CLIMATE CHANGE: IMPLICATIONS FOR FOOD SAFETY

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The positions and opinions presented are those of the authors alone, and are not intended to represent the views of FAO.

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1. INTRODUCTION

1.1 Objectives and Scope

The paper aims to identify potential impacts of anticipated changes in climate on food safety and their control at all stages of the food chain. The purpose is to raise awareness of the issue and to facilitate international cooperation in better understanding the changing food safety situation and in developing and implementing strategies to address them.

While this paper takes a broad look at a number of food safety issues and considers possible implications of climate change – it does not provide exhaustive treatment of the topic. The food safety issues covered include: agents of food-borne disease with specific consideration of zoonotic diseases, mycotoxin contamination, biotoxins in fishery products and environmental contaminants with significance to the food chain. The paper also highlights the need for adequate attention to food safety in ensuring preparedness for effective management of emergency situations arising from extreme weather events. There is much uncertainty about possible food safety implications of climate change. This paper discusses some expected effects that are supported by data; it also considers other issues that are largely speculative.

1.2 Food Safety and Its Management: The Broad Context

Assuring food safety is a complex task. Food safety hazards can arise at any stage of the food chain from primary production through to consumption. Assuring food safety therefore entails the active involvement of a number of stakeholders performing agreed, clearly defined – though necessarily interacting – roles.

This universe of actors and actions is governed by rules –food laws and regulations – and is collectively known as the food control system. The ultimate goal of this system is to ensure that food presented to consumers is safe and honestly presented. Governments face a number of constraints to running effective food control systems: primarily financial and human resource constraints. It is in the interest of all stakeholders to optimise the efficiency of the system in order to make the best possible public health impact with limited resources available. Major principles that underlie strategies for improving the efficiency and effectiveness of food control are:
- that efforts are focussed on issues that pose the greatest risk;
- that the responsibility for producing safe food rest unambiguously with the food businesses who are best placed to design and implement controls at the most appropriate point within the food production systems to ***prevent*** or minimise food safety risks;
- that government establish food safety requirements, facilitate industry's compliance with these and then ensure that the requirements are met through a range of regulatory and non-regulatory measures.

1.2.1 Proactive Food safety Management

Emerging food safety risks may require a change to the "old" way of doing things – both in terms of industry food safety management programmes and public sector food safety activities, including the development of guidance to industry on 'good practice'. A better understanding of changes that might arise is an essential first step to ensuring preparedness for those changes.

Climate change may have both direct and indirect impact on the occurrence of food safety hazards at various stages of the food chain. It is therefore necessary for governments to be prepared for those changes. Several developed countries have already initiated programmes of work aimed at identifying emerging food safety risks linked to climate change. FAO has a key role in assisting developing countries to assess the changes to their food safety situations and to promote international cooperation in improving the understanding of food safety implications of climate change.

FAO is committed to strengthening its capacity to be proactive in addressing threats to food safety along the food chain. This entails greater attention to the collection and analysis of intelligence pertinent to the early detection of food safety problems and on development of risk management guidance. Consideration of the impact of anticipated changes in climate and weather patterns on food safety and its management is consistent with the recognized priority role of FAO in ensuring preparedness for new challenges to food safety.

1.3 Climate Change – What are the Predictions?

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) dispelled many uncertainties about climate change. Warming of the climate system is now unequivocal and according to IPCC the increase in global temperatures observed since the mid-20th century is predominantly due to human activities such as fossil fuel burning and land use changes. Projections for the 21st century show that global warming will accelerate with predictions of the average increase in global temperature ranging from 1.8° C to 4°C.

Climate change does not only imply increased average global temperature. Other effects of climate change include trends towards stronger storm systems, increased frequency of heavy precipitation events and extended dry periods. The contraction of the Greenland ice sheet will lead to rising sea-levels.

These changes have implications for food production, food security and food safety. It is widely understood that the risks of global climate change occurring as a consequence of human behaviour are inequitably distributed, since most of the actions causing climate change originate from the developed world, but the less developed world is likely to bear the brunt of the public health burden (Campbell-Lendrum et al., 2007).

2. CLIMATE CHANGE AND LIKELY IMPACT ON AGRICULTURAL SECTOR

2.1 Crop Production

Crop production is extremely susceptible to climate change. It has been estimated that climate changes are likely to reduce yields and/or damage crops in the 21st century (IPCC, 2007), although, notably, effects are expected to differ widely in different parts of the world.

Climate change affects the microbial population of the macro-environment (soil, air and water) and the population of pests or other vectors. It is therefore a contributing factor to the occurrence and gravity of biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects. Abiotic factors such as nutrient deficiencies, air pollutants and temperature/moisture extremes also affect plant health and productivity. While the impact of biotic and abiotic factors on crop production and food security are more obvious, it is important to note that these factors may also have significant impact on the safety of food crops. Of further concern is the impact of climate change on the prevalence of environmental contaminants and chemical residues in the food chain. These potential food safety impacts are described in Section 4.

2.2 Animal Production

Climate change, in particular rising temperatures, can have both direct and indirect effects on animal production. Heat stress (caused by the inability of animals to dissipate environmental heat) can have a direct and detrimental effect on health, growth and reproduction. Changes in the nutritional environment (e.g. the availability of livestock feeds, and the quantity and quality of livestock pastures and forage crops) can have an indirect effect. These effects are expected to be most dramatic in temperate regions.

Climate change may affect zoonoses (diseases and infections which are naturally transmitted between vertebrate animals and man) in a number of ways. It may increase i) the transmission cycle of many vectors and ii) the range and prevalence of vectors and animal reservoirs. In some regions it may result in the establishment of new diseases. Changes in feeding practices, changes in the ecological situation in which animals are reared and increased irrigation (all consequences of climate change) may exasperate these effects. Potential food safety implications of these factors affecting livestock management are discussed in Section 4.

2.3 Fisheries

With higher temperature, global fisheries production should remain the same; however, the spatial distribution of fish stocks may change due to the migration of fish from one region to another in search of suitable conditions. Other climatic changes impacting on fisheries include surface winds (which would alter both the delivery of nutrient into the photic zone and strength and distribution of ocean currents), high CO_2 levels (which alter ocean acidity) and variability in precipitation (affecting sea levels). Climatic changes could affect productivity of aquaculture systems and increase the vulnerability of cultured fish to diseases and reduce returns to farmers. Extreme weather events could result in escape of farmed stock and contribute to reduction in genetic diversity of wild stock affecting biodiversity.

Climate change has implications for food safety. From a microbiological perspective, climate change exacerbates eutrophication (nutrient loading) causing phytoplankton growth, increased frequencies of harmful algal blooms, particularly of toxic species. Accumulation of these toxins by filter feeders (bivalve molluscs) and the subsequent consumption of these products have serious implications for humans. Furthermore, an increase in water temperatures promotes the growth of organisms such as *Vibrio vulnificus* leading to an increased risk from handling or consuming fish grown in these waters (Paz et al, 2007). Climate change (in particular temperature increase) facilitates methylation of mercury and subsequent uptake by fish.

2.4 Food Handling, Processing, Trading

Climate change impacts not only on primary production but also on food manufacturing and trade.

Emerging hazards in primary production could influence the design of the safety management systems required to effectively control those hazards and ensure the safety of the final product. Furthermore, increasing average temperatures could increase hygiene risks associated with storage and distribution of food commodities.

It is important, therefore, that the food industry be vigilant to the need to modify hygiene programmes. Of course periodic self-audits and external audits to 'test' the validity of hygiene programmes form part of 'good practice'. Governments often develop guidance to assist industry in implementing appropriate hygiene management programmes –vigilance will be required to ensure that guidance takes any emerging risks into consideration. Reduced availability and quality of water in food handling and processing operations will also give rise to new challenges to hygiene management.

It is anticipated that these risk management measures and adaptation strategies will pose greatest challenge for developing countries

3. CLIMATE CHANGE: POSSIBLE FOOD SAFETY IMPACTS

3.1 Bacteria, Viruses and Parasitic Protozoa

3.1.1 Foodborne Disease Agents: An Overview

Using the classic epidemiologic triad (host, agent, and environment), it is clear that climate, which impacts all three sectors of the triad, can have a dramatic effect on infectious disease. This is well documented and even predictable for some food and waterborne diseases of the developing world (e.g., bacillary dysentery, cholera) and perhaps less so for the developed world, where stringent public health measures (sewage disposal, clean water and hygiene) moderate the risk of diarrhoeal disease.

Evidence of the impact of climate change on the transmission of food and waterborne diseases comes from a number of sources, e.g. the seasonality of foodborne and diarrhoeal disease, changes in disease patterns that occur as a consequence of temperature, and associations between increased incidence of food and waterborne illness and severe weather events (Hall et al., 2002; Rose et al., 2001). There are also theoretical and unintended consequences of global climate change on food safety. Before discussing a few examples, it is necessary to provide some background information which helps in understanding the complexity of the interactions between climate and foodborne disease.

3.1.1.2 Sources and modes of transmission

The microflora of a food consists of the microorganisms associated with the raw material, those acquired during handling and processing and those surviving and preservation technique and storage. Bacteria, viruses, and parasitic protozoa that are pathogenic to humans and frequently contaminate the food supply can be subcategorized based on their ultimate source, i.e. those organisms which are

- i) predominantly associated with faecal matter (animals/human)
- ii) ubiquitous on the skin, nose and throat of healthy individuals;
- iii) ubiquitous in nature

Based on the above categorization, the general scenarios by which foods become contaminated with pathogens include:

- i) contact with human/animal sewage/faeces
- ii) contact with infected food handlers
- iii) environmental contamination (from air, water, food contact materials etc)
- iv) contact with raw foods etc.

Such contamination can arise along any part of the farm-to-fork continuum and may arise from any number of sources.

3.1.1.3 Factors influencing the growth and survival of pathogens

The subsequent growth and survival of pathogens after a contamination event are influenced by both ''intrinsic" and "extrinsic" parameters. Intrinsic parameters are inherent to the food and may naturally affect the rate of microbial growth (or may be manipulated to do so). Extrinsic parameters are those commonly manipulated in an effort to control microbial survival and growth.

The growth and survival of pathogens in foods is also influenced by the presence of harmless, competitive microflora. These harmless competitors do not cause foodborne disease but their relatively rapid growth rate can prevent contaminating pathogens from growing to levels high enough to cause disease in humans. The interactions between intrinsic parameters, extrinsic parameters, and competitive microflora are complex and oftentimes unpredictable. If (and when) climate change results in changes to any one of these factors, it may have undesired consequences on the safety of the food supply.

3.1.2 Data Supporting the Impact of Global Climate Change on Food Safety

Climate constrains the range of infectious diseases, while weather, which is impacted by climate, affects the timing and intensity of outbreaks (Epstein, 2001). Therefore, the two early manifestations of climate change, particularly global warming, would be expansion in the geographic range and seasonality of disease, and the emergence of outbreaks occurring as a consequence of extreme weather events (Epstein, 2001). Data supporting both of these manifestations are summarized below.

3.1.2.1 Seasonality and temperature effects on foodborne disease

The seasonality of some infectious diseases is well documented, but its relationship to potential long-term warming effects is poor characterized. Clearly, seasonal differences in disease incidence are likely to be influenced by population susceptibility and behaviours; however, environmental influences are also important considerations. Such environmental factors can impact the abundance of pathogens, their survival and/or their virulence (Fisman, 2007).

Box 1: Climatic influences (e.g. temperature, humidity) on the prevalence of some diseases:

- Increases in disease notifications, particularly salmonellosis (D'Souza et al., 2004) and to a lesser extent campylobacteriosis (Kovats et al., 2005) are frequently preceded by weeks of elevated ambient temperature.
- An eastern regional gradient has been observed in Australia for notifications of salmonellosis, i.e. rates of notification increase with decreasing latitude and hence, increasing average yearly temperature (Hall et al. 2002).
- Higher temperature and humidity in the week before infection has been correlated with decreased hospitalization rates for children diagnosed with rotavirus. This is particularly interesting because survival of the virus is favoured at lower temperature and humidity (D'Souza et al., 2008). Rotavirus is considered a significant cause of foodborne illness (FAO, 2008a).
- El Nino-associated rises in cholera have been documented for both Peru and Bangladesh, as have been increases in diarrhoeal disease in Peruvians (reviewed by Hall et al., 2002) *.

* the study of disease trends in the presence and absence of El Nino events provides a glimpse into how weather patterns may change the incidence of foodborne disease, especially since El Nino events are thought to be impacted by global warming.

