Health Climate Change impacts report card technical paper

5. Food-borne disease and climate change

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Key Messages

What we know

- Food borne disease can have both infectious (e.g. bacteria) and non-infectious causes (e.g. pesticide residues).
- Higher temperatures increase the number of cases of salmonella (H), but the incidence of salmonellosis is declining in the UK due to improvements in food hygiene (H)
- Foodborne illness caused by *Campylobacter* is an important and increasing public health issue. Environmental and weather factors play a role in transmission [M].
- For both *Salmonella* and *Campylobacter* the burden and severity of illness is greatest in older adults and young children [H]
- There has been an expansion of the biogeographical ranges of some harmful warmer water phytoplankton species into higher latitudes. For example, there has been an apparent increasein *Protoceratium reticulatum* (a producer of toxins) in UK waters [M]
- Marine vibrio pathogens, which can cause gastro- enteritis and septicaemia, have led to disease outbreaks in Northern Europe and are now being routinely isolated from UK shellfish and bathing waters in the summer.[M]
- Food safety is highly controlled at the National and EU level [H]

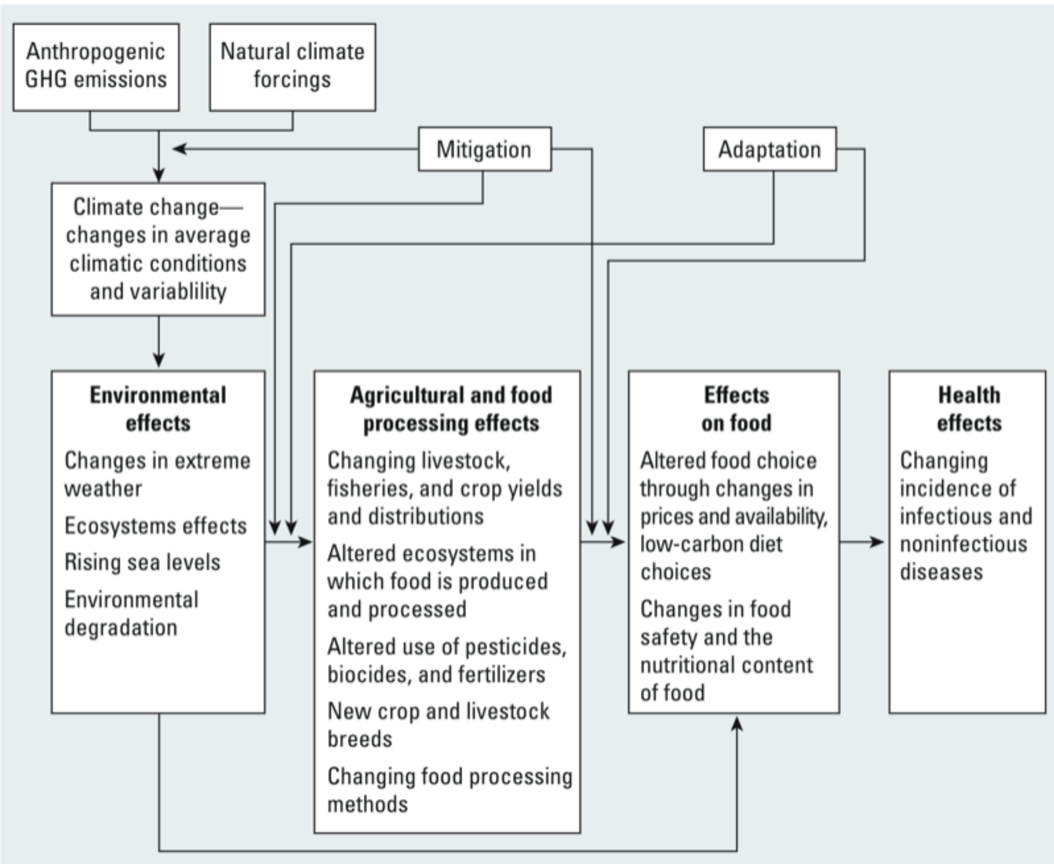
What may happen

- There are a large number of pathways through which climate change may affect food borne disease and contamination. Only a few of these have been pathways have been investigated (M)
- Higher temperatures are not likely to have a significant effect on the incidence of food poisoning cases due to salmonella because the incidence of this disease is declining (H).
- Uncertainty regarding the mechanisms by which environment and weather factors affect transmission of campylobacter, makes it difficult to make any assessment regarding climate change impacts. (L)
- Most vibrio species of human health relevance grow preferentially in warm (>15 ºC) sea water. Increasing sea temperatures around the UK may result in an increase in marine vibrio infections [L]
- The relatively high level of regulation regarding food safety from farm to fork provides the UK with resilience to adapt climate change (H)

Introduction and Scope

Climate change has the potential to have an impact upon food in the UK in a wide variety of ways. A summary of all the potential consequences is presented in Figure 1 (Lake et al. 2012). On the left of this Figure are the principal causes and impacts of climate change. These can influence the environment in a number of ways, such as increasing extremes of weather and rising sea levels. In turn, these lead to effects which impact upon agriculture and food processing. Examples of these effects include changes in crop yields, seasonal shifts in food production, altered use of pesticides and fertilisers, changing demands for irrigation water