



Agriculture and Forestry Climate Change Impacts

Report Card 2016

This publication gives an overview of how climate change is affecting agriculture and forestry in the UK, and how it might affect these two types of land use in future. It summarises the major changes that have occurred in these sectors in recent decades, including some that can be attributed to climate change ('What has happened?'), and also outlines the possible effects of future climate change ('What could happen in future?').

The card focuses on both threats and opportunities relevant to crop, livestock, wood and other production in the agriculture and forestry sectors. The aim is to improve understanding of the scale of possible change and to help inform decisions on adaptation. This publication will be useful to a wide range of people involved in agriculture, horticulture and forestry, including landowners and land managers, farmers and growers, technical consultants, processors, policymakers and those involved in land-use planning and management in the UK.

This is one of a series of Report Cards published by the former Living With Environmental Change (LWEC)¹ Network that describe the impact of climate change on different aspects of landscape and society in the UK.

Produced by a panel of experts drawn from academia and consultancy, and across the UK's agriculture and forestry sectors, the card is based on a set of nine peer-reviewed Technical Papers. Together, these papers summarise the best available science from the academic literature. All are available from the RIDE webpages.

The report card covers the following topics:

- Key climate changes
- Soil function
- Arable agriculture
- Horticulture
- Livestock production
- Forestry
- Land use systems and ecosystem services

¹ LWEC was succeeded in 2016 by the Research and Innovation for our Dynamic Environment (RIDE) Forum.

Headline messages

- Changes in the UK's climate will, in the long term, have significant positive and negative impacts on agricultural and forestry production. For agriculture, however, in the short term it is likely that technology and socio-economic factors will continue to be more influential drivers of change. In contrast, the changing climate will be particularly important for forestry due to this sector's long production cycle.
- The impacts of climate change on production will vary across the UK. For example, warmer, drier summer conditions may have a more negative impact on production in the south and east than in wetter areas in the north and west. Production in cool, wet upland areas may benefit from warmer and drier conditions, while production in lowland areas may fall.
- The impacts of climate change will also change over time, particularly as the benefits of warmer temperatures and longer growing seasons become outweighed by reductions in water availability.
- Warmer temperatures will increase the length of growing seasons and may increase production of crops such as sugar beet and leafy vegetables. Crops such as autumn-sown cereals, however, may yield less than their potential if they mature earlier. Heat stress in livestock, particularly dairy cows, may increase reducing productivity. Forest productivity will increase slightly if other factors, particularly water availability, are not limiting.
- The increasing concentration of carbon dioxide (CO₂) in the atmosphere will continue to increase plant growth generally, although the amount will vary depending on other environmental variables, such as temperature and water availability.
- Changing rainfall patterns, increased evaporative demand and reduced availability of water for irrigation all threaten agricultural production, particularly in areas where water supplies are already under pressure. Drier soil conditions will reduce growth of crops, pasture and trees. Damaging periods of summer drought are likely to become more frequent, especially in the south. Extended or repeated periods of drought may cause tree deaths, especially of young trees.
- Increased flooding, including that caused by sea-level rise, may lead to substantial losses in crop production in low-lying agricultural areas and may contribute to compaction, waterlogging and erosion of soil. Wetter autumns and winters will threaten agricultural production by adversely affecting the timing of land-management operations.
- The threats to agricultural and forestry production posed by pests and diseases will increase as a result of extension of the geographical areas in which they are found, as well as the spread of newly introduced species and an overall rise in how abundant they are. For trees, greater frequency of drought, heat stress and waterlogging is likely to increase damage and deaths resulting from attacks by pests and diseases.
- Climate change will affect the range and quality of the ecosystem services that agriculture and forestry not only provide, but also rely on. These include climate control, flood regulation, biodiversity, pollination and nutrient cycling.
- The agriculture and forestry sectors have already adapted to change by introducing new genotypes, varieties, breeds and management practices. As the climate changes, there will be a need for more anticipatory adaptation measures.
- Agriculture and forestry are components of larger biophysical, social and economic systems which will all be reacting and adapting to climate change in different ways, resulting in complex global changes whose impacts at local level are not easy to predict.

Why was the Agriculture and Forestry Report Card developed?

Agriculture and forestry are two of the main types of land use in the UK. Representing 71%¹ & 13%² of UK land area, respectively, these sectors produce food, fibre and fuel, with UK agriculture currently providing around 50% of the food consumed in this country.

Both activities contribute to economic activity, jobs in the rural sector, and the wellbeing of society. Respectively, they generate Gross Value Added of £9.9 billion and £0.5 billion (excluding processing activities) and provide direct employment for 476,000 and 14,000 people³. Both activities also meet or influence other important needs and functions including: provision of clean water and habitats for wildlife; regulation of climate and of water flows; and places for recreation. Any factors that impact agriculture and forestry will therefore inevitably affect the wellbeing of human populations, now and in the future.

Climate-related impacts may occur through gradual change or as a result of more rapid changes triggered by extreme weather events. So far, however, it has been difficult to disentangle the impacts of climate change on UK agriculture and forestry from the many other changes that these sectors have experienced due to technological and socio-economic factors, some of which may have included responses to changing climate conditions. This situation contrasts with the assessment of UK biodiversity, where there is

good evidence for many changes in semi-natural habitats that can be attributed to climate change (see <http://www.nerc.ac.uk/research/partnerships/lwec/products/report-cards/biodiversity/>).

This card focuses on the potential positive and negative effects of the changing UK climate on agriculture and forestry *productivity* (i.e. outputs per unit of land area) rather than on *total production* (i.e. outputs at the national level). This is because of the uncertainty that exists over many other interacting influences, such as commodity prices, tax and incentive regimes, regulatory frameworks, supply chains and changing consumer demand, as well as the response of the agriculture and forestry sectors themselves. The impact of climate change on some of these factors will be considered in the forthcoming Business Report Card. In addition, climate change elsewhere in the world will influence UK production by changing global patterns of food, fibre, feed and fuel production, altering consumption patterns and global demand, and consequently affecting prices. These influences are particularly hard to forecast and add considerable uncertainty to future predictions.

We have attempted to assess the level of scientific confidence attached to individual statements included in this Report Card by using a simple classification: ■ **H** high confidence; ■ **M** medium confidence; ■ **L** low confidence. For more details on this classification, see p.20.

Climate change in the UK

The UK climate is already changing. Moreover, it is extremely likely⁴ that the changes observed over the past few decades are part of global climate change, much of which can be attributed to human activity (e.g. the release of greenhouse gases from fossil fuel consumption stations and changes in the way that land is used).

What has happened

- **Concentrations of greenhouse gases in the Earth's atmosphere have increased.**

CO₂ concentration has increased 43% from an annual average of 280 parts per million (ppm) in the pre-industrial period to just over 400 ppm. Concentrations of methane and nitrous oxide (two other potent greenhouse gases emitted by agriculture and forestry) have increased by 154% and 21%, respectively.

- **Average temperatures in the UK have increased by 0.8-1°C since the 1980s.** All of the top ten warmest years on record (i.e. in the period since 1910) have occurred since 1990. These include 2014, the warmest year on record in the UK⁵. Average annual growing degree days⁶ in the period 2005-2014 were 16% higher than in the period 1961-1990. Over the recent period 2006-2015, the growing season⁷ has, on average, been 29 days longer than in 1961-1990.

- **Rainfall totals have varied from year to year.**

In the past few decades there has been some increase in annual average rainfall over the UK, particularly over Scotland⁸. The trend over the longer term is less clear, based on records of rainfall over England and Wales since 1766⁹.

- **UK seasonal rainfall is highly variable, but over the last century or so winter rainfall appears to have increased.** During the same period, summer rainfall has decreased but the trend is less clear and recently there have been some wet summers. Over the past 50 years, heavy rainfall events (i.e. a larger volume of rain released in a fixed short period) have made an increasing contribution to winter rainfall.

