Earlier and more prolific grass growth will affect both grazing and silage production. The timing of silage cuts is likely to be affected. Changes in rainfall will also affect forage growth and productivity as well as the quality of forage including the balance of species in mixed species swards. Wetter weather could produce poorer quality feed, while higher temperatures could result in spoilage of stored silage. There may also be a reduction in the number of grazing days due to adverse weather (Sugden et al., 2008).

Sward composition is also expected to change in future. Research has shown an increase in grass production with increased temperature and increased CO_2. Swards based on red clover and lucerne showed a greater yield increase over the growing season compared to grass and white clover swards. An increase in the competitive ability of white clover in mixed swards has also been reported (Defra projects CC0359, CC0357, CC0366). Grass growth will be adversely affected by a decrease in summer rainfall. Grass reseeding in autumn could be affected by increased autumn rainfall preventing cultivations (CC0366). One modelling study suggested that eastern and southern areas would lose grass production potential in the summer, particularly on light soils (CC0333) (Sugden et al., 2008).

An increase in heavy rainfall events could result in increased direct damage in terms of flooded crops and pasture, increased risks to livestock and damage to infrastructure. Livestock may have to be moved to other fields or housed indoors with an extra cost of providing feed. Milk yields may also be reduced. Flooding of pastureland can lead to contaminated areas that have to be cleared before grazing livestock could return.

In the CCRA, livestock metric analysis was based on modelling the production system, including the effects of thermal humidity and heat stress on dairy milk production. It is important to note that the losses defined in that study related to the average change in climate and did not include extreme weather events that may result in higher numbers of heat stress losses (e.g., heat wave, drought). Overall, it was reported that current UK climate does not result in losses from dairy system production or pose a major risk to dairy production and this is likely to continue in the near term (2020s). The projections going forward suggest that heat stress related losses only begin to become relevant by the 2050s. For example, for the 2050s central estimate (p50 medium emissions scenario) the percentage loss of national milk production due to heat stress is projected to be about 3 m kg yr^{-1}, less than 0.01% of UK current milk production but there would be costs related to declines in herd fertility. In the longer term (2050s, 2080s) consequences are projected to become more significant under some scenario with more humid and hotter conditions to the extent that they would impact on farmers operating on low margins and regional economies that rely on export of dairy products.

Based on a qualitative assessment, the CCRA (2012) evidence available on the climate risks related to livestock dairying production and heat stress was considered to be strong. The analysis did not however cover other livestock sub-sectors, such as pigs and poultry which could be more severely affected by heat stress.

3.3 Forestry

Most predictions suggest that forest areas are likely to increase in the future in the UK as a whole (Rounsevell et al., 2009). Some of this is likely to be as a result of an increase of productive forests, where there is commercial demand, and unmanaged forestry arising from land abandonment and subsequent development of forest. Whilst some of the reforestation is associated with a change of agricultural land to forest land, reforestation policies and strategies for green infrastructure development are also likely to play a role.

Climate change is predicted to advance the day of budburst, extending the growing season, and increasing biomass production. However, hotter, drier summers and reduced precipitation, particularly in southern England in summer is predicted to cause drought stress in most forests and increase the risk of fires. However, wetter winters are likely to increase waterlogging of soils resulting in fine root die back and therefore impairing drought resistance and tree survival in summer (Broadmeadow and Ray, 2005). Given that future storm events will likely increase in severity, tree damage and loss may also increase. The milder and wetter winter weather may reduce future pest populations less, therefore resulting in greater mortality of trees.

Moffat et al. (2012) modelled forest production changes using the UKCIP02 projects and the Ecological Site Classification (ESC) tool developed by Forest Research, for Forestry Commission land in England, Wales, and Scotland. Variables in the analysis included climate factors such as accumulated temperature, moisture deficit, wind exposure, and site factors such as soil moisture regime and soil nutrient regime. The high emission scenario was used to calculated a Yield Class (YC: m^3 ha^{-1} y^{-1}) for a number of broadleaves and conifers for a baseline (1961-1990) 2050 and 2080 scenarios and to calculated the regional production of the selected tree species in England Scotland and Wales. The area of each species was assumed to not change. The results suggested that the suitability of the current area of Britain as a whole for forestry would decrease for most broadleaf and softwood species, but that there would at a regional level be considerable variation.

In general, the suitability of land in England for the production of ash, beech, penduncculate oak, silver birch, and sycamore decreased in England and to a lesser extent in Wales, but increased in Wales. In England, the greatest decrease in land suitability for broadleaves tended to be in East England, East and West Midlands, South East England, and South West England. Land suitability was less restricted in North East England, North West England and Yorkshire and the Humber. In Wales, land suitability for broadleaves decreased to a much greater extent in South Wales than in North Wales, where some potential increases in land suitability is expected, particularly for Sweet Chestnut, but also for ash and penduncculate oak. In Scotland, a major increase in land suitability for broadleaves was expected, particularly in the Grampian and Central Scotland regions.

A similar pattern was apparent for the softwood species modelled. The suitability of the current land used for softwood production in Britain overall is likely to decline, with land suitability declining particularly in England and to a lesser extent in Wales, particularly for Douglas fir, European larch, Japanese larch, Norway spruce and Scots pine. In Scotland on the other hand, production of these species especially of Corsican pine will improve.

With the exception of Corsican pine, land suitability declines for all species in England, particularly in East England, East and West Midlands, South East England, South West England. Yield reductions were less restricted in North East England, North West England and Yorkshire and the Humber, although land suitability will nevertheless decrease for most softwoods. Land suitability for softwoods decreased to a greater extent in South Wales than in North Wales, where small improvement in land suitability might be expected for Corsican pine, European larch, Norway spruce and Sitka spruce. Within the Britain, the greatest increase in land suitability is expected in Scotland, and as for broadleaves, this is likely particularly in central Scotland and Grampians. Land suitability increases to some degrees in all parts of Scotland for Corsican pine, Lodgepole pine, Norway spruce, and Sitka spruce. But the Grampian and Central Scotland regions will become particularly suitable for Corsican pine, whilst Grampian and Highland will become at least substantially more suitable for Douglas fir, Lodgepole pine, Norway spruce, Scots pine and Sitka spruce.

