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Impact of climate change on microbiological hazards in food and drinking water in Sweden

Risk profile

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Foreword

This risk profile has been developed to raise awareness of how climate change can affect microbiological food safety in the future. The report describes disease-causing microorganisms and toxins that can affect the safety of food and drinking water consumed in Sweden, and how different stages of the food chain may be affected and which microbiological hazards are most relevant to different groups of food. The focus of the report is on a qualitative inventory and hazard identification for each food group.

The risk profile is developed on a joint initiative from the Department of Sustainable Food and the Risk and Benefit Assessment Department of the Swedish Food Agency and is intended to serve as a basis for the agency's continued work on climate adaptation. In addition, the report may serve as a basis for further and more detailed studies and various activities in the food sector. This report is a translation of the original report, which is published in Swedish.

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Content

Summary

This risk profile has been developed to increase knowledge on how climate change can affect microbiological food safety in Sweden. The focus of the report is to identify existing and emerging microbiological hazards (disease-causing microorganisms and toxins) that may be of concern and may affect the safety of food and water consumed in Sweden. Specific issues addressed are how the different stages in the food chain can be affected and which hazards are most relevant for different groups of food. Presented data are based on published scientific literature and governmental reports.

Human emissions of carbon dioxide and other greenhouse gases affect a range of climate-related factors and lead to changes beyond those natural variations that have always occurred. These climate changes are already evident and will, according to to various scenarios, continue during the next century. Globally, this means higher annual average temperatures, changing precipitation patterns, reduced access to freshwater in many regions, rising sea levels, and acidification of the oceans. In Sweden, the climate will also become warmer compared to today, especially in winter. Rainfall will generally increase, mostly in winter and spring, especially in the northern parts of Sweden. In the southeastern part of the country, increased drought and water shortages are expected. Climate change is also expected to lead to more frequent extreme weather, for instance, floods and heat waves.

A changed climate will have several effects on the environment and society that can affect food safety. Examples of such effects are changing conditions for plant cultivation, animal production, infrastructure, energy supply, and water availability.

Climate changes can impact food safety in different ways and through different routes along the entire food chain. Much of the impact occurs at the first stage, primary production, and can then propagate through the remaining stages of the chain. Two scenarios can be distinguished, and all stages of the food chain are affected by both scenarios although they may be of varying importance depending on the stage and type of activity:

- The first scenario includes the impact on food safety due to a change in the normal conditions with higher average temperature, increased precipitation or drought, and milder winters.
- The second scenario includes an increased frequency of extreme events such as torrential rains, floods, and dry periods, with consequences such as power failures and other infrastructure disruptions that can have a major impact on the food chain and, in turn, food safety.

In order to cope with the challenges of the new normal condition, climate change adaptation is needed in the production of foods and drinking water. The normal conditions in Sweden may become similar to the current situation in southern Europe, which gives an idea of what adaptation measures are necessary.

In addition, increased preparedness is needed to be able to prevent and manage extreme events that can lead to an increased presence of disease-causing microorganisms and toxins in the raw materials and in drinking and process water as well as to disturbances in infrastructure.

Changed conditions in primary production can to some extent be addressed through the application of good agricultural practice and/or certification standards. However, despite these frameworks direct control measures are more challenging to implement in the primary production stage than at later stages. At later stages of the food chain, HACCP-based procedures and prerequisite programmes such as good hygiene practices and good production practices have been used with good results in the past.

Assessing the impact of climate change on the occurrence and types of microbiological hazards is complex. This is partly because the changes that will take place are varied and can affect our environment in several different ways. It is also due to the fact that the available published studies on which the assessment is based vary greatly, both in terms of the hazards that are studied and in terms of scope and methodological designs.

Bacteria whose occurrence are likely to increase in the environment, water, animals, plants, and/or food raw materials due to a changing climate, and for which the level of evidence is judged to be high, are Bacillus anthracis, Francisella tularensis, Salmonella spp., Shigella spp., and Vibrio spp. The occurrence of all food-borne viruses are judged to potentially increase due to climate change. However, the level of evidence is intermediate for noroviruses and low for hepatitis A virus and hepatitis E virus. Most parasites are considered to potentially increase in occurrence due to climate change, but the level of evidence is low for most. For Cryptosporidium spp., Giardia intestinalis, and Toxoplasma gondii, the level of evidence is intermediate. Among the mycotoxins, it is estimated that all Fusarium toxins discussed in the report (DON, T2/HT2, ZEN, and fumonisins) will increase in occurrence, of which the evidence level is highest for DON and fumonisins. Also, aflatoxins are expected to increase in occurrence with a high level of evidence. In addition to the microbiological hazards listed, the occurrence of several other species of bacteria, viruses, and parasites as well as types of mycotoxins are also considered likely to increase, but due to limited data and in some cases conflicting indications, these assessments are more uncertain.

None of the microbiological hazards examined in the report have been judged to decrease due to climate change. However, it should be noted that some climatic factors may influence the occurrence of microbiological hazards in both positive and negative directions. Thus, locally, some of the hazards that have been assessed as possibly increasing in ocurrence may instead remain unchanged or even decrease. The long-term outcome also depends on the effectiveness of measures taken to address the challenges of climate change.

The microbiological hazards emerging due to a changing climate are likely to vary for different food groups. The disease-causing microorganisms and toxins that are assessed to have an increased importance in different food groups due to a changed climate have been compiled and discussed in this report. The increased occurrence of microbiological hazards can lead to challenges in producing safe food and drinking water. It has not been possible, on the basis of existing data, to rank the hazards. The assessment suggests that it is of greatest importance to consider which routes of transmission and types of hazards (properties, resistance) may be relevant in the different food groups because the control measures will in most cases be similar for different types of hazards.

There are many sources of uncertainty for the assessments made in this report. The main source of uncertainty include knowledge gaps associated with data on the extent to which the climate will impact on microbiological hazards, difficulties in identifying causal relationships based on correlations, knowledge gaps associated with the methodology of carrying out this type of complex assessment against uncertain future scenarios, and knowledge gaps about the future climate and its effects. A further contributing uncertainty is knowledge gaps on potential feedback mechanisms between climate change and its effects.

Despite the uncertainties, the increased food safety challenges qualitatively identified in this report are considered likely. These challenges are the consequences of the impacts that climate change under the RCP8.5 scenario may have on several of the microbiological hazards in terms of increased or potentially increased occurrence in the environment, water, animals, and/or food raw materials. Conclusions on the changed occurrence of specific microbiological hazards, the extent of the impact, and the rate of change are subject to significantly greater uncertainty. This is not least because the impact of climate change depends on the accuracy of the climate scenarios and on what measures are put in place.

The risk profile should be seen as an initial and general compilation of knowledge that can form a basis for further and more detailed studies and activities in various sectors of the food chain.

Glossary and abbreviations

Anthropogenic	Created, caused or influenced by man
Climate zone	A geographical area with similar climate. The zones include the tropical, subtropical, temperate and polar zones. Sweden is in the temperate climate zone
DON	Mycotoxin deoxynivalenol
EFSA	European Food Safety Authority.
Endemic	The permanent presence of diseases or microorganisms in a given geographical area or a population group
Fast-reacting groundwater reservoirs	Small groundwater reservoirs, which have a short response time and a large annual amplitude of water levels, and where changes in groundwater recharge due to changes in hydrological conditions are visible after a short period of time (Vikberg et al., 2015). Compare with slow-reacting groundwater reservoirs
FUM, FB1 and FB2	Fumonisin, group of mycotoxins including forms B1 and B2
HACCP	Hazard Analysis and Critical Control Points. Systems for identifying, assessing and controlling hazards relevant to food safety in a business activity
HAV	Hepatitis A virus
Hazard	Biological, chemical or physical agent in food or feed that could have an adverse health effect. Examples of microbiological hazards are the pathogen Campylobacter jejuni and mycotoxin ochratoxin A
Heat wave	There is no accepted international definition for heat waves and several definitions also exist in Sweden. A continuous period with daily maximum temperaturesof at least 25.0 °C during at least five consecutive days (SMHI, 2011); Alternatively, heat waves may be described according to how long (number of days) the longest continuous period of daily average temperatures above 20 °C during the year is(SMHI, 2020).
HEV	Hepatitis E virus
IPCC	Intergovernmental Panel on Climate Change.
Mycotoxin	Toxic secondary metabolite formed by mould fungi

Opportunistic pathogen	Microorganism that can cause disease in special circumstances
OTA	Mycotoxin Ochratoxin A
Pathogen	Microorganism capable of causing illness
RCP	Representative Concentration Pathways. Scenarios on how the greenhouse effect will be amplified in the future and referred to as radiative forcing values (the difference in balance of energy that enters the atmosphere and the amount that is returned to space) achieved in Watts per square metre in the year 2100 (SMHI, 2020)
Risk	Function of the probability and severity of an adverse health effect due to a hazard
Slow-acting groundwater reservoirs	Large groundwater reservoirs, which have a long response time and a small amplitude in water levels during the year, and where a change in groundwater recharge due to changes in hydrological conditions is only visible after a long period of time and only when the change is large enough (Vikberg et al., 2015). Compare with fast-reacting groundwater reservoirs
SMHI	Swedish Meteorological and Hydrological Institute
STEC	Shigatoxin-producing E. coli
T2 and HT2	Mycotoxins T2 and HT2 toxin
TBEV	Tick-borne encephalitis virus
Toxin	Toxic substance formed by a living organism
Vector	Organism that carries and spreads an infectious pathogen to other organisms but does not itself cause the disease
ZEN	Mycotoxin zearalenone
Zero-crossings	Number of days when the temperature has been above and below zero degrees Celsius during the same day
Zoonosis	Infections that can be transmitted between animals and humans either through direct contact or indirectly via food, environment, e.g. water and soil, or via vectors such as mosquitoes and ticks

1. Background

Sweden has a national strategy for adaptation to climate change (prop 2017/18:163) which is implemented, partly, through the Ordinance (2018:1428) on climate adaptation work on the part of government agencies (SFS, 2018:1428). This legislation states that the Swedish Food Agency has the obligation to initiate, support and evaluate the work on climate adaptation within its area of activity. The Swedish Food Agency has developed an action plan for adaptation to climate change (Livsmedelsverket, 2018b), which is to be revised in accordance with the Ordinance. In order to identify needs and effective measures to adapt the agency's activities and also to support the food sector, knowledge of how climate change can affect the food sector is required. Large knowledge gaps exist within this area.

The potential impact of climate change on food safety has been highlighted several times in the Swedish Food Agency's horizon scanning in the field of microbiology. In 2019, for example, the warm summer of 2018 and the possible impact of the climate on the formation of the mycotoxin ochratoxin A in stored cereals and the number of cases of vibriosis associated with the handling or consumption of fish and shellfish were addressed. In addition, the horizon scanning highlighted the need for a comprehensive overview of the state of knowledge of the relationship between food-borne infections and a changed climate.

In order to increase knowledge about climate change and its potential impact on microbiological food safety, the Swedish Food Agency has produced a summary of knowledge in the form of a risk profile. The overall objective of the report is to identify and describe existing and emerging microbiological hazards that can change in importance by climate change and subsequently affect the product safety of food and drinking water consumed in Sweden. The focus of the report is on overview and hazard identification for each food group.

Specific issues addressed in the report:

1. Considering the whole food chain, describe how processes, transport, storage, serving and home handling are affected by climate change and what impact they can have on microbiological food safety?
2. Which microbiological hazards and other identified vulnerabilities may arise within the food groups below? Where possible, rank hazards or types of hazards.

    - Dairy
    - Meat
    - Eggs
    - Cereal products
    - Fruits, berries and vegetables
    - Vegetable fats, nuts and seeds
    - Drinking water
    - Seafood

2. Method

The risk profile consists of a review of relevant scientific literature and government reports and summarises the state of knowledge about the impact of climate change on microbiological food safety from a Swedish perspective. The focus is on microbiological hazards for which food and drinking water are an important pathway. The risk profile is intended as a basis for the Swedish Food Agency's continued work on climate change adaptation.

The report is mainly a qualitative review of food-borne microbiological hazards that can become significant in a changing climate based on scenario Representative Concentration Pathways (RCP) 8.5. RCPs are scenarios of how the greenhouse effect will be amplified in the future and refer to the level of so-called radiative forcing measure in watts per square metre year 2100 (SMHI, 2020, Collins et al., 2013). RCP8.5 does not take any additional climate policy into consideration, which means, among other things, continued high emissions of carbon dioxide into the atmosphere, while RCP4.5 corresponds to a stringent climate policy, which means, among other things, that CO_2 emissions increase by 2040 but then decrease. The highest temperature changes in RCP4.5 are close to the mean climate scenario RCP8.5, which corresponds to a global increase in annual average temperature of just under 5 °C by 2100.

2.1 Literature search

This report is based on scientific literature and reports from Swedish and international authorities. Some of the basic information is based on reports from SMHI (2020), EFSA (2020) and FAO (2018, 2020). Searches were made between April and November 2020 in the database PubMed using combinations of keywords as set out in Annex 1. Additional searches were made in the databases FSTA and Google Scholar. The selection of the literature used was based on title and summary. In some cases, scientific articles found in the text or reference lists in the collected literature were also used.

Chapter 5 provides an overall assessment of the impact of climate change on different microbiological hazards, based on available scientific literature for the different hazards. One challenge of making predictions about the future is that climate studies often look at links between climate-related factors and some phenomenon, such as the presence of a particular pathogen or the incidence of infections with a particular pathogen, and find some degree of correlation. But a correlation does not necessarily imply a causal link (causality). Studies that intend to develop predictive models, often in the form of statistical models, have not always been able to validate their models with data that is independent of the data used to produce the model. These difficulties, together with a general lack of knowledge, reinforce the need to assess the available evidence. The level of evidence of the data on which the assessment is based was graded according to Table 1.

Table 1. Evidence levels for the assessment of existing data, adapted from (Efsa, 2006).

Evidence level	Description
High	Solid and complete data available; strong evidence is presented from most studies; various studies report similar results
Intermediate	Some available data; few references substantiating the link; some studies report conflicting results
Low	Very little or no available data; results are derived from unpublished reports rather than scientific publications; based on observations or personal comments; different studies report conflicting results

2.2 Disposition

The risk profile reviews the impact of climate change on microbiological safety in the food chain and on different food groups (Figure 1). Chapter 3 “Climate change and its effects” describes both expected direct changes in the climate and the frequency and intensity of extreme weather, as well as the impact these changes may have on the environment and society.

Chapter 4, “The importance of climate change for microbiological safety in the food chain”, describes how food safety is affected throughout the chain from primary production to consumption. The description includes pathways and ways through which this can occur — increased occurrence of microbiological hazards, increased toxin formation or growth of pathogens, or changes in survival.

Chapter 5, ‘Potentially important microbiological hazards in a changing climate’, summarises how potentially important microbiological hazards are affected by climate change and what scientific support is available for increased/unchanged/reduced occurrence of the respective hazard. A review of the various hazards can be found in Annex 2.

Chapter 6, “The importance of climate change for microbiological safety in different food groups” describes the most relevant microbiological hazards that may have an increased occurrence or potentially increased transmission via the different food groups due to a changing climate.

Chapter 7, ‘Response to questions’, answers the specific questions on the impact of climate change at the different stages of the food chain and on different food groups. This chapter also decribes the uncertainties and knowledge gaps identified.

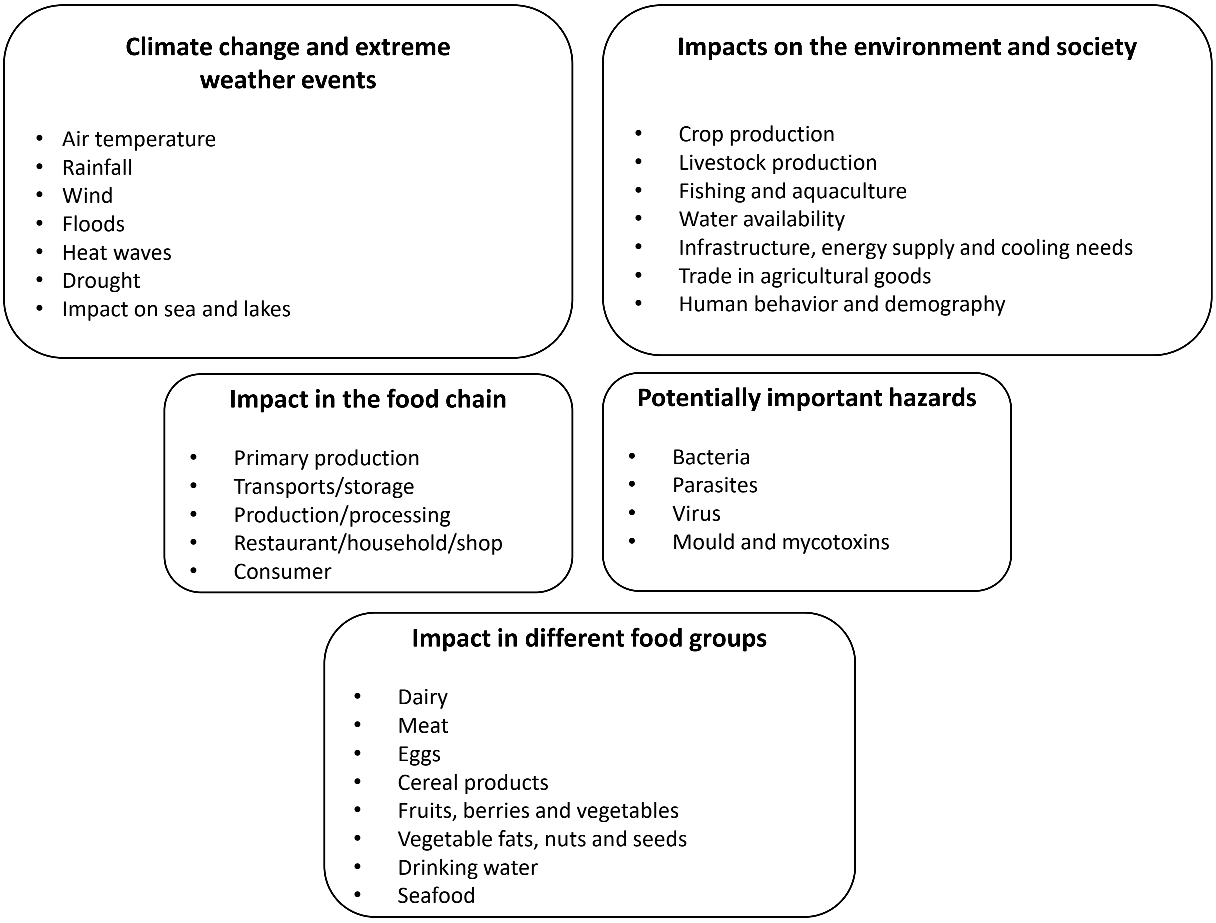

Figure 1. Schematic view of the content and sections in the report addressing the importance of climate change for microbiological food and drinking water safety.

2.3 Scope of the report

Microbiological hazards with transmission not primarily via food and drinking water, and which therefore have a limited impact on food safety, are not included in the report. The exception is legionella and some other water-borne microorganisms, which are mentioned briefly.

The impact of a change in climate on toxin-forming algae such as cyanobacteria in drinking water has previously been reported by the Swedish Food Agency (2018a) and is not included in the report. Intoxications with histamine and other biogenic amines associated with the consumption of fish, such as tuna and mackerel, and other foodstuffs, have also been excluded.

Private hunting and game handling establishments are not included in the report. The impact of climate change on farmed game is not explicitly included, but is addressed indirectly, as is wild animals, in sections dealing with ecosystem changes and the introduction and spread of pathogens.

The impact of climate change on food security and related areas such as food waste, the bio-circular economy and other sustainable development measures, as well as food spoilage and waste management, are not addressed. The possible measures and impacts of these on climate change adaptation and transitions to a changing climate are also not included in the report.

3. Climate change and its effects

Food safety is influenced by a variety of factors and a changing and more variable climate is a factor that has a profound potential to influence the occurrence and importance of different food-borne microbiological hazards. The impact of climate on food safety can occur throughout the food chain, from primary production to consumption, and may result from the predicted direct changes in the climate such as the frequency and intensity of extreme weather, as well as the environmental and societal impact of these changes. A schematic presentation of the possible changes presented in this chapter can be found in Figure 1.

3.1 Climate change and extreme weather events

The climate varies due to both natural and anthropogenic factors. Over the last 100 years, anthropogenic greenhouse gas emissions, in particular carbon dioxide, methane, nitrous oxide and ozone, have increased sharply. As the concentrations of greenhouse gases in the atmosphere increase, heat is absorbed and heat radiation back to space decreases. This leads to changes in temperature and precipitation patterns, which in turn affect other climatic factors and weather events.

Globally, climate change leads to an increase in annual average temperatures, with higher temperature rise at higher latitudes (Livsmedelsverket, 2018b). Average rainfall will increase, mostly in areas that already have good rainfall. Arid areas, that already have low rainfall, will increase. Freshwater supply will decrease in most regions except in areas in higher latitudes, where water availability is generally increasing. Seas and watercourses will also become warmer and sea levels will rise and cause flooding in coastal areas. The seas will become more acidic and closer to the poles the salinity of the seawater is expected to fall (Livsmedelsverket, 2018b).

The most important climate changes focusing on Sweden and starting from climate scenario RCP8.5 are outlined below. Unless otherwise specified, the source of information is SMHI (2020).

- **Air temperature** is expected to increase as a result of climate change and the greatest increase in temperature is expected to occur in winter and in the north. According to RCP8.5, an increase in annual average temperatures up to 3 °C compared to the reference period 1961-1990 is predicted by 2040. By the end of this century, an increase of between 4 °C and 8 °C compared to the same reference period is expected. With increasing temperatures, evaporation is expected to increase, resulting in increased humidity. The growing season is expected to increase by between 30 and 100 days by the end of the century, with the largest increase in southern Sweden. The number of zero-crossings are expected to decrease across the country by up to 20 to 30 days annually.
- **Rainfall** will generally increase in Sweden and here again the increase is expected to be highest in the northern parts. Compared to the reference period 1961-1990, annual average rainfall is forecast to increase by up to 10 % in the whole country by 2040 and by up to 40 % by the end of the century. The increase is expected to be highest in winter and spring. The number of days with heavy precipitation is also expected to increase. The mean inflow, *i.e.* the average flow of water to a lake or stream from the surrounding surface, the so-called catchment area, is expected to increase throughout the country except in south-east Sweden, where the mean inflow is expected to decrease.

- Forecasts of how **wind conditions** are affected by climate change are uncertain but suggest some increase over time in southern Sweden and no change or a decrease in the far north.
- The risk of **floods** is expected to increase over the next century due to extreme water flows in lakes and streams, increasing and more intense rainfall and rising sea levels (Regeringen, 2017). Coastal areas and areas along lakes and rivers are particularly vulnerable (Prytz et al., 2019, MSB, 2012).
- According to forecasts from SMHI, pronounced **heat waves** in Sweden may become more common in the future. Extremely warm periods that so far occurred every 20 years on average, may occur as often as every three to five years at the end of this century (Kjellström et al., 2014).
- Despite forecasts of increasing precipitation and increasing absolute humidity, the number of days of low soil moisture, **drought**, is expected to increase, but with quite large geographical variations. A marked change is expected to be apparent after 2050, with more than 35 days annually with low soil moisture in most of the country.
- A warmer climate is expected to affect **seas and lakes** in several ways (Livsmedelsverket, 2018b, Tirado et al., 2010). Sea water levels as well as water temperature will rise. The sea temperature rise is most rapid at the surface, but temperature will increase gradually even in deeper water. Higher water levels are expected to lead to intrusion of salt water into coastal groundwater, thus affecting the availability of fresh water for humans, agriculture and ecosystems in such areas. Closer to the poles, the salinity of the seas is expected to fall. In addition, the increasing carbon dioxide content in the atmosphere leads to acidification of seas and lakes.

3.2 Impacts on the environment and society

A changed climate will have several effects on the environment and society, which can ultimately affect food safety. Examples of such effects include changing conditions for crop production, livestock production, water supply, infra structure and trade patterns. Examples of such effects are described in the following section.

Crop production

The conditions for crop production is strongly influenced by the existing climate. Factors such as temperature, availability of water, and carbon dioxide concentration affect, among other things, the length of the growing season, the species that can be cultivated, the size of the harvests and the plant pests that may occur (Jordbruksverket, 2017). Climate change means that these conditions can be changed. The global forecast is that it will be more difficult to grow crops in the same way and in the same places as today, which taken together will pose major challenges (Prytz et al., 2019). Increased temperatures, reduced rainfall and droughts, and increased frequency of floods can lead to generally smaller harvests. In addition, climate change can increase crop infestation and the spread of diseases, and promote invasive species (Jordbruksverket, 2017). However, the challenges for crop production will vary greatly depending on the geographical location and how well the changing conditions can be addressed (EEA, 2019, Jordbruksverket, 2017). For Sweden, some opportunities have also been identified, mainly linked to an extended growing season and an increased condition for growing new types of crops (Jordbruksverket, 2017, Prytz et al., 2019).