- **Sea level around the UK rose on average by 1-2 mm/year in the 20th century and the rate increased to over 3 mm/year during the past decade.** Peak sea levels during storms appear to be rising at a similar rate.

- **Severe windstorms have become more frequent in the last few decades.** It is not clear, however, whether or not this is part of a long-term trend¹⁰.

- **Frequency and magnitude of flooding associated with high river flows in winter has increased over the last 30 years, particularly in the west and north.** Sea-level rise has already affected UK estuaries, increasing the impact of storm surges.

- **In 2005-2014 there were 15% fewer days of air frost and 12% fewer days of ground frost compared to 1961-1990⁵.** With the notable exceptions of 2010 and 2013, widespread and substantial deep-snow events have been relatively rare in recent decades.

- **Peak ground level concentrations of ozone – an atmospheric pollutant that can affect some sensitive crops and trees – have declined by about 30% in recent decades.** Background ozone levels in the Northern Hemisphere, however, have been steadily increasing by approximately 0.2 parts per billion per year.

What could happen

- **CO₂:** Average atmospheric concentration will continue to increase, but the rate of increase and the maximum concentration will depend substantially on global measures to reduce CO₂ emissions. By 2050, CO₂ concentration could range from a low emissions scenario of 440 ppm to a high emissions scenario of 540 ppm. By 2080, CO₂ concentration is predicted to be between 430 and 760 ppm¹¹.
- **Temperature:** All UK regions are expected to warm – more in summer than in winter (i.e. up to 4°C in summer in the south and up to 2.5°C in the north by the 2080s). The growing season will become longer.
- **Rainfall:** Climate models indicate little change in overall average UK rainfall in the 21st century, but significant seasonal and regional variations. In future decades there may be lower summer rainfall, particularly in southern and central England. In conjunction with warmer average temperatures, this is likely to increase the risk of short-term droughts. However, summer rainstorms may be heavier when they do occur. Alongside a trend towards higher winter rainfall, this may make flooding more likely.
- **Sea level:** This will continue to rise around the UK, probably at a faster rate than observed in the last century, and lead to higher peak sea levels during storms.
- **Humidity:** Relative humidity may decrease by up to 5-10% in summer, with the greatest reductions likely in southern England and smaller reductions further north. The potential trend in winter is less clear, with changes across the UK of a few percent more or a few percent less.
- **Solar radiation:** Future cloud cover is likely to decrease overall during summer, leading to an increase in solar radiation and with the largest increase expected in southern England. For winter, the trend in future cloud cover is less certain and solar radiation could increase or decrease by a few percent across the UK.
- **Wind:** Changes to atmospheric circulation may lead to a northwards or southwards shift in storm tracks (i.e. severe winds associated with low-pressure systems). There is some evidence that while wind speeds will change little up to the 2050s¹², the North Atlantic region could become calmer by 2100¹³.
- **Flooding:** While there are uncertainties in predicting rainfall and predicting rainfall and the amount of moisture transferred from the earth and vegetation to the atmosphere by the process of evapotranspiration, the risk of river flooding is expected to increase through the 21st century. Coastal flooding is also expected to increase due to sea-level rise. However, the scale of these increases is unclear and the impact will depend on the extent of changes to flood defences.

- **Snow and frost:** The number of air frosts is expected to decline substantially across the UK, except where they are already close to zero (e.g. near coasts)¹⁴. Significant future reductions in the number of snow days, mean snowfall rates and the intensity of heavy snowfall events are projected for the end of the 21st century, consistent with the projections of warming temperatures¹⁵.
- **Ozone:** During spring and summer, critical concentrations are already widely exceeded in much of the UK and climate change is likely to exacerbate the impact of ozone in future.



Key impacts across agriculture and forestry

Agriculture and forestry involve the management of plants, animals and soils – activities that are all affected by weather and climate, either directly or indirectly. For example, temperature directly affects the rate of growth and development of many plants; but it may also indirectly affect soil processes such as nutrient cycling or the frequency and severity of attacks by pests and pathogens, which in turn impact on plant or animal productivity. These effects may occur through gradual change (e.g. slow changes in temperature leading to more suitable or less suitable conditions for crops) or they may be manifested as more rapid changes triggered by particular extreme weather events (e.g. a prolonged drought causing plant death or a heat wave causing heat stress in animals).

Key climate changes that may have impacts for many or all production activities are discussed below. Specific aspects are then covered in the subsequent sections. It should be noted, however, that predicting future agricultural and forestry productivity is difficult because the influences of the various factors outlined here are likely to interact with each other (e.g. warmer temperatures are associated with drier conditions).

Increase in CO₂ concentration

Increasing concentration of CO₂ in the atmosphere will, in general, boost plant productivity ■M. This response declines, however, at higher concentrations and also very much depends on other factors, particularly temperature, plant species and availability of water and nutrients ■H. The 43% increase in atmospheric

CO₂ concentration since the pre-industrial period may have made a small contribution to the large increases in crop productivity that have occurred over this period driven by other changes in agriculture. ■L

Water use by plants decreases when they grow in higher CO₂ concentrations ■H and this may partly offset reductions in productivity caused by drier conditions ■H. There are also qualitative effects on plants, such as altering their chemical composition (typically reduced nitrogen and higher soluble-carbohydrate concentrations) and therefore their nutritional quality ■H. These effects vary between species and depend on growing conditions.

Increased average temperatures

Over recent decades, warmer average temperatures have advanced the onset of spring and delayed winter, resulting in longer growing seasons ■H. This has probably resulted in higher productivity of pasture, root crops (e.g. sugar beet), leafy vegetables and some fruit crops, although the evidence is limited ■L. For other crops, including many cereal varieties whose development is not strongly affected by day length, warmer temperatures may hasten maturity, reducing the duration of the crop and consequently yields ■H. Warmer average temperatures will also be accompanied by more frequent heat waves, which will affect both crop yield and quality ■H as well as dairy cow and other livestock productivity ■M.

Increases in temperature have already led to the northward shift of crops such as forage maize and the more widespread uptake of crops previously grown only in warmer climates (e.g. grapevines and apricots) ■H; this trend is likely to continue. For agriculture, this may happen rapidly ■M, but for forestry the change of tree species or genotypes will be slower due to the longer forest growth cycle ■M. In urban greenspace, where temperatures are already warmer, changes in the tree species used may need to be introduced more quickly. Increased temperatures will also increase the altitude limits for the growth of different crop and tree species ■H.

Water

The availability of water is key to plant productivity. The warmer, drier summers predicted as a result of climate change will reduce crop and pasture growth in many parts of the UK and so reduce yields and livestock productivity ■H. Although plants can recover from short periods of water shortage that reduce crop canopy expansion during their vegetative stage and therefore cut CO₂ uptake, prolonged periods of drought can have a permanent impact, particularly if they occur at specific stages of crop development ■H. The frequency and intensity of such droughts are likely to increase ■L. Demand for irrigation will also increase, particularly for high-value horticultural crops and potatoes ■H, which may lead to changes in where they are grown in the UK.

The projected increase in winter rainfall may also have negative impacts. Increased loss of topsoil and nutrients due to erosion is likely to occur as a result of more frequent, more intense rainfall events ■M. Waterlogging of soils can affect

tree, crop and pasture growth by restricting the flow of oxygen to the roots and therefore root function (e.g. nutrient uptake). Excess water can also increase soil compaction and restrict machinery operations and livestock movements, as well as exacerbating certain diseases ■M. Flooding submerges crops and pasture, preventing growth and development as well as physically damaging the plants and soil ■M. There may, however, be opportunities for storing excess winter rainfall for use in irrigation during the summer.

Pests, diseases and weeds

The severity of many plant disease epidemics is often driven by temperature, rainfall and soil moisture as these influence the production and release of spores ■H. Night temperatures and humidity levels are often critical in terms of providing wet conditions that enable completion of the life cycles of many pathogens ■H.