Taken together, it appears that changes in both ambient temperature and humidity do have a role in foodborne disease transmission that is independent of other factors such as population behaviour and susceptibility. It is likely that some of the first detectable changes of global climate change on food safety will be seen as longer summertime peaks of foodborne disease and/or increased geographic range (Watson and McMichael, 2001).

3.1.2.2 The interplay of ecological factors

Cholera is perhaps the best model for understanding the potential for climate-induced changes in the transmission of foodborne disease. *Vibrio cholerae* is the causative agent of this disease which produces substantial morbidity and mortality, particularly in the developing world. In certain regions, cholera is endemic, displaying characteristic waves of epidemic peaks followed by periods of relative quiescence. Peaks of disease are seasonal and associated with higher water temperature.

The three major factors driving cholera endemicity (i.e. abiotic, phytoplankton, and zooplankton) have been described by Colwell and Huq (Lipp et al., 2002) in their hierarchical model of the transmission of cholera. The interactions between these factors are extremely complex and their full description is beyond the scope of this paper; however, Box 2 illustrates the role of intrinsic parameters and microbial competition in these dynamics:

Box 2: Interaction of ecological factors on the proliferation of *V. cholerae*:

- Some investigators believe that photosynthetic phytoplankton proliferation results in elevated environmental pH. This alkaline pH:
  i) gives *V. cholerae* a competitive advantage over other marine bacteria since it thrives at higher pH and
  ii) promotes attachment of *V. cholerae* cells to zooplankton (particularly copepods); this protects *V. cholerae* cells from external stresses.
- As phytoplankton populations disintegrate, additional nutrient sources are available to stimulate the growth of the organism. Together, the interplay of these factors results in extremely high populations of *V. cholerae* in tight association with copepods.

The human factor is another important part of the equation. While cholera is predominantly a waterborne disease, foodborne transmission can occur though the use of contaminated water for food preparation or irrigation, or from consumption of molluscan shellfish. Furthermore, sewage presents an additional risk factor for disease transmission, particularly in parts of the world in which water and sewage treatment remains substandard.

3.1.2.3 Extreme weather events

Extreme weather conditions (e.g. flooding, drought, hurricanes etc) can impact on the transmission of disease. For example, periods of excessive precipitation and periods of drought influence both the availability and quality of water and have been linked to the transmission of water and food borne disease. Furthermore, extreme weather events can result in forced evacuation of refugees into close quarters. This frequently results in extreme stress, malnutrition, and limited access to medical care, all of which contribute to increased susceptibility and severity of disease.

These events are discussed in more detail and specific examples are provided in Section 3.6 on emergency situations.

3.1.3 Other Potential Impacts of Global Climate Change on Food Safety

Although perhaps more speculative, there are a number of other potential impacts of global climate change on food safety. These include i) impacts on microbial evolution and stress response; ii) pathogen emergence; iii) changes in water availability and quality; and iv) other considerations. These will be discussed briefly.

3.1.3.1 Microbial evolution and stress response

Over the course of time, many bacterial agents have developed mechanisms that allow them to survive and even grow under unfavourable or "stressful" conditions. Many of these conditions are manipulations of the same intrinsic and extrinsic parameters described above. Stress responses are encoded genetically and in many cases, initial exposure to a sub-lethal dose of a stressor will "condition" the bacterial cell, allowing it to survive even harsher conditions provided by that stressor. This is well documented for *E. coli* O157:H7, where, for instance, the organism is able to survive an acid shock as low as pH 2 after previous exposure to pH 5. In addition, as microorganisms acquire increased tolerance after pre-exposure to a sublethal stress, they frequently develop enhanced resistance to other types of stress, a phenomenon referred as cross-protection (Rodriguez-Romo and Yousef, 2005). This is relevant to global climate change in that climate-induced changes in intrinsic factors may induce stress responses that make certain bacteria more resistant.

Gene transfer between related and even unrelated bacterial species is now considered a common occurrence. This may be facilitated when multiple species are present in large and diverse communities (such as in the environment, in raw foods, or in the gut) through horizontal gene transfer or by infection with bacteriophage. Gene transfer is also an important contributor to the emergence of antibiotic resistance. We know very little about the triggers or dynamics of gene transfer events, but they are likely to be impacted by the environment. In fact, this has been documented for *V. cholerae*. For example, non-toxigenic strains of this organism can acquire genes for the cholera toxin though bacteriophage-mediated transfer events which occur naturally in the environment. More specifically, both phage infection and prophage induction seem to be sensitive to environmental triggers (temperature, sunlight, pH) (Lipp et al., 2002). This means that environmental changes may have a substantial impact on pathogen evolution and/or pathogenicity.

3.1.3.2 Pathogen emergence

Climatic change can also impact the emergence or re-emergence of infectious disease agents. Emerging foodborne pathogens are defined as infectious agents, transmitted by foodborne routes, which have (i) newly appeared in a population; (ii) were thought to be controlled but are now resurging; or (iii) have existed but are rapidly increasing in incidence, geographic range, or by some other factor. Also included in this definition are agents for which a foodborne route of transmission has been identified only recently.

Rarely, if ever, do foodborne pathogens emerge without a reason. There are some general principles of pathogen emergence, which are associated with changes in the following sectors: (i) ecology and agriculture; (ii) technology and industry; (iii) globalization; (iv) human behaviour and demographics; (v) epidemiological surveillance; and (vi) microbial adaptation (Tauxe, 2002). It is important to recognize that pathogen emergence usually occurs as a consequence of a combination of two or more specific factors. Further, emergence may not necessarily be predictable. For example, climate-induced changes in the movement of animal populations may facilitate the spread of a pathogen which previously was of low prevalence or little consequence.

3.1.3.3 Water availability and quality

Periods of excessive precipitation and drought can influence both the availability and the microbiological quality of water. This is discussed in Sections 3.5 (chemical contamination) and 3.6 (emergency situations).

Furthermore, new demands on existing water sources could occur if sea levels rise as predicted, adversely impacting water availability (Charron et al., 2008). An emerging environmental health threat is the decline in global freshwater resources caused mostly by increasing rates of water extraction and contamination. This has resulted in a decline in both water quality and quantity, especially in arid regions such as the Mediterranean and Northern Africa (Campbell-Lendrum et al., 2006). Needless to say, limited access to safe water has a negative effect on hygiene practices throughout the food chain.

3.1.3.4 Other considerations

There are many other potential impacts of global climate change on food safety. For example, climate change could result in movement of crop production areas, resulting in very different ecosystem exposures, including microbes, pests (insects), and wilds animals (rodents, reptiles and amphibians). Intermingling or crowding of food animals caused in response to natural disaster or climate induced changes in animal husbandry practices might promote the transmission of pathogens between animals, resulting in greater pathogen load in faeces and increased prevalence of carcass contamination. The list of possibilities is nearly endless, making prioritization of risk very difficult.

Nonetheless, there are a few characteristics of pathogens that may predispose them to being more sensitive to the impacts of global climate change. For example, those foodborne pathogens that cause disease at very low doses (enteric viruses, parasitic protozoa, *Shigella* spp., enterohemorrhagic *E. coli* strains) and/or have notable environmental persistence (enteric viruses and parasitic protozoa) will likely to be of great concern, particularly after adverse weather events. Those pathogens with documented stress tolerance responses (temperature, pH), such as enterohemorrhagic *E. coli* and *Salmonella* are likely to compete better in the event of climate change.

3.2 Zoonosis and Other Animal Diseases

3.2.1 Introduction

Zoonotic diseases are transmitted from animals to people in a number of ways. Some diseases are acquired by people through direct contact with infected animals or animal products and wastes. Other zoonoses are transmitted by vectors; while others are transmitted through the consumption of contaminated food or water (Table 1).

The proliferation of zoonoses and other animal diseases may result in an increased use of veterinary drugs that could lead to increased and possibly unacceptable levels of veterinary drugs in foods (FAO, 2008b). For this reason, although zoonoses transmitted to humans through the consumption of contaminated food or water are of primary importance to this paper, other animal diseases are also considered.

Table 1: Examples of some zoonotic agents that are expected to be affected by climate change and their mode of transmission

Virus	Host	Mode of transmission to humans
Rift Valley fever virus	Multiple species of livestock and wildlife	blood or organs of infected animals (handling of animal tissue), unpasteurized or uncooked milk of infected animals, mosquito, , hematophagous flies
Nipah virus	Bats, and pigs	Directly from bats to humans through food in the consumption of date palm sap (Luby *et al*. 2006). Infected pigs present a serious risk to farmers and abattoir workers
Hendra virus	Bats, and horse	Secretions from infected horses
Hantavirus	Rodents	Aerosol route from rodents. Outbreaks from activities such as clearing rodent infested areas and hunting.
Rotavirus	Humans	Faecal-oral route, spread through contaminated water and also by infected food-handlers who do not wash their hands properly.
Hepatitis E virus	Wild and domestic animals	Faecal-oral. pig manure is a possible source through contamination of irrigation water and shellfish in coastal waters

Bacterium	Host	Mode of transmission
Salmonella	Poultry and pigs	Faecal/oral
Campylobacter	Poultry	Faecal/oral
E. coli O157	Cattle and other ruminants	Faecal/oral
Anaerobic spore-forming bacteria	Birds, mammals and livestock	Ingestion of spores through environmental routes, water, soil and feeds. This has been associated with outbreaks of anthrax in livestock and wild animals, blackleg (*Clostridium chauvoei*) in cattle and botulism in wild birds after droughts. The meat and milk from cattle that have botulism should not be used for human consumption.
Yersinia	Birds and rodents with regional differences in the species of animal infected. Pigs are a major livestock reservoir	Handling pigs at slaughter is a risk to humans
Listeria monocytogenes	Livestock	In the northern hemisphere, listeriosis has a distinct seasonal occurrence in livestock probably associated with feeding of silage
Leptospirosis	All farm animal species	Leptospirae shed in urine to contaminate pasture, drinking water and feed

Protozoan	Host	Mode of transmission
Toxoplasma gondii	Cats, pigs, sheep	Cat faeces are a major source of infection. Handling and consuming raw meat from infected sheep and pigs pose a zoonotic risk.
Cyptosporidium and *Giardia*	Cattle, sheep	Faecal-oral transmission. (Oo)cysts are highly infectious and with high loadings, livestock faeces pose a risk to animal handlers

Parasite	Host	Mode of transmission
Tapeworm (*Cysticercus bovis*)	Cattle	Faecal-oral
Liver fluke (*Fasciola hepatica*)	Sheep, cattle	Eggs are excreted in faeces, and life cycle involves lymnaeid snail hosts. Human cases generally associated with the ingestion of marsh plants such as watercress.

3.2.2 Effect of Climate Change on Zoonotic Disease

Climate change is one of several 'global change' factors driving the emergence and spread of diseases in livestock and the transfer of pathogens from animals to humans. While much of the discussion from section 3 is applicable to zoonotic disease, this section focuses on the additional impacts of climate which are specific to zoonotic diseases. These include:

- Increase in the susceptibility of animals to disease
- Increase in the range or abundance of vectors / animal reservoirs
- prolonging the transmission cycles of vectors

3.2.2.1 Increase in the susceptibility of animals to disease

Climate may have a direct or indirect influence on the susceptibility of animals to disease. For example, exposure to intense cold, droughts, excessive humidity or heat may predispose cattle to complex bacterial syndromes such as mastitis. Milk from cows with severe clinical mastitis would normally not enter the food chain as the abnormality is easily detected and the milk would be discarded by the producer. But when milk of cows with sub-clinical *mastitis*, *i.e.* with no visible changes, is accidentally mixed into bulk milk, it enters food chain and can be dangerous to humans. Although pasteurization is likely to destroy all human pathogens, there is concern when raw milk is consumed or when pasteurization is incomplete or faulty (Hameed et al., 2006).