Table 6 Reported change in productivity for selected broadleaf species under climate change (developed from Moffat et al., 2012).

Country or region	Ash			Beech			Pedunculate oak			Silver birch			Sycamore			Sweet chestnut		
	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080
GB	25,458	-7%	-23%	105,448	-13%	-54%	101,512	6%	-20%	125,982	-11%	-26%	10,929	-16%	-46%	9,275	38%	58%
England	20,433	-12%	-31%	90,439	-16%	-60%	82,544	5%	-27%	43,122	-25%	-66%	8,319	-23%	-56%	9,121	38%	58%
Scotland	1,676	19%	38%	3,372	6%	6%	8,582	9%	26%	70,009	-1%	5%	1,999	9%	1%	-	-	-
Wales	3,460	9%	-10%	12,572	-1%	-36%	11,042	14%	-4%	11,935	-7%	-39%	618	-8%	-50%	198	147%	176%
England																		
East England	1,644	-26%	-38%	5,943	-27%	-59%	4,784	4%	-19%	4,332	-23%	-70%	924	-39%	-69%	417	29%	59%
East Midlands	7,170	-20%	-36%	3,044	-19%	-51%	15,421	9%	-12%	7,568	-26%	-64%	1,412	-34%	-63%	258	38%	76%
North East England	131	5%	-7%	785	9%	-16%	472	16%	15%	1,177	2%	-9%	350	12%	-13%	-	-	-
North West England	869	22%	25%	1,440	-2%	-18%	1,891	12%	11%	4,992	-14%	-25%	388	10%	-10%	48	44%	90%
South East England	4,463	-13%	-40%	49,793	-19%	-69%	36,717	1%	-46%	12,911	-33%	-89%	1,263	-30%	-77%	6,599	36%	50%
South West England	4,235	-8%	-29%	23,723	-13%	-57%	17,289	8%	-21%	4,401	-31%	-78%	1,267	-31%	-72%	1,609	45%	74%
West Midlands	1,555	-6%	-27%	3,971	-13%	-53%	6,110	1%	-21%	4,187	-30%	-66%	517	-30%	-63%	425	43%	62%
Yorkshire and the Humber	1,042	8%	-4%	2,495	4%	-19%	1,612	13%	1%	3,973	-8%	-37%	2,312	-10%	-40%	14	50%	86%
Scotland																		
Central Scotland	124	26%	40%	256	11%	8%	222	21%	29%	1,778	9%	5%	177	18%	16%	-	-	-
Grampian	62	31%	63%	460	20%	27%	181	47%	83%	4,448	5%	0%	103	34%	44%	-	-	-
Highland	178	13%	32%	212	-3%	13%	998	15%	36%	29,901	3%	17%	62	13%	34%	-	-	-
Perth and Argyll	894	21%	39%	1,630	0%	-1%	5,444	4%	22%	30,278	-8%	-2%	857	1%	-10%	-	-	-
South Scotland	367	16%	33%	821	8%	3%	1,954	13%	22%	4,068	3%	-17%	844	9%	-2%	-	-	-
Wales																		
North Wales	534	18%	20%	2,640	4%	-12%	3,870	16%	12%	4,975	-4%	-20%	223	0%	-33%	39	151%	210%
South Wales	2,942	7%	-15%	9,997	-2%	-44%	7,199	13%	-12%	6,964	-9%	-52%	394	-12%	-60%	160	146%	168%

Table 7 Reported change in productivity for selected softwood species under climate change.

Country or region		Corsican pine			Douglas fir			European larch			Japanese larch			Lodgepole pine			Norway spruce			Scots pine			Sitka spruce	
	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080	baseline	2050	2080
GB	450,746	12%	-2%	254,783	0%	-34%	28,977	-13%	-34%	263,302	-5%	-27%	602,803	10%	14%	309,630	-8%	-22%	524,828	6%	-15%	4,783,320	10%	7%
England	412,240	12%	-3%	147,392	-7%	-51%	12,902	-35%	-79%	56,779	-49%	-79%	54,112	11%	0%	111,855	-28%	-62%	179,309	-14%	-66%	734,770	1%	-19%
Scotland	12,150	22%	41%	43,708	12%	14%	14,082	6%	9%	112,923	8%	2%	511,239	11%	19%	118,296	5%	13%	319,207	20%	21%	3,257,748	11%	23%
Wales	28,192	4%	-4%	67,176	7%	-31%	2,012	-11%	-40%	102,001	3%	-41%	34,050	2%	-17%	80,537	4%	-17%	19,842	0%	-43%	801,839	19%	11%
England																								
East England	213,943	7%	-4%	10,400	-14%	-48%	801	-73%	-99%	33	-97%	-100%	503	-12%	-69%	1,149	-83%	-99%	32,269	-24%	-84%	21	-33%	-95%
East Midlands	62,366	17%	4%	1,923	-11%	-46%	653	-58%	-89%	1,232	-36%	-69%	4,736	11%	-13%	6,240	-75%	-98%	23,492	-17%	-69%	3,408	13%	-14%
North East England	2,435	32%	26%	3,494	10%	-13%	515	-5%	-37%	7,933	-25%	-71%	21,897	19%	25%	37,905	15%	6%	15,846	14%	-3%	417,041	3%	-17%
North West England	5,896	22%	13%	3,489	-25%	-29%	1,258	-22%	-8%	8,611	0%	-1%	10,110	9%	8%	8,503	8%	6%	8,163	-2%	-35%	163,100	16%	24%
South East England	62,378	11%	-20%	21,230	-10%	-69%	1,958	-51%	-99%	1,058	-100%	-100%	325	-30%	-100%	15,089	-54%	-100%	37,080	-30%	-99%	560	-65%	-100%
South West England	36,615	14%	-12%	65,758	-3%	-55%	3,905	-33%	-93%	14,553	-67%	-97%	1,995	-9%	-63%	27,295	-40%	-91%	16,116	-18%	-87%	88,978	-12%	-56%
West Midlands	27,073	26%	16%	35,896	-11%	-42%	1,542	-34%	-92%	8,544	-88%	-100%	1,938	-4%	-45%	7,864	-48%	-96%	14,485	-8%	-60%	12,220	-45%	-97%
Yorkshire and the Humber	5,950	25%	17%	6,610	7%	-21%	2,286	0%	-38%	16,328	-46%	-100%	14,452	10%	-10%	6,297	-5%	-51%	30,771	9%	-28%	65,624	-20%	-60%
Scotland																								
Central Scotland	127	54%	78%	309	-5%	-29%	619	11%	-5%	4,635	6%	-18%	10,892	9%	9%	5,405	11%	1%	9,507	8%	-14%	179,022	10%	11%
Grampian	7,218	44%	66%	8,322	25%	33%	3,060	16%	13%	14,665	15%	8%	44,641	30%	41%	16,049	24%	37%	88,253	23%	18%	217,246	8%	14%
Highland	385	2%	25%	10,747	10%	26%	4,020	3%	22%	21,098	10%	7%	300,556	11%	22%	17,118	4%	21%	152,057	22%	29%	491,267	11%	25%
Perth and Argyll	3,160	-7%	7%	11,993	4%	6%	4,762	3%	5%	33,364	5%	1%	85,670	4%	14%	43,822	-8%	5%	54,811	17%	18%	1,246,454	11%	21%
South Scotland	1,175	10%	18%	10,658	13%	2%	1,624	3%	-12%	39,152	8%	2%	66,374	9%	10%	36,624	11%	11%	15,216	9%	-2%	1,144,492	13%	28%
Wales																								
North Wales	11,890	9%	3%	26,475	12%	-7%	905	1%	0%	27,216	2%	-29%	12,649	-1%	-11%	32,055	4%	-6%	7,112	2%	-27%	373,449	14%	5%
South Wales	16,335	0%	-10%	40,799	4%	-47%	1,088	-18%	-66%	75,446	3%	-46%	21,416	4%	-23%	48,567	4%	-24%	12,881	-1%	-56%	428,398	23%	17%