The key drivers for the increased occurrence of pests and diseases will be warmer temperatures, particularly milder winters and

warmer summers ■H. For some types of insect pest, warmer conditions have already led to more overwintering, earlier development in spring and more generations per growing season ■M. Warmer conditions have also caused the spread of some pests and diseases from further south ■H. These trends are likely to continue, although extreme high temperatures may limit some pest populations ■L. While periods of drought may reduce pests such as slugs ■H, these will benefit from milder, wetter winters ■H.

Livestock productivity may be affected by increased threats from pests and diseases, including those affecting forage both before harvest and in storage ■L.

Increases in CO₂ concentration, temperature increases and water availability will all probably affect weed growth similarly to the way they impact on crops ■M. However, if temperature thresholds for growth differ between crops and weeds, or they have different life-cycle timings, competition may be altered ■L. Weeds tend to have high genetic diversity within and between

populations and this may enable some species to adapt readily to changing conditions ■L. Changes in cropping patterns and management patterns may change weed diversity ■L.

Control measures will also be affected by climate change. Weather influences the effectiveness of some pesticides ■M and the natural enemies of pests have their own 'climate ranges' which are not necessarily the same as those of their hosts. However, there is insufficient information to make reliable predictions about the impact of climate change on these natural enemies and on the effectiveness of biological pest control ■L.



What has happened

There is some evidence that loss of soil organic carbon has occurred in England and Wales in recent decades ■ **M**. Subsequent studies have shown, however, that only 10-20% of this can be attributed directly to climate change, the rest being due to land-use change and soil management practices in arable agriculture. In Scotland, a similar decline has not been observed ■ **M**.

Soil erosion in the UK has increased in recent decades due to changed management practices, especially in England and Wales, and poses a risk to the sustainability of agricultural production ■ **M**. Soil loss is caused primarily by surface water run-off but also by wind.

Use of nitrogen fertiliser on all crops and grassland approximately doubled from the early to mid-1970s up to the mid-1980s, then began to decline from the early 1990s. In some places, fertiliser applications have contributed to high nitrate leaching to the groundwater ■ **H**.



What might happen

Many soil processes will be negatively affected, which will influence key soil properties such as structure, organic matter content, water-holding capacity, pH and fertility ■ **M**. These changes will arise partly from changes in the diversity and structure of communities of living organisms within soils ■ **M**.

Erosion caused by water and wind is likely to increase because of greater seasonal differences in rainfall with higher rainfall intensities and because higher temperatures will cause more drying ■ **M**.

Higher rainfall in some areas will increase the risk of soil compaction and may cause more leaching of nitrates, depending on crop growth, nutrient uptake patterns and fertiliser applications ■ **H**.

Changes in soil organic carbon content due to climate change will vary with soil type and agricultural management ■ **H**, since it depends on the balance between carbon inputs and carbon losses. In warmer environments where water is not a limiting factor, there will be higher crop productivity and therefore more carbon inputs ■ **M**, but also higher soil respiration rates ■ **M**. This makes the net impact on soil carbon difficult to predict.

Climate change is likely to generally increase greenhouse gas emissions from soils ■ **L**.



Key climate change impacts across the landscape

Forestry

Warmer temperatures and longer growing seasons will increase growth in cooler, wetter upland areas, but drier summer conditions, particularly in the south and east will reduce growth and may cause drought stress and mortality, particularly for young trees.

Horticulture

Warmer temperatures will be beneficial for many horticultural crops overall, but to maintain production from varieties with winter chilling requirements, new varieties may be required. Lower rainfall may result in tree crops suffering from drought stress.

Livestock

Livestock productivity will be affected by the quantity and quality of feed. There may be increased incidence of some livestock diseases.

Soil

Warmer temperatures and lower rainfall may result in loss of carbon from the soil, particularly in peatland soils, with consequences for soil structure and fertility.

Groundwater

Reduced aquifer recharge and increased competition for water by non-agricultural users may restrict the availability of ground water for irrigation.

Grasslands

Grassland production is likely to increase with warmer temperatures and longer growing seasons, although changes in the seasonal timing and amount of rain will influence this.

Land use

Changes in temperature and rainfall will change the classification of land suitability in some areas, which may open up opportunities for the growing of different crops, such as those for bioenergy.

River flooding

The risk of river flooding is expected to increase in the future, affecting crop and pasture production on surrounding land.

Uplands

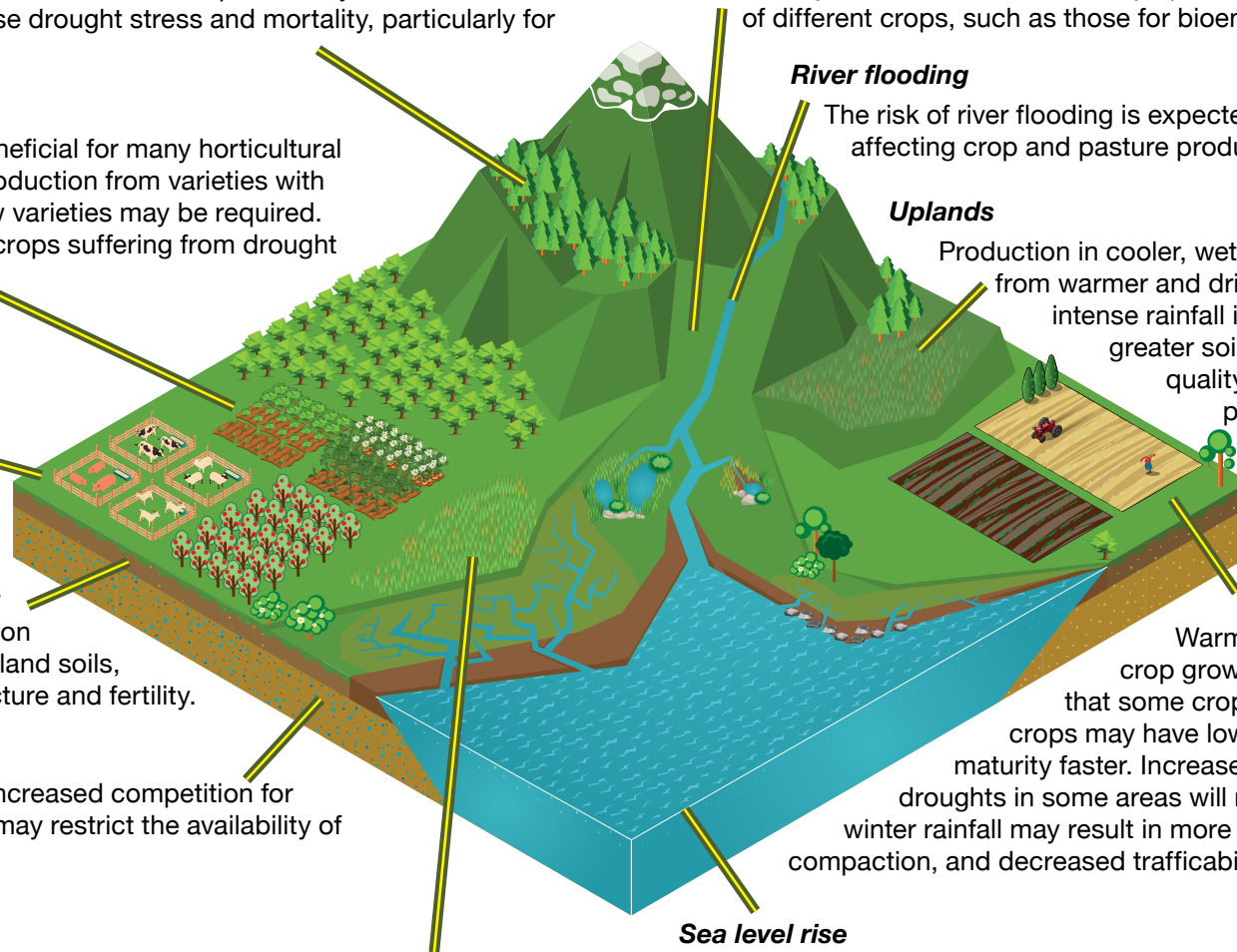
Production in cooler, wetter upland areas will benefit from warmer and drier conditions, although more intense rainfall in some areas may result in greater soil erosion. The range and quality of ecosystem services provided by upland areas may be affected both positively and negatively.