Aquatic animals are also vulnerable to climate change because water is their life-support medium and their ecosystems are fragile. Fish, including shellfish, respond directly to climate fluctuations as well as to changes in their biological environment (predators, species interactions, disease). Their related metabolic processes are influenced by temperature, salinity, and oxygen levels. Certain environmental conditions are more conducive to diseases than others (e.g., warm waters can trigger disease outbreaks and cold temperatures can limit them). For example, in the last 15 years in the US there has been a significant shift from sporadic cases of *V. paparahaemolyitic* towards outbreak associated activity. Of particular note are a series of outbreaks which occurred between 1997 and 2004 attributed to the consumption of oysters harvested from northern waters (Pacific Northwest and Alaska) (reviewed by Drake et al., 2007). In the Alaska outbreak, significantly higher mean water temperature relative to previous decades was thought to have contributed to the outbreak (McLaughlin et al., 2005). Similarly, the role of high water temperature in the emergence of *V. vulnificus* has also been observed (Paz et al., 2007)

In the aquaculture sector, problems expected from a warming environment include a greater susceptibility of disease organisms to thrive. This is particularly true for introduced aquaculture species, or if engineered fish lack the innate abilities to deal with new strains of pathogens, or if the aquaculture facility relies too heavily on chemicals to control disease. Also, in some areas, some species may already be near their upper temperature tolerances (Everett, 1996)

3.2.2.3 Increase in the range or abundance of vectors / animal reservoirs

Because of the sensitivities of vectors to climatic factors, ecological changes such as variations in rainfall and temperature could significantly alter the range, seasonality and incidence of many zoonotic diseases (CDC, 2008). Examples of sensitivities of vectors to climatic change include:

- Increased night time temperatures will result not only in enhanced vector flight activity (Purse *et al*. 2005) but also greater competence in supporting replication and transmission of viral pathogens (Baylis and Githeko, 2006).

- Cycles of drought followed by heavy rainfall provide breeding sites for midge and mosquito vectors and are associated with outbreaks of vector-borne livestock diseases (Baylis and Githeko, 2006).

- Changes in precipitation may also affect the range and distribution of arthropod vectors, and there is evidence of ticks expanding their range with decreasing rainfall (Trape et al., 1996). Conversely, increased precipitation increases the abundance of snail hosts for livestock parasites.

Vector-borne pathogens which respond most rapidly to climatic changes are likely to be rapidly evolving promiscuous agents, transmitted by rapidly reproducing, highly mobile and habitat-generalist vectors. Examples of diseases influenced by climate change and variability include Rift Valley, Bluetongue, as well as tick-borne diseases (Easterling et al., 2007).

Box 3: Rift Valley Virus - an example of a zoonotic disease whose distribution is influenced by climate change and variability

Rift Valley fever is a mosquito-borne animal and human viral disease in which the vectors are influenced by climate. Rift Valley fever virus (RVFV), is highly promiscuous between vertebrate hosts, ranging from rodents to hippopotamuses, but causes clinical signs only in ruminants and humans. This virus has been isolated from many potential vector species inhabiting a range of habitat types. Epidemics in south and east Africa follow periods of high rainfall that create breeding sites for flood-water vectors (Aedes mosquitoes), whereas those in north and west Africa, have followed construction work that created breeding sites for large river and dam-breeding vectors. In 2000, strains of RVFV (that probably originated in east Africa) escaped from Africa for the first time and infected the Arabian Peninsula, an area well connected to Europe by a 'ruminant street'. The timing and mode of pathogen responses will obviously depend on the species-specific climatic drivers (Purse et al. 2005).

Climate change will also affect the ecology of many animal hosts which are reservoirs of diseases infectious to humans. For example hantavirus pulmonary syndrome is an uncommon but sometimes fatal zoonotic disease that is linked to close contact between people and wild rodents. Longer milder summers and milder winters prolong rodent breeding seasons and reduce mortality (Charron, 2002). Furthermore, higher average rainfall has been associated with increased abundance of rodents (Parmenter et al., 1999).

3.2.2.4 Prolonged transmission cycles of vectors

Climatic factors can also influence the length of the vectors transmission cycle and thus the incidence of human infection. West Nile Virus is an example of a vector-borne zoonosis whose transmission cycle is prolonged by the early onset of spring. Human infections from West Nile Virus become more likely as the population of mosquitoes (that bite both birds and humans) increases. In temperate regions, mosquito activity begins in spring and declines in autumn. Thus an earlier spring would prolong the cycle resulting in an increased incidence of human infection (Greer et al., 2008).

3.2.2.5 Impact of climate change on farming/husbandry practices

The impact of and responses to rising temperatures for farming practice are likely to differ across the world. Livestock breeds less susceptible to heat may be used, but this change may increase susceptibility to certain pathogens. In some areas, more animals may be moved inside in an attempt to avoid heat exposure and stress, giving increased opportunity for transmission of disease. Conversely, increased temperatures will increase the length of the grass-growing season in some areas (NFU 2005), which could allow more extensive livestock grazing and greater exposure to vectors and wildlife, for example.

Changes in animal husbandry practices (e.g. Intermingling or crowding of food animals) in response to natural disaster or climate induced changes might promote the transmission of pathogens between animals, resulting in greater pathogen load in faeces and increased prevalence of carcass contamination.

3.2.2.6 Impact of climate change on veterinary drug residues in foods

Climate change may result in changes in the incidence of foodborne zoonoses and animal pests and possibly in increased use of veterinary drugs (FAO, 2008b). New diseases in aquaculture could also easily result in increased chemicals use. Consequently, there may be higher and even unacceptable levels of veterinary drugs in foods (FAO, 2008b). These issues are addressed in Section 3.5 on environmental contaminants and chemical residues in the food chain.

3.3 Toxinogenic Fungi and Mycotoxin Contamination

3.3.1 Mycotoxins and Food Safety: Introduction

Mycotoxins are a group of highly toxic chemical substances that are produced by toxigenic moulds that commonly grow on a number of crops. These toxins can be produced before harvest in the standing crop and many can increase, even dramatically, after harvest if the post-harvest conditions are favourable for further fungal growth. Human dietary exposure to mycotoxins can be directly through consumption of contaminated crops. Mycotoxins can also reach the human food supply through livestock that have consumed contaminated feed.

The problem of mycotoxin contamination of foods and the resulting public health impact is not new – it is likely that mycotoxins have plagued mankind since the beginning of organised crop production (FAO, 2001). At high doses mycotoxins produce acute symptoms and deaths but, arguably, lower doses that produce no clinical symptoms are more significant to public health due to the greater extent of this level of exposure. Particular mycotoxins may possess carcinogenic, immunosuppressive, neurotoxic, estrogenic or teratogenic activity, some more than one of these. Table 2 lists mycotoxins that are of world-wide importance meaning that they have been demonstrated to have significant impact on public health and animal productivity in a variety of countries. There are several other mycotoxins that are considered to be of regional significance (FAO, 2001).

Table 2: Moulds and mycotoxins of world-wide importance

Mould Species	Mycotoxins Produced
Aspergillus parasiticus	Aflatoxins B_1, B_2, G_1, G_2
Aspergillus flavus	Aflatoxins B_1, B_2
Fusarium sporotrichioides	T-2 toxin
Fusarium graminearum	Deoxynivalenol (or nivalenol)
	Zearalenone
Fusarium moniliforme (F. verticillioides)	Fumonisin B_1
Penicillium verrucosum	Ochratoxin A
Aspergillus ochraceus	Ochratoxin A

In recent years outbreaks of acute aflatoxicosis were reported in Kenya: 125 deaths occurred out of 317 reported cases resulting from consumption on aflatoxin contaminated maize during 2004 (Aziz-Baumgartner et al., 2005; Nyikal et al., 2004) with repeated events in 2005 and 2006. Recent surveys in Benin and Togo showed that aflatoxin levels in maize averaged five times the level of 20 ppb – the maximum tolerable limit recognised in several countries- in up to 50% of household grain stores surveyed. Another study showed a high frequency of aflatoxin M_1 contamination in a peri-urban study area in Kenya (Kangethe et al, 2007).

Economic implications of mycotoxin contamination include trade disruptions – this food safety hazard accounted for the highest number of notifications in 2006 within the EU Rapid Alert System for Food and Feed (EC, 2007). It also negatively affects productivity in the livestock and crop sectors.

Clearly there is already much that needs to be done to improve mycotoxin prevention and control in many countries. There is reason to believe that climate change can affect infection of crops with toxigenic fungi, the growth of these fungi and the production of mycotoxins. Given the great importance of this hazard, it is necessary that we understand what changes we might expect in order to better prepare ourselves to deal with this critically important issue.

3.3.2 Climate Change and its Influence on Mould and Mycotoxin Contamination

The factors governing exposure of man to dietary mycotoxins form a complex interconnected system that starts with fungi interacting with crop plants. The performance of each 'partner' is affected by the condition of the other at the same time as both respond to the prevailing conditions of weather and soil. Climate change affects all components of the system. Due to this complexity only qualitative indications can be provided on how climate change might affect toxigenic fungi and mycotoxin contamination.

Mycotoxins are produced by a large variety of fungi, each of them being characterized by its own ecological requirements. Although the impact of climate change on fungal colonization has not been yet specifically and thoroughly addressed, temperature, humidity and precipitation are known to have an effect on toxigenic moulds and on their interaction with the plant hosts. In general we know that fungi have temperature ranges within which they perform better and therefore increasing average temperatures could lead to changes in the range of latitudes at which certain fungi are able to compete. Since 2003, frequent hot and dry summers in Italy have resulted in increased occurrence of *A. flavus*, the most xerophilic of the *Aspergillus* genus, with consequent unexpected and serious outbreak of aflatoxin contamination, uncommon in Europe, even in the southern regions. Also in United States serious outbreaks of *A. Flavus* have been reported for similar reasons. Generally moist, humid conditions favour mould growth – moist conditions following periods of heavy precipitation or floods would be expected to favour mould growth. Generally speaking, conditions adverse to the plant (drought stress, stress induced by pest attack, poor nutrient status, etc.) encourages the fungal partner to develop more than under favourable plant conditions with the expectation of greater production of mycotoxins.

Box 4: Fungal Range and Fungus–Host Association

The nature of the association between plant and fungus varies. It may be intimate as in the case of the lolitrem-producing *Neotyphodium lolii,* an obligate endophyte of perennial ryegrass. Several of the mycotoxigenic fungi seem to be occasional seed endophytes more commonly found in soil apparently having found a mechanism of access to and ability to co-exist endophyticly within the host. *Aspergillus ochraceus* in coffee and cereal seeds is likely to represent such a case. The distribution and success of obligate endophyte is absolutely tied to that of the host plant so climate change will affect the fungus as it affects the host. In the other case the fungal range may be affected independently of the host since its primary ecological role, so far as is known, is not dependant on any host plant. We might expect to see some adaptation (genetic drift) of crop plants to changing climate and new selections as the result of breeding programmes which could fundamentally alter the dynamics of the crop's association with fungi.

The most widespread and studied mycotoxins are metabolites of some genera of moulds such as *Aspergillus, Penicillium and Fusarium.* Valuable reviews on mycotoxin formation have been published, one of the most recent and complete being the CAST Report (Cast Report 2003). The discussion below provides an illustration of how the climate change factors might be expected to affect mycotoxin contamination by these three main genera of moulds with a focus on temperature and precipitation. Following this, some attention will be paid to some of the less considered climate influenced factors (insect and other pest attack, soil, fertilizers and trace elements) that should be recognized and studied as potential and indirect triggers of fungi colonization and mycotoxin production.

3.3.2.1 Fusarium toxins

Species of the genus *Fusarium* are responsible for the occurrence of several major toxins in commodities including trichothecenes (e.g. Deoxynivalenol and T2-toxin), fumonisins, fusarin C, moniliformin and zearalenone (see Miller, 2008 for a thorough review). The most important species in this connection are *F. verticillioides, F. proliferatum* (section Liseola); *F. sporotrichioides, F. poae* (section Sporotrichiella); *F. graminearum, F. culmorum, F. crookwellense* (section Discolor). These fungi are probably best thought of as very close associates of plants with important stages of their natural history conducted in soil. Representatives of the genus are commonly isolated as endophytes, often asymptomaticly though many have pathogenic potential, from a great variety of plants. *F. verticillioides* is invariably present in maize, for example, often accompanied by *F. culmorum* or *F. graminearum*. As well as collectively producing numerous compounds that are active in animal systems, fusaria also produce the full array of plant growth regulators: gibberellic acid, auxins , cytokinins and the senescing agents ethylene and abscisic acid (Michneiwicz, 1989). As potential plant pathogens, mycotoxin producers and plant endophytes, this important group has the potential to reduce yields of crop plants and animal production and render more of the harvest unfit for consumption.