Broadmeadow et al (2009) produced similar results for a range of species in the UK (Figure 3). Whilst land suitability increased for some broadleaved species such as ash, oak and beech could see a potential increase in productivity under a low emission scenario, a high emission scenario was likely to see a reduced benefit to productivity and by implication a contraction of the range of these trees in England. Again, the range of Sitka spruce was likely to reduce throughout England, but increase in productivity in Scotland, Wales and Northern Ireland. However, some species such as Dwarf willow, and Downy birch were also likely to decline in area or disappear altogether.

In broad terms, it appears that northeast Scotland will see the greatest productivity and increase in broad leaved and coniferous forestry, and in both Scotland and Wales, tree lines are also likely to migrate to higher altitudes so long as grazing allows it (Ray, 2008).

Thus whilst there will clearly be challenges for UK forestry, some opportunities are available for the forestry sector. These include productivity increases for some existing commercial species in Scotland and to a smaller extent in Wales, new species of commercial trees, and the relative advantage of major commercial species in relation to other areas of Europe (Read et al., 2009). The extent to which this increase in climate space for forestry in Scotland and Wales translates into an increase in area is dependent on other factors such as the competition for land from agriculture and the effect of pest and diseases or wildfires on productivity (CCRA Scotland).

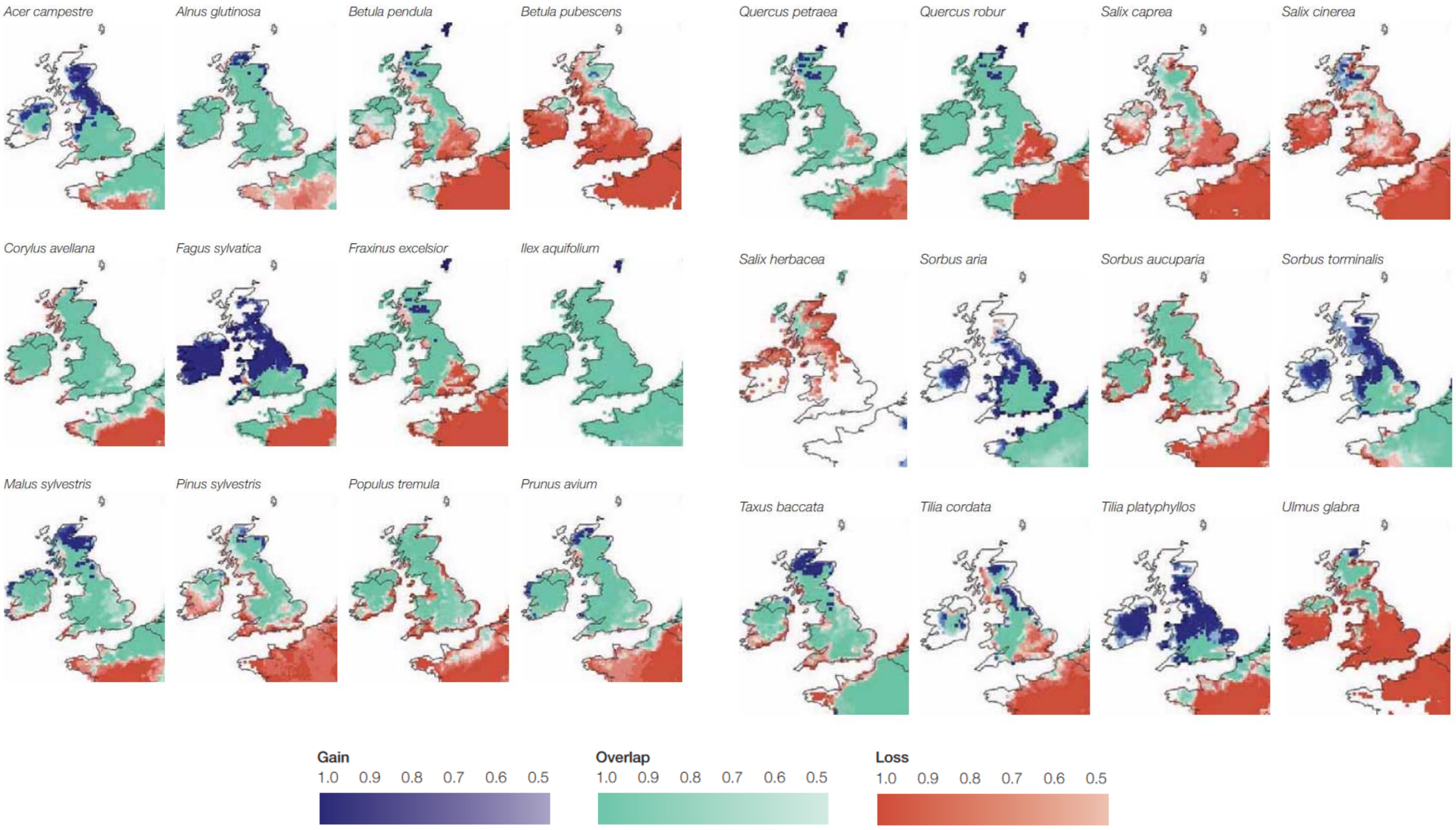


Figure 2 Changes in climate space for 24 tree species (Harrison et al. (2001) as reported in Read et al. (2009)).

3. Implications and adaptation options

4.1 Impact on rural communities

The extent to which rural communities are affected by climate change and the effects of this on changing patterns of land use and land suitability, will be heavily moderated by policy and socio-economic factors and objectives, as well as international patterns of migration and the dietary requirements of new populations. Over a period of time, farmers will need to learn how to cope with evolving agro-climatic conditions, such as increasing heat stress and drought, the increased risks from extreme events, incidence of new pests and diseases, and cultivation of new crops (food and non-food). However, the extent to which changing land use patterns and land suitability, caused by climate change, affects rural communities and employment will depend to a large extent on future agro-economic policies and underlying socio-economic factors.

Irrigated agriculture, field horticulture and, intensive root production systems for example demand more capital and labour and therefore stimulate rural economies. Knox (2010) for example, estimated that irrigated agriculture in South East England supported approximately 50,000 jobs and provided an added benefit of £3 billion to the rural economy. Given that some areas in South East England might see a reduction in these activities in the future, potentially to be replaced by more extensive non-irrigated arable systems, it is likely that the effect of rural employment opportunities will decrease. Conversely, areas which become more suitable for intensive root and crop production and where irrigated agriculture expands, will see a rise in rural employment opportunities. The same will be true in the case of areas experiencing large increases or decrease in forestry and woodland cover.