Arable land

Warmer temperatures mean that crop growing seasons will start earlier, that some crops will grow better, but other crops may have lower yields through reaching maturity faster. Increased frequency of summer droughts in some areas will reduce yields, but increased winter rainfall may result in more waterlogging, greater compaction, and decreased trafficability of land.

Sea level rise

Sea-level rise may result in loss of productive coastal land and increased risk of flooding and salinization.



What has happened

UK arable agriculture has changed substantially over the last half century. This has mainly been due to changes in agricultural practices driven by technological change, policy frameworks (primarily the EU Common Agricultural Policy), market economics and global trade. Climate change has probably had only a minor impact.

Areas under different crops have changed substantially – for example, 75 years ago oats was the most widely grown cereal; today, wheat, barley and oilseed rape account for most of the cropped area in the UK¹⁶ ■ H.

Average crop yields have increased substantially over this time, as did usage of nitrogen fertilisers until the 1980s, although phosphorus use has declined ■ H.

Different weed species have become prevalent due to changes in crop management (particularly less diverse crop rotations) and the occurrence of resistance to herbicides ■ H.

Pesticide use has increased substantially, although changing pesticide regulations have recently led to a reduction in the availability of crop protection products ■ H.



What might happen

For root crops, leafy vegetables and some perennials, warmer temperatures will increase the rate and duration of growth, resulting in higher yield potential ■ H and creating new opportunities in some parts of the UK. Increasing CO₂ concentrations will enhance this effect ■ H but declining water availability may reduce any benefit ■ M.

For crops such as autumn-sown cereals as well as some legumes and oilseeds, warmer temperatures may cause earlier maturity; if this were to happen, the potential benefit from longer growing seasons would not be realised ■ M. Increasing CO₂ concentration may slightly offset this reduction in yields ■ M.

Yields of rain-fed wheat, barley, forage maize, oilseed rape and sugar beet in some UK regions may fall or become more variable due to declining water availability ■ M.

Reduced groundwater recharge and increased competition from other water uses may limit irrigation, causing reductions in crop quantity and quality ■ L.

Increased frequency and magnitude of extreme weather events (drought, waterlogging and both high and low temperatures) will impact negatively on crop yields and quality ■ H.

Increases in ground level ozone concentrations may reduce crop yields ■ M.

The geographical distribution of crops will change ■ H. Increases in yields of cereal crops may be largest in northern England and in Scotland ■ M and their cultivation may shift northwards, while rain-fed potato production may move west ■ M.

Warmer conditions, longer growing seasons and a reduction in frosts will allow introduction of new crops ■ H; they may also allow an earlier start to the field operations season in some areas ■ M.

Vulnerability of agriculture to weather: 2012, a difficult year

2012 was an unusual year in the UK starting with **three very dry months**, (following two dry years in England).



April and the **summer months** were **mostly dull** although UK **sunshine duration** for the year was **near average**.



Fodder **maize crops** were **poor** (in NI).



Crop areas decreased by **4.2%** for oilseed and **3.6%** for cereals.



April and **June** had **record high rainfall** and **summer** was the **second wettest** in the UK-wide rainfall series from 1910.

As the **ground was too wet** to allow preparation for autumn sowing, for the next crop many farmers had to **switch to spring-sown crops**.



Quality of crops was also **affected**: the poorest since 1977.



Livestock producers were amongst the **hardest hit** by higher feed costs and increased feed use.



Total factor productivity fell by **3.2%**, the largest single year fall since records started in 1973.

UK **wheat yields** were down by **14%** due to high disease pressure throughout the spring and summer and **low sunlight levels** during grain fill, followed by poor harvest conditions.



There were problems due to **waterlogging of land** and **damage to grassland** due to poaching (loss of vegetation due to hoof damage).



What has happened

Warmer temperatures have already had an adverse impact on fruit production by reducing the incidence of chilling temperatures that are necessary to trigger development and flowering in overwintering crops ■ **M**.

Recent spells of high temperatures in warmer summers have caused reductions in yield and quality that have affected crops such as brassicas, fruit and tomatoes ■ **H**.

Most soft-fruit production now takes place in intensive protected systems with irrigation, in order to improve fruit quality and reduce soil-borne diseases. However, 70-80% of tree fruit and soft fruit production currently takes place in parts of the UK classified as being under water stress ■ **H**.

Some pollinator populations (e.g. bees) have been severely reduced due to factors such as parasites, pathogens and lack of food and suitable habitat ■ **H**, but the extent to which this is a result of climate change is unclear. It is likely that the impact of these reductions on crop yield and quality will be negative, though evidence is scarce ■ **L**.



What may happen

In the short term, for many UK horticultural crops, the net impact of an average temperature increase of 1-2°C and of longer growing seasons will be positive ■ **M**. Larger temperature increases in the longer term may be more problematic ■ **L** but will create opportunities for new varieties and crops.

Spells of high temperatures are likely to become more common and may reduce crop yields and quality by affecting establishment and flowering, as well as fruit and seed formation, depending on the crop ■ **M**.

Yields of current varieties of perennial fruit crops will be adversely affected due to receiving insufficient chilling for optimum development ■ **H**.

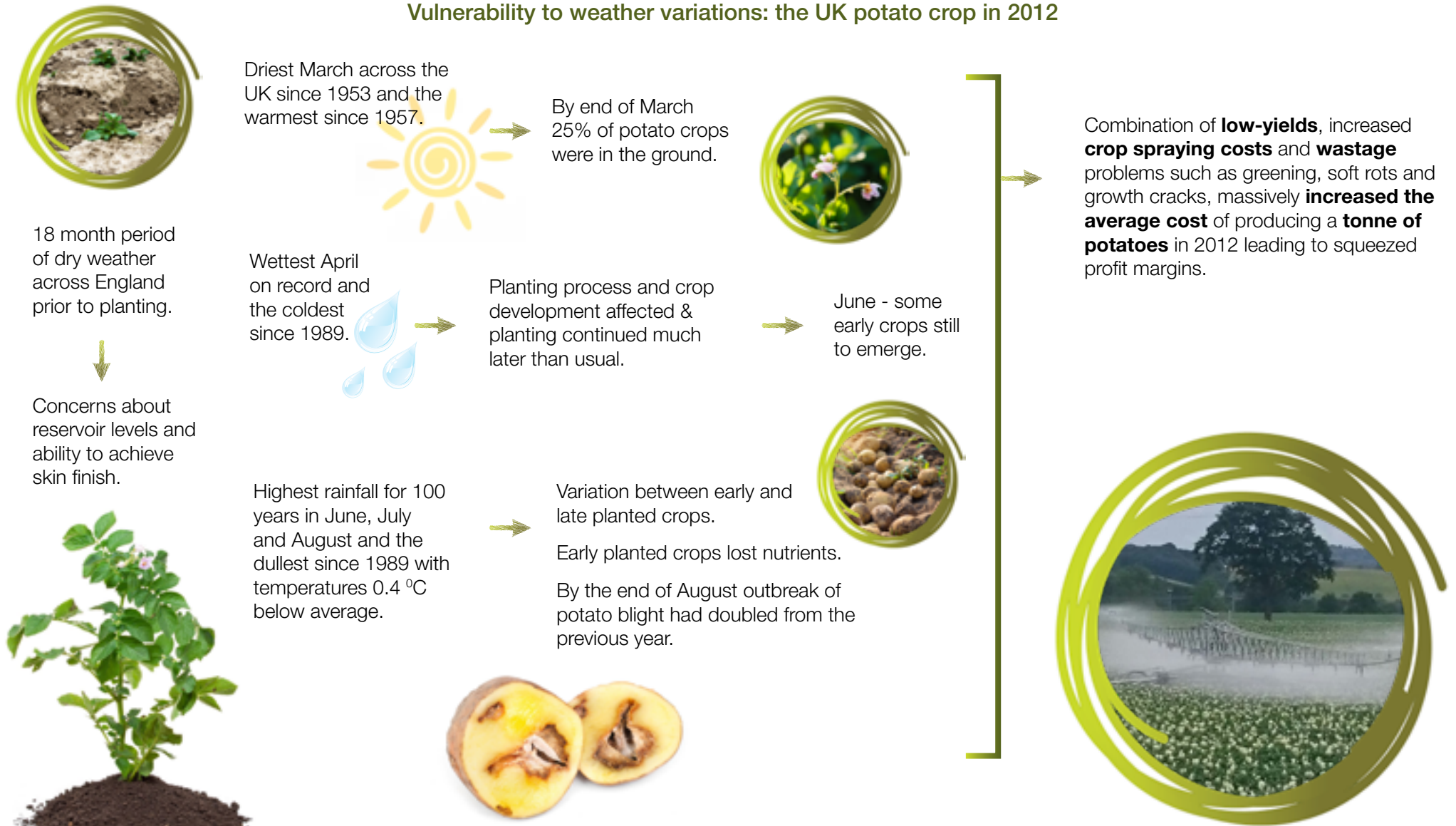
The occurrence of frosts will decline, although warmer winters could hasten flowering in tree-fruit crops, leading to more susceptibility to any late frosts ■ **L**.