and elevated temperatures along the food chain. Agriculture and food processing can also be affected by attempts to reduce greenhouse gas emissions associated with the food chain (mitigation). Examples of such initiatives include changing regimes for the application of fertilisers, different crop varieties, or a reduction in the use of energy intensive pesticides. Any impacts on agriculture and food processing associated with climate change are likely to be adapted to by further modifications to agriculture and food processing. Finally consumers may change their food choices to mitigate against climate change. An example of this could be reducing their consumption of red meat. All these changes can have implications on the types and quality of the food that individuals consume which in themselves could have impacts upon health.

Figure 1: Pathways through which climate change affects food (Lake et al. 2012) (Adapted from McMichael et al. 2006)



Given the large number of pathways, climate change may have many impacts upon food with consequences for health. In this review we focus upon two infectious diseases, *Campylobacter* and *Salmonella*. These two are chosen because, in addition to their public heath importance, there is much evidence that these infections are influenced by existing climate variability especially temperature (Lake et al. 2009a). Therefore, under a warmer climate, incidence of these infections may change, and the relationships between these and weather have been researched. In addition to these two infections the review will also consider in less detail a number of potential impacts which are less well documented in the literature.

Before proceeding it is worth noting that although the geographical focus of this review is the UK, international borders can be crossed by food-borne disease implying that changes in foodborne illness in one country may have consequences in other countries. For example, of the infectious intestinal disease recorded in the UK (of which food-borne illness is a subset) 8-12% are estimated to have been caught overseas (Food Standards Agency 2011a). Furthermore the food supply chain is global and so any impacts of the food supply chain in one country can have impacts elsewhere. Only 53% of the total food consumed in Britain is home grown (DEFRA 2013). This percentage varies by food product; in 2010 60.6% of vegetables consumed were produced in the UK in contrast to 12.1% of fruit (DEFRA 2011). Climate change impacts upon the food supply in other countries will have an impact on some of the food consumed in UK. Food and drink are also important export markets for the UK and so climate change induced food safety changes in the UK could have global consequences. In 2012 the total value of food and drink exported was £18.2bn (DEFRA 2013). Around three quarters of this is exported to other EU countries (Food and Drink Federation 2012).