In low lying flood prone areas, a shift from field horticulture, root, and arable crops to grassland or forestry systems may occur, with similar rural employment effects and requirements for new skills. Morris et al., (2013) for example estimated that the loss of value due to flooding was far greater in field horticulture and root crops than it was for grassland systems.

It is worth noting that some degree of inertia is likely because of the economic effect of existing supply chains and transport links. For example, land use patterns may not change for certain crops, even if land suitability decreases, because of the proximity of processing plants or other points of consumption, such as AD plants using maize or SRC.

4.2 Agricultural water use

Agriculture is a small but nevertheless important user of water. About 1% of national water use is water for irrigation, mostly abstracted directly from rivers and boreholes, and a similar amount is for livestock, mostly supplied through the mains system by the water companies. Predicting the effect of climate change on irrigation water demand is difficult, because the sector is highly sensitive to changes in agro-economic policy, technology and water availability and pricing. After major growth, total water use now appears to be in slow decline due to increasing yields (and hence smaller crop areas). Nevertheless, Weatherhead et al (2015) projected increases in unconstrained demand across four future scenarios ranging for +40% to +167% by the 2050s. However, as they comment, actual increases will be limited to the amount of water made available. Locally, resource constraints may cause the location of irrigated crops to be moved, giving substantial increases in some catchments alongside declines in others.

The water demand for livestock is likely to remain more stable, but will change in response to changes in numbers of animals and their location. Higher temperatures are likely to increase water demand per head, and climate change may lead to more being housed indoors and supplied with dried feeds, requiring additional water (Knox et al., 2015).

4.3 Multiple land use

The land use values given in Table 2 refer to primary land use. In practice, most land has more than one use. The consideration of multi-functional land use is thus a key concept when considering adaptation options under a changing climate.

Increasing multiple land uses can provide an adaptation to climate change (See Figure 4). For example, trees can help moderate temperature extremes and reduce flood flows, as well as providing shade to reduce heat stress in livestock and in other crops.

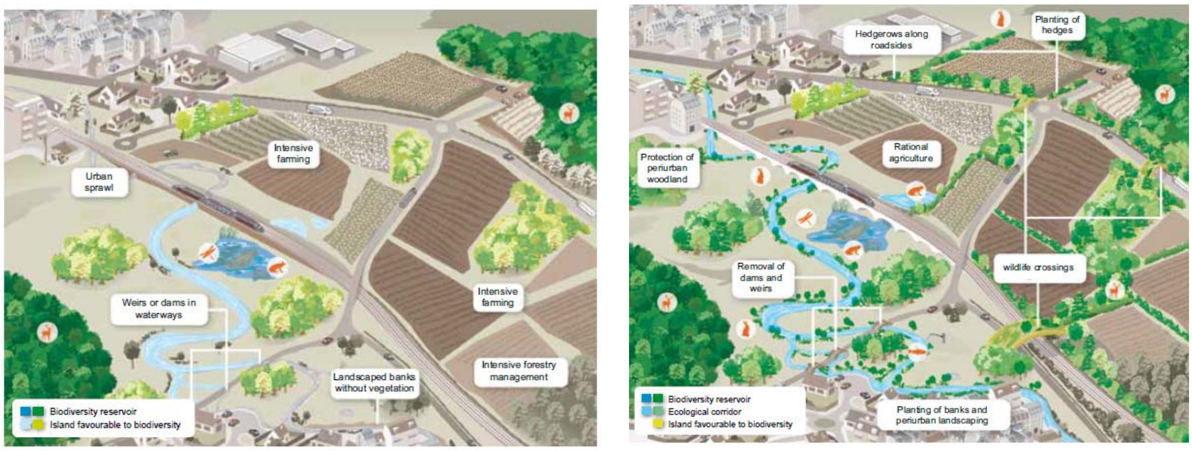


Figure 3 An adaptation to climate change could be to develop more integrated forms of land use (French Ministry of Ecology, Energy, Development and the Sea)
Source:http://www.developpement-durable.gouv.fr/IMG/pdf/plaquette_tvb_english-june2010.pdf