Drier conditions will increase the probability of loss or interruption of production in long-season crops such as salads and vegetable brassicas ■ **H**. Irrigation requirements for soft-fruit production will increase substantially (with a predicted increase of up to 30% by 2050) but the necessary water supplies may not be available ■ **M**.

Insect pollinator species will be adversely affected by changes in the timing of plant and insect lifecycles, declines due to narrower climatic niches, local or regional extinction and changing composition of pollinator communities ■ **H**. If the life-cycles of pollinators and pollinated plant species become out of step, fertilisation may be negatively affected ■ **L**.



Vulnerability to weather variations: the UK potato crop in 2012



What has happened

Unusual weather has impacted on livestock production. For example, excessive temperatures reduced milk output between April and October 1990¹⁷ and the cold spring of 2013 caused a substantial number of deaths among sheep and cattle ■H.

Increased flooding has caused reduction in pasture growth, losses of hay and silage harvest, and additional costs from pasture reseeding, extra feed purchase and additional slurry disposal because animals had to be housed for longer ■M.

Animal diseases have been affected by unusual weather, with the threat from bluetongue virus increasing due to the mild winter of 2015/16¹⁸, severe rumen fluke infections reported for the first time in the UK in 2012¹⁹ and an increase in liver fluke diagnoses in 2013 ■H.



What may happen

Overall, forage yields are likely to increase ■M and growing and grazing seasons will lengthen ■L, although decreased availability of soil water may reduce feed quality and quantity, particularly in the south ■M. There may be opportunities to grow some forage crops (e.g. maize) further north than at present ■M.

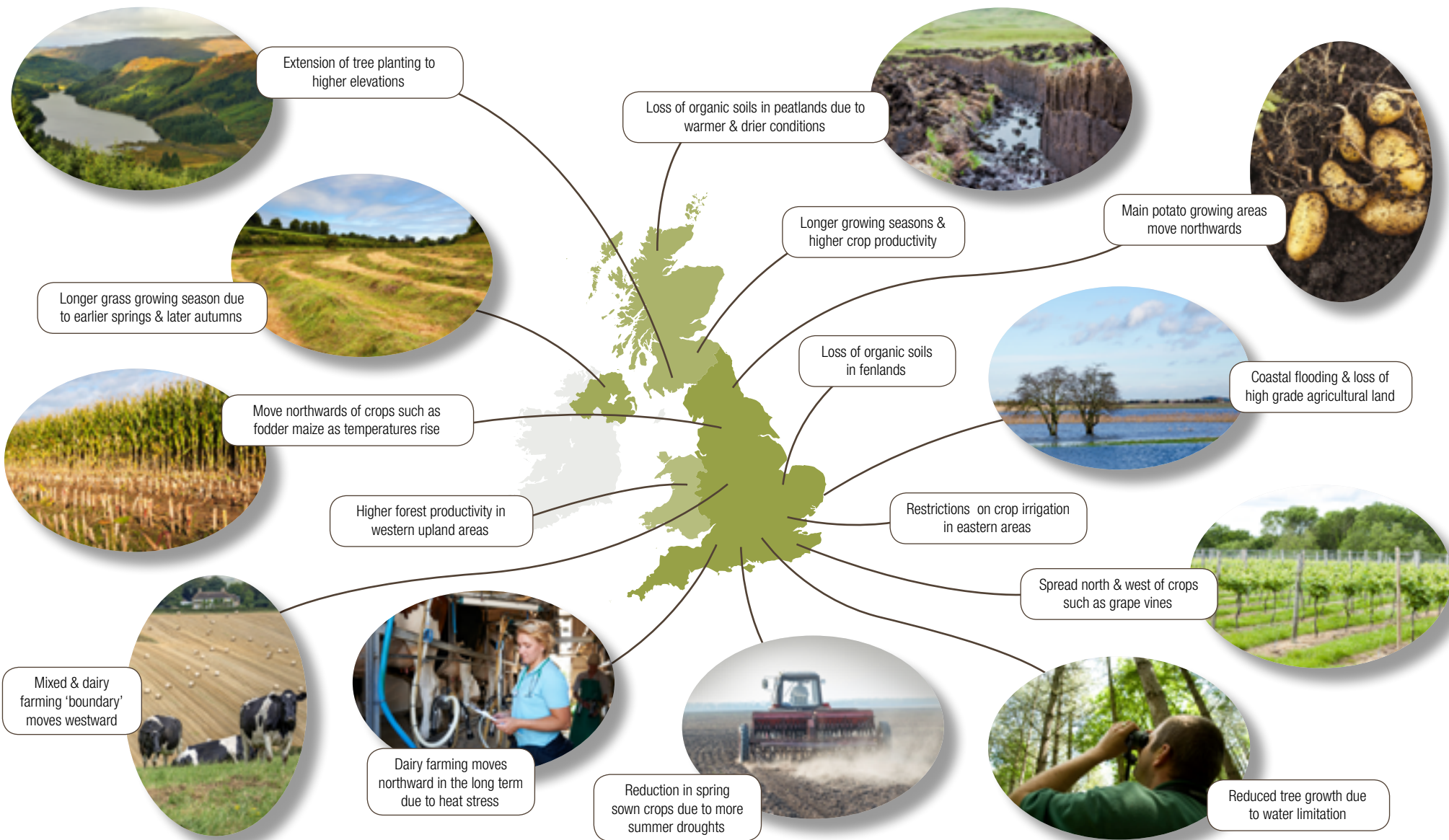
While snowfall is likely to lessen, benefiting upland livestock farming in particular, increasing frequency of other extreme weather events (e.g. flooding) may limit pasture and feed production and the ability of livestock to graze ■M. There may also be adverse effects on lambing (e.g. due to heavy rainfall) and the breeding of cows (e.g. due to high temperatures) ■M. Heat stress in dairy farming in southern England is predicted to increase in the long term but is unlikely to be a major problem elsewhere ■M.

