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4. Climate change and ruminant agriculture in the UK

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Summary

There is still a great deal of uncertainty as to effects of climate change on the ruminant sector in the UK, however it is likely that:

- With the possible exception of intensive dairy farming in the south of the country, heat stress is unlikely to be major issue for UK ruminant agriculture in the next 60 years **(M)**. However, dairy farms in the south will either need to invest in infrastructure to combat heat stress, or be replaced by new operations in the north. **(L)**
- Generally forage yields may increase by up to 35% by 2050 **(M)** and growing seasons will lengthen by up to 75 days **(M)**, however southern England is likely to become less suitable for growth of forage or traditional feed crops **(M).**
- There will be increased cost and volatility in the supply of supplementary protein and energy crops imported into the country to support livestock farming **(H)** although this might be partially offset by the availability of by-products from the biofuel industry suitable for feeding to ruminants **(M)**
- Changing climate conditions in the UK may mean this is partially countered by the ability to grow maize further north than is now possible **(L)** and by the emergence of new protein and energy crops and the development of new forage varieties with enhanced energy and protein concentrations **(M)** .
- A possible increase in extreme weather events will further exacerbate the volatility in animal feeds both in terms of imported feed but also forage quality and quantity within the UK **(M)**
- Extreme weather events may be particularly of concern at key times in relation to operations such as lambing (precipitation events), or breeding of cows (heat influence) **(M).**

There is also a probability although with a lesser degree of certainty that:

- Increased competition for land used for 1) human edible crops 2) biofuel crop growth (although this is likely to be offset by the availability of by-products suitable for use in ruminant diets, and 3) non-agriculture pressures e.g. infrastructure, flood risk management & housing may displace ruminant agriculture in some situations **(L).**
- Novel and possibly increased levels of pests, disease and mycotoxins are likely to impact the quality of feed available to ruminant stock **(L).**
- Emerging disease, particularly those transferred via insect vectors, may result in costly disease outbreaks **(L).**
- Extreme weather events might limit available grazing or ability of livestock to graze **(M).**
- Extreme rainfall events leading to erosion and nutrient leaching will make some land uneconomical or unsustainable to farm **(M).**

To counter these challenges the UK ruminant sector could:

- Increase the diversification of farm activities including a greater reliance on mixed farming systems, when appropriate, to limit the vulnerability to single points of failure.
- Develop crop/ forage varieties/species for increased thermal/drought tolerance together with new forage varieties to increase water retention in the soil so reducing flood risk during extreme weather events.

- Develop new grazing management systems to maximise gains and decrease the risk of soil damage and pathogen build-up.
- Improve nutritional management to maximise the utilisation of new and novel feed sources.
- Improve disease surveillance of existing and emerging disease to allow management interventions to be applied at a farm level and policy interventions to be applied at a governmental level.
- Develop production systems that benefit from longer grazing seasons and potentially higher pasture yields.

1.0 Introduction

Global climate change is a reality that must be faced as it will have far reaching impacts that will vary at country and industry level. Furthermore it is commonly accepted that the global population will rise to over nine billion by 2050 with an associated rise in food demand of around 60% (Alexandratos & Bruinsma, 2012). While the overall increase in energy from food per capita is not likely to be significant (2860 kcal/person/day in 2015 VS predicted 3070kcal/person/day in 2050), it is likely developing countries will have a much larger increase. This is also true for the predicted increased demand in meat (39 to 49 kg/person/year) and dairy products (83 to 99 kg/person/year) with the greatest increases in demand from developing nations (Alexandratos & Bruinsma, 2012). Thus the demands placed on agriculture will be significant; production systems must become more efficient and be aware that currently available input materials (e.g. phosphate as fertilizer) may not be as readily available in the future. Agriculture is highly sensitive to changes in weather patterns, for example the El Niño Oscillation phenomenon is currently thought to be responsible for 15-35% of the global variation in wheat, oilseeds and coarse grains yields (Ferris, 1999; Howden, 2007). The significant changes to climate which are projected make it likely that it will become more challenging to meet the greater demands required of agriculture to feed a growing global population.

This report aims to explore the issue of climate change with specific reference to the UK ruminant sector. By identifying likely changes to climate over the next century some predictions can be made as to both the indirect and the direct impacts on ruminant agriculture. This information then allows key threats and opportunities to the UK industry to be identified so mitigation and adaptation options may be explored by both ruminant livestock farmers, government and also the supply chains that support them (in terms of supply of compound feed, animal genetics, machinery and infrastructure and the supply chain through to retail that they in turn support). It is likely that over time more information will be available which will enhance our understanding of the impacts of climate change on agriculture and further inform a strategy to ensure the UK ruminant industry remains viable and profitable.

2.0 Scope of UK ruminant agriculture

Worldwide livestock agriculture accounts for a large proportion of land use, estimated at around a third of available terrestrial land, with around 3.5 billion hectares under grazing (Steinfield *et al.*, 2006; Howden, 2007). In the UK, grasslands account for around 65% of UK agricultural land (Peeters, 2004), with the majority of ruminant farms more concentrated in the south west of England, the west Midlands, the north of England, west Wales, Northern Ireland and Scotland (DEFRA, 2015) due to existing climate conditions, soils and topography. Dairy in particular is concentrated in the south west of Scotland, Wales and England (DEFRA, 2008).

The total income from farming across the UK in 2013 was estimated at £5,464 million, split £4,120 million for England, £829 million for Scotland, £298 million for Northern Ireland and £218 million for Wales (HCC, 2014). Some three times more beef is imported into the country (worth £372 million/yr) than exported, whilst sheep imports and exports are roughly equal at £380 million/yr (HCC, 2014). Currently beef is exported in the greatest quantities to the Irish Republic, the Netherlands and France, and sheep meat to France, Hong Kong and Germany. Imports are currently greatest for beef from the Irish Republic, the Netherlands, Germany, and Poland and for sheep meat New Zealand, Australia and the Irish republic (HCC, 2014). The dairy industry imports and exports relatively small quantities of liquid milk (245,Kilo tonnes VS 575 Kilo tonnes respectively) (Baker, 2015). When considering UK self-sufficiency, values for beef and veal are 77.3% and for lamb 99.6% (EBLEX, 2013). For dairy products values for liquid milk are estimated at 100% self-sufficient and 65% for cheese (NFU, 2013).