An example of how land may become more multi-functional to help manage the effects of future climate change in respect of climate change, flooding, and rural land management. Climate change is predicted to result in wetter warmer winters and a greater incidence and severity of flooding. This has led to calls for more sustainable approaches to flood risk management (FRM) that use natural processes to complement other interventions such as engineered flood defences (Environment Agency, 2010; Scottish Government, 2011; Defra, 2011). Although the largest share of economic flooding costs is borne by urban communities, agriculture and other forms of rural land management occupy a large proportion of the landscape and have an important role to play in flood mitigation and adaptation (Morris et al., 2010).

Rural land management can help mitigate flooding associated with climate change in three main ways. It can help to: (i) to slow down and retain water in the landscape by changes in land use or land management and measures such as retention ponds and field boundary features (O'Connell, et al., 2004; Posthumus et al., 2008), (ii) facilitate the conveyance and storage of flood waters in the floodplain during extreme events (Morris et al., 2004; Posthumus et al., 2010, Environment Agency, 2010) and (iii) buffer the effects of storm and tidal surges and sea level rise in coastal areas (Nicholls et al., 2007).

In coastal areas, realignment of sea defences and restoration of a salt marshes can reduce coastal erosion or flood risk elsewhere (Luisetti et al., 2011). With respect to inland flooding, different types of land-based interventions have different outcomes for managing flood risk (Figure 5). Changes in land use and management that retain/slow down water in the general landscape can help reduce flooding at the local scale and for relatively frequent high rainfall and flood events (O'Connell et al., 2004; Hess et al., 2010), especially controlling localised 'flash' and 'muddy' floods (Boardman et al., 2003). By comparison, floodplain storage is more effective for the control of large scale, large volume, extreme flood events that are associated with widespread urban flooding and greatest damage (Frances et al., 2008).

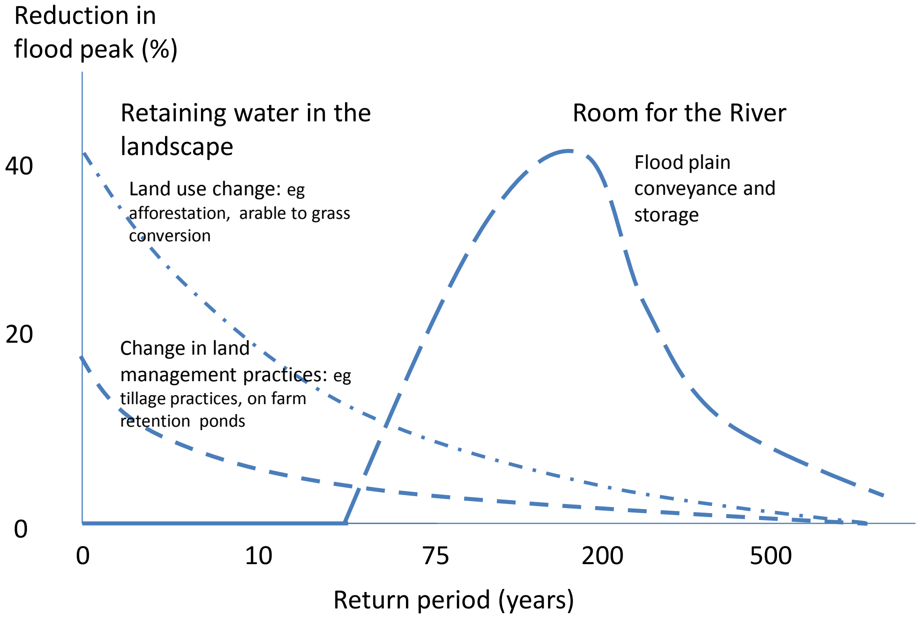


Figure 4 The effectiveness of land management interventions to control flood risk under climate change are likely to vary according to the frequency and severity of flood events. (after Frances et al., 2008).

Wetter warmer winters are likely to increase the role of water retention in the general landscape. The greater frequency of extreme rainfall events is likely to increase the need for flood plain storage, involving a restoration of the natural functions of flood plains, albeit with a greater degree of hydraulic control. At the same time, there will be scope to integrate measures to manage flood risks alongside other objectives such as nature conservation (Posthumus et al., 2010; Rouquette et al., 2011).

An international review of rural land management for flood risk management (Morris et al, 2014) shows that a range of policy types have been used, including regulatory (zoning and compliance), economic (land purchase/exchange, easements, compensation, annual and capital payments, insurance), voluntary (options for ecological restoration) and other methods (such as warning and preparedness systems). Different mechanisms each have different strengths and weaknesses when judged against criteria for policy choice, such as the balance of control given to FRM or land managers, the type of FRM problem, the type of land management intervention, the relative importance of FRM alongside other land management outcomes, and the source of funding. Although natural flood risk management has potential to mitigate the effects of climate change, it seems likely that rural land-based approaches to FRM, especially in the general landscape, will be funded and rewarded alongside other benefits such as the protection of soil and water resources and biodiversity, requiring pooled collaborative action amongst potential beneficiary organisations.