Longer grass-growing seasons may result in shorter periods indoors for housed livestock ■M, while wetter winters may reduce land accessibility and increase the periods that livestock spend indoors ■M. Outcomes will differ between lowlands and uplands, and between areas in the east and west of the UK.

Increases in cost and volatility will affect the supply of supplementary protein and of energy crops imported into the UK to support livestock farming ■H, although this could be partially offset by the availability of by-products from the biofuel industry ■L.

There may be increased occurrence of liver fluke ■M. Emerging diseases, especially those transferred via insects (e.g. bluetongue virus), could result in costly disease outbreaks ■L. Novel and possibly increased levels of pests, diseases and mycotoxins (produced by fungi) could impact adversely on the quality of feed available to ruminant livestock ■L.

Examples of future climate change impacts around the UK



What has happened

Over recent decades, the emphasis in UK forestry has expanded from wood production to providing a range of additional ecosystem services (e.g. carbon sequestration, flood control, biodiversity, nutrient and water cycling, recreation), driven by socio-economic and policy factors ■H. This has led to changes in woodland structure and diversity in some areas of the country, exceeding any direct influence of recent climate change ■H.

Warmer temperatures have already resulted in substantial changes in the timing of life cycle events (phenology), with earlier bud burst, leafing and flowering in trees ■H, although there is much year-to-year and regional variation. Leaf-fall is probably occurring slightly later, but this is not always clear ■L.



What may happen

Biodiversity in semi-natural and managed woodlands, along with associated ecosystem services, is expected to change as a result of a changing climate ■H. Woodland structure and species composition will be altered if there are more frequent or more severe droughts or more windstorms ■H.

Tree-seed production and natural regeneration could be adversely affected by rising temperatures, increased CO₂ concentration and unseasonal fluctuations in soil water availability ■L. Warmer winters may reduce germination in species that have substantial chilling requirements ■M.

Warmer, drier conditions are likely to cause poorer establishment of newly planted trees ■M.

Timber yield potential will increase in the medium term (i.e. the next 20-30 years) in the cooler, wetter uplands and the north and west of the UK due to longer growing seasons ■H. In drier areas, on lighter soils or for species that are sensitive to drought, there will be reduced growth ■H and there may be reductions in timber quality ■M. In the longer term (50+ years), reduced water availability and more frequent extreme weather events are likely to reduce both growth and yield potential in many areas ■M. The earlier start to growth could make some species more vulnerable to late spring frosts ■L, even if the overall number of frosts declines.

It is not clear whether the risk of windstorms will change, although deciduous species may face increased risk due to being longer in leaf ■L. If there is more wind damage, this will facilitate entry by some diseases and pests ■H and is likely to disrupt forest operations, timber supply, carbon stocks and the range of ecosystem services provided ■M.

Drier, warmer conditions will increase the risk of wildfire damage to woodlands ■H, particularly in the south and east of the UK in heathland habitats and also on moorlands. Wetter winters are likely to impact tree growth and stability through waterlogging and to affect forest drainage and run-off, forestry operations and infrastructure ■M.

What has happened

While there is little quantitative evidence in the UK, longer growing seasons have probably slightly increased forest productivity ■ **L**. Recent increases in productivity have occurred in continental Europe ■ **H** and are thought to be due to warming and to higher CO₂ concentration, although management changes and increased nitrogen inputs due to air pollution have probably also contributed.



There is evidence of increased storm intensity over the last century, with wetter soils and flooding resulting in increased forest damage, erosion and landslides ■ **M**. Wind damage has increased, partly because of higher tree numbers ■ **M**, causing loss of production, damage to timber and increased operational costs and risks ■ **H**.

More frequent wildfires in the last decade have increased damage to forests and woodland in continental Europe ■ **H**, but there are insufficient data to assess whether this has also been the case in the UK ■ **L**. In years when weather conditions have been suitable, however, wildfires in the UK have caused damage to forestry ■ **H**.

Although there is limited evidence regarding the current effects of climate change on forest insect pests in the UK, it is likely that some recent disease outbreaks (e.g. *Dothistroma* needle blight in pines) were partly linked to climate change ■ **M**.

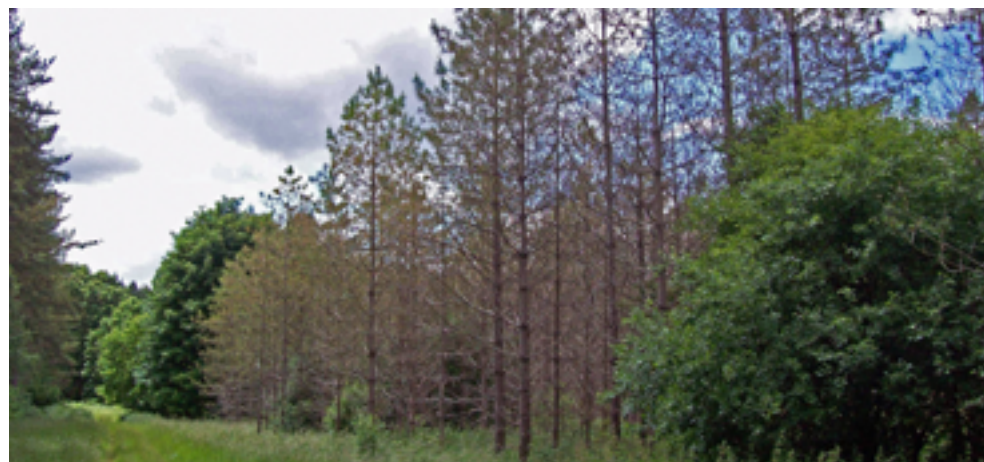
What may happen

Many forest pests and pathogens are likely to increase, either through the direct impact of climate on their abundance or distribution, or the indirect effect of increased water stress or wind damage which will increase the susceptibility of trees to attack ■ **M**. Just eight tree species account for 70% of the UK's forest area, contributing to the vulnerability to significant damage.

Some insect pests that degrade valuable timber or kill mature trees are likely to increase ■ **M**.

Pathogens that infect foliage or that have an aerial phase of the life cycle will be especially responsive to climate change ■ **H**. Milder winters will increase the ability of some pathogens to overwinter in the UK ■ **H**, earlier springs will favour the growth of other species ■ **H**, while storms with rainfall and high winds may provide more opportunities for long-distance dispersal ■ **M**.

The risks of damage to trees and to the establishment and regeneration of woodland that are posed by deer, grey squirrels and wild boar are likely to increase because of lower winter mortality and more young being produced ■ **M**, although this would depend on the control measures that are taken.



What has happened

Changes in land use, land management and ecosystem service provision have been determined more by socio-economic factors (including policy) and technological improvements than by climate change ■H.

The EU Common Agricultural Policy (CAP) has been the main driver of changes in land use since the 1970s ■H. Production was initially stimulated by direct subsidies but since then the CAP has moved towards more support for environmentally sustainable management ■H.

Since 1983, there has been a slow, small decline in the area of agricultural land in the UK ■H, largely due to woodland creation and urban and infrastructure development. There have been fluctuations between arable use and grassland as a result of the relative balance of commodity prices ■H. The area of permanent grassland and rough grazing has risen slightly since the 1970s.

Since the 1960s, there has been a shift towards a warmer, drier regime during the growing season in eastern parts of the UK, which has led to more land being classified as 'prime agricultural' in those areas ■M. The west has probably become wetter ■L.

What might happen

In the near to medium term, land-use change and ecosystem service provision are likely to continue to be determined by socio-economic and policy drivers (including requirements for mitigation of greenhouse gas emissions) and by technological improvements more than by climate change directly ■M.

In the longer term, warmer temperatures and changes in water availability will have more impact on land use and ecosystem service provision, adversely affecting key supporting services such as soil formation, plant growth, water availability and nutrient cycling ■M. The current east-west geographic division between livestock-dominated and arable-dominated farming systems could change ■L.