Livestock production

Climate change means that livestock farming and livestock production will face several challenges. Important factors affecting animal husbandry are heat waves, drought, increased parasite and disease pressure and increased susceptibility to animal diseases (Jordbruksverket, 2017, EEA, 2019, SVA, 2019). Higher temperatures and humidity can cause increased heat stress in animals, and droughts and floods can affect the production of roughage and the availability of grazing (SVA, 2019). Climate change can also drive the emergence and spread of animal diseases (McIntyre et al., 2017, SVA, 2019). The spread of diseases to animals can increase by climate change through, for example, the prolonged survival of pathogens in the environment and increased opportunities for the spread of disease vectors and reservoirs such as insects and rodents (SVA, 2019). Increased infectious pressure on farmed animals can lead to changes in the use of antibiotics and other medicines (Tirado et al., 2010). For Sweden, a couple of possibilities have also been identified, including that the grazing season can be extended and that new fodder crops could be cultivated (Jordbruksverket, 2017). However, an extended grazing season may also pose a challenge in terms of increased exposure to animal diseases associated with outdoor living (Jordbruksverket, 2017).

Fishing and aquaculture

For fisheries and aquaculture, climate change, with increased water temperatures, changes in precipitation patterns, increased sea acidification and changes in salinity and water supply, means challenges that may affect the stocks and the distribution of economically important species of fish (FAO, 2018). In addition, climate change may increase infectious pressure in fish and lead to habitat destruction problems or disturbance of reproduction and migration patterns (FAO, 2018). Sea acidification in combination with other climatic factors may also alter the occurrence of aquatic species with calcium shell or skeletons, such as shellfish and lime-scale plankton, which is likely to also affect species further up the food chain (Gomez-Zavaglia et al., 2020, Troell et al., 2017). In aquaculture, increased susceptibility to diseases in fish and shellfish may increase the use of antibiotics (Tirado et al., 2010). Algal blooms and the presence of toxins can also be a challenge (FAO, 2018).

The climate’s impact on fishing and aquaculture will continue to vary between climate zones. Today, for example, around 65 % of the world’s aquaculture production is concentrated in tropical and subtropical parts of Asia (FAO, 2018). For the temperate parts of the world, an increase in water temperature is assumed to affect aquaculture negatively overall because the species cultivated today have a lower temperature optimal (FAO, 2018). In terms of fishing and aquaculture in northern latitudes, some species are expected to decline or disappear while the ecological conditions for other species such as cod and herring can be improved, at least in the event of moderate warming (Troell et al., 2017, Gomez-Zavaglia et al., 2020). The same applies to Norwegian-farmed salmon, which today is generally grown at a slightly lower than optimum water temperature (Troell et al., 2017).

Water availability

Water availability is governed by factors that will be affected by climate change, such as the amount of rainfall, snow melting and evaporation (Livsmedelsverket, 2019a). For Sweden, climate change is expected to increase the water supply in large parts of the country. One exception is the south-eastern parts where water availability is expected to decrease, as increased rainfall is not expected to compensate for increased soil evaporation (Livsmedelsverket, 2019a).

The net effect of climate change on the supply of groundwater reservoirs, and by extension on the availability of water for different needs such as drinking water and irrigation, will vary with the type of groundwater reservoir and geography (Vikberg et al., 2015). In general, the annual average groundwater supply levels are expected to increase in most of Sweden except in the south-eastern part of the country where levels are expected to fall (Livsmedelsverket, 2019a, Vikberg et al., 2015). This applies to both slow-reacting groundwater reservoirs, which are important for the general water supplies, and fast-reacting groundwater reservoirs, which are particularly important for private water supplies (Livsmedelsverket, 2019a, Vikberg et al., 2015).

The sensitivity of surface water reservoirs depends on their size and the size of the catchment area (Livsmedelsverket, 2019a). However, reduced groundwater levels can also affect surface water based water supplies through reduced flows (Vikberg et al., 2015, Livsmedelsverket, 2019a).

Infrastructure, energy supply and cooling needs

Climate change is likely to have a major impact on our infrastructure as weather events, mainly in the form of extreme events, already cause major disturbances (SMHI, 2014). Roads and railways are vulnerable to increased rainfall and flows, which can cause problems in the form of flooded and washed away roads, damaged bridges, and increased risks of landslides and erosion (Regeringen, 2017, Transportstyrelsen, 2019). Floods can also result in increased surface run-off and temporary discharges of waste water, so-called sanitary sewer overflow, due to congestion of the pipeline system. Pollution from sewers, agriculture and industry can thus pollute water, soil and arable lands (Jordbruksverket, 2017, SMHI, 2014).

Increased precipitation may have a positive impact on the conditions for hydropower production, but the overall assessment is that Sweden’s energy supply is vulnerable with regard to climate change (Regeringen, 2017). For example, extreme heat, extreme winds and storms can have a negative impact on the energy supply due to the disruptions they cause (SMHI, 2014, Energimyndigheten, 2019). An increased incidence of damage to the electrical power distribution system leads to an increased number of power failures, which can affect *e.g.* cooling capacity and IT systems. An example of the importance of functioning electrical power supply for food safety is the need for a functioning cold chain at all stages from production to consumer (Efsa, 2020).

Trade in agricultural goods

Climate change is predicted to require an increased food productivity at global level over the next few decades, while water and soil resources are likely to decrease and become more uncertain (Huang et al., 2011, Prytz et al., 2019). The availability of arable land and water will affect production in different areas and thus the availability and price levels of agricultural products (Huang et al., 2011, Jordbruksverket, 2017). Overall, this may mean that the focus of global food production is generally shifted northwards (Jordbruksverket, 2017). Sweden is heavily dependent on food from other countries and changing conditions for global food production is expected to have consequences for Sweden (Livsmedelsverket, 2018b). This may involve trade with new countries and new products. It may also mean an increase in the need for domestic production (Livsmedelsverket, 2018b).

Human Behavior and Demography

Human factors and behaviour affect human exposure to food-borne hazards and the consequences of this exposure (Tirado et al., 2010). The changing environment brought about by climate change could affect both human exposure and the consequences of exposure. Challenges include a wide range of possible examples, from changing food availability, the ability to maintain food hygiene, and population movements to longer warm weather seasons with increased opportunities for outdoor life and barbecue (Smith and Fazil, 2019, Schnitter and Berry, 2019, FAO, 2020). In addition, the consequences of climate change may be affected by other ongoing changes in society that are not directly linked to climate change, such as an increasing proportion of older people, who are more susceptible to infectious diseases.

4. The importance of climate change for microbiological safety in the food chain

Climate change can affect food safety in different ways and through different routes along the entire chain from farm to fork (Efsa, 2020, Hellberg and Chu, 2016). Efsa has developed criteria to identify potential impacts of climate change based on the definition of an emerging risk (Efsa, 2020). These criteria reflect the ways climate change can affect food safety, and can from this perspective be summarised as changes that:

- drive the emergence of new microbiological hazards
- increase exposure to existing microbiological hazards
- increase the pathogenicity/toxicity of an existing hazard; or
- influence factors that have an indirect impact on food safety.

In order to assess the importance of the potential impact of climate change on the food supply chain based on these four criteria, it is important to understand how food-borne hazards survive and spread in the environment, including society, primary production and production environments (Hellberg and Chu, 2016). Animals and humans are primary sources of pathogenic microorganisms, leading to their presence in faeces, sewers, soil, dust and water. From there they can spread via wind, rain, runoff, insect vectors and other animals/people to the surrounding environments throughout the food chain. For toxin-forming organisms such as moulds and spore-forming bacteria, soil or plants are often primary sources which also cause them and their toxins to spread in the food chain. On the basis of the above reasoning and criteria, the climate-related factors and vulnerabilities that may ultimately lead to an increased health risk have been divided into those that involve:

- an increased occurrence of microbiological hazards (concentration in and/or proportion of food);
- an increased capacity for multiplication/growth or toxin formation; or
- a change in survival

Different parts of the food supply chain can potentially be affected in different ways by climate change due to the existence of different vulnerabilities (Schnitter and Berry, 2019). In addition, climate change and its effects in different parts of the chain can interact and reinforce or suppress each other (FAO, 2020). For example, food safety problems related to vegetables and meat often have their origin in primary production (Yeni and Alpas, 2017), although downstream management is also important for the occurrence of cases of disease. Table 2 presents the potential impact of climate change on microbiological safety at different stages of the food chain. Transport and storage is presented as a single stage despite being part of several stages of the chain. More information and references on the climate-related factors and vulnerabilities presented in Table 2 can be found in Chapter 3.

Table 2. The importance of climate change for the microbiological safety of the various stages of the food chain in terms of identified vulnerabilities. The authors' assessment is based on how changes can affect the occurrence, growth/toxin formation, and survival of microbiological hazards.

Stages of the food chain	**The potential impact of climate change on microbiological food safety**
Primary production	*Occurrence* • Increased flooding can lead to the spread of pathogenic microorganisms from e.g. sewers (via so-called overflows), storm waters and pastures to sources of irrigation water and thus to crops. • Floods can lead to the spread of pathogens to arable land and thereby to crops. • Droughts lead to water scarcity while increasing the need for irrigation water. This may involve the use of contaminated water sources and the spread of pathogens to crops. • A warmer climate means that new crops and varieties can be grown further north, increasing the likelihood of introduction of associated hazards (e.g. mycotoxins). • Some measures to reduce the climate and environmental impact of agriculture (e.g. plough-free farming and reduced use of pesticides) may contribute to increased mould occurrence and mycotoxins. • A warmer climate can lead to changes in the period farmed animals are kept on pasture, the period can become more extensive due to longer seasons but also shorter due to high presence of insects, too high temperatures or droughts. This in turn implies changes in exposure to pathogens in animal populations associated with outdoor living. • Climate change may involve the introduction of new pathogens or a wider spread of existing pathogens in animal populations. • Heat waves and other stressful climate factors can make animals more susceptible to diseases. • Higher levels of infection among animals are likely to lead to increased shedding of pathogens in manure and the risk of spreading to crops. • Climate-related challenges in the production of feed materials can lead to a deterioration of the microbiological quality of animal feed and the introduction of pathogens and mycotoxins. • Increased water temperatures may lead to an increased presence of pathogens in fish and shellfish. • Climate change can lead to an increase in the presence and spread of insects which can act as vectors and spread microbiological hazards to animals and crops
	Growth/toxin formation • Increased precipitation and higher temperature can increase the growth of bacteria and moulds in the environment. • Changes in plant phenology (e.g. earlier flowering) or agronomic factors (e.g. increased use of spring-sown crops) may increase the growth of mould and the formation of mycotoxins. • Climate change can contribute to the increased presence of insects and pests, thereby increasing infestation and damage to crops; it can reduce plant resistance enabling moulds to infect, grow/form toxin more easily. • Warm and humid weather can help to maintain a high moisture content at harvest which, if effective drying is not achieved, can lead to mould growth and toxin production.
	Survival • Climate change affects the survival of different hazards to varying degrees and in different directions. For example, survival of some bacterial pathogens is reduced in the environment at higher temperatures.
Transport/storage	*Occurrence* • Increasing challenges in primary production can lead to an increased occurrence of microbiological hazards on plant and animal raw materials, both domestic and imported (see primary production).

Stages of the food chain	The potential impact of climate change on microbiological food safety
	• Climate change can contribute to an increase in the presence of pests, such as rodents and insects, in food warehouses and in transport vehicles, leading to an increased risk of spreading of microbiological hazards; • Higher humidity and fluctuations in temperature and humidity can lead to condensation, thereby promoting contamination of food by running or dripping water.
	Growth/toxin formation • Warmer climates and extreme weather events can make it harder to maintain cold-chains. • Extreme weather conditions can cause infrastructure disruptions, with extended times for food transport, which in turn increases the potential for growth of pathogens. • Higher humidity as well as fluctuations in temperature and humidity can lead to condensation and increased moisture content, and thus poorer storage stability of dried foodstuffs such as cereals, due to increased growth of microorganisms.
	Survival No vulnerabilities identified.
Production/processing	*Occurrence* • In the production of drinking water, increased temperatures as well as floods may increase the occurrence of pathogens in raw water sources, which affects the quality of raw water input to the waterworks. • For food business operators, extreme weather that has disrupted the production of drinking water due to power failures and/or floodings may affect the availability and microbiological quality of water used in the processes and for cleaning. • Water scarcity and development towards sustainable production methods and a bio-circular economy require initiatives to reuse waste water for irrigation and also for drinking water, which can increase the occurrence of pathogens in raw materials, production environment, and food. • The increased challenges in primary production may result in a higher occurrence of microbiological hazards on plant and animal raw materials, both domestic and imported (see primary production). • Climate change can contribute to the increased presence of insects and pests, which may be carriers of pathogens, thus increasing their occurrence and transmission in the production environment; • A higher outdoor temperature will require higher power on the refrigeration/AC units and this, together with a higher humidity, can lead to drip condensation, which can result in increased dispersion and contamination in the process. • Greater variability in the availability of raw material due to e.g. drought or flooding may result in raw materials of lower microbiological quality and/or from less well-known suppliers.
	Growth/toxin formation • An increased frequency of extreme weather and associated problems such as power failures (including IT and process controls) may lead to broken cold- and freeze-chains, which may favour the multiplication and/or toxin formation of microbiological hazards. • Insufficient cooling or too slow cooling (capacity not sufficient for e.g. in heat waves) may favour growth and toxin formation. • Warmer and humid climates can promote growth and toxin formation when storing dry foods.

Stages of the food chain	The potential impact of climate change on microbiological food safety
	Survival • An increased frequency of extreme weather and associated problems such as power failures can cause processes to fail and thus not achieve the necessary inactivation of microorganisms. • Previously validated killing methods, e.g. heat treatment and high pressure treatment, may prove insufficient if more resilient microorganisms are present in raw materials/foods through evolution or migration/spread of new “species”.
Restaurant/household/shop	*Occurrence* • Climate change may lead to an increase in the occurrence of microbiological hazards on plant and animal raw materials (see primary production) and on products (see production/processing). • Extreme weather can provide more variable quality of raw water, which may affect the availability and microbiological quality of water used in facilities preparing food. • If there is a general increase in the occurrence, and perhaps new types, of pathogens in the human population, the importance of transmission via infected food handlers may increase. • Climate change can contribute to the increased presence of insects and pests, which may be carriers of pathogens, thus increasing their prevalence and spread in facilities where food is prepared; • A higher outdoor temperature will require higher power on the refrigeration/AC units and, together with a higher humidity, can lead to drip condensation, which can result in increased dispersion and contamination.
	Growth/toxin formation • An increased frequency of extreme weather and associated problems such as power failures can lead to broken cold- and freeze-chains, which may favour the growth of microbiological hazards and the formation of toxins. • An increased frequency of power failures caused by extreme weather events may cause problems with keeping food properly heated. • A higher average temperature and more frequent heat waves can lead to temperature abuse during storage of food and insufficient chilling of heated foods. • Warmer and humid climates can promote growth and toxin formation when storing dry foods.
	Survival • An increased frequency of power failures caused by extreme weather events can cause problems with heating/cooking food.
Consumer	*Occurrence* • The increased challenges in primary production and during production/processing may result in a higher occurrence of microbiological hazards on plant and animal raw materials (see primary production and production/processing). • Extreme weather events can affect the availability and microbiological quality of drinking water, including water from private wells. • Climate change can increase the spread of insects and pests, which may be carriers of microbiological hazards, thus increasing their occurrence and spread in consumers´ kitchens; • If there is a general increase in the occurrence, and perhaps new types, of pathogens in humans, the importance of transmission by infected people who cook for others may increase. • Climate change is likely to affect human behaviour and habits. For example, longer periods of higher average temperature lead to prolonged barbecue and picnic seasons, with potentially more exposure events to microbiological hazards.

Stages of the food chain	The potential impact of climate change on microbiological food safety
	Growth/toxin formation • Extreme weather events can cause power failures that lead to problems keeping food properly heated, temperature abuse during storage, or insufficient chilling of food. • A higher average temperature and increased frequency of heat waves can lead to temperature abuse during storage of foods, and insufficient chilling of heated foods. • Warmer and humid climates can promote growth and toxin formation when storing dry foods.
	Survival • Extreme weather events can cause power failures leading to insufficient heating of food.

Most of the consequences of a changing climate involve vulnerabilities that lead to increased occurrence and growth/toxin formation of microbiological hazards. This applies to all stages of the food chain as described in Table 2. The impacts on survival are fewer and less clear. The analysis at this overall level shows a high degree of similarity between the different parts of the food chain. Indeed, it is only the primary production that differs by the large number of vulnerabilities identified. Thus, primary production is strongly influenced by climate change, and it is also clear how effects are propagated through the chain and influence conditions in the downstream stages.

Another pattern is that two scenarios of climate change impacts can be identified. On the one hand, the effects that are due to generally higher average temperature, mild winters, increased rainfall or drought. One idea is to think that conditions in Sweden can become as they are today in southern Europe. On the other hand, the extreme weather events and their consequences, such as extreme rainfall, floods, dry seasons, blackouts, landslides, or other types of infrastructure problems. Food production is particularly exposed to large-scale impacts of climate and extreme events as the start of the production chain is in the field or on the farm which are directly exposed to these events (Marvin et al., 2013). From a climate change adaptation perspective, this also illustrates differences between different parts of the food chain. Changes in primary production can to some extent be addressed through the application of good agricultural practice (GAP) and/or certification standards, but despite these frameworks the challenges are potentially extra difficult since direct control measures are more difficult to implement there than in the later stages of the food chain. In the later stages, HACCP-based procedures and prerequisite programmes (PRPs) such as good hygiene practices and good production practices have been used with good results. In addition, there is a need for further preparedness to prevent and manage extreme events, which can have an increased impact on existing and emerging hazards, under the second scenario.

4.1 The chapter in brief

- Climate change can affect food safety in different ways and through different routes along the entire chain from farm to fork, and different effects can interact in the different parts of the chain.
- Much of the impact of climate change on food safety takes place in the first stage, primary production, and propagates through the rest of the chain. This poses a challenge as control measures are more difficult to implement in primary production than in the later stages of the food

chain. There, HACCP-based procedures and PRPs such as good hygiene practices and good production practices have been used with good results.

- Two scenarios for the impact on food safety can be distinguished and all stages of the chain are affected by both scenarios, although they may be of different importance depending on the operation.
    - The first scenario includes effects on food safety due to a change in the normal situation with higher average temperature, increased precipitation or drought, milder winters.
    - The second scenario includes extreme events such as heavy rainfall, floodings, drought, with consequences such as power failures and other infrastructure disruptions that can have a major impact on the food chain, and in turn on food safety.
- Plans for the production of safe food need to be adapted to a different starting point in terms of occurrences of microbiological hazards, and of conditions for problems to arise. In addition, preparedness and plans are needed to prevent the effects of extreme events that create the conditions for an increased occurrence of existing and emerging microbiological hazards in raw materials, drinking and process waters, as well as of disruptions in infrastructure.
- The needs identified in this chapter support the conclusions and consequences previously presented in the Swedish Food Agency’s report on adaptation to climate change in the food sector (Livsmedelsverket, 2018b).

5. Potentially important microbiological hazards in a changing climate

Below is a summary of the impact of climate change on microbiological hazards belonging to the main groups of microorganisms. For more information on the impact of changes on food-borne bacteria, viruses, parasites and toxin-forming moulds, see Table 3, with detailed information in Annex 2.

5.1 Bacteria

The main determinants of bacterial growth and survival are temperature, pH and moisture content/water activity. Changes in any of these factors may thus affect both growth and survival and the spread of food-borne bacteria (McMichael et al., 2006, Semenza and Menne, 2009, Tirado et al., 2010, Hellberg and Chu, 2016). However, it is difficult to predict the nature of this impact as complex systems interact, which depend on the bacteria' own characteristics as well as those of vectors, reservoirs and the environment (Hellberg and Chu, 2016). The complexity is reinforced by the fact that the same climate factor can act in both amplifying and reducing directions. One example is the effect of an elevated temperature, which generally leads to increased growth rates in bacteria (McMichael et al., 2006), while under non-growth conditions it often leads to shorter survival times (Hellberg and Chu, 2016). There are several studies that have shown a correlation between higher air temperatures and an increased number of infections with salmonella and vibrio (Fleury et al., 2006, Baker-Austin et al., 2017, Jiang et al., 2015). There is also a study that predicts that the incidence of campylobacteriosis may increase with a changed climate (Kuhn et al., 2020).

Several studies report that significantly increased rainfall and strong winds can contribute to the spread of bacteria over large geographical areas and thus contribute to increased contamination of food (Lake and Barker, 2018, Smith and Fazil, 2019). Extending the growing and grazing season or the effects on insect vectors and host animals can also contribute to increased contamination of food (Lake and Barker, 2018, Smith and Fazil, 2019). Human exposure to pathogenic bacteria may also increase as a result of changing habits and behaviours that may occur when the weather gets warmer for longer periods than before, for example, that the barbecue and picnic season can be prolonged (Kovats et al., 2004, Smith and Fazil, 2019).

A changing climate with increased susceptibility to animal diseases and an increased spread of bacterial pathogens can lead to increased use of antibiotics in food production. This can lead to increased bacterial antibiotic resistance (Efsa, 2020, Tirado et al., 2010). Recent studies point to a potential correlation between rising mean temperatures and an increased proportion of antibiotic resistance in bacteria that caused infections in humans (FAO, 2020).

5.2 Parasites

Food-borne parasitic infections are closely linked to eating habits, hygiene conditions, animal husbandry and environmental resources (Pozio, 2020). Improvements in agriculture and animal husbandry, improved sanitation and hygiene, and increased prevention and control efforts have reduced the occurrence of most food-borne parasites in industrialised countries (Pozio, 2020).

There are many different types of parasites and for many there is no specific information available on the impact of climate change. However, there are general descriptions of factors affecting the survival and spread of different parasites, which in turn affect the likelihood of infection of host animals or food contamination. Increased temperature can accelerate the development of parasites that are spread via the environment, and increased humidity promotes survival, while higher temperatures and longer dry periods may impair the survival of eggs and larvae as well as cysts or oocysts (Pozio, 2020). Heavy rains and floods can spread parasites from contaminated soils to watercourses and present higher demands on the treatment in drinking water and sewage treatment plants (Pozio, 2020). As both wild and domesticated animals are important for the life cycle of many food-borne parasites, the occurrence of parasites is also affected by the impact of climate change on animal distribution and living conditions (Polley, 2015, Pozio, 2020). Thus, effects on host animals may lead to the establishment or increased occurrence of parasites that are common in warmer countries also in temperate areas.

Due to the complex systems affecting the occurrence of parasites, as well as the relatively limited scientific evidence, the impact of climate change on most food-borne parasites is difficult to predict. Some examples of parasites for which the scientific literature support an increase due to climate change include Cryptosporidium spp., Giardia intestinalis and Toxoplasma gondii (Polley, 2015). However, climate change is likely to have an impact on several food-borne parasites and in general their occurrence and spread is expected to increase.

5.3 Virus

Climate change can affect the survival and spread of many viruses and thus their impact on human health (Annex 2). A large number of different viruses can be detected in the human gastrointestinal tract, but knowledge of their role in human health is available only for a few (Koopmans and Duizer, 2004). Among the viruses that can be transmitted via food and water, Rift Valley fever virus, nipah virus, hendravirus, hantavirus, hepatitis E virus (HEV), hepatitis A virus (HAV), tickborne encephalitis virus (TBEV), norovirus, sapovirus, astrovirus, and rotavirus are highlighted as examples internationally (Rose et al., 2001, Rohayem, 2009, Tirado et al., 2010, Gullón et al., 2017, Bosch et al., 2018, Oka et al., 2015). The importance of food and drinking water compared to other pathways varies greatly for these viruses. Viruses that are transmitted via a faecal-oral route can be divided into those that cause gastroenteritis, those that spread via the intestine and cause hepatitis, and those who multiply in the gastrointestinal tract but then migrate and affect the central nervous system or the liver (Koopmans and Duizer, 2004). Viruses do not grow in food and drinking water and therefore it can be difficult to demonstrate the effects of climate change, for instance the effect of an increase in average temperature. However, for viruses with a clear seasonality, this has provided a basis for analyses of how climate change can affect their occurrence. The main routes of contamination of food and drinking water with viruses are sewage, manure/sludge, ill persons handling food and water, and, for zoonotic viruses, wild and domesticated animals (FAO, 2008). It is assumed that all these pathways can be affected by climate change. In addition to the increased risk of transmission through floodings, it has been reported that the survival and spread of viruses are affected by environmental factors such as temperature and humidity (FAO, 2008, Tirado et al., 2010). The main food products identified as causing human cases are fresh vegetables and fruits, bivalve molluscs and oysters eaten insufficiently heat-treated, and food which, when ready to eat, has been contaminated by ill persons preparing the food, such as buffet food (Livsmedelsverket, 2020).

In a Swedish perspective, norovirus, HAV and HEV are presented in Table 3. In the group of other viruses (Annex 2), not listed in Table 3 but which may be relevant from a climate point of view, is the spread of TBEV via unpasteurised milk and cheese made from milk from infected animals. It is still unclear how important this transmission route is, but it is interesting given the increased spread of ticks northwards and a certain increase in the geographical spread of TBEV in Sweden (SVA, 2021, Folkhälsomyndigheten, 2021), as well as an increased interest in unpasteurised products. Overall, there are gaps in knowledge that make it difficult to make an informed assessment for the other viruses. In addition to the spread of TBEVs via unpasteurised dairy products, the spread of viruses transmitted via a faecal-oral pathway, whether via waste water or via food, can be expected to increase.