The Evidence; *Campylobacter*

In developed countries, including the UK, *Campylobacter* is the most common bacterial cause of diarrhoeal disease. It can cause abdominal pain and severe diarrhoea. Clinical complications include Guillain-Barre syndrome (GBS), reactive arthritis and irritable bowel syndrome. GBS requires intensive care in some 20% of cases, and even in high income countries case-fatality rates are in the range 3-10% (World Health Organisation 2012). Although poultry consumption is widely implicated as a source of *Campylobacter* infection many other factors are thought to play a role and many features of the disease are difficult to explain (e.g. the spring peak). Consequently the epidemiology of *Campylobacter* is acknowledged to be complicated (Nichols et al. 2012) and the transmission pathways for a large proportion of cases are unknown (Tam et al. 2006). In terms of quantifying UK health outcomes following *Campylobacter* infection, the best source of information is the recent Infectious Intestinal Disease 2 study (Food Standards Agency 2011a). This estimates that *Campylobacter* is the major bacterial Infectious Intestinal Disease agent in the UK, leading to over 500,000 cases and 80,000 consultations to general practice annually (Tam et al. 2012). A slightly older study focusing upon England and Wales only was conducted when *Campylobacter* incidence was some two-thirds lower estimated that it led to around 16,000 hospital admissions and 80 deaths (Adak et al. 2005). In 2008 the annual cost of acute *Campylobacter* infection was estimated to be nearly £600 million for England and Wales (BBSRC et al. 2010).Reported *Campylobacter* illness also appears to be increasing. After falls in reported cases in England and Wales in the early 2000's, cases have risen continuously since the middle of that decade (Health Protection Agency 2011). Similar trends are reported in Scotland (Health Protection Scotland 2013) and Northern Ireland (Public Health Agency 2013). These increases have been occurring in spite of biosecurity initiatives to exclude *Campylobacter* from poultry flocks (Allen VM and DG. 2005). *Campylobacter* is identified as a priority pathogen for action by the UK Food Standards Agency (Food Standards Agency 2011b). Historically, Campylobacter exhibits few outbreaks but these have been increasing and are often associated with the consumption of chicken liver pate and parfait.

Campylobacter shows a strong seasonal variability leading many researchers to believe that it may be affected by climate change. This is coupled with numerous studies indicating that *Campylobacter* infections are associated with climate variability. The most commonly reported factor is a positive association with temperature (Kovats et al. 2005; Lake et al. 2009a; Naumova et al. 2007). Association with precipitation has also been reported (Weisent et al. 2014), although not in studies from the UK. Hence *Campylobacter* is likely to be sensitive to climatic factors. However, our understanding of the reasons behind this is limited. For example the response of *Campylobacter* cases to season and weather patterns has been attributed in the literature to a variety of factors such as the cycling of the organisms in natural reservoirs, seasonality of countryside use, changes in food consumption (e.g. barbecuing associated with warmer weather), as well as changing fly populations. *Campylobacter* transmission to humans is complex ecologically with multiple hosts and transmission pathways (Kovats et al. 2005), and currently is poorly understood. Unlike other bacteria Campylobacter does not multiple outside the mammalian gut.

In terms of where the burden of disease falls, higher *Campylobacter* incidence in rural areas is a common finding in many studies, including Canada and USA (Levesque et al. 2013; Pasturel et al. 2013). However there are exceptions such as in New Zealand, where research has identified higher incidence in urban areas with the exception of young children (Spencer et al. 2012). In terms of UK studies, the highest incidence of reported cases has been confirmed in rural areas of England and Wales (Nichols et al. 2012). One of the most detailed UK studies comes from Scotland where although no overall rural excess was found, there was a rural excess in children under 5 years of age (Strachan et al. 2009), to a certain degree confirming the New Zealand findings (Spencer et al. 2012) and those from a Danish study (Ethelberg et al. 2005). Through the use of Multilocus Sequence Typing (a molecular biology technique to characterise microbial species using the DNA sequences of gene fragments), Strachan et al., (2009) were able to attribute *Campylobacter* infections to different sources. They argue that the major source of infection for young children in urban areas is chicken, whereas for rural children ruminant and other avian sources are of elevated importance. Unfortunately, limitations in the methodology prevented a recent all-Ireland study investigating urban-rural differences in incidence (Danis et al. 2009).