In terms of UK livestock feed usage it is estimated that 292 million tonnes of forage is used annually (288 grazed, 9.1 grass silage, 1.8 maize silage, 2.1 hay) (Wilkinson, 2011). This is supplemented by 5312 Kilo tonnes of cereals (4374 Kilo tonnes wheat, 764 Kilo tonnes barley, 60 Kilo tonnes oats, 114 Kilo tonnes maize) and 3609 Kilo tonnes of oilseed and associated by-products (Wilkinson, 2011). Within the EU the total consumption of feed cereals annually is around 75,017 Kilo tonnes (12,450 Kilo tonnes imported) and oilcakes and meals is 42,020 Kilo tonnes (23,751 Kilo tonnes imported) (Bouxin, 2013).

3.0 Climate change to date

During the 20th century on a global scale several changes were apparent. Firstly the lower levels of atmosphere have almost certainly warmed (IPCC, 2013) with increases over the century in Europe averaging 0.8°C (Schroter *et al.*, 2005; IPCC, 2007). This temperate increase within the northern hemisphere would appear to have accelerated towards the end of the 20th century (and into the next) with the period between 1983 and 2012 likely to have been warmest during the preceding millennium and a half (Howden, 2008; Reidsma *et al.*, 2010; IPCC, 2013). As well as sustained temperature increases; more frequent occurrence of heatwaves has been recorded throughout Europe (IPCC, 2013). In recent decades Europe has experienced an increased frequency of extreme weather events (Reidsma *et al.*, 2010). Although more difficult to quantify, due to regional and spatial variation, precipitation has similarly increased. Quantity of precipitation has increased (with high confidence during late 20th century in mid latitude areas of northern hemisphere) as has the occurrence of heavy rain events (likely to have happened globally) (IPCC, 2013). Changes to the global situation are reflected within the UK climate, with some specific data available. Average temperature was relatively stable over the 100 years pre-1970; however, since then central England has seen a rise in 1°C which is unexplained by natural variation (Jenkins *et al.*, 2009). In the remainder of the UK a similar increase of 0.7-0.8°C has been recorded since 1980 (Jenkins *et al.*, 2009). Incidence of extreme weather events such as severe rain and windstorms have been experienced more often during the past 40 years but this does not exceed that reported during the 1920’s (Jenkins *et al.*, 2009).

4.0 Climate change projections

The Intergovernmental Panel on Climate Change (IPCC) produce reports which provide projections as to likely global climate change, the most recent being IPCC Fifth assessment report (AR5) in 2015. Similarly projections for the UK have been published by UK Climate Projections, the most recent being in 2009 (Jenkins *et al.*, 2009).Projections for global surface temperature increases during the 21st century depend on the level of emissions modelled, but in general range between an increase of 0.3°C and 4.8°C (IPCC, 2013; Lennon, 2015). Across Europe this rise is projected to be between 2.1°C and 4.4°C (Schroter *et al.*, 2005). Heatwaves are very likely to occur more frequently and be longer in duration across Asia, Australia and in Europe (southern Europe more so) (Reidsma *et al.*, 2010; IPCC, 2013). In terms of temperature extremes, it is virtually certain that hot extremes will be more frequent and cold extremes less frequent with a likely increase in the number of warm days and nights experienced but a reduction in cool days and nights (IPCC, 2013).

In line with the global projections temperatures across the UK are expected to steadily increase during the 21st century. Increases in average daily temperature are projected to be between 2.1°C -3.5°C in the summer and 2.7°C - 4.1°C in the winter (Jenkins *et al*., 2009). Similarly those predicted for Ireland are of an increase in summer day temperature of 2.5°C by 2050 (Dunne *et al.*, 2009). Effects are predicted to be more pronounced during the summer months than during the winter period with differences according to region with the greatest rises expected during the summer in the south of England (up to +4.2°C range 2.2°C - 6.8°C) and the least in the Scottish Islands (just over 2.5°C (1.2°C - 4.1°C (Jenkins *et al*., 2009). As well as increases in the average temperatures the maximum daily temperatures are expected to increase between 2.8°C and 5.4°C in summer compared to a slightly lower winter increase of 1.5°C – 2.5°C, dependant on the region within the UK (Jenkins *et al*., 2009).

Again consistent with global predictions it is expected that there will be an increase in precipitation during the winter months with a decrease during the summer months (Schroter *et al.*, 2005; Dunne *et al.*, 2009; IPCC, 2013; Lennon 2015). However projected changes are highly variable across regions with limited confidence levels that range from a 16% reduction (with a 10% confidence level) to an increase of 14% (with a 90% confidence level, Jenkins *et al*., 2009). During winter months the west of the UK is most likely to see increased precipitation with increases of 9% - 70%, while the Scottish Highlands are unlikely to see large changes ranging from a reduction of 11% to an increase of 7% (Jenkins *et al*., 2009); the lower of each set of figures represent a value that the increase in precipitation is unlikely to be less than, where the upper value is unlikely to be exceeded and reality likely lies somewhere in between. During the summer period, the south of England (the area also expected to experience the greatest temperature increases) is predicted to experience the greatest reduction in precipitation (-6% to -65%) while parts of the north of Scotland may see no appreciable difference (-8% to +10%) (Jenkins *et al*., 2009). It is important to note that while most projections are made assuming no change in the level of mitigation and intervention, any changes to climate that are happening are likely to continue over the next century even if a complete cessation in CO_2 emission is to occur (IPCC, 2013).