5.4 Moulds and mycotoxins

Moulds that infect, grow and form mycotoxins in crops during cultivation are directly affected by the climate. Many moulds that form mycotoxins in growing cereals benefit from warm and humid weather, especially during the flowering stages when mould infection normaly occurs. The occurrence, species composition and degree of toxin formation are therefore likely to be affected by climate change, but the systems governing these factors are complex. It is therefore difficult to predict the exact changes (Moretti et al., 2019, Tirado et al., 2010, FAO, 2020). A warmer and more humid climate means that new crops can be cultivated in regions where it has not been possible before. For example, maize is likely to be cultivated further north as a consequence of the expected climate change. This means that moulds and mycotoxins associated with maize can become an increasing problem. Climate change can also lead to shifts in the development phases of crops, such as earlier flowering, which can favour mould infection (FAO, 2020, van der Fels-Klerx et al., 2016). Climatic conditions that stress the crop, e.g. extreme weather with droughts or floods, can in turn also affect the occurrence of moulds as the intrinsic resistance of the crop is reduced, which makes mould more likely to infect and grow and thus form toxins (Medina et al., 2015, FAO, 2020). Another aspect of extreme weather is that some mould species seem to change the toxins they form as a response to the warmer climate. This can lead to different toxin patterns than the ones we see today (FAO, 2020, Miller, 2008). Studies suggest that increased levels of carbon dioxide in the atmosphere may increase the ability of moulds to infect, grow and produce mycotoxins, the latter especially in combination with temperature and drought stress (Medina et al., 2017b, Magan et al., 2011). However, the results are in many cases based on in vitro studies with significantly increased levels of carbon dioxide and can therefore be considered preliminary.

Many mycotoxins, especially those produced by Fusarium species, may be present in free or modified form. Modified form means that they can be metabolised into derivatives of the primary toxin or conjugated with other substances. These processes can occur in plants through their metabolism, due to other microorganisms or in the production of food. Modified forms of mycotoxins have previously been overlooked in food analyses, but today it is known that these can be transformed into their free form in the human gut and thus contribute to exposure. The occurrence and composition of modified mycotoxins is likely to change with climate change, but there are still significant gaps in knowledge (Dall'Asta and Battilani, 2016, Medina et al., 2017a).

When storing crops such as cereals, the main parameters to avoidthe formation of mycotoxins are to rapidly reduce the water content as well as temperature. A water activity of 0.7 or less is generally safe, both in terms of mould growth and toxin formation, regardless of temperature (Paterson and Lima, 2010). During warm and humid weather, this can be a challenge that places high demands on the drying capacity in agriculture/cereal handling. Longer food chains, due to e.g. increased imports/international trade or a higher degree of food processing where new raw materials or residues are used to produce food, pose an increased risk of the occurrence of storage toxins such as OTA and aflatoxins (FAO, 2020).

Predictions suggest that the occurence of pests and species variability are likely to increase as the climate becomes warmer (FAO, 2020, Tirado et al., 2010, Paterson and Lima, 2011). This is another important parameter affecting the likelihood of mould growth and toxin formation in growing crops and during storage. Mould spores can spread to crops via insect vectors and a high pest pressure stresses the plant and reduces its resistance. In addition, the mechanical damage to crops by insect vectors facilitates the infection by moulds (Medina et al., 2017b, Paterson and Lima, 2010, Medina et al., 2015). In cereal storage silos, insect infestations can also contribute to the formation of so-called 'hot spots' where water activity is increased, which enables mould growth and very high levels of mycotoxins can be formed (Magan et al., 2011).

5.5 Potential change in the occurrence of different hazards

Table 3 provides an overall assessment of how bacteria, viruses, parasites and mycotoxins that cause disease via food consumption are likely to be affected by climate change. The table gives an indication and justification of the potential change in the occurrence of the hazards in the environment, water, animals and/or food raw materials that may occur due to climate change compared to the current situation. Climate change include both expected direct changes in the climate and the frequency and intensity of extreme weather, as well as the impact these changes may have on the environment and society. The potential change in occurrence may pose increased challenges to produce safe food. The focus is on the situation in Sweden, and the change in occurrence may depend on the hazard´s possibility of growth, likelihood of spreading via environment, vectors or host animals, or likelihood of introduction via non-domestic food. However, the information in Table 3 does not provide an assessment of the severity of the different hazards.

There is a great variety in the availability of published studies for the different hazards. Some hazards are well studied while others may only be mentioned briefly or as part of a group. Furthermore, in some studies it is not always clear whether reported relationships reflect correlations or also causality. In order to address these difficulties, an indication is also given of the degree of scientific evidence on which the assessment is based. A description of the different levels of evidence can be found in Table 1. In short, a high level of evidence means that there is good access to data and that several published studies have presented similar results, an intermediate level of evidence means that there is some available data but studies present conflicting results and a low level of evidence that the data is very poor. For a more detailed description of the individual hazards listed in Table 3 and references, see Annex 2.

Table 3. Potential change in the occurrence of bacteria, viruses, parasites and mycotoxins in the environment, water, animals and/or food raw materials due to climate change compared to today. The focus of the authors' assessment is on the situation in Sweden. The change in occurrence may be due to the hazards possibility of growth, likelihood of spreading via the environment, vectors or host animals, or likelihood of introduction via non-domestic food. An upward arrow (↑) indicates that the occurrence of the hazard is estimated to increase due to climate change, while an arrow to the right (→) indicates that the hazard is estimated to remain unchanged compared to today. For a description of the evidence levels, see Table 1.

Microbiological hazard	Potential change of the occurrence of hazards compared to today due to a changed climate	Brief justification (for details see Annex 2)	Evidence
Bacteria			
Bacillus anthracis	↑	Increased temperature may affect the transmission of the hazard. Extreme weather in the form of drought, rain and flooding increases the likelihood of spreading from old anthrax graves.	High
Bacillus cereus	↑/→	No relationship between varying climatic factors and the number of cases of disease has been detected. Some factors such as increased wind and longer grazing could increase the occurrence in the environment.	Low
Brucella spp.	↑	Milder winters may cause some animal reservoirs to migrate to more northern latitudes, which could increase the spread of the hazard if the animals are carriers of brucella. Increased temperature seems to increase the occurrence in endemic areas.	Low
Burkholderia pseudomallei	→	Increased temperature, combined mainly with increased rainfall and extreme weather events, increases the occurrence in endemic areas. For Sweden, it is expected that the hazard remains low.	High
Campylobacter spp.	↑/→	Cases of disease caused by campylobacter have a marked seasonal variation. In addition to seasonal fluctuations, there are studies that have shown a correlation between increased number of cases of campybacteriosis and periods of increased air temperature as well as after rain. However, there are also studies that have not shown the same relationship.	Inter-mediate
Clostridium botulinum	↑/→	Lack of data on the direct impact of climate change. Food safety may be affected if, for example, the possibility of temperature control is affected by disrupted power supply.	Low
Clostridium perfringens	↑/→	Lack of data on the direct impact of climate change. Indirect impacts could be improper hot-holding or cooling due to power failures.	Low
Coxiella burnetii	↑	Milder winters may cause some animal reservoirs to migrate to more northern latitudes, facilitating the spread of the hazard if the animals are carriers of coxiella. Increased imports of feed and increased wind may favour the spread of contaminated aerosols.	Low

Microbiological hazard	Potential change of the occurrence of hazards compared to today due to a changed climate	Brief justification (for details see Annex 2)	Evidence
Francisella tularensis	↑	Increased temperature and precipitation can benefit vectors, mainly mosquitoes, and animal reservoirs, thereby increasing the geographical spread of the hazard.	High
Listeria monocytogenes	↑/→	Lack of data on the direct impact of climate change. Extreme events affecting the power supply may result in a lack of storage capacity at the appropriate cold temperatures.	Inter-mediate
Salmonella spp.	↑	Cases of disease caused by salmonella have a clear seasonal variation with more cases during the summer period. Several studies have developed regression relationships between the number of cases of salmonellosis increases and rising air temperatures. The causal link is not fully investigated. Increased rainfall can contribute to increased spread in the environment. The occurrence can also be increased by imports of food.	High
Shigella spp.	↑	More floods can increase the spread of this hazard from e.g. sewers. Several studies from endemic areas have reported a correlation between increased temperature, humidity and precipitation, as well as more frequent flooding, and increased incidence of shigellosis. For Sweden, the occurrence in imported food may increase.	High
Staphylococcus aureus	↑/→	Lack of data on the direct impact of climate change. Extreme events affecting the power supply may result in a lack of capacity to cook, store, cool or hothold food.	Low
STEC	↑	Cases caused by STEC have a clear seasonal variation with more cases during the summer period. Climatic factors such as increased temperature have been shown in some studies to be associated with an increased number of cases of infection with STEC. Increased rainfall and more frequent extreme events may increase the spread of the hazard. The occurrence can also be increased by imports of food.	Inter-mediate
Vibrio spp.	↑	Increased air and sea temperatures, as well as higher sea water levels with saltwater intrusion into coastal areas are important for the spread. More heat waves with temporary temperature increases in coastal surface waters lead to increased occurrence.	High
Yersinia enterocolitica	↑/→	Increased precipitation can increase the spread of the hazard. An increase in the spread of the wild boar population could also increase the occurrence of the hazard. Extreme events affecting the power supply may result in a lack of storage capacity at the appropriate cold temperatures.	Low
Parasites			
Anisakis simplex	→	Lack of data on the impact of climate change.	Low

Microbiological hazard	Potential change of the occurrence of hazards compared to today due to a changed climate	Brief justification (for details see Annex 2)	Evidence
Cryptosporidium spp.	↑	Increased extreme weather events with precipitation and flooding can contribute to an increased spread of the parasite to water sources.	Inter-mediate
Cyclospora cayetanensis	↑	An increased temperature means that the parasite could be established in today's temperate areas. In addition, for Sweden, the occurrence in imported food may increase.	Low
Echinococcus multilocularis	↑/→	Uncertain how the climate change will affect. Possibly, increased populations of intermediate host animals and new main host animals and increased rainfall may contribute to increased spread in the environment.	Low
Entamoeba histolytica	↑/→	Lack of data on the direct impact of climate change. Extreme weather or other events that may cause sewage intrusion into the drinking water network could increase the occurrence.	Low
Fasciola hepatica	↑	Warmer climate especially milder and humid winters may increase the survival of the parasite and thus the risk of infection.	Low
Giardia intestinalis	↑	Increased extreme weather events with precipitation and flooding can contribute to an increased spread of the hazard to water sources.	Inter-mediate
Taenia saginata	↑	An increase in the number of extreme events resulting in the flooding of pastures with contaminated water may lead to an increase in cattle exposure to Taenia saginata parasitic eggs.	Low
Trichinella	↑/→	Lack of data on the direct impact of climate change. Warmer climate with milder winters can increase the numbers and distribution of host animals and thus the occurrence of the hazard in the environment. However, there is no data on whether climate change affect the occurrence of the hazard in host animals.	Low
Toxoplasma gondii	↑	Milder winters can increase the survival of the hazard and increased precipitation can contribute to increased spread. The hazard may also increase if the prevalence of small rodents, which act as intermediate hosts, is favoured.	Inter-mediate
Virus			
Norovirus	↑	The link to climate factors is not strong. Increased precipitation and flooding may increase spread, while increased temperatures are associated with lower survival.	Inter-mediate
HAV	↑	Lack of data on the direct impact of climate change. May increase due to more extreme precipitation events.	Low
HEV	↑/→	A warmer climate with milder winters can increase the spread of the wild boar population and thus increase the occurrence of the hazard in the country. There is no evidence that climate change can increase the prevalence in wild boars.	Low
Mycotoxins			

Microbiological hazard	Potential change of the occurrence of hazards compared to today due to a changed climate	Brief justification (for details see Annex 2)	Evidence
DON	↑	Increasing temperature and precipitation, especially during the flowering phase of cereals, favour infection and increase the incidence of DON. Milder winters and increased use of autumn-sown crops can contribute to increased occurrence.	High
T2 and HT2 toxin	↑	Increasing temperature and precipitation, especially during the flowering phase of cereals, favour infection and increase the occurrence of T2 and HT2.	Inter-mediate
ZEN	↑	Increasing temperature and precipitation, especially during the flowering phase of cereals, favour infection and increase the occurrence of ZEN.	Inter-mediate
FUM	↑	Studies have shown correlations between increased temperature and drought leading to stress in the host plant (maize) and increased levels of FUM. Increased cultivation of maize at northern latitudes is likely to lead to an increased spread of FUM.	High
Ergot alkaloids	↑/→	Increased rainfall during the flowering phase of cereals has been associated with increased levels of ergot alkaloids. However, the formation benefits from cool weather, which makes the assessment more unclear. Increased occurrence of insects can increase infection with the producing moulds.	Inter-mediate
Aflatoxins	↑	Several studies have reported a correlation between increased temperatures and drier climates in southern Europe and increased levels of aflatoxin, which is also supported by predictive modelling. Increased frequency of extreme weather and drought in countries with tropical climates can increase the levels of imported products.	High
OTA	↑	Varying effects as OTA is formed by several mould species and distribution is difficult to predict. Increased temperature, drier climate and increased levels of carbon dioxide can increase growth and OTA production ofsome species, but for others there is no change. More variable harvesting and insect infestations during the storage of cereals may increase the incidence of OTA.	Inter-mediate
Patulin	↑/→	Lack of data on the direct impact of climate change. Increased temperature may mean that the climate becomes too hot for toxin producing species, however, heavy rain and insect infestations have been shown to increase the occurence.	Inter-mediate

5.6 The chapter in brief

- Assessing the impact of climate change on microbiological hazards is complex. This is partly because the changes that will take place are complex and can affect our environment in several different ways. In addition, the available evidence in the form of published studies varies greatly, both in terms of the most frequently studied hazards and in experimental designs.

- Of the bacteria listed in Table 3, Bacillus anthracis, Francisella tularensis, Salmonella spp., Shigella spp. and Vibrio spp. are assessed, with a high level of evidence, to potentially increase in the environment, water, animals and/or food raw materials due to a changing climate. The other bacteria, with the exception of Burkholderia pseudomallei, may also potentially increase due to climate change, but due to inadequate data, this assessment is uncertain.
- Among the parasites in Table 3, all except Anisakis simplex, are assessed to potentially increase due to climate change. However, the assessment is uncertain as the level of evidence for most parasites is low. For Cryptosporidium spp., Giardia intestinalis and Toxoplasma gondii, the evidence level is intermediate.
- Of the food-borne viruses listed in Table 3, all are assessed to potentially increase due to climate change. However, the level of evidence is intermediate for norovirus and low for HAV and HEV, which makes the assessment uncertain.
- Among the mycotoxins listed in Table 3, it is assessed that all Fusarium toxins (DON, T2/HT2, ZEN and FUM) potentially will increase, of which the level of evidence is highest for DON and FUM. Further, aflatoxins are assessed to increase with a high level of evidence. The other mycotoxins are also assessed to potentially increase, but due to lack of data and in some cases conflicting results, this assessment is uncertain.
- Several climate-related factors are predicted to affect different species of toxin-forming mould in the same direction, such as increased rainfall during the flowering phase of cereal crops, increased occurrence of insects and increased likelihood of drought and heat stress in crops. This probably means increased concentrations of mycotoxins in the future and also increased problems with the co-occurence of several mycotoxins in the same food.
- None of the microbiological hazards listed in Table 3 have been assessed to decrease in occurrence due to climate change. However, it should be noted that climate change can affect microbiological hazards both positively and negatively. At the local level, it may therefore be the case that some hazards assessed as potentially increasing remain unchanged or even decrease in occurrence. The final outcome also depends on the effectiveness of the measures taken to address the challenges of climate change.

6. The importance of climate change for microbiological safety in different food groups

This chapter describes the microbiological hazards that may occur in different food groups as a result of climate change, focusing primarily on Swedish conditions. For each food group, the most relevant pathogenic microorganisms and mycotoxins that may have an increased or potentially increased spread due to a changed climate are described. The potential for control of identified hazards and any other identified vulnerabilities that may potentially pose food safety challenges is described for each food group.

The information is based on data presented in chapters 3 to 5 and published studies relevant to the respective food group. The availability of data on the correlations between microbiological hazards and climate change varies widely for the different food groups. In general, more information is available on impacts early in the food chain, especially in primary production, while this link is more rarely addressed in later stages of the food chain. This, in combination with the varying nature of the food groups, some of which are large and heterogeneous while others are more limited, means that the information presented vary in scope and level of detail.

6.1 Dairy

Microbiological hazards

Many types of microbiological hazards can contaminate milk in primary production. Pathogens can be introduced via feed, grazing, drinking water, surrounding environment, milking equipment, wild animals and vectors such as insects and ticks. In feed, the occurrence of bacteria and parasites may increase through, for example, floods and warmer climates. Mycotoxins excreted in milk if the cows are fed with contaminated feed are predicted to increase with warmer and more humid weather. More variable weather and more frequent extreme weather may lead to the use of new feed materials and suppliers, which in itself may pose a risk for poorer quality feed (van der Spiegel et al., 2012, van Asselt et al., 2017, van der Fels-Klerx et al., 2019). Zoonotic diseases in cows may increase with climate change, e.g. due to higher occurrence of pathogens in the environment, greater spread of pathogens in warmer and more humid weather, increased presence of insect vectors and increased animal sensitivity due to heat stress. Infections leading to increased antibiotic use increase the risk of resistant bacteria and drug residues in milk. Soil and manure on the teats of cows increase the likelihood of pathogens being transferred to the milk (van Asselt et al., 2017, Fusco et al., 2020). Increased rainfall and flooding mean that this may become an increasing problem in the future, especially if milder weather also leads to longer grazing periods for dairy animals.

The pathogens identified as relevant in the EU for the consumption of unpasteurised cow's milk and linked to climate change are Campylobacter spp., Listeria monocytogenes, Salmonella spp., pathogenic E. coli, Yersinia spp., Toxoplasma gondii, Cryptosporidium parvum and TBEV. As the general occurrence of these pathogens is predicted to increase, or potentially increase, there is reason to assume that the presence in unpasteurised milk may also increase. Of these pathogens, Campylobacter spp., Listeria monocytogenes, Salmonella spp. and pathogenic E. coli are currently most commonly associated with milk (van Asselt et al., 2017). In addition to pathogens, the presence of mycotoxins in feed may lead to transfer to the milk. Mycotoxins include, for example, aflatoxins, ochratoxin A, fumonisins, zearalenone and ergo alkaloids. Aflatoxin M1 is considered to be the most important hazard. As the concetrationsl in maize are predicted to increase, problems may become greater in the future if maize becomes a common feed material as a result of increased imports or if cultivation increases in Sweden due to a warmer climate (van Asselt et al., 2017, Fusco et al., 2020, van der Fels-Klerx et al., 2019).

Pasteurisation effectively kills vegetative bacterial cells, although, bacterial spores can survive. However, disease outbreaks caused by properly pasteurised milk are very rare. If the pasteurisation process is insufficient or if recontamination occurs, several microbiological hazards may be transmitted via the milk. In particular, Listeria monocytoenes has caused disease outbreaks linked to both pasteurised and unpasteurised milk (van Asselt et al., 2017, Fusco et al., 2020). There is currently a trend in some countries, such as Italy, France and the US, of increased sales and consumption of unpasteurised milk. This has led to several outbreaks of e.g. STEC and campylobacter infections (Fusco et al., 2020). If this trend continues, and increase also in Sweden, climate change can have a greater negative impact on food safety linked to milk.

Microbiological hazards expected to increase with climate change and which have caused outbreaks of disease linked to dairy products other than milk include Listeria monocytogenes, Staphylococcus aureus and STEC in cheeses (particularly non-pasteurised) and Salmonella spp. in dry milk powder. In soft and semi-soft cheeses, listeria is a problem that has caused several outbreaks of disease. The water content of these cheeses supports growth and as listeria is tolerant to high salinity and can grow at refrigerator temperatures, pathogen concentrations can be high (van Asselt et al., 2017).

Control measures

Climate change and its effects on primary milk production emphasize the importance of good animal health, good animal husbandry, control systems for feed quality and hygienic storage of feed in the future (van Asselt et al., 2017, van der Spiegel et al., 2012).

For the dairy industry, climate change can lead to a greater need for quality control of milk in order to control production. For unpasteurised milk and its products, this will be especially important. Increased occurrence of pathogens may also warrant the need for new methods of quality control and an overview of process parameters required to achieve adequate pasteurisation (van der Spiegel et al., 2012, Fusco et al., 2020). To reduce the risk of growth of potentially surviving or recontaminating microorganisms in pasteurised milk, rapid cooling and uninterrupted cold chains all the way to the consumption stage are important parameters. These are also important factors for products made of unpasteurised milk or products contaminated with e.g. listeria (van Asselt et al., 2017). More frequent extreme weather that may lead to disruptions in power supply, IT and networks can potentially become an important issue to address for the dairy industry.

In order to avoid mycotoxins in milk and dairy products, appropriate storage and control systems of feed materials are important. Research is underway to find ways to reduce the levels of aflatoxin M1 in milk. Several potentially effective microorganisms and enzymes with aflatoxin-degrading activity have been identified, but further development is required to make these methods useful in practice (van Asselt et al., 2017, Fusco et al., 2020).

6.2 Meat

Many of the studies published on meat and climate change focus on how today's meat production affects the climate through, for example, greenhouse gas emissions or how we can reduce our meat consumption. Studies on the impact of climate change on meat production often focus on effects in primary production, as this is often the point where contamination is introduced (Nastasijevic et al., 2015, Yeni and Alpas, 2017). Other aspects addressed in the literature are the importance of climate change for animal health and welfare. However, there are no studies on the impact of climate change in the later stages of production of meat, such as slaughter and processing.

Microbiological hazards

In primary production, meat-producing animals may be exposed to or infected with pathogens from the surrounding environment or via e.g. faecally contaminated feed, grazing and drinking water. Other routes of exposure in primary production are via insects or other animals acting as vectors, host animals or carriers of pathogens. Several of these exposure pathways may be affected by climate change. In addition, a warmer and more humid climate, as well as extreme rainfall and floods, can increase the exposure of farm animals to pathogens via the environment (Yeni and Alpas, 2017). Climate change can also affect both animal susceptibility to pathogens and the severity of consequences following exposure to pathogens (Nastasijevic et al., 2015). This may lead to more infections in animals, increased excretion of pathogens in faeces and increased spread of pathogens between animals via the environment and to meat via contaminated animal skins and/or carcasses. Increased exposure and increased occurrence of pathogens in wild animal populations may also affect the disease situation of domestic animals.

Meat is a large food group and there are many different pathogenic microorganisms that can occur on meat. Although the same pathogens may contaminate meat from many different animal species, *e.g.*, salmonella, other pathogens are commonly associated with specific animal species. For example, campylobacter is often linked to poultry meat; STEC and Taenia saginata are linked to beef; and Yersinia enterocolitica, HEV and Trichinella to pig and wild boar meat. Several of these pathogens may increase in the event of climate change, which could mean a higher proportion of contaminated raw meat in the future.

Control measures

Bacterial foodborne pathogens associated with meat are usually not detected in today's meat control. At the slaughter stage, control is carried out mainly by visual inspection of animals to ensure they are not dirty and by slaughtering hygienically. If bacterial pathogens become more common with climate change, further action may be needed in the future.

Today, the parasitic pressure on Swedish meat-producing animals is generally low and inspections to detect parasites, such as Trichinella and Taenia saginata, have been reduced at slaughter. The importance of these inspection elements may become more important in the future as many parasites are predicted to increase in occurrence with climate change.

In the post-mortem stages, storage in appropriate conditions is an important step to prevent the microbiological growth on meat and meat products and thus to prevent the spread of pathogens. Increasing extreme weather affecting power supply and transport may cause problems linked to broken cold chains to increase.

Other vulnerabilities

Climate change may also affect animal welfare, which is a problem in itself but may also increase the susceptibility of animals to pathogens. There are studies describing the effects of heat stress in poultry, e.g. reduced growth (Vandana et al., 2020). In addition, an increased prevalence of salmonella has been detected in heat-stressed birds (Quinteiro-Filho et al., 2012). In order to prevent heat stress in indoor animals, cooling of stables and animal houses will become more important in a warmer climate.

6.3 Eggs

Microorganisms may contaminate the inside of the egg or the surface of the egg shell. If contamination of the inside of the egg occurs before the shell is formed, it is called primary contamination (also vertical spread). If it occurs after the shell has formed, it is called secondary contamination, and may be associated with an external cross-contamination of the shell (Efsa, 2014). The egg has mechanisms to prevent the passage of microorganisms through the shell, but this ability is reduced by the degree of contamination, that is, the amount of bacteria on the shell, with the age of the hen and the egg, with increasing temperature (in particular the temperature gradient between the egg and the environment), and with humidity. The survival and growth of salmonella and other bacteria on and in the egg are also influenced by environmental factors.

Microbiological hazards

In the compilation of food-borne outbreaks with strong evidence in the EU for 2018, eggs and egg products were the category that caused the highest number of outbreaks, and this proportion has increased between 2015 and 2018 (Efsa and ECDC, 2019). The most common pathogen/food combination was Salmonella spp. and eggs/egg products. However, the situation differs between Member States, only 10 countries reported this combination. In Sweden, in the period 2008-2018, only one such outbreak was reported, and with Salmonella Enteritidis as a causative pathogen (Livsmedelsverket, 2020) and where eggs from Poland were implicated as the source of infection (Folkhälsomyndigheten, 2021). During the same period, an outbreak of Salmonella Heidelberg, linked to the consumption of tuna salad with eggs, was also reported.

