Climate Change and Foodborne Illness: Implications for Policy

Introduction

The global climate is changing in terms of average temperature, sea level rise, and the frequency and severity of extreme weather events. These inevitable changes will be significantly heightened without an earnest, coordinated, international mitigation strategy. In the realm of food safety, long-term deviations in climate will exacerbate what is already a globally uneven challenge of combating foodborne disease.

While academic and governmental researchers have made various policy suggestions to bolster foodborne disease prevention in light of climate change predictions, the ability and willingness of legislators to prioritize this issue is hampered by various forces. In addition, countries with different levels of socioeconomic resources face qualitatively divergent challenges to the implementation of proactive policy. The interaction of regulation, investment, and technology on a global scale complicates the implementation of necessary preventative actions to the extent that a clear path forward for the food safety profession has yet to emerge. Research in the fields of food safety and risk management suggests that a coordinated international prevention and monitoring system utilizing advanced pathogen identification techniques will be the most productive use of available resources to mitigate the negative impacts of climate change on foodborne illness incidence.

Climate Predictions

Climate change has become a political controversy in the United States. However, there are authoritative voices on both sides of the dichotomy calling for serious attention to the issue. In a 2014 senate hearing on climate change mitigation, four former EPA leaders under Republican presidents spoke in favor of stronger climate-related policy. William Reilly, who served under President G.W. Bush from 1989 – 1993, defended the robustness of climate change models in his opening statement:

> "Today the models are far more reliable and they are buttressed by literally thousands of credible scientific studies documenting changes underway.…Change is underway, and we can expect to see many more disruptions: more intense storms, more wildfires, the spread of pests and diseases—Dengue fever will arrive in America—storm surges that overwhelm coastal communities, heat waves and other impacts on our health, water resources, and food production, and on other sectors of our economy. The longer we delay, the more adverse the impacts will be, and the more expensive it will be to address it," (CSPAN 2014).

The Intergovernmental Panel on Climate Change (IPCC) asserts that greenhouse gas (GHG) emissions are driving these changes; the level of anthropogenic GHG emissions from 2000 -2010 was not only the highest in human history, but grew at a higher rate than in the three previous decades. Authors point to a doubling of CO_2 emissions in that time, which accounts for 76% of total GHG emissions, as a major contributor to the increases (IPCC 2014).

From a temperature standpoint, the change underway over the next 75 years is predicted to reach between 3.7°C – 4.8°C (6.7°F – 8.6°F) in global mean surface temperatures increases compared to pre-industrial levels (IPCC 2014). This stark estimate is based on current growth in the global population and economic activity assuming no additional mitigation efforts are made by the international community. Year-to-year extreme temperature recordings are also on the rise. In 2012, 15.3% of the earth's surface experienced a 1st, 2nd, or 3rd warmest year on record, while no area experienced a 1st, 2nd, or 3rd coldest year (BAMS 2014).

Temperature change alone is only one of the expected impacts to be felt due to climate change. An increase of extreme weather events is also anticipated, although to date it has been difficult to directly attribute severe weather to specific climactic shifts (BAMS 2014). Meteorologists use complex analytical models to evaluate which extreme weather events can be considered directly related to climate change. Complicating such analyses, some extreme weather events can be seen as both globally common and globally rare. For example, a "100-year" heat wave will be rare for a given location, but in an average year 1% of the earth's surface would be expected to experience such record-breaking heat. In contrast, the occurrence of an EF-5 tornado is globally rare for a given year, and changes such as sea ice loss are extreme but limited to a specific region (BAMS 2014). Furthermore, some weather events, which would not be considered rare in themselves, may cause more severe outcomes due to underlying climate shifts. The American Meteorological Society points to heavy rainfall in Northern China in 2012, which was not historically severe but led to extreme flooding due to the significant climactic drying trend seen in that region since 1970's (BAMS 2014).

Climate and Foodborne Illness

Infectious Disease and the Agricultural Environment

From an epidemiological perspective, the prevalence of infectious disease can be viewed as a product of host, agent, and environment. Therefore, any significant change in the food production environment should be expected to create change in foodborne disease incidence and spread (Jacxsens et al., 2010, Hedberg 2011). Global temperature increases, sea level rise, and extreme weather events are all likely to impact the geographic range of infectious diseases, including those that are foodborne. Since agriculture is intrinsically and dependently linked to climate, water and foodborne pathogens are of particular concern.