5.0 Indirect effects on ruminants

One of the largest impacts of climate change on the UK ruminant sector is likely to be through the effect on crop and forage growth, thus affecting availability and quality of animal feeds (Nardone *et al.*, 2010; Wheeler & Reynolds, 2013). This will occur through impacts directly within the UK on grazed forage, forage produced for conservation and winter feeding and home-grown crops and grains. Indirectly, the availability of feedstuffs that are currently imported such as soya and maize may also be affected. These impacts will vary geographically and are subject to uncertainty linked to the level of emissions and warming (Wheeler & Reynolds, 2013). Furthermore there will likely be competition for cereals to be used for direct human food and competition for land to produce crops for biofuel production (Silanikove *et al.*, 2015). It is likely that due to global shortages and escalating fuel costs, the cost of some currently imported animal feeds may become prohibitive and alternative sources of protein for use in ruminant feed will need to be sourced.

5.1 Direct impacts on UK pasture and crops

Most projections suggest that the UK will be less affected by climate change than other parts of Europe or indeed globally. Temperate countries in general are thought likely to benefit during the next century (Silanikove *et al.*, 2015), through increased pasture growth due to extended growing seasons (warmer winters and earlier spring) (Cullen *et al.*, 2009) and the effect of CO_2 fertilisation (Ainsworth *et al*., 2008). Global CO_2 increases are projected to be in the region of 100ppm by 2040 (McGrath & Lobell, 2013).

Projections suggest that in Scotland there will be increases in the grass growing season of between 25.2-75.5 days (dependent on region within the country, Topp & Doyle, 1996a). It has been suggested that there is a 15 % increase in grassland yield per degree of warming for conditions with adequate water and nitrogen (Knox *et al*., 2012). Based on this, Knox et al (2012) estimated that grass yields in the UK might increase by 20% (range 11% to 31%), by the 2020s, rising to 35% for the 2050s (range 18% to 53%), with the greatest increases seen in Scotland and Northern Ireland compared to southern England where water stress might become a limiting factor, although this will be tempered by the possibility that extreme weather events and flooding might limit the ability of livestock to graze some land (See Section 5.3).

In addition the impact of increased CO_2 and temperature is likely to be highly variable (Howden, 2008), with large differences between C3 and C4 plants likely (Larcher, 1995) due to different metabolic pathways and utilization of CO_2 for photosynthesis). C3 plants (most UK pasture grasses and feed crops) are projected to benefit more from increased CO_2 (Wheeler & Reynolds, 2013) although again variation between individual species is likely (Rotter & van de Geijn, 1999). This increased benefit is likely due to C3 plants evolutionary adaptation to more easily utilise higher levels of CO_2 than C4 plants. Average projected gains in yield of 10-20% (IPCC, 2007) have been suggested with some estimates as high as 33% (Kimball, 1983). C4 species (e.g. maize) are thought to still be likely to benefit from increased CO_2 to a far lesser extent (Kimball *et al.*, 2002; IPCC, 2007). The response to increased CO_2 is not likely to be consistent across all C3 or C4 plants, but individual species will have different responses (McGrath & Lobell, 2013). Where water availability is not limited, for the projected 100ppm CO_2 increase, McGrath & Lobell (2013) have projected a yield increase of 2.8% for barley, 0.8% for maize, 2.8% for wheat and 8.7% for soya bean. Any selective advantage of C3 VS C4 grasses may also have an effect on methane emissions from ruminants as Archimède *et al* (2011) found that ruminants fed C4 grass produced 17% more CH_4 as L/kg OM intake ($P<0.05$) compared to those fed C3 grass.

However in interpreting these potential gains it should be noted that the estimates do not necessarily take into account many other complex factors such as soil properties, precipitation and temperature (Stokes & Ash, 2006) and gains will have to be balanced by decreases in available water and increases in evaporation (Howden, 2008). Deep rooted plant, such as legumes and woody plants are likely to fare better under situations of lower water availability (Howden, 2008; Wheeler & Reynolds, 2013). Overall trends seem to suggest a more favourable situation for pasture based ruminant agriculture particularly in more northern parts of the UK although the possibility that forage quality may be reduced through lower nitrogen uptake under increased atmospheric CO_2 concentrations clearly needs further consideration (Howden, 2008).Work by Brown *et al*. (2011) evaluating agricultural land in Scotland, using a land capability approach, suggests that by 2050 much more land in the south and east may improve to be classified as ‘prime’. However some existing prime land may be downgraded due to drying out (Brown *et al.*, 2011).

5.2 Disease and pests of forages and crops

In addition to potential changes in growth yields of forages and crops, there is the potential for increased prevalence of some existing pests and disease due to climate change affecting crops and forage. Diseases and pests currently not prevalent in the UK may emerge. The prediction of effects of increased and emergent pests and diseases on yield is challenging

(Houmoller *et al.*, 2008). If, as expected, winter temperatures increase, a longer growing season may increase the time that pests and diseases are active and thus intensify the requirement for management measures (Salinari *et al.*, 2006; Lennon 2015). Higher atmospheric CO_2 concentrations might also increase pathogen pest activity and associated losses (Gregory *et al*., 2009). There is also the potential for an increase in the prevalence of vertebrate pests that may cause increasing damage to crops and forage (Rawlinson, 2008). Examples of possible changes in disease and pests s include:

- Reduction in cereal aphids in southern UK (Newman, 2005; Newman, 2006)
- Northward expansion within the UK of Grey field slug (*Deroceras reticulatum*) (Willis *et al.*, 2006)
- Increase in Fusarium ear blight of wheat in UK (Madgwick *et al.*, 2011; West *et al.*, 2012)
- Increases in mycotoxin levels in cereals and forages both pre-harvest and in storage due to increased temperatures and moisture levels (Nardone *et al.*, 2010 Paterson & Lima, 2010; Wild & Gong, 2010).