In the EU, Salmonella spp. accounts for more than two thirds of outbreaks caused by eggs and egg products, but other bacterial pathogens may also be present on the surface of the egg and/or occur in the production environment and in the chicken microbiota. Outbreaks are reported due to Staphylococcus aureus and the sporeformer Bacillus cereus, but not other sporeforming bacteria such as Clostridium perfringens which may be due to underreporting. These outbreaks often depend on how eggs have been handled and used in later stages of the food chain (Efsa, 2014). Campylobacter may occur on eggs, but it seems unusual, despite high prevalence in flocks in the EU. Other intestinal bacteria such as STEC and other pathogenic E. coli may also occur on eggs, but outbreaks have not been reported. In Japan, the presence of Coxiella burnetii on eggs and egg products such as mayonnaise has been detected, but there are no outbreaks recorded.

In order to maintain the high food safety standards associated with Swedish eggs, salmonella will be the dominant pathogen to remain vigilant against, although the predominant serotypes may change over time. This is based on previous experiences where changes in selective pressure and existing ecological niches have led to an evolution of which serotypes predominate in poultry (Foley et al., 2011). Changes in dominant serotypes occur constantly in response to changes in selective pressure, due to human actions or environmental changes, e.g. climate. In Europe, Salmonella Mbandaka and Salmonella Livingstone are more frequently detected than Salmonella Enteritidis in broilers and Salmonella Kentucky is the third most common serotype in laying flocks after Salmonella Enteritidis and Salmonella Infantis (Efsa and ECDC, 2019). The health consequences of possible changes in dominant serotypes may vary as serotypes have different ability to survive and to infect humans (Guillén et al., 2020). Other pathogens that may be relevant and spread in a changing climate are, for example, pathogenic E. coli, Campylobacter spp., Bacillus cereus, Staphylococcus aureus, etc.

Control measures

In general, the resistance of eggs increases at cold temperatures as egg quality is maintained for longer and growth of pathogens is also reduced. However, the survival of pathogens generally decreases with increased temperature and humidity. The ability to penetrate the egg shell increases with the temperature, as well as the rate of growth of salmonella and other pathogens if present inside the egg. Regular salmonella sampling has been mandatory since 1994 in laying hens. Other control measures targeting salmonella in the early stages of the chain, until eggs leave the egg packers and retail, can be expected to have a positive effect on other pathogens as well. Egg washing is used in Sweden as a way to increase the hygienic quality of eggs. Salmonella and other pathogens on the surface of the egg may be reduced when washing eggs (Leleu et al., 2011).

The net effect of climate change and the various control measures on the presence of salmonella and other pathogens in laying flocks and the environment is difficult to predict as the interaction between them is very complex (Efsa, 2019). It is possible that the challenges will increase as the drivers that can generally lead to an increase in the occurrence of pathogens in flocks and in the environment are expected to increase in a warmer, variable climate with more extreme weather.

Other vulnerabilities

Most studies carried out in the area concern salmonella and are from a production perspective. High temperatures give rise to heat stress in laying hens. Laying hens as well as broilers are very sensitive to heat stress and if ventilation and cooling do not work, it affects production and susceptibility to diseases. There is evidence that increased stocking density, larger production units and stress generating conditions, e.g. high temperature, lead to increased prevalence, persistence and spread of salmonella in laying hens flocks (Efsa, 2019). At the top of the egg production chain is the breeding pyramid for laying hens, a structure that can be seen as a general vulnerability with a great potential for the spread of pathogens or bottlenecks in the chain (Efsa, 2019). Egg washing is used in Sweden as a means of increasing the hygienic quality of eggs but can, in addition to the positive effects, result in a vulnerability in case of power failures or other operational disturbances that may affect the quality of the water, both on the source water and on possible water reuse systems. Pathogens can penetrate the egg shell depending on how the egg wash is carried out and on the properties of the egg. These properties may be affected by washing the egg, and also by the age and health of the hen, but above all by the quality of the washing water (Gole et al., 2014).

6.4 Cereal products

Microbiological hazards

Salmonella and STEC have in recent years caused several outbreaks of disease linked to cereal products, mainly in the United States and Canada. The sources of infection identified have usually been nonheat-treated cookie dough containing wheat but also wheat flour, roasted oats, puffed rice and puffed oats (Myoda et al., 2019, Livsmedelsverket, 2019c, Brar and Danyluk, 2018).

Contamination can take place during the growth, harvesting and storage of cereals and the processing and handling of products. The source of contamination is often difficult to establish, but studies on salmonella in wheat showed a high diversity of bacterial serotypes, indicating a variety of pathways. These may include soil, harvesting equipment, wildlife droppings, manure, irrigation water and production environments (Brar and Danyluk, 2018, Myoda et al., 2019).

Growth of bacterial pathogens in dried cereals or in flour is unlikely due to the low water activity. However, both salmonella and STEC can survive for a long time in a dry environment. Before grinding cereals, the moisture content, known as conditioning, is increased, which could enable pathogen growth (Myoda et al., 2019, Livsmedelsverket, 2019c). Two outbreaks of disease that occurred in the United States at intervals of 10 years could be linked from different cereal products from the same production site. The outbreaks were caused by the same strain of Salmonella Agona, suggesting that the bacterium can be established and remain in the production environment for a very long time and also contaminate heat-treated cereal products (Anonymous, 1998, Brar and Danyluk, 2018).

Myoda et al. (2019) investigated the occurrence of salmonella and STEC in post-harvest wheat over a three-year period, analysing in total around 5000 samples. The results show that contamination with salmonella was much more common in autumn than in spring wheat. The same trend also appeared for STEC, but the differences were significantly smaller. This could indicate that contamination is subject to weather conditions as cereals sown in autumn and harvested in summer are generally exposed to more humid and cooler weather than spring-sown crops. However, the authors conclude that the proportion of positive results was too low to be able to draw any firm conclusions. Some proposed pathways are likely to become more important due to climate change, leading to a possible increase in the presence of pathogenic bacteria in cereal products. For example, irrigation is likely to become more common in cereal cultivation as the climate becomes warmer (Livsmedelsverket, 2019c).

Cereal products are the main source of exposure to several mycotoxins and the presence of one or more mycotoxins (albeit at low levels) is very common in cereals. EFSA data for the years 2010-2015 show that DON and ZEN were detected in 60 % and 80 %, respectively, of all cereal samples (Moretti et al., 2019, Eskola et al., 2020). In addition, the results show that about 20% of samples from untreated cereals and about 10% of samples from food grade cereals exceeded the EU limit values for any mycotoxin.

Climate change is predicted to affect both the concentration of mycotoxin formed and the geographical presence of mycotoxin-forming moulds, which in turn are likely to lead to new mycotoxin-combinations (Moretti et al., 2019). The main effects in Europe are expected to be increased occurence of aflatoxins in particular in maize, increased occurence of trichotecens (DON, T2 and HT2) in oats and wheat, and increased occurence of ZEN in wheat, oats and maize (Moretti et al., 2019, van der Fels-Klerx et al., 2016, Parikka et al., 2012). Other likely changes include increased occurence of fumonisins in maize, increasing problems with OTA formation during the storage of cereals and increased problems with ergot alkaloids in rye (Parikka et al., 2012, FAO, 2020, Magan et al., 2011, Coufal-Majewski et al., 2016).

At the production and consumer stages, cereal products such as bread are often spoiled by moulds that can both produce mycotoxins and contribute to waste through spoilage. Genera such as Penicillium, Aspergillus, Rhizopus and Cladosporium are common on bread, and when mycotoxins are formed, Penicillium or Aspergillus is commonly the cause. Temperature and relative humidity are important factors that control mould growth. Spores of mould found on bread are airborne and are often present in both production and home environments (Garcia and Copetti, 2019, Legan, 1993). As a result, there is reason to assume that climate change will lead to increased problems of mould in later stages of the cereal products food chain.

Control measures

The highest concentration of bacteria is found in and on the outer parts of the grains. Removal of husk and bran during grinding therefore often significantly reduces the occurrence of bacterial pathogens. However, in order to avoid contamination of cereal products, hygienic production conditions are important. Especially, during conditioning of the grains and with regard to the water used in the process (Myoda et al., 2019, Los et al., 2018, Brar and Danyluk, 2018). There are also a range of active decontamination methods that have been shown to be effective in cereals (e.g. ionising radiation, ozone treatment) or under development (e.g. microwave therapy, pulsating UV light, cold-plasma-treatment). However, these methods are often costly and can affect quality. The feasibility of large-scale processing of cereals is therefore questionable. Information to consumers and producers on the preparation of cereal products, in particular wheat, is a method proposed to reduce the risks posed by bacterial pathogens in cereal products (Los et al., 2018, Myoda et al., 2019).

Mycotoxins in cereals and cereal products are often unavoidable because the toxin producing moulds are ubiquitous and toxins are stable chemical compounds. However, efforts can be made to reduce concentrations in several stages of the food chain, where interventions in primary production and drying/storage are likely to have the greatest impact in a changing climate:

- During **cultivation**, agronomic factors such as crop rotation, tillage, variety selection, use of chemical control and measures to reduce the moisture content of the crop (e.g. weed control) can affect fusarium and ergot toxins (Menzies and Turkington, 2015). In the future, the development of new varieties of wheat that are more resistant to fusarium mould and more effective fungicide treatments may play a major role (Moretti et al., 2019).
- In order to prevent the formation of mycotoxins during **storage**, the most important measure is to rapidly lower the moisture content to safe levels, i.e. levels that do not support mould growth or toxin formation. For cereals, this means a water activity of not more than 0.7. During the storage of cereals, it is important that insect pests are controlled since otherwise their activity can create

moisture pockets where, for example, high levels of OTA can be formed (Bradford et al., 2018, Magan et al., 2011, Paterson and Lima, 2010).

- In the future, cereal harvests in Sweden are predicted to increase as a result of climate change. In combination with more variable weather that increases the risk of high moisture content at harvest, this places high demands on efficient **drying** in order not to create bottlenecks where long waiting time entails the risk of high mycotoxin formation in undried cereals. In Sweden, cereals are in principle only dried using active methods, such as hot air drying, which means that the energy needs of agriculture will increase. Restructuring in the agricultural sector, such as capacity, management and logistics, is also likely to be required in order to cope with the increased need for drying (FAO, 2020, Pettersson, 2020).
- In **the mill**, cleaning, for example, where foreign objects, damaged and infestedgrains are removed is an important step which generally lowers the concentration of mycotoxins. Moreover, peeling and grinding often involve redistributing the mycotoxin so that concentrations are reduced in the food fractions such as white flour and semolina, while they are raised in coarse fractions often used for animal feed (Schaarschmidt and Fauhl-Hassek, 2018).
- Some **production processes** such as baking and roasting may reduce mycotoxin concentration in the products. The effectiveness of degradation depends on the toxin and its concentration and on process parameters such as temperature, time, moisture content and pH (Schaarschmidt and Fauhl-Hassek, 2018, Milani and Maleki, 2014).
- In order to reduce problems with mould growth at the **consumer stage**, for example on bread, hygienic conditions in bakeries to reduce the presence of mould spores are effective. In addition, for example, modified atmosphere packaging and preservatives can be used (Garcia and Copetti, 2019, Legan, 1993).

6.5 Fruits, berries and vegetables

Microbiological hazards

Climate change with increased temperature, precipitation and relative humidity can affect the production of fruit, berries and vegetables and the microorganisms associated with the production environment (Jung et al., 2014). Climate change has the greatest impact on microbiological safety in primary production, but with effects in later stages of the food chain (Kniel and Spanninger, 2017, Liu et al., 2013).

Climate change may involve the introduction of new pathogens or a wider spread of existing pathogens in animal populations, including pests and wild and domestic animals. Pathogenic intestinal bacteria from both animals and humans can be transmitted directly, or indirectly via the environment, to crops in primary production. Soil, manure and irrigation water used for agriculture are examples of sources that can contaminate crops with intestinal bacteria (Jung et al., 2014). Viruses, parasites and bacteria that occur in aquatic environments can also contaminate crops through these sources (Jung et al., 2014). In addition, increased rainfall and, in particular, more frequent extreme weather in the form of heavy rain and floods may increase the spread of pathogens, both bacteria, viruses and parasites, from e.g. sewers, pastures and stormwaters to irrigation water and farmland (Liu et al., 2013, Jung et al., 2014). Such extreme weather conditions may also lead to contamination of crops by increasing the extent of rainwater and soil splashing on the crops (Hellberg and Chu, 2016).

Bacterial pathogens such as STEC and salmonella survive quite readily in soil, manure and irrigation water (Jung et al., 2014, Hellberg and Chu, 2016). Indeed, the survival of such bacteria has been shown to decrease in manure and soil at higher temperatures, but has also been shown to increase in the same matrices under more humid conditions (Kniel and Spanninger, 2017, Jung et al., 2014). Thus, a changing climate can potentially improve the ability of pathogens to survive and/or spread into soil, water and crops. This can increase the likelihood of contamination of fruit, berries and vegetables, which increases human exposure via the consumption of such foods (Jung et al., 2014). Changing consumption patterns with a higher proportion of vegetarian food, including potentially new crops and products, can also increase such exposure.

There are several pathogens that have caused outbreaks with fruit, berries and vegetables as sources of infection, and which may become more common in a changing climate. This includes all faecal pathogens, but applies in particular to intestinal bacteria such as Salmonella spp., Shigella spp. and STEC, viruses such as norovirus and HAV, as well as protozoa such as Cryptosporidium parvum and Cyclospora cayetanensis (Jung et al., 2014, Balali et al., 2020). Cyclospora and shigella occur mainly in fruit and vegetables from tropical areas where the microorganisms are endemic (Table 3). Listeria monocytogenes, which has also been reported to cause outbreaks linked to contamination and consumption of processed fruit and vegetable products, may potentially become more common, as more frequent extreme weather affecting power supplies may impair the integrity of the cold chain (Jung et al., 2014; Tabell 2). The mycotoxin patulin occurs in fruit, berries and vegetables and above all in apples. The link to climate change is unclear, but patulin in, for example, apple products can potentially become more common due to increased frequency of heavy rain and insect infestations, which favours infection with the patulin producing mould, Penicillium expansum (Saleh and Goktepe, 2019, Zhong et al., 2018).

Control measures

Fruits, berries and vegetables are to a large extent consumed raw or minimally processed, without the killing of microorganisms. Thus, microbiological food safety is a direct consequence of prevailing conditions in the food chain, mainly in primary production (Liu et al., 2013, Jung et al., 2014, Nguyen-The et al., 2016). The main risk factors linked to primary production and pathogens in fresh fruits, berries and vegetables are animal contact with nearby livestock farming as well as with wild animals, domestic animals and pests, direct transmission from humans and the use of manure and contaminated water in the cultivation and irrigation of crops (Efsa, 2013). Such factors may become more important due to a changing climate with more frequent extreme weather conditions and a higher probability of exposure to pathogenic intestinal bacteria and waterborne bacteria following consumption of irrigated fruit and vegetables (Liu et al., 2013, Nguyen-The et al., 2016).

Thus, a changed climate places higher demands on plans and procedures to identify sources of contamination and to prevent pre-harvest contamination and through the food chain (Jung et al., 2014). For example, the ability to chill fruit and vegetables immediately after harvesting and keep the appropriate temperatures in later stages of the food chain is important to maintain quality and reduce or prevent the growth of pathogens (Jung et al., 2014). In addition, the need for crop irrigation may increase as the climate becomes warmer and drier, which requires increased preparedness in terms of access to reserve water (Liu et al., 2013). Consequently, climate change may pose new challenges for the microbiological safety of fruit, berries and vegetables.

6.6 Vegetable fats, nuts and seeds

Microbiological hazards

Significant disease outbreaks involving many cases have been caused by salmonella and linked to e.g. almonds, hazelnuts, peanuts, walnuts, Brazil nuts, sesame seeds and chia seeds, as well as processed products such as peanut butter and sesamy paste (Harris et al., 2019, Brar and Danyluk, 2018). STEC has also caused disease outbreaks linked to nuts and seeds but on fewer occasions.

Nuts and seeds are dry foods in which bacteria cannot grow. On the other hand, salmonella is well adapted for survival at low water activities, which is further enhanced by the high fat content of nuts and seeds. At low temperatures, i.e. refrigeration or freezing conditions, there is virtually no reduction in salmonella concentrations over time, and even at higher temperatures the decrease is slow. STEC also survives on the surface of nuts for a long time but to a lesser extent than salmonella (Brar and Danyluk, 2018).

The overall occurrence of both salmonella and STEC is expected to increase with climate change. It is therefore likely that risks associated with the consumption of nuts and seeds will also increase. There is a general lack of data on the occurrence of pathogenic bacteria in vegetable fats. Many unrefined oils have antibacterial properties due to high content of polyphenols (Bhat and Reddy, 2017, Delamarre and Batt, 1999, Palumbo and Harris, 2011). The occurrence of pathogenic bacteria in vegetable fats is therefore likely to be low.

Nuts and seeds are often contaminated with bacterial pathogens early in the production chain, e.g. via animal manure during cultivation or harvesting, via soil during harvest, or by humans and machinery during harvest and handling. Peanuts are inevitably contaminated with soil during cultivation which increases the likelihood of soil-borne pathogens. In almond crops it has been observed that rain during harvest increases the proportion of ground nuts and thus the likelihood of an increased occurrence of salmonella (Brar and Danyluk, 2018).

Several mycotoxins have been identified in nuts, seeds and other oilseeds and products containing them, such as oil, nut butter/paste and feed (press cake) (Brazauskienė et al., 2006, Pitt et al., 2013, Bhat and Reddy, 2017), see Table 4.

Table 4. Examples of mycotoxins associated with nuts, seeds and oil crops.

	Peanuts	Tree nuts[a]	Sunflower seed	Linseed	Sesame	Oilseed rape	Maize	Olive
Aflatoxins	X	X	X	X	X	X	X	X
Andratoxin A	X	X	X	X		X	X	X
Fumonisins	X						X	
Deoxynivalenol				X		X	X	
T2 and HT2							X	
Zearalenone	X		X				X	
Alternaria toxins			X	X				X

[a] Almonds, Brazil nuts, cashew nuts, hazelnuts, pecan nuts, pistachios and walnuts

Aflatoxins, and in particular aflatoxin B1, are the mycotoxins for which most data are available on the occurence in these products, probably because of its serious health effects (genotoxic carcinogen) but also because toxin producing mould species are often common in nuts and seeds. In general, aflatoxin concentration are highest in crops such as maize and peanuts, while tree nuts often have lower concentration as the shell partially protects against infection. However, very high concentrations can also occur in e.g. almonds and pistachios (Pitt et al., 2013, Kluczkovski, 2019). In vegetable oils, zearalenone has been shown to contribute to exposure. High concentrations were mainly recorded in vegetable oils produced from corn, soya beans and wheat germs (Efsa, 2011).

Mycotoxins can be formed in nuts and seeds both during cultivation and after harvest. The main risk factors are drought stress, insect infestation during cultivation and excessive moisture during storage. High temperatures, variable temperature, high humidity and/or high precipitation during harvesting have also been identified as risk factors (Pitt et al., 2013, Bhat and Reddy, 2017). There is a lack of data specifically linking the levels of mycotoxins in nuts and seeds with climate change (Kluczkovski, 2019). However, given the risk factors described in nuts and seeds and the general trend for aflatoxins, for example, problems are likely to increase in the future.

Major countries producing various types of nuts include the United States, Turkey, Iran, Brazil, China and Nigeria (Kluczkovski, 2019, Brar and Danyluk, 2018). As contamination with mycotoxins and pathogenic bacteria usually occurs during primary production, the impact of climate change in the respective country of production, as well as the conditions for hygienic handling in each country, will detemine the occurrence in different product types.

Control measures

The occurrence of pathogenic bacteria in nuts can be reduced by good agricultural practices that take into account, for example, soil use, manure application, water sources and hygienic harvesting (Brar and Danyluk, 2018). There are several techniques that can provide effective inactivation of pathogens, including pasteurisation techniques, such as hot steam treatment, which are effective for nuts and seeds, in addition to several traditional processing methods not originally designed as hygienisation steps, such as roasting and extrusion (Anderson, 2019).

For the control of mycotoxins in nuts and seeds, effective drying to a safe moisture content is an important factor, especially for aflatoxins and ochratoxin A, which are formed during storage. Some nuts and seeds are treated with water to facilitate peeling, in these cases effective drying is extra critical (Brar and Danyluk, 2018). Grading and removal of affected nuts are other important measures that can effectively reduce the concentration of mycotoxins. This can be done by hand, for example, of discoloured and shrivelled nuts (e.g. peanuts and Brazil nuts), by automated colour sorting, using water (“floating”) or using UV light (aflatoxin-contaminated kernels emit fluorescence). Monitoring is an important measure to find lots with high concentrations of mycotoxins, however, contamination is often heterogeneously spread, which poses a challenge in detection sampling (Pitt et al., 2013, Kluczkovski, 2019).

Mycotoxins are present in both refined and unrefined vegetable oils, but the concentrations are generally lower in refined oil. Often the reduction is large, or even complete, due to the refining steps used. However, the concentration in the final product vary depending on the design of the process, the initial concentration and the type of mycotoxin, the type of oil and the pH (Bhat and Reddy, 2017, Bordin et al., 2014).

6.7 Drinking water

Microbiological hazards

Water-related health problems are mainly associated with the consumption of drinking water contaminated with faecal microorganisms, but other routes of transmission may also be important (WHO, 2017).

Table 5 shows pathogenic microorganisms that may be present in raw water (WHO, 2017). The compilation is based primarily on global data, but this can be a good starting point for assessing which pathogens are relevant from a drinking water perspective. This is because climate change will shift the climate zones, which opens up the possibility that the importance of today's pathogens may be shifted or that new ones may become relevant in Sweden. Pathogens deemed relevant for the spread of infection via drinking water consumption are indicated in bold in the table. Thus, drinking water consumption is not the main transmission route for all microorganisms in Table 5, and other routes, e.g. by inhalation (legionella), may be just as relevant. Pathogens that are spread mainly through non-consumption routes, as well as issues relating to drinking water quality in terms of odour and taste, are dealt with only briefly or not at all.

Table 5. Compilation of pathogenic microorganisms that can occur globally in drinking water/raw water, supplemented by Swedish data, and where evidence exists for health significance. Modified tables from (WHO, 2017) and (Dryselius, 2012). Pathogens assessed as potentially transmitted via drinking water consumption are indicated in bold.

Organism	Survival and growth in raw water[a]	Infection dose[b]	Confirmed agent in illness outbreaks via drinking water in Sweden after 1980
Bacteria			
Burkholderia pseudomallei	Long, can grow	High	No
Campylobacter spp.	Moderate	Low	Yes
Pathogenic E. coli	Moderate	Low	Yes
Francisella tularensis	Long	Low	No
Legionella	Long, can grow	Moderate	No
Mycobacteria (not tuberculous)	Long, can grow	?	No
Salmonella spp.	Long, can grow	High	Yes
Shigella spp.	Card	Low	Yes
Vibrio cholerae	Long	High	No
Virus			
Adenovirus	Long	Low	No
Astroviruses	Long	Low	No
Enterovirus	Long	Low	No
SEA	Long	Low	No
HEV	Long	Low	No
Calicivirus			
Norovirus	Long	Low	Yes
Sapovirus	Long	Low	No
Rotavirus	Long	Low	No
Protozoa			

Organism	**Survival and growth in raw water[a]**	**Infection dose[b]**	**Confirmed agent in illness outbreaks via drinking water in Sweden after 1980**
Acanthamoeba	Long, can grow	Low	No
Cryptosporidium spp.	Long	Low	Yes
Cyclospora cayetanensis	Long	Low	No
Entamoeba histolytica	Moderate	Low	Yes
Giardia spp.	Moderate	Low	Yes
Naegleria Fowleri	Long, can grow	Moderate	No

[a]detection period for infectious microorganisms at 20 °C where "Short" is up to one week, "Measurable" is one week to a month and "Long" is more than a month.

[B]Infection doses for the different microorganisms are not absolute values and may vary widely depending on several factors such as genotype in the specific microorganism, and the immune status and age of the exposed person. An infection dose defined as 'Low' requires 1-100 microorganisms to cause infection in 50 % healthy adult volunteers while a 'Measureable' requires 100-10 000 and one 'High' over 10,000 microorganisms.

Another important criterion for hazard relevance in a changed climate is occurrence, growth and survival in Sweden. Several of the pathogens that can be transmitted via drinking water are not present or only to a small extent in Sweden today, but may become important in the future if the incidence of infections with these pathogens increases as a result of climate change. Then they will circulate in the water cycle via sewers, water treatment plants and raw water sources, which may pose challenges for water treatment. What challenges that will arise depends in part on the magnitude of those changes, but examples could include Vibrio cholerae, Shigella spp. and Cyclospora cayetanenesis. In addition to these, completely new pathogens may enter the cycle from other areas or new variants with new properties arise through evolution.

Pathogens that depend on a host organism usually do not multiply outside the host but may, depending on the conditions, survive longer or shorter. Survival depends on several factors, not least the temperature. Inactivation is often faster at higher temperatures and can be further amplified in surface water by the sun's UV radiation. The growth in water distribution systems is generally increasing with the availability of organic matter, biofilms and low remining concentrations of chlorine. Most bacteria that can be spread via water are relatively sensitive to chlorine and mainly becomes a problem if treatment is insufficient, fails or is missing.