4.4 Adaptation in agriculture and forestry

A key implication for rural development given that food production needs to continue is the means by which adaptation to climate change might be achieved. Adaptation strategies can be broadly broken down by a number of characteristics (Smit and Skinner, 2002). These include: intent and purposefulness (i.e., spontaneous or autonomous actions); timing (responses that are proactive, concurrent or responsive); duration (tactical or short-term vs strategic or longer-term); scale (i.e., plot, field, farm, regional) and responsibility (farmer, neighbouring farmers, agri-business, or government); form (administrative, financial, institutional, legal, managerial, organizational, political, practical, structural, and technological characteristics). Future rural land use within the UK will change as a spatially-variable consequence of the effects of climate change and agricultural/forestry developments on crop and timber productivity (annual averages and variability) in conjunction with the socioeconomic drivers affecting food and timber demand (at regional to global scales) and production costs. Land use at farm to landscape scale is likely to change most where crops or tree species lose or gain relative profitability.

4.4.1 Crops

Agricultural land use patterns have developed largely in relation to climatic conditions and on a global scale will continue to be dependent on future climatic change (Smit and Skinner, 2002) and food demand. Since crops are an annual enterprise, decisions taken regarding cropping plans are to some extent incremental, allowing for greater flexibility in adapting to climate change. However, farms need to have the right equipment, crop processing and storage facilities and markets for a mix of arable crops. This was highlighted recently in England when farmers could not refill their reservoirs but had difficulty suddenly changing crop rotations.

Modern technology such as irrigation, pesticides, fertilizers, crop and animal breeding, has allowed farmers to continue producing in more climatically difficult conditions (Lotze-Campen and Schellnhuber, 2009). Increasing specialisation may however make farms vulnerable to sustained change and some farmers may be resistant to change that may be needed for adaptation (Burton and Lim, 2005). However, agriculture in the UK is expected to maintain or even increase food production (Reidsma et al., 2009). Adaptation is already occurring for example through enhanced drought resistance in crops (Parry et al., 2005).

UK agriculture is a particularly diverse industry, incorporating international agri-businesses and family farms and ranging from outdoor crop cultivation to indoor livestock rearing. The ability to adapt to a changing climate will vary accordingly across the sector. Many horticultural businesses, for example, are highly innovative and can adapt quickly, while some sub-sectors are less able to adapt or may be able to adapt to some changes but not to others. It is important that businesses are aware of the risks from climate change in order to adapt. Seizing the opportunities and minimising the climate risks will require investment in new technologies and better management techniques (CCRA, 2012). Selected adaptation options across in the agricultural sector include (i) improved water management (e.g. water harvesting, farm storage reservoirs to store excess winter water) coupled with precision irrigation technologies to improve water efficiency during dry summer spells, (ii) changes in grassland species composition (e.g. with deep-rooting or drought-tolerant species), (iii) changes in livestock production cycles (e.g. introduction of autumn lambing and calving), and (iv) planting of trees to provide shade for livestock and windbreaks for crops.

It may be possible to increase production under climate change if farmers can exploit longer growing seasons through the use of longer duration varieties or sequential planting. Such production opportunities may decline as climate change becomes more extreme, requiring adaptation to more prolonged and frequent droughts, changes in rainfall distribution, more storms and other extreme weather events, increased and changing pest loads and changes in soil water balances (Sugden *et al*., 2008). A selection of the most feasible adaptation measures for UK farming includes:

- Changing sowing and harvest dates to cope with (benefit from) warmer springs and higher temperatures, for example, earlier sowing and later harvest to compensate for drought related losses on light soils (Richter et al., 2006);
- Improvements in seed and crop storage to deal with changes in moisture and temperature;

- Switching from spring to winter cereal production;
- Plant breeding for increased drought and flood tolerance and pest resistance;
- Building high flow/winter storage reservoirs to cope with reduced availability and reliability of summer river flows;
- Investments in new technologies to improve water and energy efficiency;
- Soil index mapping and precision farming to apply variable N, P and K to fields to reduce diffuse pollution;
- Diversification of land holdings, to extend crop rotations and towards more geographically spread cropping schedules;
- Upgrading drainage systems to cope with higher rainfall intensities;
- Adopting rainwater harvesting, water recycling and organic and artificial mulching to reduce water use;
- Changes to crop scheduling programmes with multiple cropping (e.g. of salads) to utilise extended growing seasons;
- Developing international links in the food supply chain – many agribusinesses now have a European presence to provide greater flexibility and extended season for food supply, and;
- Individual and collaborative actions working locally to protect natural resources (Leathes et al., 2008).

Small businesses and family farms with limited capacity to adapt will be most vulnerable. Conversely, large horticultural agribusinesses, with high investment capital at stake, may select risk-averse options that minimise the 'regret' under a range of possible future outcomes (e.g. high flow storage reservoirs). Whilst such investments may be marginally beneficial now, they become more attractive if the value of longer term resilience and security is taken into account. Some crop sectors, such salad and soft fruit production, may be more vulnerable since they are highly seasonal, and dependant on consumer demands and the weather. Other crops such as potatoes and field vegetables may be less vulnerable as their consumption patterns are less sensitive to the ambient weather. Given the uncertainty and long-time-scales, most responses to climate change will require combinations of adaptive management and technology. Developing this adaptive capacity will involve a commitment of resources now, both by the private and public sectors, in order to enhance future ability to cope with the uncertain impacts of future climate change. But for all these coping strategies there are both barriers and enablers to adaptation, as highlighted below.

Adaptation barriers:

- Uncertainty in climate change projections, particularly at regional and local levels;
- Uncertainty about the impacts of climate change elsewhere on crop prices and marketing options;
- Very high degree of short to medium term uncertainty in agricultural policy and markets, including speculative agricultural commodity trading;
- Negative impacts of adaptation in other sectors – for example, the implementation of adaptation measures to address the increased risks to urban areas from river flooding using agricultural floodplain land for attenuation could impact on crop productivity and land value;
- Land use restrictions e.g. due to EU regulations and/or agri-environmental support schemes could hamper crop diversification;

- Inflexibility in the abstraction licensing regime may limit the potential for water trading and allocation of water to high value cropping;
- Poor availability of finance and investment in research and technology development;
- Restrictions from Planning Regulations and development control;
- Attempts to preserve 'existing' environments (which may be impossible);
- The negative impact of energy policies on food production, and;
- Risk of overseas food suppliers failing due to extreme events, e.g. food imports from southern Europe at risk – increased vulnerability of overseas suppliers.