Whilst clearly a high degree of uncertainty exists it would seem prudent to assume that challenges from disease and pests of forages and crops will become an increasing issue in the face of climate change given the devastating speed at which new pathogens can spread within a crop (Pautasso *et al*., 2012). If home-grown feeds utilised for the ruminant sector are threatened by pests, disease or mycotoxin as detailed above then this threatens the self-sufficiency of farmers within the UK (ADAS, 2009) confounded by the likely volatility in the global market of protein sources for ruminant diets (detailed further in section 5.5) Taken together this provides further incentive for the UK ruminant sector to seek to maintain a broad and varied input base to ensure that producers are not overly dependent on a single source of feed.

5.3 Flooding

With predicted increases in extreme weather events in the face of climate change it seems likely that agricultural land will face an increased risk of flooding from rivers and sea and that some of this land may become unsuitable for the agricultural activities it is currently used for. Currently some 30,000 ha of agricultural land in the UK is subject to flooding at least once in every three years and this is predicted to increase to 35,000 ha by the 2020s, 75,000 ha by the 2050s and 130,000 ha by the 2080s (Knox *et al*., 2012). Under a projected high emission scenario (and consequent higher predicted sea levels) the risk of tidal flooding to prime agricultural land increases by a factor of ten by 2080 (Knox *et al.*, 2012).

Waterlogged land will likely cause problems for growing forage, ensuring grazing quality and access for livestock (Brown *et al*., 2008). When land experiences higher levels of water the soil becomes more susceptible to compaction and erosion meaning normal cropping and grazing activities are effected (Greenwood & McKenzie, 2001). Also of importance is the duration that grassland or crops are submerged for. Winter wheat and oilseed, for example, suffer around 20% loss if under water for less than fifteen days compared with100% loss if over 15 days (ADAS, 2014). Similarly it is thought the critical duration for loss of grassland (with ryegrass as an example) is more than ten days of being underwater (ADAS, 2014). This however is an area which is difficult to assess in terms of likely degree of impact due to insufficient data and difficulty in predicting precipitation (Jenkins *et al.*, 2009; Knox *et al.*, 2012).

5.4 Other factors

There are also potential changes in soil structure and quality, linked to climate change. Soil erosion is highly likely given increased heavy rainfall events (McKeon *et al.*, 2004). During these periods of increased precipitation the UK may experience greater soil/ nutrient leaching which as well as impacting on plant growth may also have a negative effect on water quality in the immediate area and subsequent wider environmental impacts (Bindi & Oleson, 2011). However due to the uncertainty associated within predicting precipitation effects and extreme weather events it is extremely difficult to gauge the potential impact.

Hotter, drier summer months may mean that water shortages will occur. During these periods water may not only become scarce but the quality may also be lower (Nardone *et al.*, 2010; Silanikove *et al.*, 2015). This risk was highlighted in 2011 when drought conditions from April to June in parts of England (notably Shropshire, Suffolk and Cambridgeshire) threatened wheat crops, resulting in a number of farmers using their surplus irrigation capacity to irrigate their wheat in order to minimise any subsequent yield loss. If irrigation is needed to maintain UK fodder and crop yields then significant associated costs should be anticipated (O'Mara, 2012). Projections for Scotland indicate irrigation may be needed for some cropping operations in the south and east to maintain current growing conditions (Brown *et al.*, 2008; Brown *et al.*, 2011).

5.5 Availability of feed ingredients

Europe is only partially self-sufficient in the material needed to produce compound feeds for high producing ruminants. In particular it has been noted that Europe is only approximately 30% self-sufficient in proteins for compound feeds with in soya meal mainly sourced from outside Europe (Bouxin, 2013). Across Europe climate change is likely to have the greatest impact in the south, particularly in the Mediterranean area. Lower crop productivity in this region could lead to is a reduction in available crops such as maize, soyabean and sunflower for animal feeds in the UK (Bindi & Oleson, 2011). In areas that experience temperatures over 30°C, maize yields are likely to drop by 1-1.7% for each growing degree day over this temperature,; see Lobell *et al.* (2011) for the calculation of degree day. Indeed Italian maize production was estimated to have reduced by 36% due to excessively high temperatures during the heatwave of 2003 (Cais *et al*., 2005). Globally soyabean yields are projected to either decrease by 45% or to record a small increase of 10% (dependent on emissions and climate model). It is thus likely that alternative protein sources for ruminants may be needed (Osborne *et al.*, 2013) in order to help mediate fluctuations in the cost of feeds available to ruminant producers. One suggestion is the likes of lupins, algal protein and other alternative protein sources that may help fill this so called "protein gap", but this must be explored further (Marley *et al*., 2008, Wheeler & Reynolds, 2013).

Within Europe production of both energy and protein feeds is likely to move further north (Wheeler & Reynolds 2013) with suggestion that conditions in countries such as Ireland, Scotland, southern Sweden and Finland may be suitable to allow more maize production (estimates of increases in suitable land in the range of 30-50%, Bindi & Oleson, 2011) with the northern limit for land suitable for maize cropping shifting by around 190 km per decade from the 1990s to the 2050s (Carter *et al.,* 1992). However it is possible that issues of waterlogging, flooding and soil erosion might limit this move north. The continued improvements in the digestibility and energy content of grassland due to the introduction of high sugar and more recently high lipid grasses might limit the need for feeding supplementary concentrates (Lovatt et al., 2009; Hegarty *et al.,* 2013). What is certain is that there will be more pressure on resources to produce animal forage and feed grains, so better nutritional management of ruminants and precision feeding will be essential to maximise the use of available resources (Wheeler & Reynolds, 2013).

There has been some discussion about the potential pressures placed on crop stocks for biofuel/ ethanol production rather than current use for animal feed. In the USA it has been suggested that increased diversion of corn to biofuel production will have a knock on effect down the chain to other animal feedstuffs to increase prices, with a global impact on soybean availability and price (Fabiosa et al., 2010). Currently within the EU soybean accounts for 38% of protein sources used in animal feed (mainly imported from south America) (Lywood & Pinkney, 2012). It is however hoped that through increased use of biofuel co-products (e.g. distiller’s grains) within the EU as livestock feed, this will directly displace a large proportion of protein currently obtained from soybean (Lywood & Pinkney, 2012).