A recent study in England and Wales indicates that the burden of illness is higher in less deprived areas (Nichols et al. 2012), although it is worth noting that because this study is based upon reported cases of *Campylobacte*r, some differences may be due to differential reporting between individuals in different levels of deprivation (Lake et al. 2009b). In addition, because this study is based upon an ecological measure of deprivation it does not necessarily imply that a more deprived individual is likely to have lower levels of *Campylobacter.* Similar findings also based upon ecological measures of deprivation been found in Scotland (MacRitchie et al. 2013). No similar work appears to have been undertaken in Northern Ireland.

Gillespie et al. (2008) focussed upon individuals and examined differences in incidence between individuals and their socioeconomic classification (NS-SEC for further details see Bibby and Shepherd 2001) upon *Campylobacter* incidence in England and Wales. It found that *Campylobacte*r incidence in individual's whose work was often done in an office or other professional environment was slightly higher than in those whose jobs related to more manual work. However, incidence was actually highest in people working in semi-routine occupations. A limitation of this study is that an individual's socioeconomic classification, based upon their occupation, may not accurately reflect the socioeconomic status of the household unit within which they live (Chandola et al. 2003).

In terms of ethnicity, Gillespie et al., (2008) found that in England and Wales the burden of *Campylobacter* illness was greatest in the Pakistani population in comparison to the white population. Levels in other ethnic groups such as Indian, Black and Chinese were lower. Again it is important to recognise that some of these differences may represent differences in reporting between communities and not actual disease. Similar work does not appear to have been undertaken in Scotland and Northern Ireland. Turning to gender, Gillespie et al., (2008) found that in England and Wales the burden of disease was slightly higher in males than in females, a result confirmed in Scotland (Smith-Palmer and Cowden 2008). In terms of the age distribution of reported cases (reported cases being just a fraction of the total disease burden) the highest burden appears to fall on infants (<1 year, 120 cases /100k p/a; Gillespie et al. 2008). Incidence then decreases for the ages 2-13 years (74.8 – 15.8 cases /100k p/a) but rises again until age 22 (56.3 cases /100k p/a). Incidence then remains relatively constant between ages 22 and 69 (52.7 cases / 100k p/a) before falling from age 70 onwards (Gillespie et al. 2008). It is worth noting that although incidence may be lower in the elderly, the clinical symptoms and hence the burden of disease are higher in this age group, as well as the youngest age group (Pacanowski et al. 2008). Similar distributions are reported in Scotland (Smith-Palmer and Cowden 2008) and Northern Ireland (Public Health Agency 2013) although due to differing age categories within which *Campylobacter* is reported, exact comparisons are problematic. In terms of trends over time, as the UK population ages the number of reported *Campylobacter* cases has increased in older individuals. However, as well as the absolute number of reports increasing it has also been observed that *Campylobacter* incidence is increasing in older people (Nichols et al. 2012).