Comprehensive review within the academic community has identified potential increases and geographic shifts in the prevalence of foodborne illnesses due to the effects of climate change (Altizer et al., 2013, Lal et al., 2013, Sterk et al., 2013, Semenza et al., 2011, Tirado et al., 2010, Boxall et al., 2009, Miraglia et al., 2009, Koopmans and Duizer, 2004, Patz et al., 2000). This includes bacterial contaminants such as *Salmonella*, *Campylobacter*, and *Vibrio* spp., arboviruses, parasitic agents, and even chemical hazards including mycotoxin production, increases in agricultural chemical use, and nutrient runoff (Tirado et al., 2010, Boxall et al., 2009).

Climate and Biological Hazards

Seasonal temperature changes are known to influence incidence of many biological foodborne hazards, such as disease-causing *Salmonella* spp.; researchers anticipate global temperature change to have a similar effect (Patz et al., 2000). On a regional scale, salmonellosis rates have also been shown to increase at warmer temperatures, responding with a 5 – 10% upsurge in illnesses for each one-degree Celsius increase in weekly average temperature (Kovats et al., 2004).

Runoff leading to biological contamination of agricultural water sources and land is of concern in the context of the increasing intensity of rain events documented as the climate changes. Flooding and heavy rain can overwhelm water treatment systems and lead to biological contamination of crop fields and waterways (Boxall et al., 2009).

Pathogens that are spread via blood-feeding arthropods are also extremely sensitive to change in weather and climate due to the reliance on cold-blooded vectors in their spread (Gubler et al., 2001). Additional transmission factors have also been found to be effected by temperature, for example dengue virus replication within the vector species (Gubler et al., 2001). Vector-borne diseases of concern include malaria, yellow fever, dengue fever, West Nile Virus and other types of vector-borne viral encephalitis.

Notably, malaria was a common disease in the United States in the 19th century until it was all but eliminated by 1950 due to urbanization and improved infrastructure, nutrition, and access to health care (Gubler et al., 2001). Since malaria continues to be a significant health issue in other parts of the world, this points to the importance in infrastructure and public health measures in stemming disease spread in the future.

Climate and Chemical Hazards

The impacts of agricultural chemical hazards are expected to increase with climate change, due to changes in pest and disease range, severe rain events, and use of antibiotics in livestock (Boxall et al., 2009).

Svobodová et al. (2014) found a significant geographic shift in crop pest activity by 2055 across Europe by modeling expected changes in temperature and humidity. Such shifts may lead to an increase in the use of agricultural pesticides, herbicides, and fungicides. Some researchers predict pesticide exposure by humans will increase in terms of spray and transfer drift (aerial), drinking water, and from food. (Boxall et al., 2009). However, the reaction of farmers to a changing environment in regards to pesticide application will undoubtedly vary depending on their resources. High income countries have generally decreased pesticide applications over the past twenty years after peak usage in the 1980's, while middle-income countries have imported and applied rapidly increasing amounts (Schreinemachers and Tipraqsa, 2012).

Pesticide use varies greatly within economic categories as well. For example, pesticide imports in Central America from 2000 – 2004 ranged from 1.0 kilograms active ingredient per cultivated hectare in Nicaragua to 20.3 in Costa Rica. The annual average across Central American countries within that time was 4.3 kg/ha (Bravo et al., 2011). Meanwhile, in the high income bracket, the reduction in use from the 1980's through the 2000's included a 23% lowering for the United States versus an impressive 68% by Sweden (Fernandez-Cornejo et al., 2014, Bravo et al., 2011).

The dryer summers, increasingly severe weather events, and rising atmospheric carbon dioxide levels anticipated as a result of climate change will likely affect farmers' approach to agricultural chemicals, but only within the existing context of current pesticide use. Unfortunately, the governments of the developing economies experiencing a surge in use today typically provide fewer resources towards tracking and regulating agricultural chemicals, which can lead to inappropriate use and exacerbate negative impacts (Schreinemachers and Tipraqsa, 2012, Bravo et al., 2011, Garcia-Santos et al., 2010).