Adaptation enablers:

- Mechanisms and initiatives to promote improved resource efficiency. The converse of above, including supporting education and knowledge transfer, investments, incentives, property rights, building capacity in the agriculture sector and governance systems;
- Collaborative funding of science and technology to enhance adaptability to climate change;
- Addressing market, institutional and regulatory failure, for example by payments for environmental services and conservation of natural resources;
- Water user associations providing opportunities for collective action in natural resource management;
- Tax breaks, for example capital allowance schemes, to invest in adaptation measures, and;
- Legislative enablers, such as the Flood and Water Bill which aims to help promote adaptation by providing more flexible regulation for abstraction licensing.

However, training will also be needed to encourage uptake of adaptation measures, while a lack of finance may act as a barrier to investment in such measures. Volatility in markets will add to that uncertainty. Adding to the challenge of adaptation is that considerable uncertainty surrounds (i) the way different climate impacts on this sector may interact with each other and (ii) the socio-economic changes that will have a major influence on the evolution of UK agriculture.

4.4.2 Forestry

Forestry is a more strategic industry than agriculture given typical rotation lengths of trees, and trees planted now need to be suited to climates over the next 50 - 100 years. Millar et al (2007) summarised adaptation strategies in forestry using three broad categories. These included: 1) resistance options, designed to maintain growth in the face of environmental stress, and included for example, prevention of fires and pathogen outbreaks, control of loss to deer or squirrels. However, it is normally only a short-term panacea; 2) resilience options to enhance recovery after disturbance, for example increased forest tree diversity or woodland connectivity, and; 3) response options allowing transition from one forest structure to another under different climate conditions. This option accepts that change will happen so encourages foresters to assist natural processes, such as seed dispersal, disturbance regimes etc. by change in management (e.g., rotation times, replanting, new species).

4. Conclusions

Internationally, agriculture is widely regarded as one of the sectors at most risk from a changing climate, due to the impact of increased temperatures, reduced rainfall and increased frequency of extreme events, not only in the tropics, but also in temperate environments. In the UK farming businesses also face a range of 'non-climate' risks which it is often argued present a potentially greater and more immediate threat to sustainable food production than climate change.

This paper highlights some of the key climate and non-climate impacts and risks to UK agriculture, forestry and livestock, the adaptation options, and the institutional and regulatory barriers to their uptake by farmers. It concludes that there are likely to be both positive (e.g. yield gains) and negative (e.g. increased water stress) impacts that will vary spatially across the UK and between farming and forestry systems. Both will require new investments in adaptive management and technology, including new collaborations between the public and private sectors, to enable UK agriculture to respond to the potential effects of climate change.

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6. Appendices

Appendix A

Table A.1. Summary of the confidence associated with some of the findings, in terms of the level of agreement in the literature and the amount of evidence in the literature.

	Level of agreement	Amount of evidence	Overall confidence
Agricultural land will increase in Scotland, Wales, and Northern Ireland, and decrease in England.	High	Medium	Medium
Elevated CO_2 levels should result in increased crop productivity.	Medium	High	Medium
Climate change will have major impacts on agricultural land grades with increased droughtiness changing the relative proportions of both high and low land grades.	Medium	Medium	Medium
Climate change will influence crop mix and balance of rotations.	Medium	Low	Low
Increased dependence on supplemental irrigation is expected particularly where high-value crops are grown on less well-suited soils	Medium	Medium	Medium
Flooding in coastal areas and around rivers will reduce the amount of land suitable for agriculture in low lying areas.	High	Medium	Medium
Technology, policies and socio-economic factors will affect future agricultural land use patterns to a far greater degree than climate change	High	High	High
Elevated CO_2 levels should increase tree productivity.	High	Medium	Medium
Actual tree productivity will depend on the tradeoff between elevated CO2 levels and changing patterns of droughtiness of land, pests, diseases, and wildfires.	Medium	Medium	Medium
Tree productivity is likely to increase in Scotland, Wales and Northern Ireland, and decrease in England.	Medium	Medium	Medium
The greatest increase in the productive range of forestry appears to be in Scotland.	Medium	Medium	Medium
Competition for land for other land uses, such as agriculture, and to meet carbon reduction policies particularly in peat soils, or for rural development policies will also affect the total area of forestry.	High	Medium	Medium
The multifunctional importance of agricultural and forestry could become more important in the future.	Low	Low	Low

Appendix B

The UK Climate Change Projections briefing report (Jenkins et al., 2010) states that temperatures have increased by about 1^{o}C since the 1970s and that sea levels have risen by about 1mm yr^{-1} in the 20 century. Looking forwards, the UK Climate Change Projections (UKCP09[1]) provides a range of projections for the UK. These are probabilistic and based on low, medium, and high emissions scenarios.

Broadly speaking, by the 2080s and relative to a 1961-1990 baseline, these projections anticipate hotter drier summers and warmer wetter winters. Under a medium emissions scenario, the central estimate (50% probability) anticipates that temperatures rise across the UK , but more so in summer than in winter. Summer mean temperatures rise the least in the Scottish islands (by 2.5^{o}C) and most in southern England (by 4.2^{o}C). These changes are projected to be accompanied by increases in mean daily maximum temperatures in summer