The Evidence; *Salmonella*

Infection with *Salmonella* bacteria leads to diarrhoea, fever and abdominal cramps, usually 1 – 3 days after the initial infection. Symptoms generally last for 4-6 days but in some individuals the patient may need to be hospitalised. Although there are a number of potential pathways of transmission for *Salmonella*, the consumption of raw or undercooked eggs or poultry are recognised to be of major importance. Several thousand *Salmonella* species (serotypes) have been identified and these have differing routes of transmission. For example *Salmonella* Enteritidis is commonly associated with eggs whereas *Salmonella* Typhimurium is associated with a wider variety of foods (Lake et al. 2009a). The second, more recent Infectious Intestinal Disease (IID2) survey is the best source of information on the incidence of *Salmonella* infection and estimates that there are just under 39,000 cases of *Salmonella* a year leading to just over 11,000 GP consultations (Tam et al. 2012). This is a large reduction in cases in comparison to the early 1990's. In contrast to *Campylobacter*, *Salmonella* outbreaks are common and so as an illness it is likely to be prominent in public consciousness of food poisoning. Nonetheless *Salmonella* is not a priority pathogen identified by the Food Standards Agency for specific action (Food Standards Agency 2011b). Older research focusing upon England and Wales at a time when *Salmonella* incidence was slightly higher, estimated that in 2000 it led to over 8,500 hospital admissions and 119 deaths (NB more estimated deaths than Campylobacter; Adak et al. 2005). It has been estimated that the average cost of a *Salmonella* case is around £1,000 (Santos et al. 2011). Multiplying this by the estimated community cases produces an estimate of total of UK cost of £39million p/a (This assumes that the costs of reported and non-reported cases are similar and so is probably an overestimate). Although current cases are low new Serovars may emerge with health consequences in the future (Cogan and Humphrey 2003).

In terms of highlighting whether *Salmonella* is higher in rural or urban areas no UK studies appear to have been conducted. No difference has been found in studies in the USA, Germany and France (Arshad et al. 2008; Delarocque-Astagneau et al. 2000; Karsten et al. 2009). One study in New Zealand found higher incidence in rural areas (Lal et al. 2012). This lack of association with local residence and rural areas, where livestock source may be expected to be more prevalent, is backed up by recent microbiological work suggesting that local domestic animals (e.g. cows and sheep) are unlikely to be a major source of *Salmonella* in humans (Mather et al. 2013).

There are also no UK studies examining where the highest burden falls in socioeconomic terms. US studies have found lower incidence among areas with lower educational attainment (Chang et al. 2009; Younus et al. 2007). However, a further study in Canada found higher incidence in areas of low and high median family income (Varga et al. 2013). The relevance of both these studies to the UK is unknown. Again there are no UK studies examining differentiation between varying ethnic groups, but there is some evidence from the US that minority populations suffer a greater burden of *Salmonella* (Chang et al. 2009). Further research confirms these findings and suggests that these higher rates are not due to a single food source, but may be due to patterns of food handling or food purchase among these populations (Quinlan 2013). Again the relevance of these data to the UK is unknown.

In terms of the age distribution of cases there is data available for England in 2010, indicating that the reported highest incidence is in the under 4s (395 cases / million) falling to 113 cases / million in the 5-9 age bracket and 77 cases / million in the 10-14 year age bracket. From age 15 upwards the incidence is fairly constant at between 86 – 93 cases / million (Health Protection Agency 2011). A similar age distribution is reported in Scotland (Health Protection Scotland and Food Standards Agency (Scotland) 2013) and Northern Ireland (Public Health Agency 2013). Although changes in age distribution have not been reported, the increasing use of proton pump inhibitors may increase susceptibility to *Salmonella* (Leonard et al. 2007). The use of these in the older population is increasing.

Climate Change Impacts; *Campylobacter*

This review has presented evidence that *Campylobacter* is associated with weather; incidence is greater in the summer and during periods of warmer weather incidence is also elevated. Therefore, it would seem a logical extension to assume that climate change would have an impact upon this disease. Although European Infectious Disease experts share a broad agreement that climate change will impact upon *Campylobacter*, this does not appear to be the case in the UK (Semenza et al. 2012). However, this is somewhat at odds with other UK sources (e.g. North West Public Health Observatory 2012) which do suggest a moderate impact. This ambiguity may be due to uncertainty over the exact pathways through which weather affects incidence. Weather may be associated with *Campylobacter* but we are unsure as to why. However, outside the UK there are some projections of changes in *Campylobacter* as a result of climate change. Cullen (2009) projects increases in *Campylobacter* in Ireland of between 2 and 3%. A study in Montreal forecasts that by 2055, *Campylobacter* could increase 23% resulting in about 4,000 additional cases (Allard et al. 2011). However, given that such studies effectively treat the mechanisms involved as a “black box” it could be argued that these projections are highly uncertain. Until there is more understanding of the causal mechanisms, estimating future *Campylobacter* incidence appears somewhat premature.