In addition, increased agricultural runoff due to heavy rains can exacerbate nutrient pollution, even without an increase of application. The use of nutrient addition (fertilizer) is not anticipated to increase in response to climate change. However, runoff and concentration within stressed waterways can increase the level of pollution caused by these applications (Boxall et al., 2009).

As weather conditions become warmer or more extreme, livestock health will be increasingly strained either by outdoor conditions or by being increasingly housed indoors (Cogliani et al., 2011). This could exacerbate widespread use of antibiotics in animal production. Although antibiotics are an important tool in animal and human health care, the overuse of antibiotics can select for antibiotic-resistant pathogens, which can be an issue in human disease as well as livestock disease (Cogliani et al., 2011; Oliver et al., 2011).

Global Distribution of Foodborne Diseases

Few statistics are currently available on average annual incidences of specific foodborne diseases on a global scale. In 2006, the World Health Organization launched an international research agenda to estimate the global burden of foodborne disease in an effort to support evidence-based policy making on the issue (WHO, 2014). The full report, due out in 2015, will be extremely valuable in assessing the global distribution of foodborne illness in annual cases and deaths, serving as a critically needed first step in tracking the progression of these diseases and relative vulnerability of different populations.

As an illustration, preliminary results include global assessments of the distribution of nontyphoidal *Salmonella* gastroenteritis. Authors estimated that 80.3 million of 93.8 million (85.6%) of annual *Salmonella* gastroenteritis cases are foodborne, and approximately 155,000 (0.17%) of total cases led to death (Majowicz et al., 2010). The distribution of cases skews heavily to Eastern/Southeastern Asia and Central Europe, with 1.49% and 0.95% of the entire population, respectively, suffering from the illness in a given year. This is compared to only 0.24% in Western Europe and 0.51% in North America. While consequently the number of deaths due to nontyphoidal *Salmonella* is a smaller percentage of the population in the latter regions, the rate of death per number of cases is equivalent across the four areas, ranging from 0.164% across Asia to 0.167% in Western Europe (adapted from Majowicz et al., 2010).

Mitigating Negative Impacts

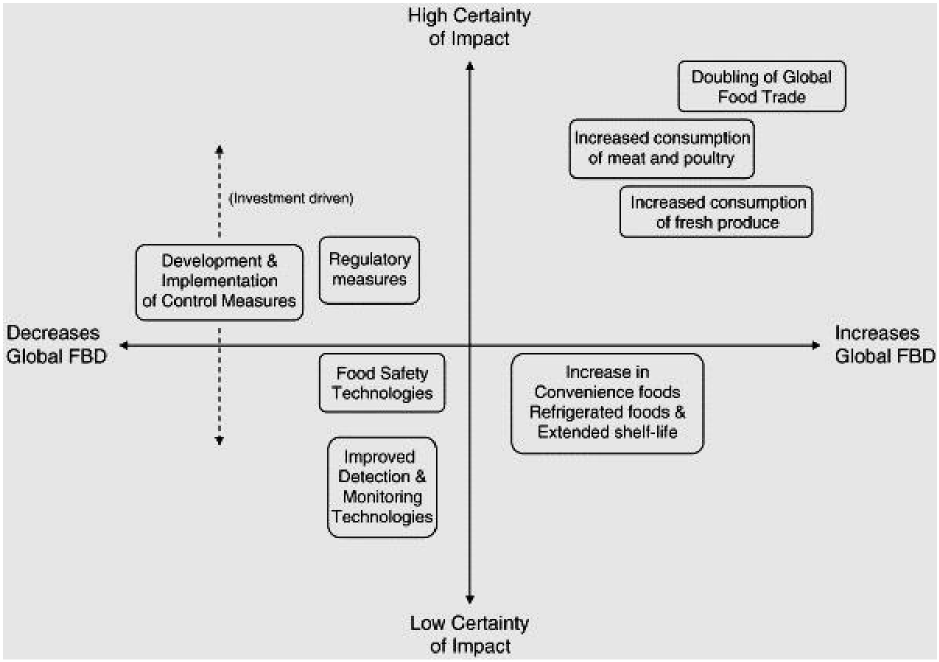
Nearly 10 years of research under the WHO Global Burden of Foodborne Disease agenda will hopefully shed new light on foodborne illness challenges across diverse regions. Understanding the current realities of illness distribution, which reflect dynamic interactions of climate, infrastructure, and health policy, will provide a basis for evaluating the potential impacts of climate change on foodborne illness in the future.