Some of the pathogens mentioned by the WHO Guidance (WHO, 2017) and in Appendix 3 are considered not relevant to the issues raised in this report on the grounds that:

- They are mainly spread via pathways other than the consumption of drinking water
    - Legionella, Acanthamoeba, Naeglaeria fowleri,
- The importance of drinking water transmission is assessed as low;
    - Burkholderia pseudomallei, Pseudomonas spp., Toxoplasma gondii, enterovirus, Balantidium coli, Dracunculus medinensis (for geographical reasons), Faciola hepatica.
- The importance of drinking water transmission is uncertain but assumed to be low:
    - Atypical mycobacteria, blastocystis, Cystoisospora belli, microsporidias,

Control measures

The water-borne outbreaks are mainly caused by insufficient treatment of raw water and/or failures in the distribution of drinking water such as pipe breakage, cross-connection of water pipes, pressure drop (Nygård et al., 2007, Säve-Söderbergh et al., 2017, Säve-Söderbergh et al., 2020, Tornevi et al., 2016). The raw water treatment needs to achieve a sufficient reduction of pathogenic microorganisms, which is dependent on the type of microorganisms present in the raw water, their concentration and how the concentration vary over time and space (in the volume of water), and the capacity of the barriers present in the waterworks (Gale, 1996). Since the capacity of a barrier to reduce or kill microorganisms may be different for different microorganisms, several barriers/treatment steps are often necessary. The management and the systems for production of safe drinking water are not fundamentally altered by the forecasts of a warmer climate and its consequences. Protection of raw water sources and management of treatment processes remain the most important elements. However, the treatment processes need to have sufficient capacities and flexibility to handle possible new pathogens with greater resistance and a potentially greater variation in concentrations in the raw water associated with higher temperatures, increased rainfall and extreme weather. Climate change poses the same challenges for private water sources. The awareness and preparedness for the protection and management of private water sources also needs to increase in a changed climate.

In addition, it is important that the treatment steps are validated and verified continuously. It may be useful to look at the problems and experiences in southern Europe. The new revised Water Framework Directive (EU, 2020) applies to the whole of the EU and problems occurring in southern Europe should be well addressed through the implementation of the Directive in these countries (Aleljung, 2020). There may be geographical/regional differences in Sweden that need to be taken into account. For example, some areas often have high organic matter concentrations in the raw water and some areas are more vulnerable to extreme weather with large water flows and landslides (MSB, 2012).

Other vulnerabilities

Drinking water production, as well as other food production, are also vulnerable to disruptions in the form of extreme events and disruptions in infrastructure, and the likelihood of this is increasing according to climate projections. Increased preparedness is needed in the form of, for example, redundancy in terms of power supply and access to alternative raw water sources. Plans for repair, refurbishment and maintenance of sufficient capacity are required, both in the short term (e.g. need for backwashing of filters) and in the long term (access to water during dryer periods of the year when availability generally may be lower).

There are several climate-related factors that interact and may pose challenges for safe drinking water production. Periods of drought or less precipitation reduce the availability of surface and groundwater, which means that low-flow water recepients will have a higher proportion of treated sewage water and presumably higher concentrations of pathogens. Droughts can also affect the water distribution system and their performance, illustrated by several water pipe breaks that occurred in Skåne during the dry period 2018 in areas with clay (Aleljung, 2020). Floods can lead to overflow of sewers and treatment plants and too much water can short-circuit groundwater supplies, i.e. the unsaturated soil zone is filled with water, with pathogen penetration as a possible consequence. Another possible consequence is the impact on the infrastructure in terms of physical damage to buildings and distributions systems, land- and mudslides, and power failures. Increased average air temperatures provide a warmer raw water and potentially a changed chemical composition and warmer drinking water with increased potential for growth of pathogens (over 25 °C increases the risk of legionella), increased problems with growth and biofilms in the water distribution system, and possibly more frequent occurrence of opportunistic pathogens that thrive in the distribution system. Increased temperatures may also increase the frequency of problems related to odour and taste in drinking water.

Vulnerabilities due to the effects of climate on the environment and society include the importance of changing industrial, agricultural and forestry practices that may affect the quality of raw water. Climate change can have a number of negative impacts on drinking water production and many food businesses, in primary production and later stages, depend on large amounts of water. Water scarcity and development towards sustainable production methods and a bio-circular economy also lead to initiatives to re-use waste water for irrigation and also to drinking water with possible implications for food safety. The negative impacts identified in the section may therefore spill over to other food production.

6.8 Seafood

Microbiological hazards

Climate change has a significant impact on coastal and marine aquatic ecosystems, and hence on fisheries and aquaculture (Gomez-Zavaglia et al., 2020). Warmer air and water temperatures, increased acidity in the seas, increased sea water level, as well as changes in the intensity of precipitation and wind are the main factors that affect the production and capture of fish and shellfish, both farmed and wild caught (Gomez-Zavaglia et al., 2020, FAO, 2018, Kniel and Spanninger, 2017). The complexity and possible interactions between these factors makes it difficult to assess in detail the impact of climate change on fisheries and aquaculture (Troell et al., 2017, Regeringen, 2017). However, climate change has an impact on food safety by improving the conditions for the survival and growth of many types of pathogenic microorganisms in aquatic environments and in fish and shellfish.

A changing climate can cause disturbance of reproduction and migration patterns, lead to physiological stress and increase susceptibility to certain bacterial and parasitic diseases of aquatic species (FAO, 2018, Troell et al., 2017, Karvonen et al., 2010). Most often these are not zoonotic microorganisms, except for example Vibrio vulnificus, which can infect humans as well as shellfish and fish such as eel, tilapia and carp (SVA, 2020d). In particular, farmed fish and shellfish are exposed to disease infestations as their relatively large biomass compared to wild caught provides a good breeding ground for pathogens (Troell et al., 2017). Increased susceptibility to bacterial diseases can in turn increase the global use of antibiotics in food production, especially in aquaculture, which can drive the emergence and spread of antibiotic resistant bacteria (Tirado et al., 2010, Efsa, 2020).

Growth has been shown to increase at higher water temperatures in several naturally occurring pathogenic bacteria such as Vibrio spp., Listeria monocytogenes, Clostridium botulinum and Aeromonas hydrophila. The same applies to bacteria occurring in aquatic environments due to faecal contamination such as Salmonella spp., Campylobacter spp., Escherichia coli, Shigella spp. and Yersinia enterocolitica (Efsa, 2020, FAO, 2018) and Annex 2. Warmer temperatures in sea and brackish waters are particularly important for the occurrence of Vibrio spp. in fish and shellfish. In Europe and the United States an increase in vibrio outbreaks has been observed with seafood as a source of infection mainly caused by Vibrio parahaemolyticus and, to a lesser extent, Vibrio vulnificus (Froelich and Daines, 2020, Baker-Austin et al., 2017, Baker-Austin, 2020). The number of cases of disease of vibriosis has been reported to increase in areas on the North Atlantic coast in recent years (Efsa, 2020, Baker-Austin et al., 2017, Kniel and Spanninger, 2017), an increase linked to increasingly warmer seawater temperatures (Vezzulli et al., 2016).

Seasonal variations and changes in temperature cycles and rainfall patterns also favour the occurrence of certain food-borne viruses, such as noroviruses, in edible aquatic species, and alter the population dynamics of aquatic species hosting food-borne parasites (Efsa, 2020). It has recently been speculated that increasing the use of plant feed in fish and shellfish farming may increase the occurrence of mycotoxins in such products (Troell et al., 2017, FAO, 2020).

The above-mentioned pathogens or groups of pathogens have been reported to cause food-borne illnesses worldwide to varying degrees as a result of the consumption of insufficiently heated or raw dishes of seafood such as oysters and mussels. Of these pathogens, Vibrio spp., in particular Vibrio parahaemolyticus, is considered particularly important from the point of view of climate change in marine aquatic ecosystems. Several studies show that the occurrence of these bacteria will increase with a warmer climate, even at our northern latitudes (Efsa, 2020, Froelich and Daines, 2020, Baker-Austin et al., 2017 and Table 2). Norovirus, which is the most common cause of food-borne illness via bivalve molluscs both in Sweden and globally (Livsmedelsverket, 2017), is also predicted to be more easily transmitted due to climate change as a consequence of an increasing impact of sewage water affected water in the growing areas (Efsa, 2020). HAV is also spread via faecally affected water and food such as oysters and bivalve molluscs, and is expected to increase in importance due to climate change (Annex 2). As a result, food-borne disease caused by such pathogens can become even more common in the long term unless successful control measures can be implemented. The direct impact of climate change is unclear as regards the occurrence of Listeria monocytogenes in raw food materials, such as salmon. However, extreme weather events affecting the power supply may result in a reduced ability to store food at cold temperatures, which is important for listerias ability to multiply in processed products and thus its ability to cause disease.

Control measures

In the case of fish and shellfish, climate change has the greatest impact on food safety in the primary production stage, but with effects also at later stages of the food chain (Kniel and Spanninger, 2017). In order to reduce the risk of falling ill as a result of the consumption of fish and shellfish, food business operators need to identify relevant hazards and address them in their plans and procedures. This could be done for example by continuously controlling for pathogens in farming areas and by securing uninterrupted cold chains from harvest to distribution (and consumption) in order to reduce or prevent the growth of pathogens (Gomez-Zavaglia et al., 2020). Improved early detection systems for pathogens in fish and shellfish and associated farming areas, epidemiological surveillance systems and rapid infection tracing in the event of food-borne outbreaks, as well as strengthened control systems for pathogens in raw materials can also contribute to improving food safety in a changing climate (Gomez-Zavaglia et al., 2020).

7. Response to questions

This report aims to respond to questions about the impact of climate change on food-borne microbiological hazards and on microbiological product safety for food consumed in Sweden. This concerns the importance of both expected direct changes in the climate and the frequency and intensity of extreme weather, as well as the indirect effect these changes may have on the environment and society. The responses are based on a qualitative review and assessment of published scientific literature.

As regards information about the impact of climate change on different pathogenic microorganisms and toxin-forming moulds, there is a wide variation in the number of available studies. Some microorganisms have been studied extensively while others hardly at all. Furthermore, there are methodological difficulties in attempting to demonstrate causality. Based on the information available, an assessment has been made of how different microbiological hazards can be affected by a changed climate. This is summarised in Table 3, with in-depth information in Annex 2. Specific questions on the impact of climate change on different parts of the food chain from farm to fork (sub-question 1) and for different food groups (sub-question 2) are answered below.

7.1 Sub-question 1

Question:

Considering the whole food chain, describe how processes, transport, storage, serving and home handling are affected by climate change and what impact they can have on microbiological food safety?

Response:

Climate change can affect the food chain at all stages, from farm to fork. Table 2 presents a summary of the climate-related factors and vulnerabilities that may affect microbiological food safety in primary production, during transport/storage, in production and processing, in restaurant/household/shopping and at the consumer stage. The identified vulnerabilities are divided into those that involve: an increased occurrence of microbiological hazards (proportion contaminated and/or concentration), an increased capacity for multiplication or toxin formation, and a change in survival. Transport and storage are presented as a single stage but is often part of several stages of the chain. Primary production, including drinking water production, was considered particularly important and vulnerable as microbiological hazards are often introduced at this stage, affecting the occurrence of hazards, and thus food safety, throughout the whole food chain. The different stages of the chain can also interact since subsequent management activities such as control or lack of control measures affects the consequences of the effects in primary production on later stages.

Two scenarios of the impact of climate change on food safety in the whole food chain can be identified:

- The first scenario includes the impact on food safety due to a change in normal conditions with higher average temperatures, increased precipitation or drought and milder winters.

Climate change according to RCP8.5 could mean a new normal climate in Sweden similar to that currently prevailing in parts of southern Europe.

- The second scenario includes an increased frequency of extreme events such as torrential rain, floods, and dry periods, with consequences such as power failures and other infrastructure disruptions that can have a major impact on the food chain and, in turn, food safety.

All stages of the chain may be affected by both scenarios, although they may be of different importance depending on the stage of the food chain and the type of operation. Both scenarios are likely to lead to an increased occurrence of microbiological hazards in raw materials and favourable conditions for growth and toxin formation, which will pose greater challenges than today for the production of safe food. The potential changes in primary production can to some extent be addressed through the application of good agricultural practice (GAP) and/or certification standards, but despite these frameworks, the challenges are potentially extra difficult as direct control measures are more difficult to implement in primary production than in later stages of the food chain. At later stages, HACCP-based procedures and prerequisite programmes such as good hygiene practices and good production practices have been used with good results in the past. Additional requirements to meet climate change, is that the food control system needs to be designed for the new conditions under the first scenario and that further preparedness is needed to prevent and manage more frequent extreme events under the second scenario.

7.2 Sub-question 2

Question:

Which microbiological hazards and other identified vulnerabilities may arise within the food groups below. Where possible, rank hazards or types of hazards.

Response:

For each food group below, the food-borne microbiological hazards - patogens and toxins - for which the occurrence in food may increase or potentially increase due to a change in climate, are described below. Focus is primarily on Swedish conditions. Due to limitations of the available data, it has not been possible to rank hazards. It is considered most important to consider which routes of transmission and types of hazards (characteristics, resilience) may be relevant in the different food groups as in most cases control measures will be similar for different types of hazards. Therefore, the potential for management of identified hazards and other identified vulnerabilities that could potentially pose food safety challenges in the food group are briefly described. The microbiological hazards for each food group linked to climate change are summarised in Table 6.

Dairy

- Milk is often contaminated in primary production where microbiological hazards can be introduced via feed, grazing, water, surrounding environment, milking equipment, wild animals and vectors such as insects and ticks. As there are many routes of introduction, it is possible that an overall increase in the occurrence of such hazards due to the climate will also increase their occurrence in raw milk.

- The main microbiological hazards in raw milk linked to climate change are Campylobacter spp., Salmonella spp., pathogenic E. coli and aflatoxin M1. In addition to these, Listeria monocytogenes, Yersinia spp., Toxoplasma gondii, Cryptosporidium parvum and TBEV have a link to dairy products and a changed climate. Some hazards are particularly relevant for specific products such as listeria in soft and semi-soft cheeses and salmonella in dry milk powder.
- Quality management factors that are likely to become even more important for the dairy industry in a changing climate include good animal health, hygienic husbandry, control systems for feed quality and hygienic storage of feed, quality control of dairy raw materials, adequate pasteurisation (validated, verified, supervised) and uninterrupted cold chains. Pontential failures in power and IT supply can have a major impact on the dairy industry.

Meat

- Meat-producing animals may be exposed to or infected with pathogens from the surrounding environment, via contaminated feed, grazing or drinking water, or via insects or other animals acting as vectors or hosts of pathogens. Several of these routes of exposure may be affected by climate change, which may result in an even greater exposure of meat-producing animals to pathogens.
- Climate change can also affect both animal susceptibility to pathogens and the severity of pathogens. This may lead to more infections in animals, increased excretion of pathogens in faeces and increased transmission of pathogens between animals via the environment and to meat via contaminated animal skins and/or carcasses.
- Many different pathogenic microorganisms can contaminate or infect meat or meat-producing animals. Several of these are also predicted to increase due climate change, which could mean a more contaminated meat raw material in the future. Examples of such pathogens are Salmonella spp., Campylobacter spp., STEC, Yersinia enterocolitica, HEV and Toxoplasma gondii.
- Changes in wild animal populations may also impact on the disease situation in domestic animals.
- Many of the bacterial pathogens associated with meat are difficult to detect through today’s meat control. If bacterial pathogens become more common with climate change, further control measures may be needed in the future.
- After slaughter, storage under appropriate conditions is an important step to prevent the microbiological growth on meat and meat products and thus to prevent the transmission of pathogens. Increased frequency of extreme weather events affecting power supply and transports can lead to more frequent problems linked to broken cold chains.

Eggs

- For eggs, Salmonella spp. will be the dominant pathogen to remain vigilant against in order to maintain the good situation in Sweden, although the dominant serotypes may change over time. However, the health consequences of any changes in dominant serotypes may vary as serotypes have different ability to survive and to infect humans.

- Other pathogens that may be externally present on the surface of the egg and/or occur in the production environment and in the chicken microbiota may also be relevant, e.g. pathogenic E. coli, Campylobacter spp., Bacillus cereus, Staphylococcus aureus.
- While the net effect of climate change and the different control measures on the occurrence of Salmonella spp. and other pathogens in laying flocks and the environment is difficult to predict, it is possible that the challenges will increase. This is due to the fact that drivers that can generally lead to an increase in the occurrence of pathogens in flocks and in the environment are increasing in a warmer, variable climate with more extreme weather conditions.
- The egg production chain is vulnerable, not least because of bottlenecks in the breeding pyramid and the need for reliable supply of power and cooling capacity, as poulty are very sensitive to heat stress, which affects, among other things, susceptibility to disease.
- The egg has mechanisms to prevent the passage of microorganisms through the shell, but this barrier is reduced by the degree of contamination, that is, the amount of bacteria on the shell, with the age of the hen and the egg, with increasing temperature (in particular the temperature gradient between the egg and the environment), and with humidity.
- Egg washing is used in Sweden to reduce the presence of microorganisms on the surface of the egg and this practice requires good routines and good water quality when running this operation.

Cereal products

- Contamination with pathogenic bacteria can occur during the growth, harvesting and storage of cereals and the processing and handling of products. Salmonella spp. and pathogenic E. coli have caused several illness outbreaks linked to products containing oats and wheat flour and, as these pathogens are predicted to increase in a changing climate, their occurrence in cereal products may also increase.
- Cereal products are the main source of exposure to several mycotoxins and the presence of one or more mycotoxins is very common in cereals. Climate change is expected to lead to an increase in the occurrence of aflatoxins in particular in maize, an increase in the occurrence of trichotecenes (DON, T2 and HT2) in oats and wheat, and an increase in the occurrence of ZEN in wheat, oats and maize, as well as a potential increase in the occurrence of ergot alkaloids in rye and the formation of OTA during the storage of cereals.
- Removal of husk and bran during grinding often significantly reduces the concentration of bacterial pathogens as these occur mostly in the outer parts of the kernel. In order to avoid contamination, hygienic conditions of production are important, in particular in the conditioning of the grains and with regard to the water used in the process.
- Mycotoxins in cereal products are often unavoidable because moulds are ubiquitous and toxins are stable chemical compounds. However, several efforts can be made to reduce concentrations, and in a changing climate, efforts in primary production and storage are likely to be particularly important. Such efforts are proper crop rotation, tillage, variety selection, use

of chemical control and measures to reduce the moisture content of the crop in the field, control of pests, and rapid lowering of moisture content to storage stable levels after harvest.

Fruits, berries and vegetables

- Climate change may lead to the introduction of new pathogens or a wider trasnmission of existing pathogens in animal populations, pathogens which can then be transmitted to crops in primary production. Soil, manure and water used for cultivation and irrigation can contaminate crops with intestinal bacteria from both animals and humans. A changing climate can potentially improve the ability of pathogens to survive in and spread from such sources, increasing the likelihood of contamination of fruit and vegetables, and increasing exposure via the consumption of such foods. Changing consumption patterns with more vegetarian foods, including potentially new crops and products, can also increase exposure.
- Increased rainfall and, in particular, extreme weather may also increase the spread of water-related pathogens from e.g. waste water, pastures and stormwaters to irrigation water and farmland. It may also lead to contamination of crops by increasing the amount of rainwater and soil splashing on crops.
- There are several pathogens that have caused outbreaks with fruit, berries and vegetables as vehicles of transmission and may become more common in a changing climate. This concerns in particular intestinal bacteria such as Salmonella spp., Shigella spp. and STEC, viruses such as norovirus and HAV, as well as protozoa such as Cryptosporidium parvum and Cyclospora cayetanensis. Cyclospora and shigella are mainly associated with imported products from tropical areas where the microorganisms are endemic. Listeria monocytogenes, which has also been reported to cause outbreaks linked to contamination and consumption of processed fruit and vegetables products, can potentially become more common, as extreme weather affecting power supply may impair the ability to store food at the right temperature. Patulin, which occurs for example in apples, can potentially increase due to increased occurrence of insects and more heavy rain, which may benefit the toxin producing fungus.
- A changing climate means that production of fruit, berries and vegetables, which today are largely consumed raw or minimally processed, requires efficient plans and procedures to identify hazards and prevent contamination in primary production and throughout the food chain. Climate change and more extreme weather events can pose new challenges such as access to microbiologically safe irrigation water, as well as the ability to cool fruit, berries and vegetables after harvesting and at later stages of the food chain.

Vegetable fats, nuts and seeds

- Bacteria cannot multiply in dry foods such as nuts and seeds, but both Salmonella spp. and pathogenic E. coli can survive for a long time on the surface as well as in products containing them. Salmonella spp. and to some extent STEC have caused several outbreaks of disease linked to nuts and seeds.
- Several mycotoxins have been identified in nuts, seeds and oilseeds as well as in products containing them. Aflatoxins are considered to be the main problem. Maize and peanuts are

crops where aflatoxins can occur at high concentrations while tree nuts often have lower concentrations.

- Nuts are often contaminated with bacterial pathogens early in the production chain, e.g. via animal manure during cultivation or harvesting, soil when harvested, or humans and machinery during harvesting and handling. Mycotoxins can be formed in nuts and seeds both during cultivation and post-harvest and the main risk factors are drought stress and insect infestation during cultivation, and too high moisture content during storage. High temperatures, variable temperature, high humidity and/or high precipitation during harvesting have also been identified as risk factors for the formation of mycotoxins. Given the risk factors described in nuts and seeds and the general trend of salmonella, pathogenic E. coli and aflatoxins, it is likely that the occurrence of these hazards will increase in a changing climate.
- Exposure to pathogenic bacteria via the consumption of nuts can be reduced by good agricultural practice that takes into account e.g. soil use, manure application, water sources, hygienic harvesting, etc. For mycotoxins in nuts and seeds, effective drying to safe moisture content and removal of low-quality nuts are important control measures, as well as sampling and control.

Drinking water

- The following pathogens are assessed as relevant to production of drinking water based on possible climate change and the criterion that drinking water consumption is a confirmed transmission route:
    - Bacteria: Campylobacter spp., different groups of pathogenic E. coli, Francisella tularensis, Salmonella spp., Shigella spp., Vibrio cholerae
    - Virus: calicivirus (noro- and sapovirus), HAV, adenovirus, astrovirus, rotavirus
    - Protozoa/parasites: Cryptosporidium spp., Entamoeba histolytica, Giardia spp., Cyclospora cayetanensis
- Other routes of transmission may be equally important for these hazards but drinking water treatments need to address them in the design of barriers. Several of the viruses and protozoa are the main concern, while most bacteria are susceptible to chlorination and becomes a problem mainly if the treatment is missing or failing.
- Several of the relevant pathogens that can be transmitted via drinking water are not present, or only to a small extent, in Sweden today, but may become important in the future if the incidence of infections with these pathogens increases as a result of climate change. Then they will circulate in the water cycle via sewers, water treatment plants and raw water sources, which can pose challenges for water treatment. What challenges that will arise may depend in part on the magnitude of the changes. In addition, new pathogens may enter the cycle from other areas or new variants with new properties arise through evolution.
- The management and systems for the production of safe drinking water are not fundamentally altered by the predictions of a warmer climate and its consequences. Protection of raw water sources and the management of treatment processes remain the most important elements.

However, the dimensioning of the treatment should have sufficient capacities and flexibilities to handle a supposedly greater variation in the concentration of pathogens in raw water associated with higher temperatures, increased precipitation and extreme weather, and possibly also new pathogens with greater resistance to inactivation. In addition, it becomes even more important that the treatment steps are validated and verified and monitored continuously.

- Drinking water production as well as other food production is vulnerable to disruptions in the form of extreme events and infrastructure disruptions, and the likelihood of this is increasing according to climate projections. Increased preparedness is needed in the form of, for example, redundancy in terms of power supply and access to alternative raw water sources.
- Most food businesses, in both primary production and processing, depend on large quantities of water. These identified negative impacts on drinking water can therefore spill over to other sectors of food production.

Seafood

- Climate change has an impact on food safety by improving the conditions for the survival and growth of many types of pathogenic microorganisms in aquatic environments and fish and shellfish.
- Growth has been shown to increase at higher water temperatures in several naturally occurring pathogenic bacteria such as Vibrio spp., Listeria monocytogenes, Clostridium botulinum and Aeromonas hydrophila. The same applies to bacteria occurring in aquatic environments due to faecal contamination such as Salmonella spp., Campylobacter spp., Escherichia coli, Shigella spp. and Yersinia enterocolitica.
- Seasonal variations and changes in temperature cycles and rainfall patterns also favour the occurrence of certain food-borne viruses, such as noroviruses, in edible aquatic species, and alter the population dynamics of aquatic species hosting food-borne parasites.
- Vibrio spp., in particular Vibrio parahaemolyticus, is considered particularly important for climate change in marine aquatic ecosystems, as recent studies show that the occurrence of these bacteria will increase with a warmer climate, even at our northern latitudes. Norovirus, which is the most common food-borne hazard transmitted via bivalve molluscs consumption both in Sweden and globally, is also predicted to be more easily transmitted due to climate change as a consequence of an increasing impact on wastewater affected water in the farming areas. As a result, food-borne disease caused by such pathogens can become even more common in the long term unless successful control measures can be implemented. The direct impact of climate change is unclear as regards the occurrence of Listeria monocytogenes in raw materials, such as salmon. However, extreme weather events affecting the power supply may result in a reduced ability to store food at cold temperatures, which may affect the ability of listeria to multiply in processed products and thus its ability to cause disease.
- Increased susceptibility to bacterial diseases in fish and shellfish can increase the global use of antibiotics in food production, in particular in aquaculture, which can drive the emergence and spread of antibiotic resistant bacteria.