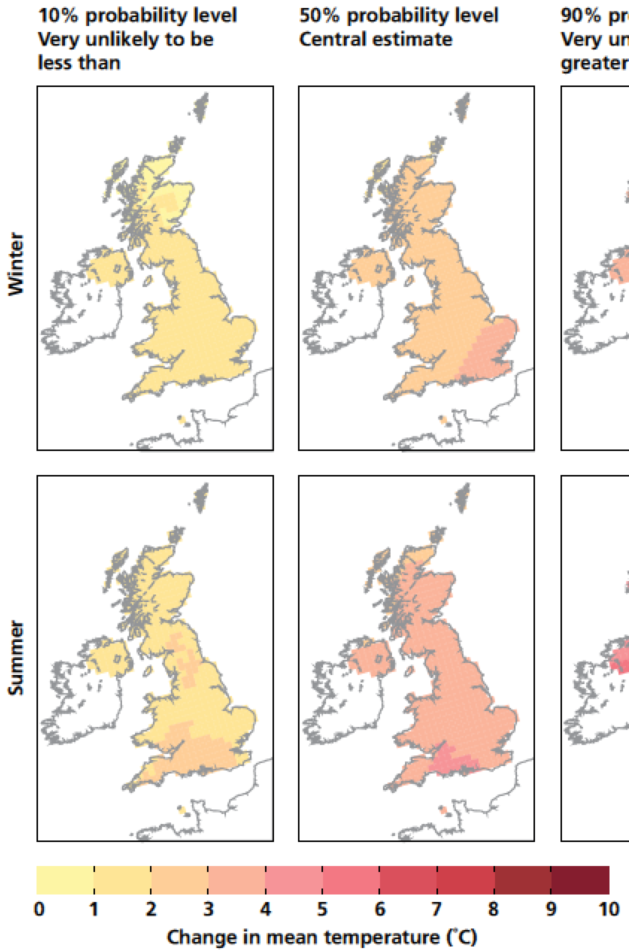
[1] UKCP09: http://ukclimateprojections.defra.gov.uk/

(2.8 – 5.4^{o}C for the 10% to 90% probabilities) and winter (1.5 – 2.5^{o}C) and mean daily minimum temperatures in summer (2.7 – 4.1^{o}C) and winter (2.1 – 3.5^{o}C) (Figure 1).

Whilst annual precipitation in the central estimate shows little change, greater intra-annual variation is expected, with summers tending to become drier and winters wetter. For example, large reductions in mean summer precipitation by as much as 40% are expected in parts of southern England, although in parts of northern Scotland, little change is expected. Winter precipitation is expected to increase marginally over the Scottish highlands, but substantially over the western part of the UK. Sea level rises are expected to be between 12 and 76 cm and because land is subsiding relatively more quickly in southern UK the effect of this rise is expected to be greater in the south than the north.

However, the degree of uncertainty should also be noted; some of the probabilistic projections show changes in the opposite direction and/or very different regional patterns of change

In addition to such trends, many experts believe that more extreme weather events can be expected, given that the warmer atmosphere will contain more energy. Whilst it is difficult to link specific extreme events to climate change, the Adaptation Sub-Committee (ASC) suggests that the increasing pattern of extreme events does appear to be linked to climate change and is likely to become “more normal” in the future (ASC, 2013).


10% probability level
Very unlikely to be
less than
50% probability level
Central estimate
90% probability level
Very unlikely to be
greater than
Winter
Summer
0 1 2 3 4 5 6 7 8 9 10
Change in mean temperature (°C)

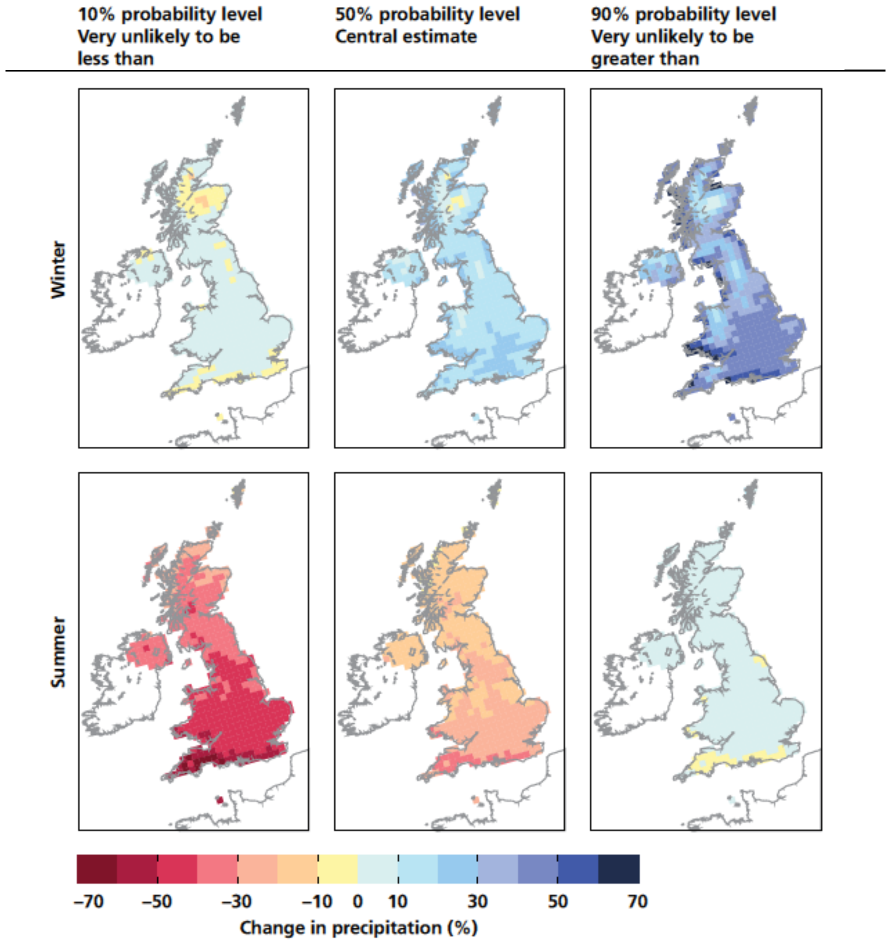

10% probability level
Very unlikely to be
less than
50% probability level
Central estimate
90% probability level
Very unlikely to be
greater than
Winter
Summer
−70 −50 −30 −10 0 10 30 50 70
Change in precipitation (%)

Figure 5 UK climate change projections for 2080 (relative to 1961-1990 baseline) for mean annual temperature and mean precipitation under 10, 50, and 90% probability levels for the medium emissions scenario (Jenkins et al., 2010).

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