Maize is grown from tropical to temperate regions and throughout its range *F. verticillioides* is usually present as an endophyte. In addition, members of the Discolor group are found and *F. graminearum,* considered to be the more virulent plant pathogen, tends to predominate in the warmer temperate regions (periods of daytime temperatures of 25-28^{o}C) with *F. culmorum* more common in the cooler temperate regions. In wheat, barley and rye the Discolor group species predominate noting these grains' range is limited to cooler regions than is maize. Strains of *F. graminearum* produce either deoxynivalenol (DON) or nivalenol (NIV) and zearalenone (ZER) while *F. culmorum* produces only DON and ZER. Already there are reports that a series of warm European summers has seen the occurrence of the formerly predominant species, *F. culmorum*, fall to be replaced by *F. graminearum.* European strains of this species commonly produce NIV so further warming due to climate change would be expected to favour *F. graminearum,* the species that is the more virulent plant pathogen and perhaps a shift to a NIV/ZER contamination pattern from DON/ZER pattern in Europe and Asia. In the Americas this would not occur since most American *F. graminearum* strains are DON producers. At temperatures above about 28^{o}C, however, Liseola species are strongly favoured.

Liseola group species do not produce trichothecenes or ZER but they do produce fumonisins (FM) and moniliformin (MON). Though *F. verticillioides* can be considered ubiquitous in maize (*F.proliferatum* is also common), FM and MON are not and one reason for this lies in the interaction of maize and this endophyte of maize.

It is reported that FM occurrence is correlated to drought stress and indeed, dry season maize as in southern and east Africa can contain large amounts of this toxin in maize of very good appearance while Fm in significant amounts in north temperate zones is much less common. Because *F. verticillioides* is favoured at higher temperatures one could anticipate that a warming trend would see the region where this fungus can dominate the other maize-borne Fusarium species shifting to higher latitudes. At the same time, higher temperatures would cause higher evapo-transpiration rates so that even if there were to be no reduction in rainfall, drought stress would be more common and therefore so should FM and perhaps MON. If the scenario of less reliable or shifting annual rainfall patterns is also realised, it could intensify this effect.

Box 5: Maize and mycotoxin risk

Maize is a particularly problematic commodity in the context of mycotoxins and looks to become more so given the nature of the predicted changes to climate. It has a relatively high water requirement and under drought stress conditions that could be predicted to occur more frequently in a climate change scenario, its *Fusarium* symbionts and *A. flavus* both seem to produce more of their respective mycotoxins. Under these conditions a person's meal could contain significant quantities of all of fumonisin, trichothecene, aflatoxin and zearalenone. This combination of factors that global climate change is predicted to make more commonplace, already occurs in the tropics and there is no doubt at all that many people are exposed to cocktails of mycotoxins from maize with adverse health consequences that we probably underestimate (Strosnider et al., 2006).

The potential problem of increased mycotoxin risk could be aggravated by the problems of food scarcity - in extremis, populations will consume food of a quality that would normally never enter the food chain.

F. verticillioides is also common in rice, where it is an important pathogen responsible for bakane (foolish rice disease, the symptoms are caused by gibberellic acid production by the mould) and a sheath rot, and though FM has been detected in rice and isolates from rice are as capable of FM and MON production as isolates from maize, these compounds are currently not common in this commodity (Desjardins, et al., 1999). There is little work in this area but it is worth mentioning that detailed analysis of naturally contaminated rice showed almost none of the FM was in the white rice fraction.

3.3.2.2 Aspergillus and *Penicillium* toxins

These important toxigenic fungi occupy an ambiguous ecological position. It is certain that many, perhaps most of the species of these genera are primarily soil fungi but the most important species, from the point of view of mycotoxin contamination, appear to be genuine associates of plants. Of the host of toxic compounds collectively produced by this group, the three most important are aflatoxin, ochratoxin and patulin.

Aflatoxin (AF), produced by *A. flavus, A. parasiticus* and *A. wentii*, is a genotoxic carcinogen, is also a potent acute toxin, and is widely distributed but associated especially with maize, groundnuts, tree nuts, figs, dates and certain oil seeds such as cottonseed.

The producing fungi are widely distributed from the tropics through the low latitude temperate zone but can occur almost anywhere in food systems. There doesn't appear to be a single mode of infection of the host plant but high toxin levels tend to be correlated with some sort of damage or stress of the host. In Maize, attack of the cob by various caterpillars, head blight (caused by *Fusarium* spp.) and drought are all reported to stimulate AF accumulation. In groundnut, infection takes place during flowering but, usually, strong development of the fungus and appreciable AF contamination is seen after drought conditions during crop development. In pistachio it may be that mechanical damage caused by premature splitting of the hull and navel orange worm attack are important contributory factors leading to late infection of the seed but it is clear there is infection of un-split fruit (Thomson & Mehdy, 1978; Sommer et al., 1986). The impact of climate change on plants adapted to a semi-arid climate, like pistachio, is unclear. There are reports that periods of higher than average temperatures and reduced annual rainfall in Kerman Province in Iran has been linked to nut deformity and increased levels of aflatoxin contamination (Ministry of Jihad- e-Agriculture I.R. of Iran 2008).

Some species of *Aspergillus* and *Penicillium* genera are also producers of two other important mycotoxins - OTA and Patulin – specific discussion of these is not included here. Plant stress does not seem to be an important factor in these cases.

3.3.2.3 Insects and other pests

Pest and disease agents can favour colonization by toxigenic fungi and mycotoxin contamination in several crops. The response of insects and plant diseases to the foreseen climate change is poorly understood and Petzold and Seaman (2005) conclude that the precise impacts of climate change on insects and pathogens are somewhat uncertain. However, most of evidence indicates that there will be an overall increase in the number of outbreaks of a wider variety of insects.

Fungal distribution and cycle are largely influenced by insect attack in a number of ways including the lowered resistance of plants to stress and the mechanical damage (wounds) on kernels that favour infection by the fungus. The influence of these factors depends on the characteristic of the insect, the plant and the fungus. Notably, there are reported examples of the ability of insects to protect plants from fungal attack (Dowd,1992a). The relevance of the insect attack on mycotoxin contamination has been reviewed in some detail by Dowd (1992b).

3.3.2.4 Soil

Characteristics of soils are largely influenced by climate change and they are also very relevant for fungal infestation. The topic is not well investigated but it deserves more focus.

Climate change can potentially alter the transfer and the bioavailability of trace elements from the soil to the plant (Cubadda, personal communication). Deficiency of nutrients or excess of toxic elements may results in lower resistance to insect, pests and plant diseases including the attack of toxigenic fungi and the consequent biosynthesis of mycotoxins.

Fertiliser regimes may affect fungal incidence and severity of colonization either by altering the rate of residue decomposition, by creating a physiological stress on the host plant or by altering the crop structure. For *Fusarium* colonization, higher N inputs extend the stages during which wheat is susceptible to infection and a longer flowering period and later ripening was reported. The risk of nitrate leaching in crop fertilized with mineral or organic N is weather and soil dependent. There is a need to better understand this issue.

3.3.2.5 Post-harvest conditions

It is common for commodities to contain mycotoxigenic fungi at harvest and not uncommon for there to be mycotoxins present. Up to the point of harvest, the status of the plant will play a major role in determining the degree of mycotoxin contamination. Thereafter, fungal development and mycotoxin production will be controlled by post-harvest handling techniques and practice. In the simplest terms this will consist of some kind of cleaning, which may be conducted concomitantly with harvest, drying and storage where stability is maintained by restricting water availability to a level well below that required for fungal growth. Climate change could impinge on this part of the food chain especially in regions where capital investment on such production infrastructure is lacking.

3.4 Harmful Algal Blooms and Fishery Product Safety

3.4.1 Impacts of Harmful Algal Blooms

During recent decades, there has been an apparent increase in the occurrence of Harmful Algal Blooms (HABs) in many marine and coastal regions (Fig. 1, Hallegraeff 1993). Quantitatively estimating the extent of this apparent increase in HAB events is difficult due to the fact that the increase in HAB occurrences may be a result of increased awareness and better monitoring (Hallegraeff 1993, Glibert et al. 2005). Toxin-producing HAB species are particularly dangerous to humans. A number of human illnesses are caused by ingesting seafood (primarily shellfish) contaminated with natural toxins produced by HAB organisms; these include amnesic shellfish poisoning (ASP), diarrheic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), azaspiracid shellfish poisoning (AZP), paralytic shellfish poisoning (PSP), and ciguatera fish poisoning (Table 1, Fleming et al. 2006). These toxins may cause respiratory and digestive problems, memory loss, seizures, lesions and skin irritation, or even fatalities in fish, birds, and mammals (including humans) (Anderson et al. 2002, Sellner et al. 2003). Some of these toxins can be acutely lethal and are some of the most powerful natural substances known; additionally, no antidote exists to any HAB toxin (Glibert et al. 2005). Because these toxins are tasteless, odourless, and heat and acid stable, normal screening and food preparation procedures will not prevent intoxication if the fish or shellfish is contaminated (Baden et al. 1995, Fleming et al. 2006).

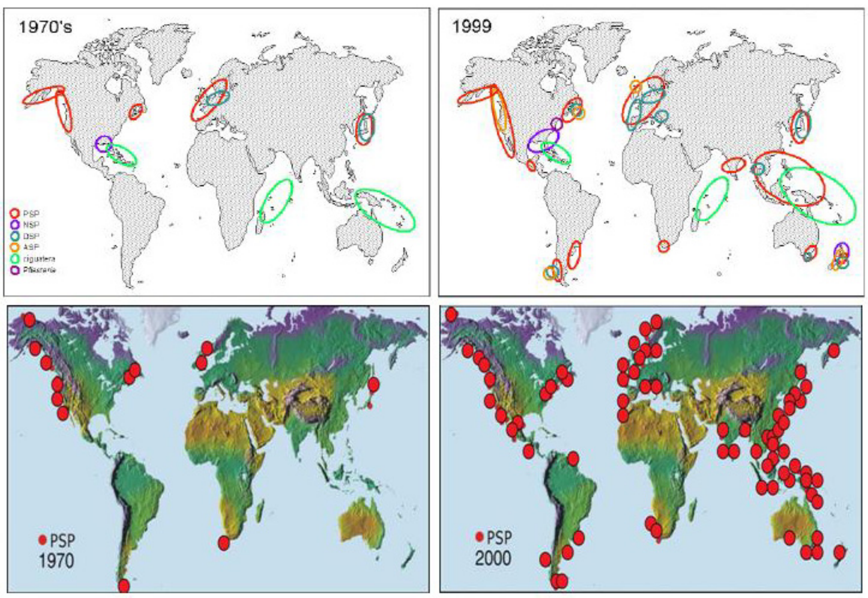

Figure 1: Global distribution of HAB toxins and toxicities (reproduced from Dolah (2000) and detail of increase in PSP outbreaks (from Glibert et al. (2005)).

In addition to human health effects, HABs also have detrimental economic impacts due to closure of commercial fisheries, public health costs and other related environmental and socio-cultural impacts (Trainer & Suddleson 2005; NOAA - CSCOR 2008).

Table 3: Examples of HAB-forming algae and their effects on food safety (Faust & Gulledge 2002, Sellner et al. 2003).

Poisoning	**Functional group**	**Species**
diarrheic shellfish poisoning (DSP)	dinoflagellates	*Prorocentrum* spp. *Dinophysis* spp. *Protoperidinium* spp.
paralytic shellfish poisoning (PSP)	dinoflagellate	*Alexandrium* spp.
neurotoxic shellfish poisoning (NSP)	dinoflagellate	*Gymnodinium* spp.
amnesic shellfish poisoning (ASP)	diatoms	*Pseudo-nitzschia* spp.
ciguatera fish poisoning	dinoflagellate	*Gambierdiscus* spp.

3.4.2 Impact of Temperature Change on Persistence and Patterns of Occurrence of Algal Communities

Changes in climate may be creating a marine environment particularly suited to HAB-forming species of algae. Two major functional groups of marine algae, or phytoplankton, cause toxic HABs – diatoms and dinoflagellates. The majority of HAB-forming phytoplankton species are dinoflagellates, with approximately 10 – 12 taxa primarily responsible for the current expansion and regional spreading of HABs in the sea (Smayda 1997). Dinoflagellate abundances have increased to the detriment of diatom populations in some marine ecosystems, such as the North-East Atlantic (Edwards et al. 2006), the Grand Banks area of the North-West Atlantic (Johns et al. 2003) and Baltic Sea (Wasmund & Uhlig 2003). This shift in community composition has been linked to increased sea surface temperature (SST); in the North-East Atlantic, increased SST during winter months has resulted in an earlier growth and succession of flagellates (Edwards & Richardson 2004, Edwards et al. 2006). Additionally, dinoflagellates are well-suited to stratified water (Margalef 1978) and therefore may not only respond physiologically to temperature, but may also respond indirectly if climate warming enhances stratified conditions or if stratification occurs earlier in the season (Edwards & Richardson 2004). Experimental results suggest warming SST and increased water stratification may lead to an increase in growth rates of some HAB taxa including *Prorocentrum* spp. and *Dinophysis* spp. (Peperzak 2003). Increasing SST has also been found to lead to decreased surface nutrient concentrations which favour the smaller dinoflagellates and are detrimental to the larger diatoms (Bopp et al. 2005). Thus, it appears that in some areas regional climatic changes favour dinoflagellates over diatoms, therefore increasing the likelihood of occurrence of HAB-forming species. However, the extent to which regional climate change will influence HAB dynamics is uncertain as separating the effects of climate change from natural variability remains a key scientific challenge.