Schijven et al. (2013) examines the use of a decision support tool for determining the links between *Campylobacter* and climate change. Instead of simply examining associations between weather and *Campylobacter* they use a Quantitative Microbial Risk Assessment approach and split their analysis into a number of pathogen pathways (drinking water, bathing water, oysters and chicken fillet). Within each pathway a number of models are used to estimate climate change impacts. For example the chicken fillet pathway consists of a prevalence in poultry flocks module, a consumption of chicken module and a dose response module. The results indicate that *Campylobacter* cases associated with poultry consumption are likely to increase under climate change whereas risks associated with the drinking water pathway are likely to decrease due to increased inactivation in warmer temperatures. Current UK research (www.enigmaproject.org.uk) is attempting to analyse the environmental influence on a number of transmission pathways and use these to predict changes in disease due to climate change. Such disaggregated approaches appear to offer a potential way forward.

Climate Change Impacts; *Salmonella*

Like *Campylobacter* there are strong links between *Salmonella* and the environment especially ambient temperature. However, in contrast to *Campylobacter* there is a much clearer biological mechanism explaining why higher temperature leads to a higher incidence of *Salmonella*. At elevated ambient temperatures *Salmonella* reproduction is enhanced. However, in spite of this biological mechanism, UK Infectious Disease experts still do not consider *Salmonella* to be one of the diseases most likely to be affected by climate change (Semenza et al. 2012). This may be because control measures appear to have substantially reduced the disease burden since the early 1990's to the point where it is not considered a priority pathogen.

Globally there have been some attempts to model future *Salmonella* increase, notably in Australia. A recent Australian study estimated by 2050 an extra 4000 – 7000 *Salmonella* cases annually in the country (Bambrick et al. 2008). A second Australian study found that, assuming that all other factors remain constant, salmonellosis might increase by up to 33% by 2030, and 56% by 2050 in South Australia (Zhang et al. 2012). A recent study in Europe under the climate change A1B scenario, estimated that the number of *Salmonella* cases could increase by between 5,600 and 6,800 (5.6 – 6.8%) by the 2020's and by 9,300 to 16,900 (9.3 – 16.9%) by the 2080's depending upon the level of mitigation. No specific details are provided for the UK although the study does highlight the UK as one of a number of countries where the largest increases in cases occurs, relative to population (Kovats et al. 2011). It is not clear from the report whether this is a real effect or due to differential reporting across the EU.

Climate Change; Other Potential Impacts

In addition to *Salmonella* and *Campylobacter* other intestinal infectious diseases vary seasonally or are sensitive to weather conditions. Consequently climate change could affect many other intestinal infectious diseases. This could occur through indirect mechanisms such as changes to animal husbandry or changes to the ecological systems in which these organisms live. However, currently there is a lack of evidence on which organisms are likely to be affected and what the public health importance of these may be. For example recent work has indicated that warming sea-temperatures are driving vibrio disease in temperature regions (Baker-Austin et al. 2013) but the public health consequences for the UK remain unclear. There are also many different mechanisms through which pathogen prevalence changes could occur, such as changing animal husbandry affecting animal to animal transmission, or new weather patterns altering the survival of pathogens in the environment (FAO 2008). As a result of this complexity identifying systems and pathogens most likely to be affected is nearly impossible (FAO 2008). It is suggested that pathogens with low infective doses are most likely to be affected by climate change (e.g. enteric viruses, *Shigella* spp., enterohemorrhagic *E. coli* strains and parasitic protozoa). Those with significant environmental persistence (e.g. enteric viruses and parasitic protozoa) are likely to be most affected alongside pathogens with recognised stress tolerance responses to pH and temperature (e.g. enterohemorrhagic *E. coli* and *Salmonella*) (FAO 2008).