6.0 Direct effects on UK ruminants

Although it is likely that indirect effects of climate change, such as feed and forage availability and quality, will have the greatest impact on UK ruminant production there are also several direct effects of likely climate change that should be considered. With increased temperature it is already known and well documented that animal performance (growth, milk production, and wool production), reproduction and health and welfare can be negatively affected (Howden, 2008; Singh *et al.*, 2012; De Rensis *et al.*, 2015). There is also the potential for increased occurrence of endemic disease where the likelihood of infection may change spatially and possible emergence of tropical diseases transmitted by new vectors (Gale *et al.*, 2008).

6.1 Temperature and heat stress.

Of the direct effects likely to impact on ruminants, higher temperatures and resultant heat stress (HS) are possibly the most influential (Bindi & Oleson, 2011). When the average temperature is at a sustained higher level or a period of heatwave occurs (with high peak temperatures, especially where there is no night time recovery period) there is potential for animals to experience heat stress (Brown-Brandl *et al.*, 2006). This is defined as a situation where the animal is unable to effectively dissipate heat generated through metabolic processes (Mader & Davis 2004). Under normal circumstances ruminants maintain their body temperature within a relatively narrow range (+/- 0.5°C), with the comfort zone for dairy cattle suggested as between 5-25°C (NRC, 1981; Henry *et al.*, 2012). There is however some evidence that animals may be able to acclimatise to heat to a certain degree (Bryant, 2007). Often a temperature humidity index (THI) is used to calculate days when conditions are such that livestock may be affected

Where THI = (Dry bulb temperature ^{o}C) + (0.36* dew point temperature ^{o}C) +41.2 (Mader and Davis 2004).

In cattle, generally THI <68 is acceptable, at a THI-72-78 mild HS is likely, while at THI- 78-89 severe HS is indicated, THI 89-98 indicates very severe HS and THI 98> likely results in mortality (Mader & Davis 2004; Chase, 2006; De Rensis *et al.*, 2015). Ambient temperatures of 30-31°C (in Florida) have resulted in rectal temperatures in dairy cows which indicate hyperthermia (Dikmen *et al.*, 2009). Less literature has been published for sheep and goats. It would appear that these animals are more resilient to heat stress, reaching a THI threshold of 82 before they are distressed (Marai *et al.*, 2007; Renaudeau *et al.*, 2012), but they have a lower optimum comfort zone at 13-20°C (Lopez Armengol, 2015).

Signs of HS include lowered feed intake, increased respiratory effort (panting), sweating and altered blood acid base balance (Mader 2003; West, 2003; Mader & Davis 2004; Brown-Brandl *et al.*, 2006; Dunn *et al.*, 2014; De Rensis *et al.*, 2015). These physiological alterations result in poor growth and lower production (primarily through suppressed appetite), altered production characteristics (e.g. lower milk yields, reduced beef quality) and decreased fertility (Christopherson & Kennedy 1983; Morand-Fehr & Doreau 2001; West, 2003; Gregory, 2010; Dunn *et al.*, 2014; De Rensis *et al.*, 2015). Animals in intensive production systems are particularly at risk of HS due to their inability to self-select areas of shade and air movement (Howden, 1999; Brown-Brandl *et al.*, 2006; Renaudeau *et al.*, 2012). High producing animals such as dairy cows are at the greatest risk as they are under significant metabolic demand (Johnson *et al.*, 1963; West *et al.*, 2003; Bryant *et al.*, 2007; Renaudeau *et al.*, 2012; De Rensis *et al.*, 2015). The extent to which an animal copes with increased temperatures and their susceptibility to HS depends on factors such as their breed, previous exposure, health status, production demands and coat colour (darker colours are more sensitive) (Brown-Brandl *et al.*, 2006; Portner and Knust, 2007).

Currently in the UK it is unlikely that the most at-risk animals (dairy cows in intensive systems) experience HS. The regions which experience the greatest THI are in the south and east of England and in 1950-2000 the average annual days where a THI of greater than 70 was recorded was 2.65 (Dunn *et al.*, 2014). Projected increases of temperature will likely affect the dairy industry differently in different regions. Under the medium emissions scenario Scotland and the north east of England are the least likely to experience high THI days . Farms in the midlands, Wales and the south west of England may experience between 20 and 30 days of THI >70 per year, however those in the in the south east of England are likely to experience >40 days per year (Dunn *et al.*, 2014). Wall *et al.* 2010 suggested that that predicted impacts of heat stress in dairy cattle would result in 1.8 times higher mortality between 2050 and 2080 in the south east of England compared with the north west of the country. This suggesting either a redistribution of the industry and/or a need for enhanced capital investment to combat HS in these areas.

6.2 Reproductive performance (in response to HS).

Reproductive processes are negatively affected by increased temperatures and HS. As above effects are greater at higher levels of THI with a linear response in terms of days open (period between calving and conception) as THI increases above a threshold of 70 (St-Pierre *et al.* 2003). In cattle the following fertility impacts have been found:

- Increased numbers of animals showing anoestrus
- Decreased oestrus behaviour, making heat detection for artificial insemination harder
- Oocyte quality reduced
- Increased likelihood of ovulation failure
- Reduced conception rates
- Increased risk of early embryonic loss due to decreased blood flow to uterus
- Increased risk of late embryonic/ early foetal loss

(Gangwar *et al.*, 1965; Roman-Ponce *et al.*, 1978; Lopez Gatius *et al.*, 2003; Lopez gatius, 2004; Lopez Gatius *et al.*, 2005; Amundson *et al.*, 2006; Upadhaya , 2010; De Rensis *et al.*, 2015).