The relationship between phytoplankton biomass and HAB species toxicity is complicated. Toxic HABs can have harmful effects even if the species is not dominant and toxin production may be related to hydroclimatic conditions and can very among strains within a species, even during the course of one bloom event (Barin et al. 2005). Some species, such as *Alexandrium fundyense*, can cause significant toxicity in shellfish even when present at very low abundances (Barin et al. 2005) while others are only toxic at high concentrations

(Anderson et al. 2002). Even some species of the same genus possess varying levels of toxicity (Trainer & Suddleson 2005). Furthermore, if bacteria growth increases with climate change, the toxicity of some HAB species may also increase; however further work is needed to define the relationship between bacteria and algal toxin production (Richardson 1997).

In addition to changes in community composition, increased SST has resulted in changes in geographical distribution of some phytoplankton groups and species. The spatial-temporal distribution of several HAB-forming dinoflagellates in the North-East Atlantic has recently been studied with respect to regional climate change (Edwards et al. 2006). Since 1990, areas of the North Sea and North-East Atlantic which have warmed the most have significantly increased in abundance of both toxic HAB-forming dinoflagellates such as *Prorocentrum* spp. and *Dinophysis* spp. as well as *Noctiluca* spp. and *Ceratium furca*, the decomposition of whose blooms result in oxygen depletion which may lead to benthic mortalities (Fig. 2, Edwards et al. 2006). Areas undergoing rapid warming may therefore be among the most vulnerable to increased HABs. Additionally, biogeographical boundary shifts in phytoplankton populations made possible by climate change also have the potential to lead to the poleward-spread of HAB species normally suited to milder waters (Edwards et al. 2006). This may result in an increased number of HAB species in some marine and coastal regions.

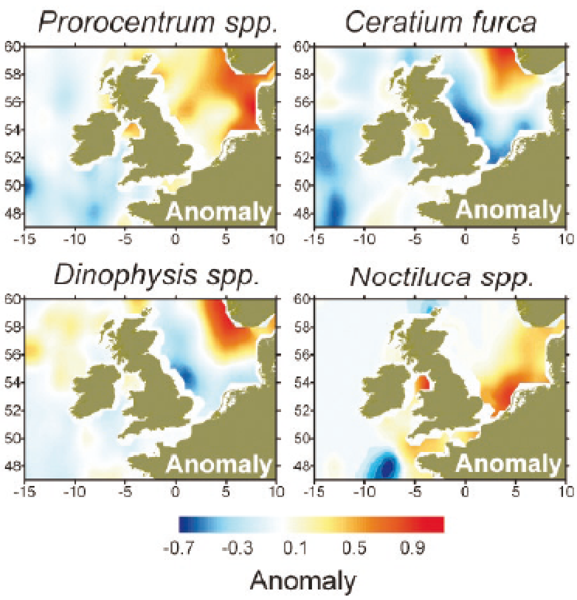

Figure 2: Anomaly maps signifying the difference between the long-term mean (1960-1989) and post-1990s distributions of some key dinoflagellate species in the North-East Atlantic. Shades of red signify values above the long-term mean and shades of blue signify values below the long-term mean. Reproduced from Edwards et al. (2006).

Besides a general spread in their distributions, there is also evidence that HABs are becoming more frequent in some regions. In the eastern North Sea, for example, the frequency of occurrence of exceptional blooms has tripled since 1980 (Edwards et al. 2006). This increase is almost certainly related to changes in the hydroclimatic regime of the region, including hydro-climatic factors such as increased sea surface temperature, decreased salinity, variability in wind speed and changes in inflow from the North Atlantic to the North Sea. Additionally, some HAB-forming dinoflagellates form resting cysts during their lifecycles. Cysts sink to the sea floor and when environmental conditions are conducive to growth they break open to're-seed' the area with the species. Some cysts can remain viable for tens of years, but if growth conditions occur more frequently, if for example one of the requirements is SST above a certain minimum temperature, cysts may be expected to reseed more often, causing HAB blooms (Dale 2001).

3.4.3 Acidification of Waters and Effect on Harmful Algal Communities

As yet there is no evidence linking any aspect of HABs to ocean acidification. However research regarding ecological effects of ocean acidification is in its infancy and the extent of current knowledge is limited. For example, it is widely expected that increasing acidification will reduce calcification of marine organisms. However, recent research has found increased calcification in the phytoplankton species *Emiliania huxleyi* (Iglesias-Rodriguez et al. 2008). Although no HAB-forming species are calcareous, much further research is needed into the ecological effects of ocean acidification. It is possible that ocean acidification may cause changes in HAB dynamics through changes in phytoplankton community composition, however, there are insufficient data to draw any conclusions about the impacts that increasing CO_2 might have on the growth and composition of HAB-causing marine phytoplankton (The Royal Society 2005).

3.4.4 Impact of Sea-level Rise, Increased Precipitation and Flash Floods on Harmful Algal Communities

In addition to changes in climate, increased anthropogenic nutrients are thought to be a key cause of HABs (Sellner et al. 2003). Sea level rise, increased precipitation and flash floods are most likely to affect harmful algal communities through increased nutrient release to coastal and marine waters. Two key nutrients required for phytoplankton growth, nitrogen (N) and phosphorus (P), are found in fertilizers and animal and human waste; however silicon (Si), which is only required for diatom growth, is not added to the environment through human activity. Therefore run-off from land, including floodwaters and increased river flow due to heavy precipitation, is likely to be richer in N and P than in Si, leading to an imbalance of these nutrients in coastal regions. Increased concentrations of N and P without a corresponding increase in Si may cause changes in phytoplankton community composition, favouring dinoflagellates, which have no biological requirement for Si, at the expense of diatoms (Officer & Ryther 1980, Smayda 1990). Such a shift in the phytoplankton community towards dinoflagellate dominance may result in increased numbers of HAB species in regions prone to increased anthropogenic nutrients.

Flash flooding and sudden storm events may release ‘pulses’ of nutrients into coastal waters. High nutrient pulses have been found to alter the phytoplankton functional group composition of receiving waters (Paerl et al. 2007). In the Easter Mediterranean, for example, a sudden pulse of high nutrient water lead to an increase in phytoplankton biomass and the dominance of *Pseudo-nitzschia calliantha*, a toxic HAB species (Spatharis et al. 2007). In some regions climate change is expected to result in increased storminess (Carter et al. 2007). If this is the case, nutrient pulses may then become more common as flash floods and storm deluges release sudden bursts of nutrient-rich water to coastal seas, resulting in alterations to phytoplankton community composition and increased occurrence of HABs.

Climate change is predicted to cause a rise in sea level of at least 0.6 m by 2100 (Nicholls et al. 2007). As the sea reclaims low-lying land, areas that are currently intensively farmed or urbanised may be drowned, causing the addition of nutrients, particularly N and P, to coastal systems. Additionally, as sea levels rise, wetland habitats are lost. Wetlands act as natural filters for anthropogenic nutrients and are therefore important in regulating nutrient loads to coastal waters. Wetlands and mangrove habitats also provide a natural form of protection from storm surges and flooding (Nicholls et al. 2007). Without these habitats, coastal waters may be more prone to increased levels of nutrients and nutrient imbalance. Developing countries, in which natural coastal landscapes are often sacrificed for economic or development schemes, may be particularly at risk. Additionally, developing countries often lack food safety standards employed in developed regions as well as the health care capacity to deal with outbreaks caused by shellfish or fish toxicity (Nicholls et al. 2007).

Measures taken in order to prevent or lessen the severity of impact of sea level rise and flash flooding may also alter nutrient loads to coastal waters. For example, the Iron Gates dam built on the Danube River was found to more efficiently retain Si than N or P. This, along with increased N and P loads, resulted in an increase in non-diatom blooms in the northwest Black Sea, including those of some HAB species, as well as an increase in bloom intensity (Humborg et al. 1997, Moncheva et al. 2001).

Increased precipitation and flash flooding may affect HAB communities through changes in salinity as well as changes in nutrients. Several HAB-forming species appear to be responding particularly well in regions which are both warming and becoming increasingly fresh (Edwards et al. 2006). For example, Norwegian coastal waters of the North Sea have experienced a decrease in salinity related to increased precipitation and increased terrestrial run-off. At the same time, several HAB-forming species such as *Ceratium* spp., *Dinophysis* spp., *Protoperidinium* spp., and *Prorocentrum* spp. have increased in abundance in this region (Edwards et al. 2006). In some places, sea level rise will increase water depths, leading to increased tidal exchange and reduced salinity. If climate change does result in increased freshwater run-off to coastal waters which are also warming, the species mentioned above could serve as an example of what may occur in other coastal regions undergoing similar changes.

3.5 Environmental Contaminants and Chemical Residues in the Food Chain

There are many pathways through which global climate change and variability may impact environmental contamination and chemical hazards in foods. The section that follows synthesises existing evidence of chemical contamination of the environment associated with climate-related extreme events, ocean warming and changes in surface temperature and humidity that could result in food safety chemical hazards. The discussion below also highlights challenges for animal and plant health management and discusses possible implications for chemical residues in foods and in the environment.

3.5.1 Flooding and Environmental Contamination

Contamination of agricultural and pastureland soil with PCBs and dioxins have been associated with climate change related extreme events, particularly with the increased frequency of inland floods. Soil contamination can be attributed to remobilisation of contaminated river sediments which are subsequently deposited on the flooded areas. In other cases, contamination of the river water bodies, and subsequently of the flooded soils, may have resulted from mobilization in upstream contaminated terrestrial areas such as industrial sites, landfills, sewage treatment plants etc.

Following the huge Elbe and Mulde floodings in Central Europe in 2002 a series of research and monitoring programmes were conducted in order to assess the contamination of the flooded and to identify transfer into the food chain. Results of the monitoring programmes showed very high levels of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) present in soil in periodically flooded pastureland riverside of the dikes, and grazing on the floodplains revealed a significant transfer of PCDD/Fs into milk (Umlauf et al. 2005). While the uptake of contaminated soils during grazing is an important factor considering the transfer into the food chain, barn feeding of properly harvested greens from the same floodplains is less critical (Umlauf et al. 2005).

Sources of chemical contamination of floodwater following Hurricane Katrina included oil spills from refineries and storage tanks, pesticides, metals and hazardous waste (Manuel, 2006). Several chemicals, such as hexavalent chromium, manganese, p-cresol, toluene, phenol, 2, 4-D (an herbicide), nickel, aluminium, copper, vanadium, zinc, and benzidine were detected in flood water. Trace levels of some organic acids, phenols, trace cresols, metals, sulfur chemicals, and minerals associated with sea water were also detected (EPA, 2005). Concentrations of most contaminants were within acceptable short-term levels, except for lead and volatile organic compounds in some areas (Pardue et al., 2005).

3.5.2 Contamination of Waters

Higher water temperatures, increased precipitation intensity, and longer periods of low flows exacerbate many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salts (Kundzewicz,et al,2007). In regions where intense rainfall is expected to increase, pollutants (pesticides, fertilisers, organic matter, heavy metals, etc.) will be increasingly washed from soils to water bodies (Boorman, 2003; Environment Canada, 2004). Higher runoff is expected to mobilise fertilisers and pesticides to water bodies in regions where their application time and low vegetation growth coincide with an increase in runoff (Soil and Water Conservation Society, 2003).

Because of compaction, heavy rainfall after drought can result in more severe runoff and an increased risk of certain types of contamination. Alternating periods of floods and drought can therefore aggravate the problem.

3.5.2.1 Ocean warming

Increasing ocean temperatures may indirectly influence human exposure to environmental contaminants in some foods (e.g., fish and mammal fats). Ocean warming facilitates methylation of mercury and subsequent uptake of methyl mercury in fish and mammals has been found to increase by 3–5% for each 1ºC rise in water temperature (Booth and Zeller. 2005). Temperature increases in the North Atlantic are projected to increase rates of mercury methylation in fish and marine mammals, thus increasing human dietary exposure (Booth and Zeller 2005).