Table 6. Microbiological hazards for different food groups that may become important in a changing climate. For justifications and details on the importance of hazards in the respective food group, see Chapter 6.

Food group	Microbiological hazards that may have an increased or potentially increased occurrence in food due to a change in climate
Dairy	Campylobacter spp., Salmonella spp., STEC and other pathogenic E. coli, Listeria monocytogenes, Yersinia spp., TBEV, Toxoplasma gondii, Cryptosporidium parvum, aflatoxin M1
Meat	Salmonella spp., Campylobacter spp., STEC, Yersinia enterocolitica, HEV, Trichinella, Toxoplasma gondii
Eggs	Salmonella spp., STEC and other pathogenic E. coli, Campylobacter spp., Bacillus cereus, Staphylococcus aureus
Cereal products	Salmonella spp., STEC and other pathogenic E. coli, DON, T2 and HT2, ZEN, aflatoxins, fumonisins, OTA, ergot alkaloids
Fruits, berries and vegetables	Salmonella spp., Shigella spp., STEC, Listeria monocytogenes, norovirus, HAV, Cryptosporidium parvum, Cyclospora cayetanensis, patulin
Vegetable fats, nuts and seeds	Salmonella spp., STEC and other pathogenic E. coli, aflatoxins
Drinking water	Campylobacter spp., STEC and other pathogenic E. coli, Francisella tularensis, Salmonella spp., Shigella spp., Vibrio cholerae, norovirus, sapovirus, HAV, adenovirus, astrovirus, rotavirus, Cryptosporidium spp., Entamoeba histolytica, Giardia spp., Cyclospora cayetanensis
Seafood	Vibrio spp. (Vibrio parahaemolyticus), Listeria monocytogenes, Clostridium botulinum, Aeromonas hydrophila, Salmonella spp., Campylobacter spp., STEC and other pathogenic Escherichia coli, Shigella spp., Yersinia enterocolitica, norovirus, HAV

7.3 Uncertainty and knowledge gaps

There are many sources of uncertainty for the assessment made in this report. The main source of uncertainty include knowledge gaps associated with data on the extent to which the climate will impact on microbiological hazards, difficulties in identifying causal relationships based on correlations, knowledge gaps associated with methodology of carrying out this type of complex assessment against uncertain future scenarios, and knowledge gaps about the future climate and its concrete effects. A further contributing uncertainty is knowledge gaps on potential feedback mechanisms between climate change and its effects.

Despite the uncertainties, the increased food safety challenges presented qualitatively in the report are considered likely (probability of 66-90 %) according to EFSA's terminology for uncertainty (Efsa, 2018). These challenges are the consequences of the impacts that climate change according to RCP8.5 scenario may have on several of the microbiological hazards in terms of increased or potentially increased occurrence in the environment, water, animals and/or food raw materials. Conclusions on the changed occurrence of specific microbiological hazards, the extent of the impact, and the rate of change are subject to significantly greater uncertainty. This is not least because the impact of climate change depends on the accuracy of the climate scenarios and on what measures are put in place.

With regard to the many data gaps at a detailed level, they are so many that it makes no sense to list them in this report. The complexity of the issues covered by the report requires further methodological development with broad perspectives similar to the EFSA report (Efsa, 2020) in terms of areas of competence and resources. This input should therefore be seen as an initial and general synthesis of knowledge, which can serve as a basis for further and more detailed studies and activities in various sectors of the food chain.

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Annex 1. Literature search

Table B1. Search strings and databases, as well as relevant search results and total number of hits, in the literature search.

Search strings	Database	Number of hits	Relevant hits
Campylobacter AND “climate change”	PubMed	20	9
(“Shiga-toxin producing” OR STEC OR VTEC OR EHEC OR “Escherichia coli”) AND “climate change” AND review	PubMed	14	3
(“Shiga-toxin producing” OR STEC OR VTEC OR EHEC OR “Escherichia coli”) AND (climate OR climatic), 2016-2020	PubMed	360	9
Vibrio AND “climate change” AND review, 2016-2020	PubMed	14	8
“Limate change” AND virus AND food NOT plant	PubMed	87	4
Salmonella AND “climate change”	PubMed	49	9
Sea AND climate	PubMed	87	5
Hepatitis E AND climate	PubMed	79	6
Norovirus AND climate [TI]	PubMed	9	6
Listeria AND “climate change”	PubMed	6	4
“Fasciola hepatica” AND “climate change”	PubMed	26	3
Echinococcus AND “climate change”	PubMed	5	3
Cryptosporidium AND “climate change”	PubMed	29	
Toxoplasma AND “climate change”	PubMed	16	5
Anthrax AND “climate change”	PubMed	13	5
Anisakis AND “climate change”	PubMed	2	1
(Climate change OR global warming) AND mycotoxins AND review	FSTA	37	8
Brucell* AND “climate change” AND review	PubMed	13	5
Burkholderia AND “climate change” AND review	PubMed	3	3
(Coxiell* OR “Q fever”) AND “climate change” AND review	PubMed	6	3
“Bacillus cereus” AND “climate change”	PubMed	5	2
“Clostridium botulinum” AND climate	PubMed	33	0
(Shigella OR shigellosis) AND (“climate change” OR climatic), 2016-2020	PubMed	62	11
“Staphylococcus aureus” AND “climate change”	PubMed	17	2
(Francisella OR tularaemia) AND “climate change”	PubMed	16	8
“Climate change” AND (“fresh produce” OR vegetables OR fruits OR berries) AND (“food safety” OR “food chain” OR “food system”) AND review	PubMed	13	5
(Pathogen* OR microorganism*) AND “climate change” AND (“fresh produce” OR vegetables OR fruits OR berries) AND (“food safety” OR “food chain” OR “food system”) AND review	FSTA	9	5
“Climate change” AND (fish* OR aquaculture OR seafood) AND (“food safety” OR “food chain” OR “food system”) AND review	PubMed	43	5
(‘Climate change’[tiab] OR ‘climate changes’[tiab] OR ‘global warming’[tiab] OR ‘greenhouse effect’[tiab]) AND (mycotoxin*[tiab] OR ‘ochratoxin A’[tiab] OR Deoxynivalenol[tiab] OR ‘T-2 toxin’[tiab] OR ‘HT-2 toxin’[tiab] OR patulin[tiab] OR ‘ergot alkaloid*’[tiab])	PubMed	82	32
Meat AND “climate change”	PubMed	310	5
(“Climate change”[tiab] OR “climate changes”[tiab] OR “global warming”[tiab] OR “greenhouse effect”[tiab]) AND (mycotoxin*[tiab] OR “ochratoxin A”[tiab] OR Deoxynivalenol[tiab] OR “T-2 toxin”[tiab] OR “HT-2 toxin”[tiab] OR patulin[tiab] OR “ergot alkaloid*”[tiab]) AND review	PubMed	23	11

Search strings	Database	Number of hits	Relevant hits
Poultry [TI] AND (“table egg”[TW] OR “layer hen”[TW]) AND (pathogen* OR salmonella)	PubMed	31	5
Poultry [MH] AND egg*[AB] AND (“climate” OR “climate change”)	PubMed	63	8
Drinking water pathogens climate change	Google Scholar	Many	Exploratory
“Limate change”[tiab] AND (dairy[tiab] OR milk[tiab]) AND (“food safety”[tiab] OR “microbiological hazards”[tiab] OR pathogen[tiab])	PubMed	8	2
“Climate change” AND (dairy OR milk) AND “food safety”	Google Scholar	Many	Exploratory
(“Climate change”[tiab] OR “climate changes”[tiab] AND (“food safety” OR contaminant* OR microorganism*) AND (grain OR cereal OR “dry goods” OR nuts OR seeds OR “vegetable fats” OR “rape seed” OR “oil”)	PubMed	53	10
(‘Rapeseed oil’[Title/Abstract] OR ‘vegetable oil’[Title/Abstract] OR ‘olive oil’[Title/Abstract] OR ‘sunflower oil’[Title/Abstract] OR ‘sesame oil’[Title/Abstract] AND (‘food safety’[Title/Abstract] OR ‘microbiological hazards’[Title/Abstract] OR ‘pathogen’[Title/Abstract])	PubMed	127	3
“Climate change” AND (food safety OR contaminant* OR microorganism*) AND (grain OR cereal OR dry goods OR nuts OR seeds OR vegetable fats OR rape seed OR oil)	Google Scholar	Many	Exploratory

Annex 2. Microbiological hazards — in-depth review

Bacteria

Bacillus anthracis

Foodborne infection — characteristics, sources and routes of transmission

Bacillus anthracis is a spore-forming bacterium that causes anthrax (anthrax). The spores, a kind of protective resting stage for the bacteria outside the body, survive for a very long time in the environment. The spores are resistant to dehydration, extreme heat and cold, and tolerate a wide pH spectrum. Furthermore, spores can survive in the soil for decades and can withstand mechanical stresses in the environment such as during flooding (Walsh et al., 2018).

The bacterium can infect all mammals, but ruminants such as sheep and cattle are the most susceptible animal species. Humans are usually infected via the skin after direct contact with body fluids or tissue from sick or dead animals or with contaminated animal products. Infection can also be transmitted by inhalation of spores or by ingestion of contaminated meat. The last known human case in Sweden occurred in 1965 (Folkhälsomyndigheten, 2021), while the last reported cases in ruminants occurred in 2016 (SVA, 2020b). It is mainly bovine animals that have been affected, but the outbreak in 2016 also included horses, sheep and moose.

Importance of a changing climate

The incidence of B. anthracis and anthrax outbreaks is closely linked to, and varies with, climate (Lewerin et al., 2010, Walsh et al., 2018). According to a model of Walsh et al. (2018) increased temperature has a significant impact on the distribution of the bacterium at the northernmost latitudes. The geographical distribution is predicted to increase over the next 30 years with continued warming (Walsh et al., 2018). Outbreaks can be caused, among other things, by extreme weather conditions and weather changes such as rains and floods followed by droughts or the reverse (Epp et al., 2010, Lewerin et al., 2010, Maksimovic et al., 2017). As a result, bacterial spores in soil and land from old anthrax graves (animals that died of anthrax were buried during anthrax outbreaks) are concentrated and reach the surface, with a higher risk of exposure to grazing ruminants and to humans in contact with the exposed animals. Watercourses affected by old anthrax graves are believed to have been relevant for the spread of the infection to cattle during the anthrax outbreaks that occurred in Sweden in 2008 and 2011 (Lewerin et al., 2010, Larsson and Bergdahl, 2011). During the last outbreak in Sweden in 2016, heat and drought led to heavy grazing in the pastures. This had the consequence that the animals grazed closer to the ground, resulting in increased exposure to soil and dormant anthrax spores (SVA, 2018). An anthrax outbreak in Siberia in 2016, killing more than 2000 reindeer and one human being, was the first outbreak in the region in 75 years. The Russian outbreak was probably caused by high summer temperatures and melting of the permafrost so that spores in the upper layers of thawed soil were released from old anthrax graves (Waits et al., 2018, Maksimovic et al., 2017). However, other factors such as low vaccination rates, increased stocking density and increased susceptibility to infection of the reindeers due to heat were also relevant for the outbreak (Hueffer et al., 2020, Waits et al., 2018, Walsh et al., 2018).

Thus, there is an increased likelihood of anthrax spores spreading from old graves as a result of a changed climate in the form of warmer temperatures and more extreme weather events.

Bacillus cereus

Foodborne infection — characteristics, sources and routes of transmission

Bacillus cereus is a spore-forming soil bacteria. The spores are resistant to heat. and as they germinate and grow, two different main types of toxins can be formed. B. cereus is spread from soil to food raw materials and can be present in many types of products, such as dairy products, vegetable dishes, starch-rich foods such as rice and rice dishes, as well as heat-treated products such as puddings and sauces.

Different strains of B. cereus have different growth requirements. Some are cold-tolerant (psychrotrophic) and can grow at 4-5 °C while others can multiply only at higher temperatures (mesophilic), max. 55 °C. The optimum growth temperature is about 30 to 40 °C.

The impact of a changing climate

Two studies from South Korea have investigated the relationship between climate variables and the incidence of B. cereus infections (hospital admissions). Kim et al. (2015) examined the link between temperature and relative humidity and the number of cases of disease in the years 2003-2012, while Park et al. (2018b), in addition to temperature and humidity, also compared rainfalls, solar radiation and cloudiness with the number of cases in 2011-2015. None of the studies showed a correlation between B. cereus infection and any of the climatic variables studied.

Several hypotheses of the impact of climate change on B. cereus have been proposed. It has been suggested that global warming can contribute to a shift from psycrotrophic B. cereus strains to more mesophilic strains in the environment in areas that today have temperate climate (Carlin et al., 2010). Another hypothesis is that increased wind due to climate change can contribute to an increased spread of bacterial spores e.g. from B. cereus (Hellberg and Chu, 2016). Studies have shown that the presence of B. cereus in raw and pasteurised milk is more common in late spring and summer than in autumn and winter, probably linked to outdoor grazing of dairy animals (Hellberg and Chu, 2016). If climate change leads to changes in the length of the grazing season (increased or reduced), this could affect the presence of B. cereus in milk.

Overall, data do not suggest that climate change will significantly affect the occurrence of B. cereus in any direction, but the data is relatively limited.

Brucella spp.

Foodborne infection — characteristics, sources and routes of transmission

Brucella are bacteria which cause brucellosis, and those with the greatest zoonotic potential are Brucella melitensis, which occur mainly in sheep and goats, B. abortus in cattle and B. suis in pigs and wild boars. In addition, newly emerging species potentially infecting humans have been detected in various host and carrier animals (Hull and Schumaker, 2018). Brucellosis has not been detected in food-producing animals in Sweden since the 1950s (SVA, 2020a). Also small rodents can be reservoirs (Revich et al., 2012). The bacterium can survive long periods in the environment, but it is not known to what extent the bacterium can grow outside its host (Rodriguez-Morales, 2013, Hellberg and Chu, 2016). Its optimum growth temperature is 37 °C (Adams and Moss, 2008).

Unpasteurised milk and milk products from sheep and goats are the most common sources of infection of brucellosis in endemic areas such as the Middle East, Africa and South America, but the handling and consumption of contaminated meat from different animal species is also a possible food-borne pathway (Fredriksson-Ahomaa, 2019, Ganter, 2015). A few Swedes are infected each year with brucellosis (Folkhälsomyndigheten, 2021). Most have been infected abroad in endemic areas, while domestic disease cases are very rare. In the EU, cases are reported mainly in Italy, Greece and Spain (ECDC, 2019).

Importance of a changing climate

A literature review has shown a significant correlation between warmer climates associated with El Niño periods (actually the climate indicator "Oceanic Niño Index"[1] used to predict El Niño) and the number of reported cases of human or bovine brucellosis in, for example, Mexico, Peru and Brazil during or at the end of the 1990s (Rodriguez-Morales, 2013).

In a warmer climate with milder winters and less snow rodents and wild animals that are carriers or reservoirs of Brucella spp. can survive better and migrate to more northern latitudes. In this scenario, the bacterium can spread to new animal populations and areas where it is not endemic today (Fredriksson-Ahomaa, 2019, Parkinson et al., 2014). The spread of pathogens with wind and dust particles may increase in a changing climate in some regions (Hellberg and Chu, 2016). There is some, but weak support that brucella can spread over short distances via airborne dust; however, the viability of the bacteria was not examined (Hellberg and Chu, 2016).

Climate change can thus increase the spread of Brucella spp. and consequently the number of brucellosis cases, potentially also in Sweden. However, several knowledge gaps exits (Rodriguez-Morales, 2013).

Burkholderia pseudomallei

Foodborne infection — characteristics, sources and routes of transmission

Burkholderia pseudomallei, which causes melioidosis, is a bacterium found in soil and water in tropical countries, mainly Southeast Asia and Northern Australia (WHO, 2017, Inglis and Sousa, 2009, Merritt and Inglis, 2017). The bacterium can grow and survive well in water, over a month at 20 °C (WHO, 2017). Humans are usually infected via contact with contaminated soil or water that enters small wounds in the skin, or via the ingestion of water or by inhalation of water or soil dust (Folkhälsomyndigheten, 2021). The relative importance of these routes of transmission is unknown (WHO, 2017). Animals such as sheep, goats, pigs and rodents can also be infected and spread the bacterium to new areas. B. pseudomallei is not subject to notification under the Swedish

[1] The "Oceanic Niño Index", a measure of the deviation from the normal sea surface temperature in the Eastern Central Pacific Ocean, and which is the common way by which each El Niño period is determined, measured and predicted.

Communicable Diseases Act and there are no documented drinking water-related outbreaks or cases in Sweden (Folkhälsomyndigheten, 2015, Schönning, 2021).

Importance of a changing climate

Increased temperature combined with changes in precipitation patterns and more frequent extreme weather events are expected to affect the occurrence and epidemiology of B. pseudomallei (Merritt and Inglis, 2017). Several studies have shown a link between increased maximum rainfall and cases of melioidosis (Merritt and Inglis, 2017). Disease cases are detected throughout the year in endemic areas, but the highest number of cases occurs during rain periods when the occurrence of the bacterium in the environment, including raw water sources, may increase due to rain or flooding (WHO, 2017, Merritt and Inglis, 2017). In addition, increased number of cases have been observed following storms in Taiwan and cyclones in northern Australia, strengthening the link between extreme weather events and melioidosis (Merritt and Inglis, 2017). Also dense cloud cover has been shown to be associated with the number of cases, probably due to higher humidity in B. pseudomallei containing soils (Merritt and Inglis, 2017).

B. pseudomallei has been detected in different types of ticks in areas where the bacterium is endemic (Dehhaghi et al., 2019). A warmer climate with temporarily or permanently increases in population density and spread among ticks would potentially favour such vector-borne spread of the bacterium (Dehhaghi et al., 2019).

In conclusion, extreme weather events due to a changing climate will increase the risk of melioidosis caused by B. pseudomallei in tropical countries and may gradually increase the spread of the bacterium outside its main endemic area (Merritt and Inglis, 2017, Inglis and Sousa, 2009). Under conditions in Sweden, it is assessed that the occurrence of the bacterium remains low.

Campylobacter

Foodborne infection — characteristics, sources and routes of transmission

Campylobacter is one of the most common causes of food-borne disease in Sweden. Campylobacter can be found in the intestines of food-producing animals, such as birds, pigs, cattle and sheep, and can thus be spread to meat via faecal contamination (Kovats et al., 2005). Chicken meat is a known source of infection, as well as unpasteurised milk. Campylobacter is a thermophilic and microaerophilic bacterium which does not grow at temperatures below 30 °C or at atmospheric oxygen levels. But the bacterium can still survive in the environment and cause the spread of infection (Hellberg and Chu, 2016, Bronowski et al., 2014). For example, contaminated drinking water has caused several outbreaks of campylobacteriosis (Andersson et al., 1997, Bartholomew et al., 2014, Bronowski et al., 2014, Hellberg and Chu, 2016, Jakopanec et al., 2008). However, much remains unclear about the transmission routes for campylobacter in the environment (Djennad et al., 2019).

Importance of a changing climate

A number of studies have reported a seasonal variation and an impact of climate factors on human campylobacteriosis cases, although illness peak numbers may occur at different times of the year in different countries (Kovats et al., 2005, Nylen et al., 2002). In Europe and Canada, a seasonal peak is often reported during the summer, which could indicate that temperature is an important factor for the bacterium (Kovats et al., 2005, Semenza et al., 2012b). Studies have shown correlations between increased outdoor temperature and the number of confirmed cases of campylobacteriosis (Fleury et al., 2006, Kuhn et al., 2020), but there are also studies where such relationships have not been demonstrated or been unclear (Bi et al., 2008, Park et al., 2018a). The fact that studies report inconsistent results may indicate that different sources of infection are important and that these may be more or less affected by the climate.

Heavy rainfall can lead to an increased spread of campylobacteriosis via the environment, as increased amounts of water spread bacteria from contaminated soil to crops and drinking water sources. For campylobacter, there are studies that have shown that waterborne outbreaks increase after rain, especially if precipitation follows after a time of drought, and heavy spring rains (Semenza et al., 2012b, Kuhn et al., 2020). At the same time, there are studies that report that increased rainfall and surface run-off will not increase the risk of exposure of campylobacter in surface water due to dilution (Sterk et al., 2016). A simulation study predicts, based on a non-validated model, that the number of cases of campylobacteriosis may double by 2080 due to climate change in Sweden, Norway, Denmark and Finland (Kuhn et al., 2020).

The overall assessment is that the prevalence and spread of campylobacter may increase in the event of climate change, but the assessment is uncertain as different studies present different conclusions.

Clostridium botulinum

Foodborne infection — characteristics, sources and routes of transmission

Clostridium botulinum is an anaerobic, spore-forming bacterium that can be found in the environment, in soil and sediment, as well as in the intestine of fish and mammals. C. botulinum consists of four different serotypes (Type I-IV) that have the ability to form severe nerve toxins, known as botulinum toxin, which causes the disease botulism. The spores are very resistant to external environmental factors and can survive both drought and heating. Botulinum toxin is formed when the spores turn into growing bacteria and start to grow. Examples of foods that cause botulism include improperly preserved foods, homemade spice and vegetable pickles stored at too high temperatures, and vacuum-packed salted or smoked fish.

The impact of a changing climate

C. botulinum has been listed as a bacterium potentially affected by climate change (Hellberg and Chu, 2016, Lake and Barker, 2018, Tirado et al., 2010). In the environment, spores of C. botulinum may benefit from drought, for example, because durable spores are given increased space when other microbiotia is disadvantaged (Hellberg and Chu, 2016). However, there is little literature describing how C. botulinum could be affected by climate change. The overall assessment is therefore uncertain.

Clostridium perfringens

Foodborne infection — characteristics, sources and routes of transmission

Clostridium perfringens is a bacterium found in, e.g. soil and in the intestine of warm-blooded animals. The bacteria multiply in oxygen-free environments and form heat-resistant spores. Common sources of food poisoning are, for example, soups and stews served after storage at abusive temperatures (e.g. due to too slow cooling) allowing the bacterium to grow. The toxin is formed in the intestine.

The impact of a changing climate

C. perfringens has been used as an indicator for the spread of bacteria during precipitation (Hellberg and Chu, 2016). In short, a positive correlation has been shown between increased rainfall and the detection of C. perfringens and other indicator organisms in the surrounding watercourses. Studies have also shown elevated levels of C. perfringens in drinking water reservoirs following extreme rain weather (Hellberg and Chu, 2016). Extreme drought could possibly benefit stress tolerant sporeforming bacteria such as C. perfringens (Hellberg and Chu, 2016).

Due to the lack of studies, it is considered uncertain how C. perfringens can be affected by climate change (Smith and Fazil, 2019). The risk of food poisoning caused by C. perfringens may increase in the event of extreme weather affecting the power supply and subsequent failures to maintain sufficiently high temperatures in hot food or rapid chilling of food.

Coxiella burnetii

Foodborne infection — characteristics, sources and routes of transmission

Coxiella burnetii, which causes Q fever, is a bacterium that multiplies inside tissue cells. The organism is highly resistant to external environmental factors by forming resistant spores under adverse conditions (Dehhaghi et al., 2019). It is spread to humans mainly via food-producing animals such as cattle, sheep and goats, and via their environment (Eldin et al., 2017). Infection with Q fever occurs in food-producing animals in both Sweden and other EU countries (SVA, 2020c). Also small rodents, birds and reptiles can be reservoirs (Revich et al., 2012, Ganter, 2015).

Inhalation of aerosols containing the organism is by far the most common route of exposure (Baud and Greub, 2011, Oyston and Davies, 2011). Unpasteurised milk and milk products thereof are possible sources of contamination for coxiella, but there is currently not convincing evidence that the consumption of such products from coxiella-infected animals leads to food-borne Q fever in humans (Eldin et al., 2017, Pexara et al., 2018). In Sweden, individual human cases are reported annually. Domestic cases are very rare. Most commonly, people have been infected in the Mediterranean region (Folkhälsomyndigheten, 2021).

Importance of a changing climate

Warmer temperatures with milder winters can favour the density and the distribution of populations of rodents and other animal reservoirs, which in turn can contribute to the spread of an organism like C. burnetii more northwards (Parkinson et al., 2014). Vector-borne spread of the bacterium via different types of ticks can also become more common in a changing climate, at least in areas such as Australia where the bacterium is endemic (Dehhaghi et al., 2019). The spread of pathogens with wind and dust particles may increase in a changing climate in certain regions (Hellberg and Chu, 2016). The spread of C. burnetii, which is mainly distributed via airborne aerosols and resistant to external environmental factors, can be favoured in a situation with more frequent storms and other extreme weather conditions (Efsa, 2020).

A warmer climate with periods of extremely dry years can result in smaller yields, which in the long run can increase imports of animal feed. This increases the likelihood of the spread of pathogens that may accompany the feed, for example C. burnetii (NRK, 2018).

The assessment is that C. burnetii can eventually become more common at our latitudes through changes such as increased wind, increased imports of feed and increased distribution in some animal reservoirs, but that the evidence for this is low.