Other Food-borne Effects

In addition to gastrointestinal infections climate change may have other impacts on food quality. For example within agriculture one impact of climate change may be changes to the seasonal patterns and abundances of pest species and plant diseases both in the UK and globally. Boxall et al., (2009) highlight that these changes will lead farmers to alter their use of herbicides, pesticides (Hirschi et al. 2012) and fungicides in response. This may alter the levels of these residues in food. However, predicting the exact consequences is challenging, as highlighted by Chen and McCarl (2001). This study examined the likely influence of climate changes upon pesticide usage in the US and found that the response varied between crop type and also between geographical location. Their results indicated that in overall terms, pesticide usage would increase under climate change. The same could be argued for livestock management, as higher temperatures may increase the incidence of vectors, hosts or even new pathogens in livestock (Harrus and Baneth 2005), leading to altered use of biocides and veterinary medicines (Kemper 2008), resulting in changed levels of residues in food.

In addition to changing farming practices, climate change may also affect the transport of food contaminants. Changing soil properties may affect the bioavailability of heavy metals (Boxall et al. 2009), while more extreme weather could increase the transport of contaminants by flooding. Climate change might affect the rate of transport of contaminants and also the type of material being transported. For example, the extreme flooding associated with hurricanes Rita and Katrina in the US were found to have mobilised previously untouched highly contaminated urban soils (Plumlee et al. 2007).

Another likely impact of climate change is rising food prices. A recent study, the Inter-Sectoral Impact Model Intercomparison Project, estimates that by 2050 globally crop yields will decline by 17% but with differences depending upon region, climate model, crop model and crop type (Nelson et al. 2014). In total, taking into account farming adaptation (varying input use and management practices, and expanding production into new areas) an overall yield reduction of 11% is projected. This is estimated to produce a 20% increase in crop prices but this effect will vary by region and crop type.

If food prices rise under climate change then this is a public health concern as rising prices often result in less healthy food choices (Cummins and Macintyre 2006). Of particular concern is that highly processed foods with high sugar and fat contents (i.e. less healthy foods) are often cheaper than healthier alternatives. More processed food is also less sensitive to food price rises as the cost of the raw ingredients is a smaller component of the total cost. Therefore, increases in food prices may lower the quality of dietary intakes and lower nutritional status. It could also elevate obesity risk. These impacts often fall hardest upon the poor (Green et al. 2013) and so have the potential to elevate current inequalities in obesity. For example in the UK, obesity rates are highest amongst women of lower social class (National Obesity Observatory 2012) and rising food prices may increase these inequalities. For men there appears to be less inequality in obesity prevalence. Further impacts of climate change upon the nutritional quality of food are presented elsewhere (Lake et al. 2012).

Climate Change Adaptation

In terms of future risks to food from climate change and how these may be adapted to, it is important to recognise that agriculture and food processing are strictly regulated to minimise food-borne disease risks in the UK. For example the EU Food Hygiene Regulations (EC 2004) sets down basic food hygiene rules across the EU. Regulations such as these provide the UK with resilience against any changes in food-borne disease threats associated with climate change. In addition, the monitoring of the levels of disease-causing agents, such as *Salmonella* and *Campylobacter* in food, is essential. Across the UK this is the responsibility of the Food Standards Agency, Public Health bodies (Public Health England, Public Health Wales, Health Protection Scotland, and the Public Health Agency for Northern Ireland) and other public and private bodies. The monitoring of food quality is vitally important for food produced outside of the EU where the UK has less control on production methods.

Financial and logistical constraints mean that monitoring can only test a tiny fraction of food, highlighting the importance of HACCP (Hazard Analysis and Critical Control Point) type risk assessment along the entire food chain. This could be used to find areas experiencing notable climate change or rapid adaptations by agriculture. In such areas, changes to food-borne disease risks are most likely.