3.5.2.2 Sea level rise

Sea level rise related to climate change is expected to lead to saltwater intrusion into aquifers/water tables in coastal areas.[1] This will extend areas of salinisation of groundwater and estuaries, resulting in a decrease in freshwater availability for humans, agriculture and ecosystems in coastal areas. One-quarter of the global population lives in coastal regions; these are water-scarce -less than 10% of the global renewable water supply- (WHO, 2005) and are undergoing rapid population growth. Millions of poor people in developing countries

[1] There are no data in the literature associating climate related sea level rise with freshwater groundwater chemical contamination.

may experience limited use of water as a food ingredient due to underground water salinisation caused by climate related sea level rise.

3.5.3 Soil Contamination

3.5.3.1 Alternating periods of droughts and floods

Agriculture soil and water contamination and variation on levels of contaminants have been associated with alternated periods of floods and droughts. The frequency of these seasonal periods will be increased due to climate variability and change.

Arsenic-rich groundwater is widely used for irrigation in Bangladesh during the dry season leading to increased levels of arsenic (As) in soils. Monsoon flooding leads to a reduction of topsoil-As contents almost to levels existing before irrigation. However, there are indications that As concentrations in soil are increasing over-time because of irrigation with As-contaminated water. Data are, however, insufficient in terms of quantity and quality and it is thus still unclear under what specific conditions and over what period of time As is accumulating in the soil. There is a risk of As contamination in soils affecting crop production. Concentrations of this contaminant in rice are increasing over time because of the prolonged input of contaminated irrigation water (Islam et al. 2005; Heikens, 2006; Dittmar et al, 2007).

3.5.3.2 Environmental degradation and accelerated desertification

Impacts of Climate Change in physical systems or processes are exacerbated in areas where the environment has been damaged by humans for agriculture, mining or industrial purposes. This may lead to very highly contaminated "hot spots" and therefore of local food supply.

An illustrative example is the Aral Sea in Central Asia, which was once the fourth-largest lake in the world and has been one of the world's largest environmental disasters during the last 20 years. In the Aral Sea area, agriculture mis-management (e.g. cotton monoculture, over irrigation, pesticide abuse) and accelerated desertification due to both environmental degradation and climate change, have resulted serious contamination of soil, water and local foods with high levels of POPs and dioxins, leading to critical health and socio-economic impacts to local populations (Muntean, 2003).

3.5.4 Pesticide Usage and Residues in Crops and the Environment

Climate change as a driver will have different effects on the various types of plant pests. Based on studies of individual species, climate change may affect: pest developmental rates and numbers of pest generations per year; pest mortality due to cold and freezing during winter months; or host plant susceptibility to pests (FAO, 2005).

Farmers will need to find ways to control pests in the scenario of climate related change. The concept of Good Agricultural Practices (GAP) should, to the extent feasible in a given farming system, seek to include the three pillars of sustainability; GAP should be economically viable, environmentally sustainable, and socially acceptable; inclusive of food safety and quality dimensions (FAO, 2003).

Pesticides, both chemical and natural, that are presently commonly used, could in fact be no longer appropriate to the new agricultural scenario (climate, plant, environment). For instance, many pesticides have limited activity in dry conditions (Muriel et al. 2001), probably necessitating higher dose levels or more frequent applications to protect crops. On the other hand there is some evidence of faster degradation of pesticides due to higher temperatures (Bailey, 2004).

Integrated pest management (IPM) programmes serve to respond to problems associated with established pests. These initiatives build on lessons learned in countries including on the impact of changing crop-pest relations caused by cropping intensification, expansion of cropped areas, new crops and introductions of crops, pest introductions, and pest population dynamics and evolution. All these factors are influenced by climate variability and change and will need to be reassessed to adapt to the impacts of new climatic conditions.

The current trajectory for warming and more extreme and unpredictable weather could have catastrophic effects on agricultural yields in the tropics, subtropics and temperate zones. Disease outbreaks could take an enormous toll in developing nations, and overuse of pesticides could breed widespread resistance among pests and the virtual elimination of protective predators (Rosenzweig et al. 2005). It is projected that warming and increased precipitation and accompanying diseases would increase the use (and costs) of pesticides for certain crops such as corn, cotton, potatoes, soybeans and wheat (Chen and McCarl 2001). This has already happened in Brazil in when excessive rains in 2004 favored the development soybean rust leading to an increased level of fungicides used to control the disease (Rosenzweig et al. 2005).

Climate related changes in ecological conditions, increased crop pests, suitability of new areas to potential quarantine and unpredictability may all together lead to the misuse and/or abuse of pesticides usage. This may threaten the health of poor farmers, may contribute to environmental contamination with pesticide residues and may lead to increased residues in crops.

3.5.5. Veterinary Drug use and Residues in Foods and the Environment

Climate change may result in changes in the incidence of foodborne zoonoses and animal pests and possibly in increased use of veterinary drugs (FAO, 2008b). New diseases in aquaculture could also result in increased chemicals use. Consequently, there may be higher and even unacceptable levels of pesticide and veterinary drugs in foods (FAO, 2008b).

Climate change is only one of several ‘global change’ factors driving the emergence and spread of diseases in livestock and the transfer of pathogens from animals to humans, ecosystem diversity, function and resilience. Other factors include changes in the structure of the livestock industry, in breeding and husbandry practices and in international trade in livestock and animal products (FAO 2008c). These factors are not independent from each other and climate change interacts with each of them.

Climate change will be especially important to vector-borne diseases and macroparasites of animals and may also result in new transmission modalities and changes in host species. Changes in species composition and interactions will augment the emergence of unexpected events, including the emergence of new diseases and pests. While most developing countries are already subject to an enormous disease burden, both developing and developed countries will be subject to newly emerging diseases (FAO, 2008c).

Bluetongue and Rift Valley fever, as well as tick-borne diseases, will be strongly influenced by climate change (Easterling et al., 2007). Climate may also have a direct or indirect influence on the onset of complex bacterial syndromes, such as bovine mastitis, which usually require antibiotic treatment; this leading to residues in foods (Schroeder, 1997). Concerns associated with aquaculture in a warming environment include a greater susceptibility to disease, introduction of pathogens and antibiotic-resistant pathogens, heavy use of antibiotics and environmental contamination with pesticides (Shriner et al., 2007).

Countries' attempts and plans to implement good animal husbandry and good aquaculture practices may be challenged by climate variability and change, particularly in developing countries, where frequently these practices are already difficult to implement and biosecurity measures are not in place. Risk assessments, protocols for use of veterinary drugs, pesticides, and/or establishment vaccination programmes will have to be re-assessed in view of the new challenges to animal health management derived from climatic variability. This together with the implementation good husbandry, aquaculture and veterinary practices will prevent the misuse of veterinary drugs and chemo-therapeutants in animal farming and aquaculture settings and limit the risks of unacceptable residues of veterinary drugs in foods and discharge of chemo-therapeutants and pesticides into the environment.

3.6 Emergency Situations

3.6.1. Increased Frequency of Climate Related Emergency Situations

According to the 4th IPCC assessment report, climate change is altering disaster risk patterns in three main ways:

- increase in frequency and intensity of extreme events, such as more frequent extreme temperatures and heavy precipitation, more intense tropical cyclones and expanded areas affected by drought and floods;
- changes in geographical distribution of areas affected by hazards;
- increase in vulnerability of particular social groups and economic sectors due to sea level rise, ecosystem stress and glacier melting.

By 2020, between 75 and 250 million people are projected to suffer increased water stress in sub-Saharan Africa and by 2080, 2 to 7 million more people per year, will be affected by coastal flooding (Yohe et al. 2007).

The number of reported climate related disasters (e.g. droughts, floods, wind storms, forest fires etc) significantly increased from an average of 195 per year from 1987 to 1998 to an average of 365 per year from 2000 to 2006. Of the 262 million people affected annually by climate disasters between 2000 and 2004, more than 98 percent lived in developing countries (UNISDR/CRED 2007). Climate variability is expected to result in more frequent and extensive disasters, with the most severe consequences on the food and water security, safety and livelihoods of vulnerable coastal and agriculture dependent populations.

Climate change related environmental degradation has been associated with war and other forms of conflict leading to major humanitarian and food crisis. By increasing the scarcity of basic food and water resources, environmental degradation increases the likelihood of violent conflict (LEAD 2006).

3.6.2 Food Safety, Natural disasters and Humanitarian crises

During or following natural disasters, such as the recent cyclone in Myanmar, the earthquake in China, the tsunami in South East Asia 2005, or the hurricanes in New Orleans in 2005, food in affected areas may become contaminated with dangerous microbiological and chemical agents. Consequently, populations are at risk of outbreaks of foodborne diseases, including hepatitis A, typhoid fever and diarrhoeal diseases, such as cholera, dysentery, norovirus infections and to the exposure to toxic chemicals through contaminated foods and water (see Section 3.5).

Climate related increasing frequency and severity of droughts and the consequent loss of livelihoods is a major trigger for population movements that are leading to major humanitarian crisis. The UN projects that there will be up to 50 million people escaping the effects of environmental deterioration by 2020. Forced migration frequently results in extreme stress, food and water emergencies, malnutrition, diarrhoea, limited access to medical care, all of which contribute to ill health. Poor health status leads to increased susceptibility to both microbiological and chemical food hazards and associated diseases.

Food safety risks associated with natural disasters and emergencies are mainly linked to unsafe food storage and cross contamination from the environment or from people during food handling and preparation. In many cases cooking may be impossible in emergency situations due to the lack of electricity, facilities or fuel. Poor sanitation, including lack of safe water and toilet facilities, and close personal contact can compound the risks of illness among these already susceptible groups.

3.6.3 Food Safety Measures in Emergencies

When natural disasters strike, food safety is a crucial public health concern that has been too often neglected. Under the conditions that may occur during and after natural disasters and emergencies, the following issues require immediate attention (WHO, 2005a):

- Preventive food safety measures
- Inspecting and salvaging food
- Provision for safe food and water
- Recognition and response to outbreaks of foodborne disease
- Food safety education and information of affected populations.

To be able to effectively carry out these functions during an emergency situation requires the involvement of various groups who are aware of their roles and trained and equipped to execute them and it also requires a high level of coordination among all parties. These conditions can only be met if good emergency response plans are prepared and practised ahead of the emergency and there is a local and national political will to support these plans.

Changing climate patterns have increased the urgency to invest in disaster risk reduction, preparedness and response plans. These plans should address food safety risks in the aftermath of natural disasters along the whole food chain. This requires intersectoral assessments of national infrastructural and operational capacity building needs for emergency preparedness and response.

Box 7: Norovirus Outbreak – Example from Hurricane Rita

This norovirus outbreak serves as an excellent example of what can occur in the event of forced evacuation due to a major weather event. Mutiple infection control measures which were instigated soon after the identification of the norovirus outbreak; however, the rise and fall of the epidemic curve coincided with the arrival and relocation of the evacuees respectively. Although one predominant virus cluster type was implicated, there were at least 3 different norovirus strains circulating and substantially more genetic diversity among strains than would be anticipated. This suggests multiple sources of infection or perhaps a mixed source such as sewage. Of course, crowded conditions, close personal contact, insufficient sanitation, and lack of adequate toilet and hand-washing facilities all contributed to the outbreak. This outbreak underscores the dilemma for poorer nations, for which evacuation and relocation would have taken longer, crowding would have been more severe, enforcement of infection control measure difficult if not impossible, and access to health care limited.

3.6.3.1 Scope of preparedness and response plans

Preparedness and response plans must consider the whole food chain. Agricultural production may be adversely affected by flooding associated with natural disasters. When crop fields have been contaminated or damaged, assessments should be carried out to establish measures to reduce the risk of pathogens, hazardous chemicals, natural toxins etc. (e.g. delayed harvesting, heat treatment) or to assure disposal (FAO, 2005; WHO, 2005a).

Necessary inspection of food industries, slaughterhouses, markets and catering establishments in order to ensure safe operation and that damaged/contaminated foods are not marketed may be difficult in the aftermath of natural disasters. Proper disposal of food stocks found to be unfit for human consumption should be done under the supervision of appropriate authority.

National emergency prevention and response plans countries should have provisions for water and food distribution and mass feeding after natural disasters and mechanisms to assure their safety depending of the degree of infrastructural damage.