Where water is not a limiting factor, there may be increases in land classified as prime agricultural land. If drought risk is taken into account, particularly in the east of Scotland, the area of prime agricultural land will be reduced ■H.

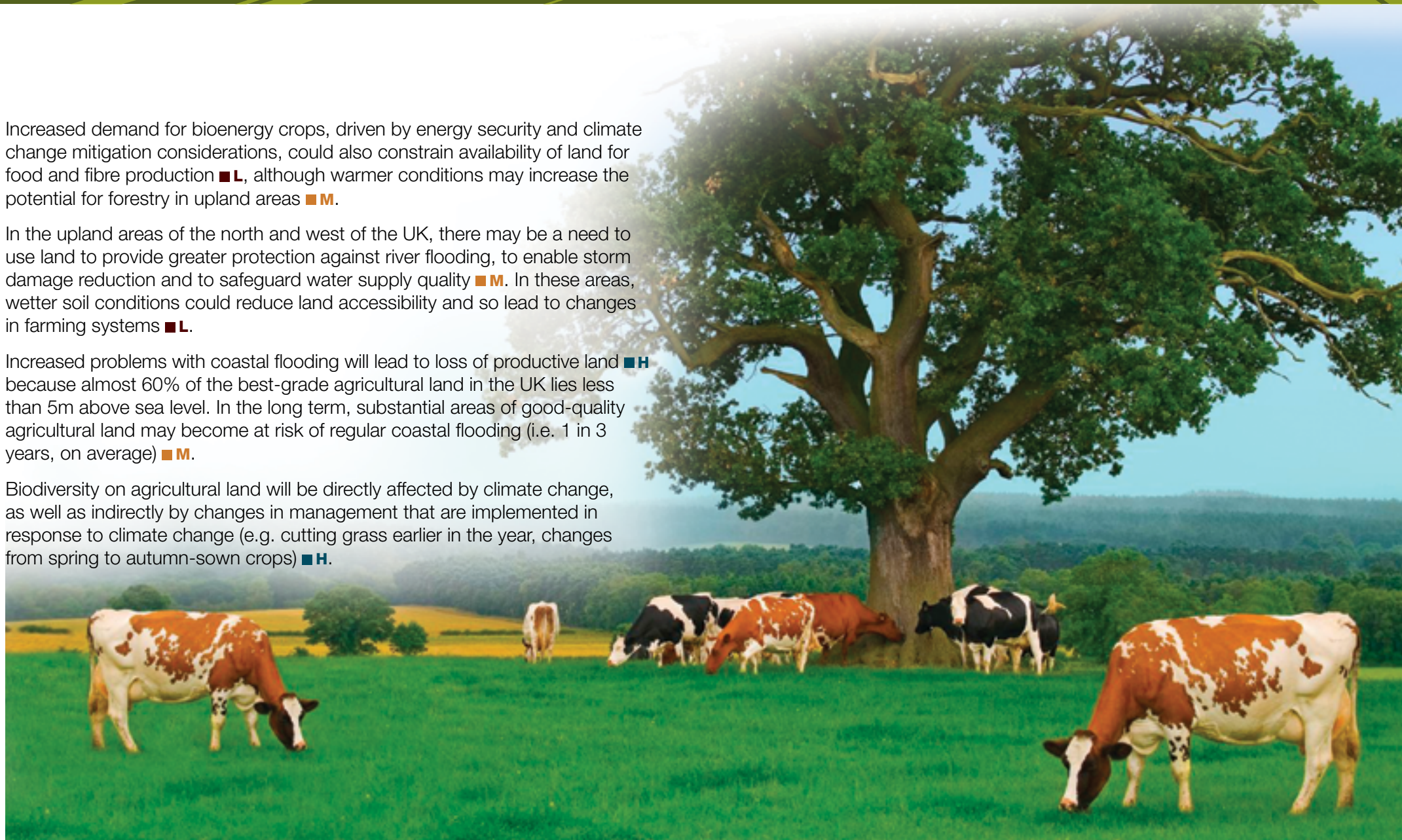


Increased demand for bioenergy crops, driven by energy security and climate change mitigation considerations, could also constrain availability of land for food and fibre production ■ **L**, although warmer conditions may increase the potential for forestry in upland areas ■ **M**.

In the upland areas of the north and west of the UK, there may be a need to use land to provide greater protection against river flooding, to enable storm damage reduction and to safeguard water supply quality ■ **M**. In these areas, wetter soil conditions could reduce land accessibility and so lead to changes in farming systems ■ **L**.

Increased problems with coastal flooding will lead to loss of productive land ■ **H** because almost 60% of the best-grade agricultural land in the UK lies less than 5m above sea level. In the long term, substantial areas of good-quality agricultural land may become at risk of regular coastal flooding (i.e. 1 in 3 years, on average) ■ **M**.

Biodiversity on agricultural land will be directly affected by climate change, as well as indirectly by changes in management that are implemented in response to climate change (e.g. cutting grass earlier in the year, changes from spring to autumn-sown crops) ■ **H**.



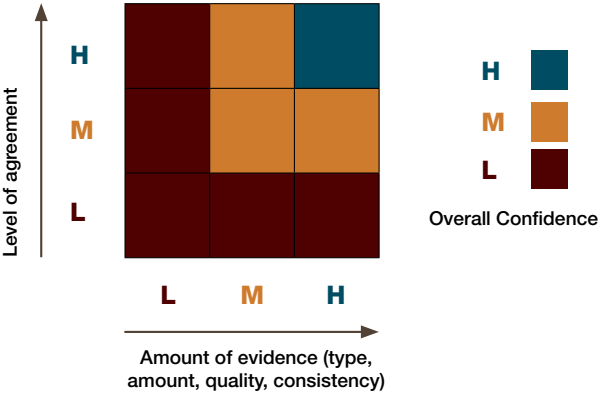
Confidence assessments and gaps in evidence

Confidence assessment

When discussing climate change impacts, it is important to indicate how much confidence we have in particular pieces of evidence. This helps to prioritise the actions and measures that are to be taken. Evidence that has a high level of confidence associated with it provides a strong basis for taking action, whereas evidence that has a

low level of confidence associated with it suggests that more data may need to be collected before committing to a response. The level of confidence that we should attach to any statement is primarily determined by (i) the amount of evidence collected, (ii) how representative that evidence is, (iii) our understanding of the processes

being affected, and (iv) how much agreement there is between different sets of evidence or different experts. Confidence assessments should be part of a wider risk assessment that also considers the seriousness of a potential change and the practicalities of responding to it.



During development of this Report Card's supporting Technical Papers, a version of the confidence scales developed by the Intergovernmental Panel on Climate Change (IPCC) was used to indicate, where possible, the confidence with which a trend could be identified or an impact predicted. For the purposes of this card, we have simplified these to provide an overall confidence level of High (H), Medium (M) or Low (L).



Uncertainties and gaps in evidence

This Report Card has shown where particular uncertainties exist and has also revealed several gaps in evidence and information:

- There is little clear evidence of existing impacts in the UK agricultural and forestry sectors that can be attributed directly to climate change. This is because of the many other changes brought about by technological and socio-economic factors, and because of the reactive adjustments of agriculture and horticulture, in particular, to changing weather conditions.
- Much of our understanding of future climate change comes from assessing the effect of single factors on individual components (e.g. the impact of temperature on crops or diseases), but information is scarce on responses to multiple factors and on how whole farming or forestry systems could be affected. This is partly due to the often complex interactions between direct biophysical impacts on plants, animals and soil, and indirect effects through pests and pathogens, or through management, demand, profitability and other socio-economic factors.
- Current operational management and advisory systems for farming, horticulture and forestry have been built on substantial information from past climate conditions, but how well these systems will perform in future climates is very uncertain.
- The implications of future climate change for the food and fibre processing industries are largely unexplored.
- The economic consequences of climate change for agriculture and forestry are largely unquantified, partly because of the difficulties in assessing impacts in a global system.
- While it is likely that climate change will not affect agricultural and forestry production in a progressive, predictable way, by their nature it is very difficult to identify particular 'tipping points' beyond which change will be irreversible.
- Sustainable production depends on key supporting services in agricultural and forestry ecosystems, including water and nutrient cycling and pollination. These supporting services are likely to be affected by climate change but the precise way in which they will be impacted remains very uncertain.