Directions for Policy

Need Areas and Institutional Obstacles

The potential economic and social impact of climate change-related disease risk is taken so seriously by international institutions that even the World Bank has commissioned research on the subject (World Bank, 2014). The resulting policy suggestions focus on improvement of surveillance systems as key to both outbreak response and predictive modeling. Additional recommendations on need areas from academic researchers include development of predictive epidemiological models, increased epidemiological surveillance, improvement of detection methods to aid in monitoring, and improved collaboration among agencies and services (Tirado et al. 2010, Quested et al. 2010, World Bank 2014). The exact results of changing relationships between environment, agents, and hosts will not be completely predictable and will vary greatly from region to region. This reinforces the importance of a focus on surveillance and detection in food safety policy.

However, policymakers must consider climate and environmental risks within the interrelated contexts of social, economic, political, and technological factors. Quested et al. (2010) predicted impacts of various regulatory and technologic developments on microbial-based foodborne illness, finding the most salient approach for reducing future foodborne disease burdens lays in the development—and effective implementation—of control measures for pathogens within the food system (see figure below). In this analysis, detection and monitoring are put to best use in assisting the development of these control measures. The authors underscore the importance of investment to develop these methods as well as food risk management systems including Hazard Analysis Critical Control Point (HACCP).



Visual representation of the key factors likely to impact on foodborne disease. Whether factors are likely to increase or decrease the global burden of foodborne disease is plotted against the certainty of their impact. (Quested, et al., 2010).

Obstacles facing governments in the development and implementation of food safety policies can include lack of expertise and infrastructure—such as water treatment facilities or well-equipped monitoring labs—domestic pressures of a civil, political, or economic nature, other overwhelming public health challenges, or even widespread noncompliance to existing food safety regulations (Akhtar et al. 2014, Zach et al., 2012, Quested et al., 2010). Furthermore, the socioeconomic status of a population can be determinant of overall vulnerability to foodborne disease. While these challenges are more prevalent in nations with developing economies and infrastructures, so-called "developed" countries suffer from unique impediments in ensuring the safety of their food systems.

In the United States, eight agencies within no less than three separate administrative departments (USDHS, USDHHS, and USDA) have some role in monitoring the safety of imported foods on the federal level alone. The inspection rates and level of enforcement authority vary greatly between these agencies, and coordination of information and resources is insufficient to meet the challenges inherent to a piecemeal regulatory system. Examples of this lack of coordination include the failure to share relevant inspection results among and even incompatible computer systems (Zach et al., 2012).

Food Safety Policy in the 21st Century

However, major regulatory change is on the horizon in the US. Once implemented, the Food Safety Modernization Act of 2011 (FSMA) will be the most comprehensive overhaul to food safety legislation in seventy years. While enforcement improvements are included in this law, such as granting the FDA the mandatory recall authority, changes do not extend to the point of consolidating the food safety regulatory or inspection framework in the country (FDA 2014, "Food Safety Legislation Key Facts"). Broadly, the currently proposed rules under the FSMA focus on field hygiene and water testing in produce production, and hazard-based (HACCP or similar to HACCP) written safety plans for food processors.

As global trade in food has increased over the past decade, other nations with developed economies have moved to consolidate their food safety regulatory activities in contrast to the US approach. The political will for these changes in Europe may have been bolstered by consumer perceptions that the deadly outbreaks of Bovine Spongiform Encephalitis ("mad cow disease") in the 1990s were mishandled due to fragmentation of the food safety regulatory system at that time (Zach et al., 2012).

These events led to the establishment of both an independent European Food Safety Authority and an official rapid alert system to communicate potential outbreaks across the EU. Since 2006, the European Union has also mandated that foods for human consumption meet microbial standards based on scientific risk assessments (Cocolin, 2011). The strengths of the European rapid alert system (Rapid Alert System for Food and Feed, or RASFF) include mandatory recall authority, the ability to share information among governments, industry, and consumers across member states, and an emphasis on product testing as part of an active monitoring regime for contaminants (Zach et al., 2012).