Francisella tularensis

Foodborne infection — characteristics, sources and routes of transmission

Francisella tularensis is a bacterium that causes tularemia. It occurs in two clinically relevant forms; a more virulent subspecies F. tularensis subsp. tularensis, mainly found in North America, and a milder F. tularensis subsp. holarctica, which is spread throughout the northern hemisphere, including Sweden (Hennebique et al., 2019). The most common reservoirs in Sweden are hares and rodents, such as voles.

F. tularensis is mainly transmitted by mosquitoes and ticks and via direct contact with infected animals. A more unusual route is the consumption of water contaminated by infected animals, and the handling or consumption of insufficiently heat treated meat from such animals. The bacterium can survive for a long time in different aquatic environments (Hennebique et al., 2019). Between 1988 and 2018, 40 drinking waterborne outbreaks and cases of harpest were reported in Europe, mainly Turkey. Of these two occurred in Sweden (Hennebique et al., 2019). The number of people suffering from tularemia in Sweden fluctuates from year to year, with major outbreaks in some years associated with mosquitos (Folkhälsomyndigheten, 2021). The isolated domestic cases of disease via drinking water have all been linked to private wells (Hennebique et al., 2019, Folkhälsomyndigheten, 2021).

Importance of a changing climate

Both increased temperatures and precipitation are indirectly important for the spread of F. tularensis by increasing the distribution of infected animals (warmer climate) and vectors carrying the organism (warmer and more humid climate) (varmare och fuktigare klimat; Waits et al., 2018). For example, a Swedish study examined correlations between climatic factors and increased risk of tularemia in high-risk areas due to spread via mosquitoes, and showed that both high air temperature in the previous summer and high rainfall in the current summer are important for the risk of contracting the infection (Desvars-Larrive et al., 2017). Recent Swedish studies (Ma et al., 2020, Ma et al., 2019) have shown that relatively small changes in climate and the landscape's water conditions can significantly increase the number of cases of disease, and that tularemia can become more common in the future, at least in the middle and northern parts of Sweden.

Overall, F. tularensis is assessed to have an increased geographical spread with a changed climate, and thus tularemia can become more common at our northern latitudes (Waits et al., 2018, Ma et al., 2020, Ma et al., 2019). If the occurrence of F. tularensis increases in the environment by spreading via mosquitoes and infected hares and rodents, drinking water-borne outbreaks of tularemia may also become more frequent in the long term.

Listeria monocytogenes

Foodborne infection — characteristics, sources and routes of transmission

Listeria monocytogenes is a commonly occurring bacterium that can survive and grow in many different environments and temperatures (Hellberg and Chu, 2016, Semenza et al., 2012b). Listeria is found in several animal reservoirs as well as in aquatic environments and is tolerant to high salinity, drought and acidic conditions (Hellberg and Chu, 2016). Important traits of listeria is its abilities to persist and grow for long periods on surfaces, multiply at refrigerator temperatures and without access to oxygen, for example in vacuum packaging. In products with a long shelf life in refrigerators, listeria can grow to unsafe levels before shelf life has expired. The main sources of infection are processed ready-to-eat food that has often been contaminated during the manufacturing process (Hellberg and Chu, 2016).

Importance of a changing climate

There seems to be no seasonal variation in the outbreaks of listeria (Park et al., 2018a, Semenza et al., 2012b), and some studie believe that listeria will not increase due to climate change (Semenza et al., 2012b). However, L. monocytogenes has been reported in international studies to occur more frequently in soil and farm environment in winter and the excretion of the bacterium in ruminants has been shown to be highest during the colder part of the year (Hellberg, 2016). Milder winters with temperatures above freezing point and fewer zero-crossings can potentially favour the occurrence of listeria in the environment (Hellberg 2016), but this is uncertain. Extreme events that affect the power supply may result in reduced ability to store foods cold, which can have a major impact on the growth of listeria, and thus the risk of listeriosis (Chersich et al., 2018). Water shortages or deterioration in water quality may affect the cleaning of process equipment negatively, increasing the potential for listeria contamination of food products (Chersich et al., 2018).

Overall, the conclusion is that it is uncertain whether the occurrence of L. monocytogenes will increase due to climate change.

Salmonella spp.

Foodborne infection — characteristics, sources and routes of transmission

Salmonella spp. is a group of pathogens that may be present in the intestine of many different animals, including birds. The Salmonella enterica species is divided into more than 2000 serotypes/serovars and all are considered pathogenic but to varying degrees. Host-specific serotypes (infecting only one or a few species) such as S. Dublin (bovine cattle) and S. Choleraesuis (pigs) can cause severe disease in humans while serotypes with a wide host spectrum are more likely to cause milder symptoms except in particularly sensitive groups such as children, immunodepressed and elderly. The serotypes that cause most human cases are S. Enteriditis and S. Typhimurium.

Via contaminated stools, Salmonella spp. can spread to other environments such as soil, pastures and water. Food can be contaminated with salmonella through direct or indirect contact with faeces of animals or infected persons. For example, vegetation can be contaminated via fertilisation or irrigation with contaminated water. Chicken meat and eggs are common products contaminated with salmonella, but due to a successful Swedish Salmonella control programme, salmonella in meat and eggs from Sweden is very rare.

Salmonella can generally survive very well in the environment outside a host organism (Hellberg and Chu, 2016). There are large variations in the ability of different types of salmonella strains to survive and grow, ranging from psycrotrophic to thermophilic strains, but most types have a growth optimum of 37 °C (Hellberg and Chu, 2016).

As with other pathogens, changes in selection pressure and existing ecological niches can lead to an evolution of the types that predominate among different host animals, e.g. the common serotypes in poultry (Foley et al., 2011). In the United States, theories have been put forward that the emergence of S. Enteritidis, which was primarily associated with rodents, took place when measures were taken to control the serotypes of disease in birds, S. Pullorum and S. Gallinarium. The explanation put forward is that this opened up a niche for S. Enteritidis due to less competition ("no competitive exclusion") since S. Gallinarium and S. Enteritidis express the same immunodominant O9 lipopolysaccharide on the cell surface, but where S. Gallinarium had a better ability to colonise and survive when adapted to poultry (Foley et al., 2011). Changes like these occur constantly in response to changes in selectivity pressure, depending on human action or environmental changes, e.g. climate.

Importance of a changing climate

Temperature is an important factor in the growth of salmonella and growth increases with increased temperature (McMichael et al., 2006). Thus, the occurrence of salmonella in manure, for example, may increase due to climate change, possibly contributing to an increased spread of the bacterium in the environment. As regards the survival of salmonella in the environment, studies have shown that survival in manure and fertilised soil decreases at higher temperatures but that survival in soil increases under humid conditions (Hellberg and Chu, 2016).

Increased rainfall can contribute to the spread of salmonella in the environment to a wider areas of land and watercourses (Hellberg and Chu, 2016). Thus, the bacterium can spread to agricultural and pastures or to watercourses used for irrigation or as a source of drinking water. Heavy rainfall can also lead to contamination of crops grown in the open by increasing the amount of rainwater and soil splashing on crops (Hellberg and Chu, 2016).

There are several studies showing seasonality of salmonellosis, with more cases in the summer compared to winter. There are also studies showing correlations between climatic factors, mainly temperature, and the number of cases of salmonellosis. A study from South Korea reports that climate factors such as increased temperature, relative moisture content, precipitation, UV irradiation and cloudiness were statistically related to hospitalisation due to confirmed infection with salmonella. Significant correlations between increased outdoor temperatures and cases of salmonella have also been described in studies from, among others, Europe (Kovats et al., 2004, Cherrie et al., 2018), Australia (Zhang et al., 2010), the United States and Canada (Fleury et al., 2006, Jiang et al., 2015). Different regression relationships estimate, that for each degree Celsius in temperature increase, there is an increase in relative risk of salmonellosis of 1.2 or 4.1 % (Fleury et al., 2006, Jiang et al., 2015).

However, it is not entirely clear what the reason for the link between salmonellosis cases and the climatic factors is. It may be that increased temperature causes the animals to excrete more salmonella, which increases the likelihood of exposure to the infection (Pangloli et al., 2008, Semenza et al., 2012c) or that increased temperature causes problems at the production stage or in the kitchen, e.g. with storage/storage of food at too high temperature (Semenza et al., 2012c).

In conclusion, the assessment is that the occurrence of salmonella in the environment, and the risk of human exposure and salmonella infection may increase in due to climate change.

Shigella

Foodborne infection — characteristics, sources and routes of transmission

Shigella is an intestinal bacterium that causes shigellosis (bacillary dysentery) and consist of four species; Shigella dysenteriae, S. boydii, S. flexneri and S. sonnei. Man is the only reservoir of importance. The bacterium spreads the faecal-oral pathway through direct contact with infected people, via drinking water contaminated with waste water, or via contaminated food, such as vegetables and fresh spices handled by infected humans or irrigated with contaminated water. Shigella is therefore particularly common in countries with poor sewage and drinking water treatment.

Importance of a changing climate

Several studies from China, Korea, Taiwan and Vietnam, where shigella is endemic, show a positive correlation between shigellosis and climate factors such as increased temperature, humidity and precipitation (Song et al., 2018, Chen et al., 2019, Yi et al., 2019, Lee et al., 2017, Liu et al., 2020). In some of the studies, the incidence of shigellosis has been linked to seasonal variation, whereas other studies indicate that the incidence will increase even after adjustment for seasonal variation (Song et al., 2018). According to a literature review of 58 Chinese studies in the 21st century, the incidence of shigellosis will increase 3.6 to 14.8 percent for each 1 degree Celsius rise (Yi et al., 2019). Several studies in different areas of China have also shown a link between more frequent and more severe floods and the incidence or the burden of the disease of shigellosis (Liu et al., 2017a, Liu et al., 2017b, Zhang et al., 2016, Liu et al., 2016).

Consequently, the occurrence and spread of shigella is considered likely to increase due to direct climate-related changes such as increased temperature and more extreme weather events, or changes such as deficiencies in water treatment or increased use of contaminated water in fruit and vegetable production. The occurrence of shigella in imported food products may also increase.

STEC and other pathogenic E.coli

Foodborne infection — characteristics, sources and routes of transmission

Disease-causing (pathogenic) E. coli has specific properties that enable them to colonise the intestines, produce toxins and other proteins that are important for the ability to cause gastrointestinal infection in humans. There are several types of pathogenic E. coli, the most important of which is shigatoxin-producing E. coli (STEC).

STEC may be naturally present in the intestines of ruminants such as cattle, sheep and goats. Wild animals such as wild boars and birds can be temporary carriers of STEC. STEC O157:H7 has a very good persistence in both water and soil and manure (Hellberg and Chu, 2016, Eriksson, 2010). Food can be contaminated with STEC through direct or indirect contact with faeces from animals or from infected persons. For example, vegetation can be contaminated by fertilisation or irrigation with contaminated water. In Sweden, food-borne outbreaks with STEC have occurred in connection with ingestion of insufficiently heated minced meat, unpasteurised milk, leafy vegetables and drinking water from private wells.

STEC, like other E. coli bacteria, can start growing at about 7-10 °C, with an optimal growth temperature of around 37 °C. STEC survives in acidic environments and can, under optimal conditions, grow at pH 4.4 (Adams and Moss, 2008). The STEC bacteria causing illness in humans are called enterohaemorrhagic E. coli (EHEC).

Importance of a changing climate

Cases of illness caused by STEC have a clear seasonal variation with more cases during the summer months (ECDC, 2021). Most studies report increased occurrence and excretion of STEC in cattle during the summer months (Hellberg and Chu, 2016, Liu et al., 2013). However, factors other than temperature, such as day length and summer grazing, may also affect the relationship and in a few studies no seasonal effect has been observed (Hellberg and Chu, 2016, Liu et al., 2013).

The survival of STEC in soil and manure at different temperatures varies. Some experimental studies have shown lower survival at 4-5 °C compared to 12-15 °C or 21 °C, while others have shown high survival even at the lower temperatures (Hellberg and Chu, 2016). Survival appears to be lower with repeated freezing and thawing of the soil, events that can potentially decrease with a warmer climate, but this is uncertain. Soil survival is likely to decrease during droughts. Among other things, it has been shown in laboratory studies and field trials that the level of STEC decreases with increased salinity or decreased water content in the soil. In water, STEC has been shown to survive better at temperatures of 4-8 °C compared to 21-25 °C (Hellberg and Chu, 2016). The relationship between wind and the spread of STEC is poorly investigated. According to Sargeant et al. (2004), wind is an important factor in spreading STEC in the farm environment, as the presence of STEC O157:H7 in the faeces of cattle on an American livestock farm was positively associated with wind speed.

Hydrological effects can play an important role in spreading STEC and other E. coli to the soil and various water sources for irrigation and consumption (Hellberg and Chu, 2016). Overall, there has been a positive correlation between precipitation and the concentration of E. coli in rivers and estuaries. Several studies have reported an increase in the occurrence of STEC O157:H7 in agricultural run-off or drainage due to extreme weather with larger rainfall. Such weather conditions may also increase the extent to which rainwater and soil splashes and pollute the crop directly if STEC bacteria are present in the soil (Hellberg and Chu, 2016). In addition, climate change in the form of a warmer and drier climate may increase the frequency of irrigation in the long term, thus indirectly offer opportunities for contaminaton of crops with STEC and thus increasing the subsequent risk of infection with STEC via the consumption of such foods (Liu et al., 2013). The presence of STEC in imported food products may also increase.

A study from South Korea has shown a statistical correlation between climate factors such as temperature, relative humidity, precipitation, UV irradiation and cloudiness, and hospitalisation due to infection with STEC O157:H7 (Park et al., 2018a). In a similar study from Canada, there was a significant correlation between increased outdoor temperature and number of confirmed cases of pathogenic E. coli (Fleury et al., 2006). A meta-analysis of published data up to 2010 has shown a significant increase, 8 percent, in the incidence of E. coli-associated diarrhoea for each 1 degree Celsius rise of the average monthly temperature (Philipsborn et al., 2016).

In conclusion, the assessment is that the occurrence of STEC and other pathogenic E. coli may become more frequent as a result of a change in climate.

Staphylococcus aureus

Foodborne infection — characteristics, sources and routes of transmission

Staphylococcus aureus is a bacterium commonly found in the environment, skin or nose in humans and animals. S. aureus has a very good ability to survive under dry conditions, and can grow in foods with low water activity (Hellberg and Chu, 2016). Foods typically associated with food poisoning caused by S. aureus are those handled manually. The bacteria must be able to grow in food in order to form the heat-resistant toxin that causes food poisoning.

Importance of a changing climate

Information in the literature about the influence of a changed climate on S. aureus is very limited. It is mentioned that the bacterium can spread with wind, and that more frequent storms could contribute to increased spread in the outdoor environment (Hellberg and Chu, 2016). A study from South Korea included S. aureus, but did not report any relationship between climatic factors and number of cases admitted to hospitalisation due to the bacterium (Park et al., 2018a). However, outbreaks have occurred during production stops due to power failures, during which the bacterium could multiply (Adams and Moss, 2008). More frequent power failures could thus cause problems with S. aureus in the food chain. If the ability to keep food hot is reduced, the conditions for growth of staphylococci may also be favoured.

Overall, it is uncertain whether the occurrence of S. aureus will increase due to climate change.

Vibrio spp.

Foodborne infection — characteristics, sources and routes of transmission

Vibrio spp. grows optimally in salinity of approximately 1-3 %. The bacteria have an optimal growth temperature of approximately 37 °C, but can grow to about 10 °C (Adams and Moss, 2008). The bacteria are naturally found in warm coastal waters and can occur in fish and shellfish in such waters. Pathogenic species, mainly Vibrio parahaemolyticus but also V. vulnificus and Vibrio cholera, have been reported to cause international outbreaks after consumption of raw or insufficiently heated seafood dishes (Baker-Austin et al., 2017). In the case of V. parahaemolyticus, such outbreaks have largely been caused by a few specific clones that have spread globally (Baker-Austin et al., 2017). V. cholerae (toxigenic types O1 and O139) also cause drinking water-borne infections, cholera, especially in areas with poor sanitary conditions.

Importance of a changing climate

Temperature is the most important external factor for growth of vibrio bacteria. Thus, an elevated sea temperature, in the short or long term, is important for the presence and concentration of vibrio in sea food and water (Baker-Austin et al., 2017, Froelich and Daines, 2020). The second most important factor for the tolerance and growth of the bacterium is salinity. V. cholerae can survive in fresh water, while other vibrio species only occur in brackish and salt water. V. vulnificus is generally more sensitive to salt than V. parahaemolyticus, but has been shown to survive at higher salinity concentrations as the ambient temperature rises. Thus, higher seawater levels with intrusion of saltwater further inland also have an impact on the presence and concentration of vibrio in coastal areas (Froelich and Daines, 2020). Strong winds and storms can lead to intrusion of water further inland than normal. The combination of warmer seas and higher seawater levels increases the occurrence and spread of vibrio bacteria, including to sea waters at northern latitudes. In this way, fish and shellfish in these waters can be more frequently contaminated. The consumption of such products thus entails an increased risk of exposure to and disease of vibriosis (Froelich and Daines, 2020). In Europe and the United States, an increase in vibrio outbreaks associated with sea food has been observed, caused mainly by V. parahaemolyticus but also V. vulnificus (Baker-Austin et al., 2017, Froelich and Daines, 2020). These outbreaks are believed not only to be linked to increased production and consumption of such products, but the effects of a changing climate are also believed to play a role.

According to the US Centre for Disease Prevention and Control (CDC, 2021), infections with vibrio follow a marked seasonal variation. The highest number of cases occur between May and October, but an increasing number of cases also occur during the autumn months. Such increases are likely to be largely due to bathing-associated infections, but also due to a higher proportion of infections associated with the handling or consumption of fish and shellfish in affected areas (Froelich and Daines, 2020). Heat waves in areas at northern latitudes, with temporary temperature increases in coastal surface waters (higher than 18 °C) and increased distribution of vibrio bacteria, may temporarily increase the occurrence of vibrio bacteria (Baker-Austin et al., 2017, Froelich and Daines, 2020). For example, the warm summer in Sweden in 2018 led to a sharp increase in the number of domestic cases of infection with vibrio; 133 cases in 2018 compared to 15 and 21 cases in 2017 and 2016, respectively (Folkhälsomyndigheten, 2021). During the unusually warm summer of 2014, 89 cases were detected in Sweden and Finland, including several cases that had been reported in the vicinity of the Arctic Circle (Baker-Austin et al., 2017). An experimental study of Vezzulli et al. (2016) reported that warmer seawater temperatures had a significant impact on the spread of the bacterium and coincided with an increase in recent years in the number of cases of vibriosis in areas on the North Atlantic coast.

Overall, this suggests that the spread of Vibrio spp. will increase with a warmer climate — warmer seawater temperatures and more heat waves, even at our northern latitudes.

Yersinia spp.

Foodborne infection — characteristics, sources and routes of transmission

Yersinia enterocolitica and Y. pseudotuberculosis are common in the environment and occur naturally in the intestines of, primarily, pigs, sheep, cows and wild animals such as wild boar. Via animal feces, bacteria can contaminate soil and watercourses and thereby also spread to other animals. Porc is the most common source of infection for Y. enterocolitica, but yersinia bacteria can also be found in, for example, unpasteurised milk, untreated drinking water and vegetable irrigated with contaminated water.

Y. enterocolitica may grow over a wide temperature range of -1 °C to 40 °C, with an optimum of approximately 29 °C (Adams and Moss, 2008). Unlike many other bacteria, they can grow also at refrigerator temperatures, which can be a problem in products that are stored for a long time in cold, such as vacuum-packed porc.

Importance of a changing climate

Y. enterocolitica has been reported in international studies to occur more frequently in soil and farm environment in winter and the excretion of the bacterium in pigs has been shown to be highest during the colder part of the year (Hellberg and Chu, 2016). Milder winters with temperatures above freezing point and fewer zero-crossings can potentially favour the presence of yersinia in the environment (Hellberg and Chu, 2016), but this is uncertain. In the United States and other countries, infection with yersinia in humans is most common in the winter months (Hellberg and Chu, 2016, CDC, 2021). In Sweden, yersinia has previously had a clear seasonal variation with the highest number of reported human cases during the summer. However, for the last compiled five-year period, 2014-2018, there was no statistically established difference between the summer months and the rest of the year (Folkhälsomyndigheten, 2021).

Several studies have reported increased occurrence of Y. enterocolitica in agricultural run-off or drainage due to higher rainfall (Hellberg and Chu, 2016). However, a recent South Korean study has shown that the domestic incidence of yersinios did not increase due to any combination of climatic factors studied; precipitation, temperature, relative humidity, UV radiation and cloudiness (Park et al., 2018a). An increased spread of the wild boar population may increase the occurrence of the bacterium in the country. Extreme events affecting the power supply may result in a failure to store food sufficiently cold.

Overall, the incidence of yersinia could potentially become more frequent as a result of a changed climate.

Parasites

Anisakis simplex

Foodborne infection — characteristics, sources and routes of transmission

Anisakis simplex is a nematode parasite found in salty waters and can infect fish. A. simplex is often found in wild-caught sea fish such as herring, mackerel and cod. Humans can be infected by eating raw or insufficiently heated fish containing anisakis larvae.

Importance of a changing climate

Warmer waters may increase the presence of tropical fish species in northern latitudes. There is already an increased occurrence of tropical fish in the North Atlantic, several of which have been shown to carry parasites such as A. simplex (Rodríguez et al., 2019). However, whether climate change will affect the presence of A. simplex in fish in general is uncertain.

Cryptosporidium spp.

Foodborne infection — characteristics, sources and routes of transmission

Cryptosporidium spp. is a protozoa, which may be found in the intestines of infected humans and animals such as cattle, sheep, goats and deer. Infected humans and animals secrete the parasite in their faeces. The parasite has a life cycle in which it undergoes different stages and spreads via oocysts formed in the host during a sporulation phase. Cryptosporidium spp. infects humans mainly via faecally contaminated water or crops irrigated with contaminated water, although infection via direct contact with infected animals and humans may also occur. Cryptosporidium oocysts are durable and have a long survival in the environment (Dumètre et al., 2012). Cryptosporidium is also tolerant to chlorine, which means that they can survive chlorination during drinking water treatment (Young et al., 2014).

Importance of a changing climate

Cryptosporidium spp. has been assessed as sensitive to changes in the environment (Lal et al., 2013, Young et al., 2014). A seasonal variation has been observed for outbreaks of cryptosporidiosis, with more outbreaks in the summer months (Young et al., 2014). An increased temperature can prolong the season for optimal distribution of oocysts but can also reduce survival in the environment (Pozio, 2020). Increased precipitation and flooding have been shown in several studies to increase the likelihood of cryptosporidium to contaminate surface waters (Lal et al., 2013, Pozio, 2020, Young et al., 2014). A meta-analysis of published data up to 2013 has shown that the probability of detecting cryptosporidium oocytes in freshwater increases by 2.6 times during and after extreme precipitation (Young et al., 2014). The same study also showed that the levels of cryptosporidium in freshwater increased after extreme weather events (Young et al., 2014). The reason for this may be increased run-off from contaminated soil surfaces or overflow of waste water. As a result, extreme weather events can lead to increased contamination of cryptosporidium in drinking water sources or water used for crop irrigation.

Overall, the assessment is that the spread of cryptosporidium can increase in a changing climate.

Cyclospora cayetanensis

Foodborne infection — characteristics, sources and routes of transmission

Cyclospora cayetanensis is a protozoan parasite, most common in tropical and subtropical countries. C. cayetanensis can infect humans via the consumption of food, mainly vegetable, or drinking water contaminated with sporulated oocysts (Almeria et al., 2019). However, much remains uncertain about the life cycle of the parasite, what induces sporulation, survival in the environment and the importance of various routes of infection (Almeria et al., 2019).

Importance of a changing climate

The incidence of C. cayetanensis infection is seasonal. In some countries (Mexico, China, Guatemala, Honduras, etc.) there has been an increase in cases during warm seasons due to high rainfall, while in others (Peru and Turkey) the increase has been observed during the dry and cooler seasons (Almeria et al., 2019).

Climate change can promote the eatablishment or increased occurrence of parasites that are common in warmer countries, such as C. cayetanensis, in today’s temperate areas (Pozio, 2020). The presence in imported products may also increase.

Echinococcus multilocularis

Foodborne infection — characteristics, sources and routes of transmission

Echinococcus multilocularis are tape worms that have foxes as the main hosts and small rodents as intermediate hosts. Raccoon dog can also serve as the main host for E. multilocularis. Parasitic eggs are spread to the environment via feces from main hosts. Humans may be exposed to eggs excreted in faeces through various routes of infection, such as direct contact with foxes, dogs and their faeces or via unheated food and water. Infection with E. multilocularis can cause the disease alveolar echinococcos (AE) in humans, which is a severe chronic disease that requires lifelong treatment. The optimal temperature for survival of eggs in the environment has been shown to be between -18 to 4 °C (Atkinson et al., 2013).

Importance of a changing climate

A changing climate may affect the spread of E. multilocularis both by affecting parasites' eggs in the environment and by affecting the main and intermediate hosts. However, there are no causal links between individual climatic factors and AE in humans (Atkinson et al., 2013). A complicating factor is the long incubation period of the disease. The survival of parasitic eggs may be adversely affected by higher temperatures and longer dry periods, while increased moisture levels may have a positive impact on survival (Pozio, 2020). Heavy rain and flooding can contribute to an increased spread of eggs from contaminated soils to water, which could contaminate sources of drinking water (Atkinson et al., 2013). The climate may also influence the occurrence of main and intermediate hosts, which in turn may affect the occurrence and spread of E. multilocularis. For example, an increased density of small rodents has been shown to be related to humane cases of AE (Atkinson et al., 2013). Studies have shown that if there are plenty of small rodents that foxes can eat, the secretion of parasitic eggs increases in the environment (Atkinson et al., 2013). If this occurs close to populated areas, the risk of human infection increases. The spread of E. multilocularis is also affected by the spread of alternative main hosts such as the raccoon dog, a species which is predicted to benefit from climate change (Atkinson et al., 2013).