To reduce the negative impacts of climate change and to maximise any benefits and opportunities arising from it, farmers, foresters and other land managers will need to take active adaptation measures. While some of these measures will happen continuously as the climate changes, others will require long-term planning, particularly in the forestry sector. They will also need to be compatible with mitigation measures being taken to reduce greenhouse gas emissions from the land-use sector. While uncertainty over the timing and extent of changes may be a barrier to action, careful choice of adaptation actions should increase resilience to current threats as well as to future changes – the so-called ‘no regrets’ approach.

Some key adaptation actions that need to be considered are:

- Developing new crop and grassland varieties, livestock breeds and tree genotypes and introducing new species better suited to future climate conditions and resilient to pests, diseases and other factors.
- Adapting crop and livestock management practices to benefit from warmer temperatures and longer growing seasons (e.g. by choosing different sowing, harvesting, lambing and calving dates), while avoiding the adverse effects of extreme conditions (e.g. through the provision of shade or shelter for livestock). Livestock housing may need more ventilation in hot spells and increased biosecurity provisions to guard against new diseases.
- Improving soil, water and crop management to reduce erosion, flooding, compaction and losses of soil organic carbon, and to improve the efficiency of water and fertiliser use.
- Improving water supply for agriculture by increasing capacity for water capture and storage.
- Actively managing woodlands to improve forest structure, diversify tree species, increase resilience to greater weather variability and extreme events (e.g. fire and wind), and improve infrastructure (roads, drains and bridges) so it can cope with wetter conditions.
- Taking adaptation measures in all parts of the forest wood supply chain, from nurseries to sawmills.
- Increasing diversity in farm businesses to build adaptive capacity, as well as resilience to extreme weather events and economic shocks.
- Developing an ‘adaptive management’ approach that comprises a continuous cycle of planning and implementing management changes, then monitoring and evaluating them, and subsequently revising them.



This Report Card is based on a set of nine Technical Papers commissioned from experts who were asked to review existing evidence for climate change impacts on different aspects of agriculture and forestry as well as possible impacts in the future. Each Technical Paper was reviewed by other experts. We also consulted Technical Papers previously prepared for the Biodiversity and Water Resource Report Cards. They can be accessed using the links below.

Technical papers

- Land-use systems: A.R. Graves, J.W. Knox, J. Morris, P.J. Burgess, K. Weatherhead and I.P. Holman.
- Soil function: M. Abdalla and P. Smith
- Arable crops: G.R. Squire, D. Cammarano, T.J. Daniell, A.C. Newton, P.J. White.
- Livestock – ruminants (beef, sheep and dairy): C.J. Newbold and K. Dougal.
- Horticulture (field, protected and tree crops): R. Collier and B. Thomas.
- Tree and stand-scale growth and productivity: M. Lukac.
- Pests and diseases of trees: D. Wainhouse, D. Inward, S. Denman, S. Green and J. Webber.
- Risks for woodlands, forests management and production: B. Nicoll.
- Forest Ecosystem Services & Climate Change: D. Ray, L. Sing and B. Nicoll.

Other references

- ¹ Defra Agriculture statistics, 2015.
- ² Forestry Commission statistics, 2015.
- ³ Agriculture GVA and employment figures are for 2014, and those for forestry are for 2013.
- ⁴ In the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Working Group 1: climate science), 'extremely likely' is defined as a 95% confidence level.
- ⁵ Kendon, M., McCarthy, M. and Jevrejeva, S. (2015). State of the UK Climate 2014. Met Office.
- ⁶ 'Growing degree days' are the day-by-day sum of the number of degrees by which the mean temperature is more than 5.5°C.
- ⁷ Calculated with the Central England Temperature record as the period where daily mean temperature is above 5°C for more than 5 consecutive days
- ⁸ The Met Office National Climate Information Centre (NCIC) UK climate statistics 1910-2014 based on the methodology of Perry and Hollis (2005) <http://www.metoffice.gov.uk/climate>.
- ⁹ England and Wales Precipitation Series 1766–2014, based on the methodology of Alexander and Jones (2001).
- ¹⁰ Hanna, E. et al. (2008). J Climate, 21, 6739-6766. Donat, M.G. et al. (2011). Natural Hazards and Earth Sciences, 11:1351-1370.
- ¹¹ These concentrations are from the IPCC for the Representative Concentration Pathways RCP 2.6 and RCP 8.5.
- ¹² Pryor, S.C and Barthelmie, R.J. (2010). Climate change impacts on wind energy: A review. Renewable and Sustainable Energy Reviews, 14(1), 430-437.
- ¹³ Dobrynin, M., Murawsky, J and Yang, S. (2012). Evolution of the global wind wave climate in CMIP5 experiments. Geophysical Research Letters, 39(18), L18606.
- ¹⁴ Jones, P. D., Kilsby, C. G., Harpham, C., Glenis, V. and Burton, A. (2009). UK Climate Projections Science Report: Projections of future daily climate for the UK from the Weather Generator. University of Newcastle, UK.
- ¹⁵ Brown, S., Boorman, P. and Murphy, J. (2010). Interpretation and Use of Future Snow Projections from the 11-member Met Office Regional Climate Model Ensemble. Met Office Hadley Centre, Exeter, November 2010.
- ¹⁶ https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453220/structure-jun2015provcrops-eng-13aug15.pdf and UK National Ecosystem Assessment technical report (2011), Provisioning Services, G. Edward-Jones et al, Ch. 15.
- ¹⁷ Unsworth, M. H., Scott, R. K., Cox, J. S. and Bardell, K. (1993b). Impact on Agriculture and Horticulture. In: M. G. R. Cannell & C.E.R. Pitcairn (eds): Impacts of Mild Winters and Hot Summers in the United Kingdom 1988-90. London, HMSO.
- ¹⁸ <https://www.gov.uk/government/publications/qualitative-risk-assessment-bluetongue-virus-btv-8-entry-into-the-uk>
- ¹⁹ <http://beefandlamb.ahdb.org.uk/wp-content/uploads/2013/06/CHAWG-Annual-Report-2014.pdf>

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Further guidance on how agriculture and forestry can adapt to climate change is available from:

National Adaptation Programme: <https://www.gov.uk/government/publications/adapting-to-climate-change-national-adaptation-programme>

Adaptation Scotland: <http://www.adaptationscotland.org.uk/>

Climate Change Risk Assessment (CCRA): <https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/climate-change-risk-assessment-2017/>

Forestry Commission England: <http://www.forestry.gov.uk/england-resilience>

Forest Research: <http://www.forestry.gov.uk/fr/infid-5zyfex>

Other sources of information:

Review of Land Use and Climate Change. An assessment of the evidence base for climate change action in the agriculture, land use and wider food chain sectors in Wales. Report to the Welsh Government. ADAS, Leeds. <http://thecccw.org.uk/wp-content/uploads/2015/02/ADAS-review-of-LUCC-final-report-2014.pdf>

Adaptation Sub-Committee (2013). Managing the Land in a Changing Climate. Progress report 2013. <https://www.theccc.org.uk/publication/managing-the-land-in-a-changing-climate/>

Combating Climate Change: a role for UK forests (2009). Eds. D.J. Read, P.H. Freer-Smith, J.I.L. Morison, N. Hanley, C.C. West and P. Snowdon. HMSO.

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