Resilience against and adaptations to food-borne disease threats benefit public health through reduced illness. They also have potential benefits for the agricultural sector, manufacturers and retailers through reduced costs associated with product recalls and loss of consumer confidence in the UK and worldwide. However, reducing food-borne illness often costs money and it is important to ensure the cost-effectiveness of any interventions.

The monitoring of human disease associated with food consumption is also important in terms of adaptation. This was recently highlighted by the VTEC O104 outbreak in Germany in 2011 which was identified through health surveillance (Chattaway et al. 2011) and led to measures to control the disease outbreak. In the UK Public Health Bodies of the UK identify food-borne disease. These bodies identify food-borne disease outbreaks as well as longer term trends in incidence. An excellent example of health surveillance leading to adaptation is the report into the deaths of 19 people from *Salmonella* Typhimurium in 1984 at the Stanley Royd hospital. The report into this outbreak led to food safety improvements across the UK (Hugill 1986). More problematic are incidences of food borne illness imported from overseas where the UK has less ability to investigate and act. However, though the EU wide Rapid Alert System for Food and Feeds the UK is alerted to food safety issues as they arise within other member states.

If human disease outbreaks are detected or food monitoring detects abnormalities, then food chain traceability is another essential element of adaptation to respond to issues as they arise. This is essential because, as highlighted by the recent horse meat issue, food chains can be complex (Food Standards Agency 2013). This is covered by the EU General Food Law Regulation which contains requirements for food chain traceability.

Climate change moves the climate into unknown territory and this could make current regulations and food monitoring inadequate to deal with future threats. Horizon scanning is one way that such threats could be anticipated. This highlights the need for horizon scanning to predict threats and the importance of groups such as the Human Animal Infections and Risk Surveillance (HAIRS) group which identify and evaluate threats posed by new or re-emerging infectious diseases. Given the large uncertainties created by climate change systems such as food early warning systems (Marvin et al. 2009) or food risk detection systems (Groeneveld et al. 2008) play an important role in mitigating and adapting to climate change induced food threats.

Conclusions / Evidence Gaps

This paper has highlighted many pathways through which food may be affected by climate change. However, it has also highlighted that many of these impacts may be indirect and that only a few of these potential impacts have been examined rigorously. Consequently there is a huge degree of uncertainty as to what the overall impact of climate change will be. Clearly there is much future work to be done and it is possible that some of the most notable consequences (e.g. emergence of new bacteria strains) are largely unknown.

One of the highlighted illnesses in this paper is Campylobacter, an important cause of gastrointestinal illness and an increasing public health issue. Although there is reasonable evidence that incidence is linked to the environment and weather, uncertainty as to the precise mechanisms makes it difficult to assess the likely impact of climate. Should climate change increase incidence, and should this follow the current patterns of illness then individuals of higher socioeconomic status and those living in more rural parts of the UK are most likely to be affected. Older and younger individuals are most at risk. Given the uncertainty as to the precise mechanisms through which the environment and weather affect Campylobacter, more research is urgently required.

Salmonella is another illness examined which exhibits positive associations with ambient temperature. In contrast to Campylobacter there is a clear understanding of some of the mechanisms underlying this association. So although climate change may increase incidence, because the incidence of *Salmonella* is declining in the UK these changes are likely to be relatively small. Any changes are likely to affect the young and old disproportionally.

It is argued that the UK has a reasonable capacity to adapt to any changes in food safety associated with climate change. Agriculture and food processing are highly controlled industries and regular monitoring of food quality is undertaken. In addition, monitoring of disease outbreaks and sporadic cases occur and such information is often used to improve public health. Therefore, should climate change increase disease incidence it is likely that the UK will be able to reasonably adapt to the impacts. However, in a new climate regime the ability of current regulations and monitoring to deal with new threats is unknown. This report highlights horizon scanning or real time food early warning systems as useful tools as we move into a more uncertain future.

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