Food safety legislation in the European Union, United States, and that authored by the International Standards Organization over the past ten years has emphasized the importance of consistent batch traceability throughout the food supply chain (Ruiz-Garcia et al., 2010). Accordingly, researchers have proposed new web software and tracking technology including RFID systems. However, regulations proposed enforcing the latter have met resistance among some farmers especially in the US (USDA 2010, USDA APHIS 2014).

Notably, livestock traceability rules under the FSMA in the US have been reduced in scope due to industry skepticism. According to the USDA (USDA 2010):

> "the basic tenets of an improved animal disease traceability capability in the United States…will:
>
> - Only apply to animals moved in interstate commerce;
> - Be administered by the States and Tribal Nations to provide more flexibility;
> - Encourage the use of lower-cost technology; and
> - Be implemented transparently through federal regulations and the full rulemaking process."

This represents a drastic cut in the reach of the initially published rules, which would have applied the National Animal Identification System (NAIS) to intrastate producers as well as interstate commerce. While enforcing recalls in future outbreaks will surely be hampered by the lack of mandatory livestock trace back, the change reflects controversy within and outside of meat producing industries. Concerns among farmers and ranchers ranged from property rights to the expense of electronic tagging, while meat systems with existing traceability industries such as pork and turkey production, expressed support for a mandatory national livestock identification system (USDA APHIS, 2009).

On a wider global scale, the World Health Organization has released a three-pronged, decade-long plan to address international foodborne and zoonotic disease risks (WHO 2013). This is in addition to the undergoing Global Burden estimate described above. The strategic plan strives to reduce the impact of these diseases among member states by providing scientific advice and guidance, increasing risk communication and health promotion efforts, and encouraging the development of risk-based food safety systems within member nations. Specific activities planned under this project include risk assessments, policy guidance, and support for food safety inspections (WHO 2013).

Market-Based Initiatives

An alternative to reliance on governmental regulation of food safety is retailer-mandated certification systems, which are in place across Europe and North America. Such market-based programs provide safety certifications to farms abiding by food safety guidelines. The voluntary Good Agricultural Practices (GAP) program in the US may be seen as a combination of the governmental and market models; guidelines are provided by the USDA but certification to date has been voluntary. On an international level, retailers in developed economies may also use these certification programs to validate the safety of imported foods. Herzfeld et al. (2011) found that among importers from developing economies, the number of farms certified by programs such as GlobalGAP and BRC Food Technical Standard is positively correlated with an exporting nation's strength of institutions and the presence of existing trade relations with the home country of the standards. While no evidence was found to suggest developing nations were excluded from such agreements with international retailers, the certification of farms was not randomly or even distributed across potential exporting nations (Herzfeld et al., 2011).

Developments in Technology

There are many support technologies for the identification and tracking of pathogens throughout a food production system or following an illness outbreak. As governments, institutions, and businesses weigh investment priorities, advancements in these technologies is slowly making them accessible to a broader set of applications. International organizations will also need to evaluate technologies in the context of balancing the sensitivity, scope, and utility of a method with its expense and infrastructure requirements (World Bank 2014).

Pathogen Identification

The World Bank describes key attributes of a successful surveillance system as having high detection sensitivity and specificity, simplicity, adaptability to be scaled to event impact, and cost-efficiency. In addition, the geographic reach of surveillance in practice can be improved by field diagnostic kits now available for some diseases, while active monitoring programs can be assisted with geospatial and information technology (World Bank 2014).

Traditionally, testing of foods for pathogens has relied on growing cultures from food samples on selective media plates. This method has drawbacks however, such as the relatively long time necessary to culture and analyze organisms, the potential to provide false negative results if pathogen cells are stressed, and a low sensitivity if cell numbers are very small. This can pose a risk of missing pathogens that may have a very low infective dose and still cause a public health problem even if not observed in culture (Cocolin, 2011). To address some of these limitations, much attention has been brought to developments in molecular methods such as polymerase chain reaction (PCR). This DNA-detection method does not require isolation and culturing of cells for identification (Cocolin, 2011).

A major advantage of PCR is the ability to identify the presence of the target organism whether or not the population was active at the time of sampling. This avoids the risk of false negative results possible with culture-dependent methods (Cocolin, 2011). However, this benefit must be considered in the context of the target pathogen; if the presence of only dead cells does not pose a public health risk, a positive PCR result may be misleading. It is also relatively quick compared to culturing, and can be very specific (i.e. low risk of false positive result) to a target organism if executed with the correct primers (Cocolin, 2011).