Knox *et al.* (2012) estimated that financial losses due to reduced reproductive efficiency in the UK dairy herd were likely to be £1 million/yr in 2020 (range £0-3 million/yr) rising to potentially £4 million/PA (range £0-51 million/ yr) in 2080. In sheep, it has been shown that in ewes decreased oestrus behaviour, lowered conception rates and losses early in pregnancy occurred in response to HS (Lopez Armengol, 2015), whilst in rams reduced spermatogenesis and sperm quality have been reported (Marai *et al.*, 2008; Lopez Armengol, 2015). However in the UK this is only likely to affect early lambing flocks in the foreseeable future.

6.3 Animal Disease.

Climate change is likely to both change the prevalence of current endemic disease in the UK and also lead to the emergence and spread of disease not currently found in the UK. In general, pests and disease are thought to be moving poleward at a rate of around 2.7km/yr since the 1960’s (Bebber *et al.*, 2013). In the southern hemisphere, tropical parasites are similarly moving poleward (Sutherst, 2001). Modelling of change in disease occurrence at a regional spatial level has proven challenging (Rose and Wall, 2010; Van Dijk *et al.*, 2010). Others have suggested that it may be possible to gauge the likely diseases and pathogens that may affect the UK in response to climate change by looking at what is currently happening in southern Europe (France and Spain). However the complexity of factors involved in disease transmission and spread limit the accuracy of this approach (Gale *et al.*, 2008).

Changes to diseases currently found in UK: It has been suggested that there is a link between the occurrence of gastrointestinal (GI) parasites and climate (Bennema *et al*., 2010) with changes observed in parasite abundance and seasonality in recent years (van Dijk *et al.*, 2010). The free-living larval stages of GI parasites are thought to be the most likely to be affected by climate change as temperature, UV exposure and rainfall will likely influence their ability to survive on pasture and hence infect animals (Van Dijk *et al.*, 2010). Higher temperatures and lower UV levels may also promote winter survival of larvae; likewise less frequent frost events will increase larvae survival rates (Kutz *et al.*, 2005; Van Dijk *et al.*, 2010, Skuce et al., 2013). However this will not necessarily result in greater animal infection rates if livestock are housed and do not have access to pasture at these times. Although one likely effect of climate change could be a decrease in housing and increase in year round grazing due to greater forage availability, it is possible that different management systems, zero grazed v zero housed, might be a possible way to mitigate the risk of climate change. During warmer, drier summer periods, larvae on pasture will die faster and potentially reduce infection rates (Van Dijk *et al.*, 2010). There has been a greater prevalence of liver and rumen fluke in the UK in recent years possibly because warmer, wetter conditions have supported further increases in their snail host and thus greater animal infections (Taylor, 2004; Gale *et al.*, 2008). Given current projections one might expect this trend to continue in the foreseeable future. However as for other GI parasites regional differences and parasite species are expected to give rise to large variation in infection, , with some factors favouring increases and some decreases (Van Dijk *et al.*, 2010). Resistance to anthelmintic drugs and availability and efficacy of management strategies to prevent resistance through pasture management at the farm level adds further complexity (Wolstenholme *et al.*, 2004; Van Dijk *et al.*, 2010). Liver fluke has been projected to increase in incidence along the west coast of the UK (Fox et al., 2011). However one of the main drivers in the models used is rainfall which, as previously mentioned, is challenging to accurately predict in relation to climate change. What is more likely is a change in seasonality with increased incidence of fluke in the autumn and spring and lower incidence in the summer, although changes are likely to be modest under the lower emission scenario (Caminade *et al*., 2015).

There is likely to be an increase in native flies and insects during hotter, wet periods with a negative effect on livestock health and welfare in general and specifically through increased levels of mastitis and blowfly strike in sheep (Singh *et al.*, 1996; Howden, 2008; Gaughan *et al.*, 2009; Rose & Wall, 2010). Of perhaps lesser likelihood but with a greater potential impact is the concern that bacterial and fungal disease spread could increase during flooding events, leading to outbreaks of rare conditions such as botulism and anthrax (Baylis & Githenko, 2006; Gale *et al.*, 2008).

Vector borne disease. As with parasitic disease, changes in distribution and range due to climate change of those transmitted by vectors are difficult to predict. Many models are currently unable to account for many complexities such as transmission cycles and behavioural and ecological factors that are not likely to respond in a simple way to increased temperatures or emissions (IPCC, 2013). There is however good evidence that disease spread by arthropod vectors has increased in Europe during recent years. However there are still questions regarding how these may be directly linked to climate change with any confidence, (Medlock & Leach, 2015) and other farm management changes such as enhanced tree cover and provision of wetter areas for agro ecological reasons may also be important (Kluiters *et al.*, 2013).

A striking example of emerging risk was the outbreak of blue tongue virus (BTV) in cattle, transmitted by the cullicoides midge, through northern Europe in 2006 followed by the south of the UK in 2007 (Landeg, 2007). This disease was thought to originate from sub Saharan Africa and prior to appearing in northern Europe had not been seen previously in southern Europe (Meiswinkel *et al.*, 2007; Gale *et al.*, 2008). This not only demonstrates the potential for vectors to move geographically if conditions are suitable, but also the complexity of predicting events, as they do not necessarily follow a predictable pattern.

Within the UK as the climate changes, there is a possibility for existing arthropods to adapt and become competent to act as vectors for disease currently transmitted by similar species in other regions (Gale *et al.*, 2008). Also possible is the expansion in current geographical range of foreign vectors into the UK, especially in southern England (Medlock *et al.*, 2006). As well as arthropod vectors, migrating birds pose a risk as disease reservoirs to bring a tropical disease into the UK (Waldenstrom *et al.*, 2007). An example is the introduction of the zoonotic West Nile Virus into the USA in 1999 (thought to be via bird reservoirs), where over a seven year period the country went from being disease free to having West Nile Virus endemic (during 2006, 20,000 human cases, 770 deaths, and an estimated 215,000 illnesses were reported) (Kilpatrick *et al.*, 2006; Diaz *et al.*, 2008).