Investigation of and response to suspected foodborne disease outbreaks are required in order to limit their spread. The effectiveness of response depends to a great extent on preparedness, the capacities for investigation and verification, and coordination between relevant government and other agencies that contribute to managing public health risks.

During natural disasters and humanitarian crisis, proper risk communication is the most effective tool for timely provision of information to the public on food-related risks and the actions they should take to minimize those risks.

4. ADDRESSING FOOD SAFETY IMPLICATIONS OF CLIMATE CHANGE

Section 3 of this paper described impacts that climate change might be expected to have on major food safety issues. There is still much to be understood about the food safety implications but awareness of possible new challenges is the first step to preparing to address them. This Section looks at ways in which countries can proactively promote strengthening of food safety management programmes so as to ensure effective control all significant hazards along the food chain in the context of a changing environment.

4.1 Foodborne Disease including Zoonosis

The potential for climate-induced changes to have an impact on the prevalence of some foodborne disease is explained and illustrated in Section 3.3. Strategic and effective food safety management requires that we understand microbiological hazards and how their presence in foods can be prevented or maintained within tolerable levels.

Improving our ability to understand and to control emerging microbiological hazards at all stages of the food chain will require efforts in a number of key areas including mathematical modelling; application of new scientific tools that allow us to characterize complex microbial communities; improved epidemiological surveillance, new tools for monitoring or screening programmes for foodborne pathogens; strengthened animal health surveillance; and improved coordination among food safety, public health and veterinary health services.

4.1.1 Predictive Models

When available, inferences can be made based on existing data, such as studying disease trends in presence and absence of El Nino events (Greer et al., 2008). Another approach is the application of mathematical modelling. Finally, molecular-based population genetics studies may provide information on microbial population changes occurring in response to environmental stresses.

Some have advocated that the effects of climate variability driven by natural cycles such as the El Nino-southern oscillation (ENSO) can be used to predict, at least in part, the impact of global climate change (Lipp et al., 2002). There is evidence for a correlation between El Nino events and cholera outbreaks, particularly in South America.

From a mathematical modelling perspective, Fluery et al (2006) recently used time series analysis along with epidemiological data to predict the impact of ambient temperature on the risk of disease caused by three foodborne pathogens (*Salmonella*, *Campylobacter*, and *E. coli*). Lobitz et al. (2000) used remote sensing data to indirectly measure *V. cholerae* behaviour as a function of ocean temperature and surface height, providing a means by which to predict conditions conducive to pandemic disease. Koelle et al. (2005) reported a complex theoretical framework for predicting the evolution of seasonal infectious disease dynamics based on a combination of host-pathogen dynamics, pathogen evolution and adaptation, and climate change. The use of mathematical models in microbial ecology is an emerging field, and though not yet applied to climate change, this is a promising new direction for that field.

Another emerging field is that of molecular ecology, where scientists use advanced molecular biological methods, specifically nucleic acid sequence comparisons and genomics-based approaches, to characterize complex microbial communities. This field is expanding rapidly and these sorts of studies can provide information about the overall composition of microbial communities; the relationship between pathogens, commensals, and other organisms in the environment; and the effect of environmental changes on these relationships. Furthermore, these methods are applicable to the study of microbial evolution, and virulence factor acquisition and expression as a function of changes in environmental exposures. When combined with geoinformatics (the combination of remote sensing, geographic information systems, and statistical modelling for the characterization of spatial distributions and relationships), it should also be possible to model the distribution and spread of pathogens as a function of climate change.

4.1.2 Foodborne Disease Surveillance/ Animal Disease Surveillance

The need for improved epidemiological surveillance for early identification of emerging food and waterborne diseases is undisputed. Large public health initiatives have been implemented over the last decade in the developed world. While these have not answered all our questions, they have provided much needed preliminary data about the prevalence of foodborne diseases, and trends in their annual incidence. Ideally, a global approach to epidemiological surveillance should be taken, since the agents (or for that matter, humans) do not respect artificial boundaries. Of particular importance is the rapid investigation of unusual outbreaks, with inclusion of environmental investigation to ascertain if climate change is a factor. In addition, public health systems must be able to mobilize and respond quickly to emerging and re-emerging foodborne diseases of infectious origin.

4.1.3 Foodborne Pathogens: Monitoring and Surveillance

Ideally, epidemiological surveillance should be supplemented with the direct detection of pathogens in foods and/or the environment. While pathogen detection methods are widely used in the clinical realm, their use in food and environmental applications is complicated. In virtually all instances, pathogen detection methods involve many steps resulting in a lengthy assay. Most rapid methods developments have sought to shorten detection time by introducing methods based on DNA hybridization or enzyme immunoassay. However, since these methods are still relatively insensitive, lengthy cultural enrichment steps remain necessary. Even the highly sensitive and specific polymerase chain reaction (PCR) is hampered by volumetric constraints, matrix-associated inhibition, and the inability to distinguish between viable and inactivated pathogens. There is a clear need to focus research efforts in the development of sensitive and specific methods to detect pathogens in complex sample matrices such as foods. An ideal method would be rapid (results in a few hours), easy, inexpensive, field deployable, and provide enumerative results. We are many years away from this but progress is necessary, particularly for use in the developing world where rapid detection could make a substantial difference in disease containment.

In the absence of truly rapid methods for pathogen detection, microbiological indicators are used. These serve as easy-to-detect surrogates, usually for the presence of pathogens associated with fecal contamination. Historically, fecal coliforms or generic *Escherichia coli* have served in this capacity. While these have been, and continue to be useful for some screening their presence bear little relationship to *Vibrio* or enteric viral contamination of water and molluscan shellfish. Alternative indicators have been proposed but unfortunately, none of these is ideal and few have been thoroughly evaluated. In the absence of effective microbiological indicators, it will be extremely difficult to monitor the impact of global climate change on the transmission of several of the important foodborne pathogens.

4.1.4 Improved Coordination among Public Health, Veterinary Health, Environmental Health and Food Safety Services

Human, animal and environmental health is inter-related. Strengthened communication and cooperation among professionals in these areas would be particularly valuable as we seek to predict, recognize, and mitigate the impact of global climate change on infectious disease, including foodborne illness. Promotion of such cooperation worldwide would result in holistic, multi-disciplinary solutions to difficult problems for which a single discipline does not have an answer. Such an initiative – "One Health" concept - has been launched in the US.

4.2 Mycotoxin Contamination

The real problem with developing a strategy for the reduction mycotoxin levels in food, whether for the present or for some potential worsening of conditions due to climate-related changes in the future, is not in formulating the strategy but rather in implementing it. Chronic exposure, arguably the most important form of exposure, is subtle and the connection between cause and effect is difficult to substantiate so authorities move reluctantly. On the one side implementation requires significant technical capacities and on the other side, because it is often seen as a 'theoretical' risk, it is sometimes difficult to foster the political will to act.

Elements of national-level policy are listed and discussed below. ***Implicit in each of the aspects listed below is a bolstering of existing capacity alongside creating new capacity*** as, for example, a programme of monitoring means more analytical capacity for current methods will be required as well as execution of new analyses. Some of the points discussed below are ably considered for aflatoxin by Strosnider, et al., 2006.

4.2.1 Prevention of Mycotoxin Contamination

This is not to suggest that complete prevention is plausible since, as discussed previously, mycotoxins at some level are a natural consequence of plant and fungal interaction. The aim is to prevent the occurrence at levels that might cause harm. To formulate a prevention strategy, the aetiology of toxin contamination must be ascertained in order to focus efforts to maximum effect. This often requires applied research which presupposes investment in the technical facilities and in the human resources to support such work. This science-based approach to developing risk-based mycotoxin prevention and control programmes has shown promising results (FAO, 2006).

4.2.2 Monitoring and Predictive Modelling

Monitoring can include monitoring of markers or metablolites in populations in order to have a measure of exposure to toxins it also refers to monitoring of mycotoxins in commodities. Monitoring data can contribute to the identification of an emerging problem, they can provide feedback on the efficacy of "Good practice guidelines", they can contribute to the conduct of risk assessments to support science-based maximum limits for contamination. Models have been proposed that work from meteorological and insect population data for the prediction of mycotoxin outbreaks (Hooker and Schaafsma, 2005; De La Campa, et al., 2005).

4.2.3 Maintenance of Strategic Food Stocks

Want of food can lead to increased consumption of unfit food so by maintaining stocks of staple foods, of good quality, in secure storage facilities, this eventuality can at least be forestalled in an emergency. This is, of course, costly and requires careful attention to food quality and safety management particularly in relation to control of incoming stocks, 'first-in-first-out' storage management, and monitoring of storage conditions.

4.2.4 Agricultural Policy and Public Information Review

Mycotoxins are not generally understood by the public and as an essentially invisible threat are difficult to publicise effectively. Nevertheless, informing the pubic as to the risks of exposure and the nature of the food that carries these risks might help to reduce use of or trade in substandard food in times of need.

Climate change may make production of certain crops difficult in some areas – apart from posing an obvious food security problem, conditions of plant stress (such as drought stress or stress caused by insect damage as noted in Section 3.3) can lead to increased mycotoxin production. Under conditions of a changing environment development of revised guidance on GAP or IPM programmes for selected crops may improve performance and reduce mycotoxin risks. Introduction of new crop varieties or establishment of replacement crops are also likely to be elements of a food security strategy. It should be noted that the introduction of new crop varieties could fundamentally alter the dynamics of the crop's association with fungi. There have been reports of the possible role of biotechnology in the development of crops that can grow under marginal conditions (resistance to drought, salinity and insects) (Thomson, 2007). Making use of new technologies to address challenges presupposes the capacity to assure that they do not pose unacceptable risk to consumers or to the environment.

4.3 Harmful Algal Blooms and Fishery Product Safety

The apparent increase in the occurrence of HABs and the recognition that changes in climate may be creating a marine environment particularly suited to HAB-forming species of algae underline the need for governments to ensure that existing risk management measures are adequate and are in line with international recommendations. Countries are encouraged to implement integrated shellfish and micro-algal monitoring programmes, as part of Marine Biotoxin Management Plans to strengthen risk management capability and to enhance consumer protection (FAO/IOC/WHO, 2005).

4.3.1 Predictive Modelling

Improved capacity to predict HABs is important for more effective risk management and prediction of HABs depends on modelling exercises as well as an understanding of their ecology.

There is much ongoing research to improve our understanding of the factors that influence population dynamics of harmful algae. Until recently, most research on HABs had been conducted at the local scale, but several national and international programmes studying and monitoring the ecology of HABs now exist (Glibert et al. 2005). The international dimension is important for understanding and addressing the global impact of climate change on HABs.

Micro-algal monitoring coupled with operational oceanographic, meteorological, and remote sensing data, including modelling and other measurements are being used in the prediction of HABs. Traditional approaches, such as microscopic examination and analysis of toxins, resulting in species level of identification are unsuitable to real-time observation; however, new techniques and observational strategies for HABs are emerging and evolving.

HAB prediction is complex as it includes conceptual descriptions of ecological relationships and statistically based empirical models as well as numerical models. Predictions depend on observations which provide both input to models as well as data for model validation and error prediction (Barin et al. 2005). The effects of climate-related changes increase the complexity of the system (Refer to Section 3.4) and underscore the need for continued effort and international cooperation in this field.

4.3.2 Other Risk Management Guidance

Improved capacity to predict HABs is an important risk management tool but other tools are needed as well. While these are not specific to climate change, as mentioned earlier the increased likelihood of biotoxin contamination events makes it worthwhile to focus attention on these requirements. The Joint FAO/IOC/WHO ad hoc Expert Consultation on Biotoxins in Bivalve Molluscs (2004) recommended that, among other things, member countries be encouraged to generate more toxicological data (with studies conducted according to OECD guidelines) and that member countries be encouraged to improve and validate toxin detection methods in shellfish.

4.4 Environmental Contaminants and Chemical Residues

Section 3.5 addresses the impact of climate change and variability on environmental contaminants and chemical residues in the food chain. To ensure the safety of foodstuffs, efforts are required in a few key areas to address these impacts.

4.4.1 Research Priorities and Data Needs for Developing Predictive Models

Basic information is required on the impact of climate change and variability on the fate of chemical contaminants, pesticides and other chemo-therapeutants in the environment. Impacts of ocean warming and acidification on the bioaccumulation of contaminants in aquatic species and on the structure and distribution of food webs, needs more research from the physical-biochemical point of view and the geographical distribution of aquatic species. Few studies have investigated the impacts of future climate change scenarios on aquatic biota and there is a need for data on future trends in aquatic primary production, nutrient supply and temperature sensitivity and on the combined response to elevated CO_2 and climate change of diseases, pests, weeds (Easterling, 2007).