Innovations in PCR technology such as the additional ability to quantify target organisms and monitor specific genes that indicate an organism's reactions to environmental stimuli have greatly increased the technique's potential applications in food safety monitoring. The method ameliorates but does not completely solve the issue of identifying pathogens present in small numbers (Cocolin, 2011). Furthermore, Real-Time PCR is one of the only means of identifying enteric viruses as there is no effective culturing method. However, identification of viral and parasitic pathogens in food has yet to expand far beyond research laboratories (Jacxsens, 2010).

While the benefits of a rapid, sensitive, and specific diagnostic method have the potential to advance the monitoring of foodborne illness outbreaks, the demands of cost and training will be prohibitive in many countries. Major investments would be necessary by governments to incorporate qPCR in a comprehensive monitoring regime, and may serve to further concentrate the availability of lab services as opposed to making them more accessible in underserved regions (Cocolin, 2011).

Risk Assessment

Science-based risk assessments of agriculture and food processing systems have received attention and research over the past few years, including high priority status in the US FSMA. It has already become common practice in many regulatory organizations; agencies including the EPA, FDA, and OSHA commission risk assessments for various relevant hazards (Haas, 2014).

Quantitative Microbial Risk Assessment (QMRA) utilizes the risk assessment framework in the identification of potential microbial hazards in a given food system (Haas et al., 2013). QMRA models are developed to be site- and pathogen-specific. This includes identifying potential hazards, evaluating the health effects of varying levels of the hazard, and determining the probable exposure in the human population.

Other researchers, such as Schijven et al. (2013) have developed pathogen-specific modeling tools that evaluate infection risk in the context of current and projected climates. The Schijven et al. research was funded by the European Center for Disease Prevention to develop a risk evaluation tool to aid professionals in agriculture and water treatment in long-term decision-making. Founded in QMRA principles, the tool incorporates climate attributes of annual temperature and precipitation ranges, as well as number of heavy precipitation events. For example this system can evaluate the increased risk of Norovirus infection in a wastewater treatment system by incorporating projected annual flooding capable of system overflow, among other variables.

QMRA is inherently dependent on solid predictive microbiology estimates (Haas et al., 2013). While this will be available for many scenarios of known pathogens in agriculture in the current environment, a more complex analysis is necessary to adapt these predictive models to estimate exposure under novel climate conditions.

Modeling for Food Safety Management

Researchers including the IPCC have been grappling with the balance of developing adequately comprehensive climate scenario risk models with those that can be flexible enough to also reflect various levels of climate change in response to mitigation activities (Jacxsens, 2010).

Jacxsens, et al. (2011) developed and have made publicly available online software to support food producers in maintaining and validating food safety management plans. The diagnostic function of the tool set helps the producer evaluate the level of risk inherent in the food or processing environment, and matches that risk to a suggested level of pathogen monitoring. The authors even suggest the implementation of their diagnostic program by governments to evaluate the potential impacts of specific regulations on the risk level of a given food chain. These tools were validated themselves by implementation in meat, dairy, and produce production systems (Jacxsens, et al. 2010, 2011).

The software described by Jacxsens et al. (2010, 2011) was developed as part of a five-year, €11 million international food safety project commissioned by The European Commission from 2005 to 2010. The project funded research to "design new molecular-based methods to detect, predict and characterise pathogens along the entire food chain," (European Commission, 2005). Now, in 2014, the Commission's programming is centered around a "European Bioeconomy" with much less emphasis on food safety projects (European Commission 2014).

<u>Conclusion</u>

While countries with few socioeconomic resources suffer from significant challenges in preventing the spread of foodborne disease, such as lacking infrastructure and pre-existing heavy infectious disease burdens, nations that do possess the assets to lead innovation in the field must often first overcome domestic challenges including fragmented food safety systems and political resistance. Technologies and tracking software are continuously advancing and adapted to use in foodborne disease prevention, but implementation of such methods on a global scale appears all but impossible under the current unequal distribution of relevant infrastructure. The focused efforts underway by international institutions to track the global distribution of these diseases and coordinate a food safety response are perhaps the most promising collaborations to move decision-making on the topic forward on a global scale.

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