Currently it is highly probable that many tropical diseases enter the UK either in live infected hosts (humans, livestock imports) or through intermediate hosts or reservoirs (such as birds). At present this may result in a small pocket of disease in the immediate area. However, the current climate does not allow the disease to spread and maintain itself due to the lack of a suitable vector. As an example it is known that imported car tyres carry eggs of arthropod vectors from Asia to South America and into Europe, with little impact currently as these vectors cannot currently survive under local conditions (Medlock & Leach, 2015). In the future as the climate becomes more suitable for the vectors, protecting the country from disease entry will become more important (Gale *et al.*, 2008; Medlock & Leach, 2015).

6.4 *Potential impacts of climate change on production and enteric methane emissions*

Given that dry matter intake is the primary driver of enteric methane production (Blaxter & Clapperton, 1965) and increases in fodder availability are predicted (as described above) one might expect overall enteric methane production for the ruminant sector to increase. Furthermore, given the possibility that many production systems might decrease the inclusion of cereals or compound feeds (given the possibility of price increases or at very least price fluctuations) and the inherently higher methane production per unit of output associated with forages VS cereal based productions systems (Knapp *et al.*, 2015), one might also expect the emission yield (i.e. grams of CH_4 per unit of milk or meat) to increase. This will be further exacerbated if, as discussed above, there is an increase in incidence of disease outbreaks as loss of productivity due to disease has been described as a major cause of enhanced emissions per unit of output (Gill *et al.*, 2010). These increases in emissions might be partially compensated for if the increased price and volatility of imported protein result in farmers decreasing the crude protein content of ruminant diets (as lower crude protein in the diet is associated with lower faecal and urinary N excretion and thus potentially decreased N_2O emissions (Arriaga *et al.*, 2010, Schils *et al.*, 2013). Additionally, if as noted above, novel forages such as high sugar grasses (which have been shown to decrease GHG emissions by circa 20% (Newbold, 2010)) become more popular this might further reduce emissions.

7.0 Key threats, opportunities and options for adaptation in the UK ruminant sector

Without doubt one of the biggest threats to the continued success of the UK ruminant sector is the lack of knowledge particularly at a regional level as to the likely effects and when they may become an issue (Henry *et al.*, 2012). There is a need to plan for a wide array of projected scenarios particularly in regards to crop and forage yields when actual yields may be very different (Reidsma *et al.*, 2010) and highly susceptible to unpredictable weather events. To be able to respond and adapt to climate change farmers, managers and policy makers must believe that changes are real and will have tangible impacts (Howden, 2007; Gill, 2011). There is some evidence, from southern Africa, that financially secure farms are more susceptible to extreme climatic conditions, as they are slower to adapt to events, as they do not feel the same immediate pressure that a poor farmer does (Reidsma *et al.*, 2010).

Below are some of the key threats to the UK ruminant sector from projected climate change:

- Southern England likely to become less suitable for growth of forage or traditional feed crops
- Feed cereals less likely to be imported (through reduced global yields)
- Competition likely to be high for land used for 1) human edible crops 2) biofuel crop growth
- Pests, disease and mycotoxins likely to have greater impact at a regional level
- Extreme rainfall events likely to influence soil erosion, nutrient leaching and access to land for both grazing and forage conservation operations
- Water demand will be high both for direct animal use and irrigation in the south of the UK
- HS is likely to become a factor in intensive dairy systems, in the south of the UK
- Changes to existing as well as emerging disease may result in costly disease outbreaks

However the UK along with New Zealand, Canada and the eastern USA fall within one of the areas geographically projected to be less affected by climate change and thus potentially to thrive (Howden, 2008). Whilst the arguments for and against increasing meat and dairy production are complex (Ripple *et al*., 2014), it is likely that there will a continued increasing global demand for meat and milk from a growing human population (Scollan *et al.,* 2011) and ruminants are able (unlike monogastrics) to convert forage and fibrous material, otherwise indigestible to humans, into useable products (Gill *et al*., 2010; Wilkinson, 2011) providing new market opportunities for UK agriculture. In support of this opportunity climate change provides some of the key opportunities to the UK ruminant sector in terms of:

- Increased areas for grazing and forage possible across the UK, particularly in northern England and Scotland
- A possible increased area suitable in the UK for growing animal feed cereals (i.e. maize), subject to problems with soil erosion waterlogging and flooding.
- Utilisation of by products from other industries as animal feed sources, e.g. distillers' /bioethanol grains
- Use of alternative protein sources such as lupins, algae etc.
- Extended grazing seasons and therefore potentially reduced winter feed and housing bills
- Increased use of legumes within grazing and as conserved forages
- Increased areas in the north of England and Scotland suitable for dairy farming

7.1 Adaptation

While changes to climate and consequent impacts to the UK ruminant sector are certain, both the nature and extent of possible adaptations needed in farming systems is at present unclear. Changes will be progressive over centuries and as such there is not a sudden need for adaptation, allowing time for planning and implementation. That said there must be consideration given to likely outcomes, as there is a pressing need for decision makers to implement policy to support necessary changes at a farm level (Reidsma *et al.*, 2010; Howden, 2008). Successful adaptation will be dependent on the individual farm and regional economy and farmers' desire to change (Reidsma *et al.*, 2010; Gill, 2011). It is possible that extensive and expensive adaptations if employed now may not end up being worthwhile in the face of actual change. Time spent now ensuring that farms are more resilient and efficient under the current climate and occurrence of extreme weather events will surely help to partly future proof the sector (Bindi & Oleson, 2011).