4.4.2 Monitoring Programmes

Integrated monitoring and surveillance of i) water, soils and foods for contaminants and chemical residues, ii) crops for pesticide residues iii) animal products for veterinary residues and iv) emerging animal and human diseases is essential to address climate related environmental changes. The data generated may be used in the identification of emerging problems and food contamination trends and may contribute to risk assessments.

4.4.3 Good Agricultural, Animal husbandry, Aquaculture and Veterinary Practices

These practices ensure the safety and quality of agricultural, aquaculture and animal products. They may need to be adapted or revised in light of changing climatic conditions.
In relation to good veterinary practices, the appropriate use of veterinary drugs and chemicals in terms of safety, quality, amounts, frequency and timing and withdrawal times, are particularly important in a changing environment. The agriculture and sector offers multiple opportunities for climate change mitigation and environmental protection through the implementation of good animal husbandry and agriculture practices[2].

4.4.4 Data Exchange

Good data exchange mechanisms are required at both national and international level. These should cover the distribution of animal and plant diseases, pests, ecological conditions including climate, and associated usage of pesticides, veterinary drugs and chemo-therapeutants will be needed to enable risk assessment, prevention, monitoring and control.

4.5 Emergency Situations

The need to address food safety management in emergency situations is not specific to climate change. However the expected increase in frequency of extreme weather events renders the need for early warning systems and disaster preparedness in general more urgent.

4.5.1 Preparedness for Emergencies

In light of the above, countries should review/develop food safety emergency plans as well as review and update other Disaster/emergency plans to ensure adequate consideration of food safety management issues in those situations.

Developing and ensuring the capacity to implement such plans may require investment in trained human resources and in facilities.

At international level priorities for action include strengthening preparedness for effective response through:

- expanded contingency planning, especially in areas prone to flood, windstorms or drought, and promotion of prevention and adaptation in the rehabilitation phases.
- more flexible funding mechanisms at the international level that allow development and humanitarian resources to be invested in preparedness.

The FAO is in the process of streamlining its prevention and management framework for food-chain crisis to ensure effective bridging between early warning, preventive actions and response to threats in the food chain. An integral component of this streamlining is the extension of the FAO EMPRES (Emergency Prevention System for Transboundary Animals and Plant Pests and Diseases) programme to also cover food safety. Its primary purpose is the prevention and early warning of food safety emergencies. EMPRES-food safety will enable

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[2] Green house gases emissions can be reduced through improved diets can reduce enteric fermentation, improved manure management and biogas. Water pollution and land degradation can be tackled through better irrigation systems, fertilization schemes, better management of waste, improved animal diets that increase nutrient absorption (LEAD, 2007).

FAO to provide greater support to INFOSAN, particularly in accessing relevant information from the agriculture sector, analysis trends and providing technical assistance to prevent emergencies.

4.5.2 Development of Tools for Rapid Detection or Removal of Contaminants

Tools for rapid foodborne pathogen detection would be an important asset for food safety management in emergency situations (see Section 4.1).

Developments in technologies that could lead to simple and inexpensive removal of chemical and microbiological contaminants from water should be closely followed as such tools would also greatly facilitate improvements in food hygiene management in emergencies.

Such tools are under development notably these are both areas where nanoscience and nanotechnologies are expected to have considerable impact on food safety.

5. SUMMARY AND CONCLUSIONS

Existing guidance on food control systems (FAO/WHO, 2003) remains valid in the face of additional challenges that may be posed due to climate change related phenomena. In fact, these challenges highlight the need for many countries to intensify their efforts to implement programmes of food safety management that are in line with FAO/WHO guidance.

The discussions in Section 3 and 4 point to several common themes that deserve particular attention in ensuring that emerging risks are recognised as early as possible and that countries are prepared to respond promptly to these. These inter-related issues are outlined below.

5.1 Interdisciplinarity

Assuring food safety is a complex issue as it involves considerations from pre-production through to final home preparation of the food product. Recommendations on food safety management emphasise the need for broad input and coordination even though this remains a challenge in many countries. Recognising, understanding and preparing for the impacts of climate change further highlight the need to promote interdisciplinary approaches to addressing challenges affecting food safety given the inter-relationships among environmental impacts, animal and plant health impacts and food hygiene. .These inter-relationships are further complicated by the broader public health implications of climate change as well as the food security implications.

5.2 Application of Good Practices

Principles of Good hygiene practice, Good agricultural practice, Good animal husbandry practices, Good veterinary practice, Good aquaculture practice, etc remain the cornerstone of national food safety management strategies to address challenges posed by climate change. Guidance in applying these principles may have to be adjusted as a better understanding develops of changes in the occurrence and prevalence of chemical and microbiological hazards and of insects, pests and their vectors as affected by climate change and other factors.

Developing sound and practicable codes and guidelines may in some cases require applied research to better understand the new "dynamics" and to evaluate different approaches for controlling the problem.

As new information becomes available regarding the impact of climate change on food safety hazards, governments and industry associations could play a big role in reviewing and updating as necessary current guidance. In many developing countries the main challenge remains that of developing a policy framework that helps small and lesser developed businesses to overcome constraints to applying any kind of good practice programmes (FAO/WHO, 2006).

5.3 Monitoring and Surveillance – Food and Environment

Integrated monitoring and surveillance of both the environment and food for hazards is critical for the early identification of emerging problems and changing trends. While monitoring and surveillance programmes are currently implemented in many countries they may need to be reviewed and amended as necessary to address emerging hazards arising from global climate change. The data generated from these progammes contribute significantly to predictive modelling and risk assessments and should be shared readily both at national and international level. At international level relevant information can be circulated through networks such as INFOSAN (International Food Safety Authorities Network). This network provides a mechanism for the exchange of information on both routine and emerging food safety issues.

There is a clear need to focus research efforts in the development of rapid methods to detect pathogens/contaminants in complex sample matrices such as foods. Development of these methods will allow a rapid response to results generated from monitoring and surveillance programmes.

5.4 Disease surveillance – Human and animal

Epidemiological surveillance is a critical component of public health and is essential not only for the early identification of emerging diseases and trends but also for resource planning and measuring the impact of control strategies. A global approach to epidemiological surveillance should be taken and should involve collaboration between professionals involved in human, animal and environmental health. Of particular importance is the rapid investigation of unusual outbreaks. This is essential at both national and international level. The International Health Regulations is an example of an international framework for the coordination of the management of events that may constitute a public health emergency of international concerns, and will improve the capacity of all countries to detect, assess, notify and respond to public health threats.

Such surveillance programmes are essential in allowing us to recognise and respond to emerging risks due to climate change.

5.5 Predictive modelling

Predictive modelling is the process by which a model is created or chosen to predict the probability of an outcome. It has potential to predict the probability of global climate change on ecological systems and emerging hazards. It is currently being exploited along with other tools (operational oceanographic, meteorological, and remote sensing data) by the marine sector for the prediction of HABs. Other examples are available; however, this tool could be exploited in many more sectors to predict the probability of global climate change on ecological systems and emerging hazards.

Predictions depend on the quality and quantity of available data; therefore, international collaboration is essential to ensure good models are developed. Further, climate related changes increase the complexity of the system and underscore the need for continued effort and international cooperation.

5.6 Risk Assessment

Risk assessment provides the scientific basis for the development and adoption of food safety standards and for guidance on other food safety measures. Climate change related effects may give rise to emerging food safety risks that influence priorities for risk assessment. For example, if mixtures of mycotoxins become more common in crops (Text Box 5), it may become important to carry out risk assessments and propose revised maximum limits. New data from monitoring and surveillance programmes on frequency and levels of occurrence of mycotoxins could also affect decisions on appropriate limits and national or international levels.

A number of Joint FAO/WHO expert bodies have been set up to carry out risk assessments on food additives, food contaminants, pesticide residues, veterinary drug residues and microbiological hazards. Other Joint FAO/WHO ad hoc expert committees are set up to deal with other emerging issues as they arise. FAO and WHO member countries can influence the prioritisation of risk assessment work carried out at international level according to clearly established criteria (FAO/WHO, 2007). In case of emerging hazards related to the impact of climate change, member countries could have access to risk assessment advice.

Apart from the question of the availability of international risk assessment mechanisms it is important to emphasise the need to build the capacities of experts in developing countries to fully understand how these assessments are carried out so that they can make informed decisions on their applicability to the local context in light of new data coming out of their own monitoring and surveillance programmes.

FAO, in collaboration with many international, intergovernmental and governmental bodies, has supported the development of a standardized training programmed to assist countries in understanding and carrying out GM food safety assessments (FAO, 2008).

5.7 Early warning and emergency response systems

Enhanced early warning systems are essential to reduce the risk of the lives and livelihoods of vulnerable people posed by climate change related natural disasters and emergencies. This requires good collaboration and communication between sectors (e.g. veterinary, food safety and public health) at national and international level.

Emergency preparedness is also essential. Countries should review/develop food safety emergency plans as well as review and update other disaster/emergency plans to ensure adequate consideration of food safety management issues in those situations.

5.8 Strengthened dialogue with the public

Food safety is ensured through the implementation of adequate control measures at every step along the food chain, i.e. from farm to fork. To ensure consumers play their role, it is important they are aware of the hazards associated with foods and the relevant control measures. Education of consumers is therefore essential and governments have a role to play in this regard. Some hazards such as mycotoxins are not generally understood by the public and as an essentially invisible threat are difficult to publicise effectively. Nevertheless, informing the public about typical foods susceptible to mycotoxin contamination and the risks to public health might help reduce both the use and trade of substandard food in times of need.

5.9 New Technologies

Section 3 highlights a number of scientific and technological innovations that are expected to play a major role in helping us to understand and to deal with the food safety challenges posed by climate change. Examples include, new filtration devices based on developments in nanotechnologies that can remove a range of chemical and microbiological contaminants from water and even from soils; rapid pathogen and contaminant detection using novel techniques (including nanotechnologies); new molecular biological methods such as nucleic acid sequence comparisons and genomics-based approaches to characterise complex microbial communities and their interactions; genetically modified crops that are suitable for growth in marginalised lands, etc.

Clearly different countries have differing capacities to directly participate in the development of these scientific and technological applications but it is important for all countries to strive to remain updated with developments so that they can make best use of new opportunities and, perhaps, influence the prioritisation of research investments.

Attention must be paid to the need to develop capacities and mechanisms within countries to assess and manage any environmental or food safety risks that might be associated with various applications of these new technologies. As noted above, FAO/WHO has provided and continues to develop guidance on GM food safety assessments. FAO/WHO are currently preparing to hold an expert meeting on the potential food safety implications of nanotechnology applications in the food and agriculture sectors.

5.10 Investment in Scientific and Technical capacities

A common theme in several of the above-listed issues is the need for applied research to provide a better understanding of problems and new approaches for dealing with them. The ability to use science to find solutions depends on prior investment in human resource development. In many developing countries there is need for more careful planning to encourage the development of the competence that they need to address pressing problems. In many cases, it is already possible to make better use of the available competencies at national level by encouraging linkages between government services, universities, private sector associations, etc.

Careful assessment of food safety capacity building needs by national authorities is also essential in order to make best use of training and education opportunities including through technical assistance from interested donors and international organizations.

5.11 International Dimension

The whole issue of climate change in all of its dimensions is a global concern and international organizations have a major role in ensuring coordinated approaches to dealing with all aspects.

The need for sharing of data and information coming out of food safety and disease monitoring and surveillance and the role of international networks in facilitating this has been noted above. Regional or international cooperation on selected research areas of common interest would also allow better outputs for a given set of resources.

As new food safety risks emerge, the international community needs access to timely scientific advice to guide risk management choices. As climate change may be a factor leading to the emergence of food safety risks it is useful to consider ways in which the mechanism for provision of scientific advice could be made more responsive to increased and unscheduled demands for advice. The Joint Global Initiative for food related scientific advice (GIFSA) that was recently established by FAO and WHO should at least partly address this need. GIFSA is a mechanism to facilitate mobilization of funds in a transparent manner for the conduct of expert meetings on critical food safety issues requested by Codex and by FAO and WHO member countries.

The food safety challenges raised by climate related changes highlight the need for continued emphasis on food safety capacity building to developing countries. Coordination among donor agencies and international organizations providing technical assistance in this area remains a central issue

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