Smit and Skinner (2002) suggested four main avenues for adaptation:

1. Farm production practices
2. Farm financial management
3. Technological developments
4. Governmental programmes and insurance

What are likely to be required ultimately are changes in management in terms of seasonal timing of farming activities and potentially change in geographical location to maximise gain and minimise loss due to climate change (Howden, 2008). Below are some suggestions of potential adaptations:

Cropping adaptations (Howden, 2007; Lawson *et al.*, 2009; Macleod *et al*., 2013; Kole *et al.,* 2015);

1. Crop/ forage varieties/species for increased thermal/drought tolerance
2. New forage varieties to increase water retention and reduce flood risk during extreme weather events through enhanced root development and soil water retention
3. Water management technologies to use water more efficiently and prevent negative effects from extreme precipitation and flooding, possible by increased use of managed riparian zones.
4. Changing crops/forages according to season and location
5. Sporadic fluctuations in animal feed costs are likely, therefore the use of home grown feed where practicable may minimise the impact on ruminant farmers, suggesting a move to mixed farming systems to spread risk

Livestock adaptations; (Finch *et al.*, 1984; Howden, 2007; Howden, 2008; Henry *et al.*, 2012)

1. Grazing management to maximise gains (timing, type of plant, rotation)
2. Breed of animal and selection of animals best suited to changing conditions, HS resiliance, disease resistance, alternate species (e.g. utilisation of goats for dairy that are more HS resistant than cows)
3. Nutritional management to maximise feed utilisation
4. Infrastructure changes to avoid HS in summer and to protect against wet conditions in winter
5. Disease surveillance and importation control

As suggested, sustainable practices, which maximise resource use efficiency and potential gains within agriculture, are going to be essential for resilience to climate change. The term ‘precision agriculture’ relates to the use of technology and practices which allow site specific conditions to be monitored and consequently applications of fertiliser or pesticide (for example) to be used only when necessary (Tey & Brindal, 2012). Technologies currently include global positioning systems, remote sensors and variable rate applicators and allow remote collection of data which informs practice by the farmer/ farm manager (Tey & Brindal, 2012). New technology and understanding by stakeholders will assist in achieving maximum gains with minimum waste.

7.2 Consequences for supply chains and primary processors

There is increasing understanding amongst major retailers that they play an important role in reducing greenhouse gas emissions throughout their supply chains (Plambeck, 2012) and all major retailers now have corporate society responsibility policies (NFU, 2014). Major retailers through their supply chain have the potential to be major agents of social change through increased visibility of the carbon cost of different feedstuffs (Gadema & Oglethorpe, 2011) but also by requiring and supporting primary producers to implement specific policies to reduce greenhouse gas emissions (ASDA, 2011). At the same time climate change is a major concern throughout supply chains; increasing price volatility and potentially security and continuity of supply (Gledhill *et al.*, 2013). It is thus perhaps not surprising that there has been a move towards increased accountability along the supply chain in order to help identify areas in which mitigation and adaptation strategies might best be applied (Environment Agency, 2013).

7.3 Impact on Economics

Due to large uncertainty surrounding the timing, magnitude and location of actual impacts on UK agriculture, economic impacts are challenging to predict (Wreford *et al.*, 2015). Direct effects of increased temperature on livestock are perhaps the easiest to project due to temperature models identified as being more accurate. Thus estimates of the likely loss in national milk production and cost of reduced fertility due to heat stress by 2080 have been estimated at around 12 million kg/yr and £4 million per year respectively (under medium emissions scenario) (Knox *et al.*, 2012). Economic impacts of heat stress on livestock production are thought likely to be minor (Knox *et al.*, 2012). Part of the complexity in predicting economic impacts is the large effect that implementation of adaptation measures may have. Figures will alter dependent on what measures are implemented, how successful they are and will vary at a regional and farm level (Wreford *et al.*, 2015). Recent estimates by Wreford *et al.* (2015) suggest that by the end of this century, accounting for the cost of adaptation measures, there is a likely net present value (NPV) of £636-1,850 million benefit in terms of disease surveillance to combat emerging and exotic disease. Similarly a £0.82-3,279 million benefit linked to infrastructure and shelter modifications for heat stress in livestock (although this figure does include non-ruminants). To predict economic impacts of climate change on ruminant agriculture in the UK more accurately, further information regarding mitigation and adaptation measures at a regional level must be obtained.

8.0 Conclusion

With projected global increases in temperature, alterations to precipitation and increased frequency of extreme weather events during the next century there are likely to be far-reaching impacts on agriculture. In the UK, and in particular the ruminant sector, there are many climate factors that are likely to disrupt current activities or will require adaptations to be made to prevent loss of product and income. Impacts are likely to be highly variable according to region and socio-economic conditions.

The largest effects are likely to be indirect, through alterations to forage and crop production, thus causing difficulties in sourcing adequate traditionally used feed to meet production demands. There is a real need to develop home-grown protein and energy sources and develop alternate protein sources that will also be resilient against competition for land use for human edible crops or biofuel crop growth. Pests, disease and mycotoxins are likely to have an increasing influence on plant growth and animal feed production, but this impact will vary by geographical region. Direct effects likely on production animals are heat stress in the south of the UK, particularly in intensive and high production systems. On these farms infrastructure investment will be needed to counteract temperature effects. Damage to water logged areas , may mean that operations will have to be stopped (in affected areas throughout the UK) and new ones started in areas less susceptible to water logging. Changes to current endemic disease prevalence and spatial range are likely, as is the increase of emerging tropical disease especially vector transmitted ones. These disease impacts are likely to be region specific but may have a large financial impact across the UK.

In general impacts will be region specific with greater negative effects likely in the south. There are conversely likely to be some potential benefits with areas in the north becoming suitable to grow crops such as maize, whilst in the south, deeper rooting legumes and grasses may predominate to help counteract occasional drought periods. In the UK, extension of the grazing season is possible and some activities may become more productive than they are currently. There are likely to be a host of negative and positive impacts, of which the net balance is difficult to currently predict. What is certainly needed is better monitoring, data collection and targeted planning (Lennon, 2015) to try to pre-empt changes, inform policy and drive adaptation.

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