In conclusion, there is much uncertainty about the impact of climate change on E. multilocularis.

Entamoeba histolytica

Foodborne infection — characteristics, sources and routes of transmission

Entamoeba histolytica are intestinal protozoan parasites. The parasite occurs worldwide but is most common in countries with poor sanitary access. Humans are mainly infected via the consumption of drinking water contaminated with parasite cysts or vegetables irrigated with contaminated water. Outbreaks in Sweden have occurred via drinking water contaminated with waste water.

Importance of a changing climate

There is little evidence in the literature on the impact of climate change on E. histolytica. It is conceivable that events that increase the risk of sewage intrusion into the drinking water distribution systen, such as extreme precipitation events, may also increase the likelihood of the spread of parasitic diseases including E. histolytica (Pozio, 2020).

Fasciola hepatica

Foodborne infection — characteristics, sources and routes of transmission

Fasciola hepatica (liver fluke) are parasitic flatworms of the class Trematod that mainly infect sheep and cattle. Infected animals excrete eggs via faeces, and the life cycle is completed in fresh water in freshwater snail (Galba truncatula, formerly known as Lymnaea truncatula) and aquatic plants such as water cress. Humans can be infected by consumption of watercress containing the parasite. Both the egg stage of F. hepatica and the freshwater snail (Galba truncatula) that act as intermediate host require a temperature of 10-25 °C and a humid environment to be able to develop (Fox et al., 2011).

Importance of a changing climate

Both the egg stage of F. hepatica and the intermediate G. truncatula are sensitive to climatic factors (Fox et al., 2011). In terms of temperature, 10-25 °C is required to enable the development of parasite eggs and the intermediate host (G. truncatula). Both parasitic eggs and intermediate host are susceptible to dehydration. With warmer and humid winters, the survival of the parasite can increase and therefore also the risk of infection (Fox et al., 2011). Studies from the UK and New Zealand have, through modelling, predicted that infection with F. hepatica will increase with climate change (Fox et al., 2011, Haydock et al., 2016).

In conclusion, the assessment is that F. hepatica may increase in Sweden due to a changed climate.

Giardia intestinalis

Foodborne infection — characteristics, sources and routes of transmission

Giardia intestinalis are protozoan parasites, which can be found in the intestines of humans and animals. Infected humans and animals excrete the parasite in their faeces. Giardia has a life cycle consisting of two forms, i.e. as cyst and trophozoite. It’s the cysts that are transmitted from one host to another. When the cysts infect the intestines of a new host, they develop into trophozoites, which in turn can multiply and form new cysts. Giardia’s cysts are durable and have a long survival in the environment (Dumètre et al., 2012). Giardia infects humans mainly via faecally contaminated water or crops irrigated with contaminated water. Infection via direct contact with infected animals and humans may also occur. Giardia is also tolerant to chlorine, which means that they can survive chlorination during drinking water treatment (Young et al., 2014).

Importance of a changing climate

There is a seasonal variation in giardia outbreaks, with increased frequency during warmer months (Lal et al., 2013). An increased temperature can prolong the season for optimal distribution of oocysts, but can also reduce survival in the environment (Pozio, 2020). Increased rainfall and flooding have been shown in several studies to increase the likelihood of giardia contaminating surface waters (Lal et al., 2013, Pozio, 2020, Young et al., 2014). A meta-analysis of published data up to 2013 has shown that the probability of detecting giardia cysts in freshwater increases by 2.9 times during and after extreme precipitation (Young et al., 2014). The same study also showed that the level of giardia in fresh waters increased following extreme weather events (Young et al., 2014). The reason for this may be increased run-off from contaminated soil surfaces or deu to temporary discharges of waste water.

As a result, extreme weather events can lead to increased giardia contamination of drinking water sources or water used for crop irrigation.

Overall, the assessment is that the spread of Giardia intestinalis may increase in a changing climate.

Taenia saginata

Foodborne infection — characteristics, sources and routes of transmission

Taenia is a bandworm parasite. The species T. saginata has bovine animals as intermediate host. Cattle can be infected by taenia eggs if they graze on pastures (or fodder) contaminated with human faeces. Parasite eggs develop into larvae (dynt) in the cattle's gastrointestinal tract and then migrate and form cysts in the organs and muscle tissue. The most common route of infection is when humans consume raw or insufficiently heated beef containing infectious cysts.

Importance of a changing climate

An increase in the number of extreme events leading to the flooding of grazing land by sewage contaminated water may lead to an increase in cattle exposure to T. saginata parasitic eggs (Pozio, 2020).

Trichinella

Foodborne infection — characteristics, sources and routes of transmission

Trichinellas are nematodes, which can infect several species of mammals including humans. The route of infection for humans is the consumption of insufficiently heated meat containing Trichinella larvae. There are several species of Trichinella and in Sweden Trichinella is detected mainly in wild animals, such as wild boar, bear and seal.

Importance of a changing climate

Climate change can lead to an increase in occurrence or the establishment of parasites in new areas by affecting species that are host or intermediate host to the parasite. However, there is little information about the impact of climate change on Trichinella specifically. There is a study linking an increased incidence of Trichinella infections in parts of Europe, after consumption of wild boar meat, with milder winters and an increased wild boar population (Pozio, 2020).

How the occurrence of Trichinella in Sweden will be affected by climate change is uncertain.

Toxoplasma gondii

Foodborne infection — characteristics, sources and routes of transmission

Toxoplasma gondii are protozoan parasites, which are common throughout the world and have cats as the main host. Through cats faeces, large amounts of oocysts of toxoplasma can spread to the environment where they sporulate, which occurs after 1-5 days under favourable conditions, and may infect other animals (Meerburg and Kijlstra, 2009). Humans can be infected by the consumption of tissue cysts in insufficiently heated meat from infected animals or by food contaminated with oocysts from e.g contaminated water (Meerburg and Kijlstra, 2009, Tenter et al., 2000). Sporulated oocysts of toxoplasma are durable and can survive for a long time in the environment (Tenter et al., 2000).

Importance of a changing climate

Climate factors have a major impact on how well oocysts survive in the environment (Meerburg and Kijlstra, 2009). The occurrence of T. gondii is higher in warm, humid areas and lower in hot, dry and very cold areas (Meerburg and Kijlstra, 2009). Moisture seems to increase the tolerance of oocysts to heat (Afonso et al., 2006). It has also been shown that the seroprevalence of T. gondii is higher in people in warmer countries (France) compared to colder countries (Denmark, UK) (Tenter et al., 2000). Milder winters could help to increase the survival of oocysts in the environment and thus contribute to increased human infection via contaminated food (Meerburg and Kijlstra, 2009). If the amount of oocysts increases in the environment, it also increases the likelihood of spreading to watercourses in the event of extreme rainfall and run-off. Contamination of drinking water following extreme weather events has been noted from Canada, among others (Meerburg and Kijlstra, 2009). Changes in the ecology of the host and intermediate host animals, such as increasing numbers of small rodents, may also affect the occurrence of toxoplasma (Meerburg and Kijlstra, 2009).

In conclusion, the assessment is that climate change may increase the incidence of T. gondii in Sweden.

Virus

Norovirus

Foodborne infection — characteristics, sources and routes of transmission

There is evidence that extreme weather such as extreme rainfall and floodings affect the spread of norovirus to raw water and food in primary production the most, but also survival is affected (Mohammed and Seidu, 2019, Smith and Fazil, 2019). Increased air temperature generally reduces the survival of norovirus (Sterk et al., 2013). There are reports from outbreaks that support the importance of heavy rain and flooding as the cause of norovirus cases both via oysters, and via drinking water (Hassard et al., 2017, Sterk et al., 2013), including contamination also via groundwater sources (Andrade et al., 2018). Many times norovirus can not be detected in a food or drinking water due, among other things, to methodological limitations and the fact that norovirus cannot be cultivated. This means that much of the knowledge about norovirus is based on studies of other culturable viruses, so-called surrogate viruses. Norovirus, like sapovirus, belongs to the human calicivirus group. Sapovirus is also spread via the faecal-oral pathway and transmission is commonly person to person, but sometimes sapovirus is transmitted also through contaminated food and drinking water. However, outbreaks appear to occur less frequently than for norovirus (Oka et al., 2015).

There is a clear seasonal variation of norovirus infections but it is rather poorly understood. Seasonality is assumed to reflect biological and environmental factors affecting the spread, virulence and survival of the virus in the host populations (Rohayem, 2009). Most cases of norovirus occur in the period October to April, peaking in February and March. Food-borne outbreaks in Sweden were reported to a greater extent between December and May according to a summary of reported food poisonings for the years 2008-2018, but outbreaks were also reported in summertime (Livsmedelsverket, 2020). One complication is that non-food and drinking water transmission routes are at least as important and may have different seasonality. Rohayem (Rohayem, 2009) proposes a hypothetical scenario in which norovirus remains in a population during the summertime via transmission of high doses of virus in the environment up to 4 weeks after disease (sometimes asymptomatic) and that changes in surface structures in a similar way as for influenza viruses allow a new cycle to start the next season. This happens when the environmental factors change, with lower temperatures and perhaps higher humidity that affects dispersion (via aerosols - vomiting), but perhaps also changes in survival and virulence. In addition, there are also changes in human behaviour - proposed closed spaces indoors, but this is hypothetical. Climate change can also indirectly affect norovirus infections through, for example, the impact on migration with dense populations of people allowing the start of epidemics and emergence of new strains. Periods that promote the spread and emergence of viruses may amplify possible direct effects of climate change in terms of the occurrence and number of cases of norovirus.

Importance of a changing climate

An understanding of how climate factors affect the seasonality of norovirus is important to understand if and how climate change can affect disease caused by norovirus. The effect may also be different for different routes of infection. A few studies (Semenza et al., 2012a, Semenza et al., 2012b) highlighted a lack of information about the relationship between climate variables and important pathogens, including noroviruses. Among the studies available, the association with norovirus and climatic factors was relatively weak while it was stronger associated with food determinants such as different types of foods (Semenza et al., 2012a). Norovirus infections occur both in the northern and southern hemispheres and in the equatorial region, but the winter peaks in Europe and North America are not reflected in the Southern Hemisphere, which in Australia occurs in December (Semenza et al., 2012b). This suggests that climate contributes but is not the main factor, only one of several factors impacting on the number of cases of norovirus. Thus, the relationship between climate factors and norovirus is not strong, partly due to lack of data, but norovirus has been associated (positively or negatively) with temperature, precipitation patterns, extreme precipitation, seasonal variation, floods, outdoor activities, shellfish production, and consumption habits.

Overall, the assessment is that the importance of norovirus can increase due to increased opportunities for transmission due to both direct climate impacts and indirect effects of climate change despite the fact that increased temperature is associated with lower survival.

Hepatitis A virus (HAV)

Foodborne infection — characteristics, sources and routes of transmission

Hepatitis A is a contagious disease caused by a virus, HAV, which globally is spread mainly via the faecal-oral route, e.g. effluent-influenced water. In principle, the disease affects only humans and is widespread in countries with poor drinking water hygiene, but can also be transmitted from person to person or via faecally affected water and food, such as oysters, bivalve molluscs, strawberries. The incubation period is long, two to six weeks, on average four weeks, and a person is contagious seven to ten days before the symptoms manifests. About 100 cases are reported annually in Sweden, of which just under half have been infected in Sweden (Folkhälsomyndigheten, 2021). There are vaccines for hepatitis A.

HAV infections occur throughout the year but some periods appear to be associated with higher incidences in most countries (Fares, 2015). The reasons for this are not entirely clear, but both climate and behavioural factors such as hot holidays, bathing habits, sexual contacts, tattooing, poor hygienic and sanitary conditions and eating habits can play a role. HAV is a highly resistant virus in the environment but there are studies that indicate that survival of HAV is increased at reduced temperatures and sunlight (Rose et al., 2001), and that mutation rates increase at higher temperatures and carbon dioxide levels (Tarek et al., 2019).

An overview of published studies show some dominance of cases during spring-summer in most countries, but there is no clear trend between countries and it may vary between different studies even within the same country (Fares, 2015). Again, this may reflect the different routes of infection where, for example, spreading via oysters may reflect eating habits in one country but not another.

Importance of a changing climate

A Spanish study showed that extreme precipitation (>90 percentile in Spain) was associated with more than 20 % increase in HAV risk two weeks later (incubation time), and each extra day of precipitation increased the risk by an additional 3 % (Gullón et al., 2017). In the same study, an increase in risk was found two weeks after each extra storm day, defined as a day of thunderstorms.

Overall, there is little data on climate change and HAV infections, but food-borne HAV is estimated to be able to increase in importance as a result of climate change.

Hepatitis E virus (HEV)

Foodborne infection — characteristics, sources and routes of transmission

HEV is spread via food and water and can cause hepatitis E, which is an inflammation of the liver. There are four genotypes of HEV that infect humans: genotypes 1-4. HEV-1-2 only infects between humans, while HEV-3-4 is zoonotic, i.e. also between animals and humans. The genotype that dominates in Sweden and Europe is HEV-3. HEV-1-2 is found in Africa, Asia and Mexico. HEV-4 occurrs in Japan and China. Almost all hepatitis cases in Europe are caused by HEV-3. Most people do not get ill even if they are infected with HEV-3, but people in special risk groups may experience hepatitis. These people have either liver disease, suffer from alcohol abuse or have severely impaired immune systems, such as organ transplants treated with stem cells and blood cancer patients during treatment. Domestic pigs and wild boars are the main sources of HEV-3. In Europe, pig products, such as sausages, are therefore the most important route of transmission for HEV-3 in humans. In particular, HEV-3 can be found in non-heat-treated products such as cold smoked, fermented or air-dried sausages containing livers of domestic pigs or wild boars. Also non-heat-treated sausages but without liver as an ingredient may contain the virus, but the risk is lower. In countries where HEV-1 is present, pregnant women are at risk of severe liver failure if they are infected. However, the risk for pregnant women to be infected with HEV-1 in Sweden is considered negligible (Livsmedelsverket, 2019b).

Importance of a changing climate

Very little has been published about HEV specifically related to climate change, and most of the overview articles recognise its importance from the perspective of an emerging risk (van der Poel, 2014, Denner, 2019). One scenario that is already factual is that wild boar is becoming more common, in part because milder winters with less snow benefit them (Fredriksson-Ahomaa, 2019). Wild boars are reservoirs for several human pathogens among others HEV, with a reported seroprevalence of 8 % in the wild boar population (Wang et al., 2019). Human seroprevalence was reported in a study among

Swedish blood donors to be 16 % (Norder et al., 2016). The effects of climate change in Sweden will probably depend on how the prevalence of HEV changes in domestic pigs but especially in the wild boar population as it increases.

Overall, it is considered possible that the prevalence of HEV type 3 in wild boar may increase as a result of climate change, but this is uncertain. Climate change is considered less likely to cause such major changes in the types of HEV, or to such severe deterioration or disturbance in water and sewage treatment, so that the waterborne spread of HEV-1 could become a threat.

Other viruses

Other viruses that have been identified as causes of food and drinking water-borne infection include enteroviruses (polio, soon eradicated, Coxsackie virus), sapovirus, rotavirus, astrovirus, and adenovirus (Bosch et al., 2018). In addition to HEV, Nipah virus has been reported to spread via contaminated pig meat in an outbreak with high mortality due to encephalitis in Malaysia. Another example that may be relevant from a climate point of view is the spread of TBE virus via unpasteurised milk and cheese made from milk from infected animals (Balogh et al., 2010, Paulsen et al., 2019). It is still unclear how important this route of transmission is, but it is interesting given the increased spread of TBE virus in Sweden.

Overall, there is a lack of data in order to make an informed assessment for the other viruses, but in addition to TBE virus spread via unpasteurised dairy products, the spread can be expected to increase by viruses transmitted via a faecal-oral pathway, regardless of whether it takes place via waste water or via food.

Mycotoxins

Aflatoxins

Foodborne infection — characteristics, sources and routes of transmission

Aflatoxins are a group of mycotoxins produced by several species within the genus Aspergillus, the most important being A. flavus and A. parasiticus. The majority of species producing aflatoxin are included in the so-called ‘storage flora’ which grow in food stored at improper conditions. The exception is A. flavus, which also occurs as field flora and infects and forms toxin in crops pre-harvest (Medina et al., 2017b, Moretti et al., 2019). There are four forms of aflatoxin: B1, B2 G1 and G2. A fifth form, aflatoxin M1, is a metabolite of B1 and is present in milk from cows fed with contaminated feed (van der Fels-Klerx et al., 2016).

The main sources of exposure to aflatoxin are, for example, maize, nuts, peanuts, but they may also be present in wheat, rice, buckwheat, dried fruit (van der Fels-Klerx et al., 2016, FAO, 2020). In Europe, aflatoxin has mainly been a problem in products imported from tropical and subtropical regions where the climate is warm enough to support the growth of A. flavus and A. parasiticus.

Optimal conditions for the growth of A. flavus and A. parasiticus are 35°C and water activity of 0.99, however, growth can take place down to a_w 0.81 at 30-37°C. For aflatoxin formation, 33°C and a_w 0.95 are optimal (Sanchis and Magan, 2004).

Importance of a changing climate

In the field, the presence of A. flavus and thus aflatoxin contamination increases in hot and dry conditions. This species is tolerant to drought and the resisteance of some crops, such as maize, is reduced during dry conditions and they are thus more easily infected (Moretti et al., 2019, van der Fels-Klerx et al., 2016).

Increasing temperatures have already contributed to problems with aflatoxins during certain years in southern Europe. In 2003 and 2004, very high temperatures and droughts in Italy resulted in a reduction of the commonly occurring F. verticillilliodies linked to contamination of feed maize with fumonisins, which was replaced by A. flavus producing aflatoxin B1. Subsequently, problems with aflatoxin M1 in milk and cheese production were also noted. Similar weather conditions in the Balkans in 2013 had the same effect with the occurrence of aflatoxins in maize. In Italy, the problems in the northern parts of the country returned in 2015 when the summer was also unusually warm and dry (FAO, 2020, Medina et al., 2017b, van der Fels-Klerx et al., 2016)

Battilani et al. (2016) has modelled the future occurrence of aflatoxin B1 in maize and wheat grown in Europe related to field contamination. IPPC scenarios for +2 and +5°C were used for weather data such as minimum and maximum temperature, precipitation and solar radiation. Together with an estimate of the phenology of the crop (growth phase, flowering, ripening) these data were the basis for a risk index for different zones in Europe.

The results showed that, under the current climate, there is a risk of aflatoxin formation in maize in the Mediterranean and Balkan countries, but the risk of exceedances of the EU maximum level value (5 μg aflatoxin B1 per kg of unprocessed maize) is relatively low (Battilani et al., 2016). In the +2°C scenario, the geographical region at risk of aflatoxin was not extended, but predicted concentrations are significantly higher than today. In large parts of southern and south-eastern Europe, levels are predicted to exceed the maximum level values even in years of relatively lower occurence. In the +5°C scenario, the geographical zone for maize cultivation is significantly extended (up to 60th latitude, central Sweden). However, the concentrations were generally predicted to be lower than in the +2°C scenario because the climate in several zones would be unfavourable to A. flavus. In all scenarios, the highest predicted concetrations of aflatoxin were found in maize in the Mediterranean countries and the Balkans.

The risk of aflatoxin formation in wheat was predicted to increase in both the +2°C and +5°C scenarios, especially in Italy, Eastern Europe and the Baltic Sea (Sweden, Finland and Baltic) zones. However, the models did not show a risk of high concentrations in any scenario and the authors conclude that the risk in wheat can be considered negligible (Battilani et al., 2016).

Post-harvest aflatoxin formation occurs when crops and foodstuffs are stored at too high water content while temperatures are high enough to support the growth and production of toxins of aflatoxin-forming strains (Cotty and Jaime-Garcia, 2007). Rain, irrigation or humid weather in close proximity to harvest or during drying (if carried out by non-active methods, e.g. wind drying in the field) has been shown to correlate with increased aflatoxin levels in e.g. cotton seed.

In conclusion, data clearly suggest that warmer and drier weather in southern Europe will result in higher aflatoxin concetrations in particular in maize. A warmer, drier and/or more variable climate in regions outside Europe is likely to mean that a wider spectrum of imported products than those traditionally considered to pose a risk, may contain aflatoxins, both as a result of toxin formation in the field and during storage.

Ergot alkaloids

Foodborne infection — characteristics, sources and routes of transmission

Ergot alkaloids are a group of mycotoxins formed primarily by species in the genus Claviceps, of which Claviceps purpurea is the most important (Coufal-Majewski et al., 2016, Tittlemier et al., 2015). C. purpurea infects monocotyledons including grasses, and the toxins occur in cereals and cereal products. The most common alkaloids formed by ergot in cereals are ergotamine, ergocristine, ergosine, ergocornine and ergocryptine. Ergot alkaloids occurrence in rye is the main problem, but they also occur in wheat, barley and oats. C. purpurea can infect the host plant via airborne spores (ascospores) during flowering and rye, unlike other cereal crops, is cross-pollinated with large open flowers making this crop more susceptible to infection. After infection, the fungus grows in the flower and forms both a sticky sweet liquid, containing spores (so-called conidia) that are further spread by insects, and also resting stages, known as sclerotia or ergot (Coufal-Majewski et al., 2016, Debegnach et al., 2019). This is a type of survival structure that can spread the fungus further with new airborne spores and contaminate cereals with ergor alkaloids as these are produced in the sclerotium structure. The formation of sclerotia takes about 4-8 weeks after infection and optimal conditions are cool and humid weather, about 18-20 °C. Studies have shown that at temperatures above 25 °C the formation of sclerotia, and thus the spread of infection, takes longer.

Importance of a changing climate

Problems with ergot alkaloids in cereals have increased in recent years in some countries, such as Canada and the United Kingdom (Menzies and Turkington, 2015, Tittlemier et al., 2015, Tittlemier et al., 2019). Changes in agronomic practices such as ploughing-free cultivation and the establishment of crop-free edge zones are assumed to be largely responsible for increasing prevalence. Wild grasses and non-ploughed crop residues serve as a source of ergot infection (Tittlemier et al., 2015, Tittlemier et al., 2019, Orlando et al., 2017). However, data suggest that changes in climate also affect the occurrence of ergot alkaloids. Cool and humid weather is beneficial for the occurrence of ergot because it promotes the formation of sclerotia and the release of ascospores, and partly prolongs the flowering phase of the host plants during which infection can occur. These weather conditions have been associated with increased levels of ergot alkaloids in Canadian wheat. Increased occurrence of insects with climate change can potentially contribute to increasing problems with ergot in the future as insects are one of the routes of transmission (Paterson and Lima, 2010, Coufal-Majewski et al., 2016).

Overall, it is estimated that problems with ergot alkaloids may increase in the future due to increased rainfall mainly during spring and an increased occurrence of insects. However, the formation of ergot alkaloids benefits from cool weather, which makes the assessment more uncertain.

Fumonisins

Foodborne infection — characteristics, sources and routes of transmission

Fumonisins (FB) are a large group of mycotoxins, the most important in foods being FB1, FB2 and FB3. FB-producing species are mainly Fusarium verticillioides and F. proliferatum and closely related species, but also of some Aspergillus species within the group nigiri can produce fumonisins. Fusarium grows and produces toxin mainly in the field. Maize and maize products are the main sources and FB-producing species are found everywhere where maize is grown. Other sources include rice, wheat, oats and millet. In foods such as grapes, coffee and peanuts Aspergillus species are more common FB-producers. Modified forms of fumonisins have been identified in, among others, maize, but their relevance is still relatively unknown. (Dall'Asta and Battilani, 2016, Kamle et al., 2019, Paterson et al., 2014)

Optimal conditions for fumonisin production for F. verticillioides and F. proliferatum are 25-30 °C and a water activity of about 0.93-0.95 (Dall'Asta and Battilani, 2016, Magan et al., 2011, Ksenija, 2018). Due to similarities in favourable growth requirements for fumonisin and aflatoxin-producing species, these mycotoxins often occur together (FAO, 2020, Marroquín-Cardona et al., 2014). This is particularly a problem in maize.

Importance of a changing climate

Fumonisins are currently common in temperate-tropical climate zones, e.g. in Africa, Asia and the Mediterranean region (Perrone et al., 2020). The two main factors that control mould growth and the production of fumonisins are temperature and water activity. It has been shown that high temperature (max 30-35°C) and drought during the flowering phase in maize favor infection and growth of the fungus. During later stages of cultivation and before harvesting, heavy rainfall and heat have been shown to benefit toxin production (Cendoya et al., 2018, Kamle et al., 2019, Marroquín-Cardona et al., 2014). Increased CO_2 concentrations have been shown to increase the sensitivity of maize to F. verticillioides infection, however no effect on fumonisin concentrations was observed (Medina et al., 2017b). Experiments with co-cultivation of A. flavus and F. verticillioides show that the competitive situation can induce a higher production of mycotoxin and that the effect is amplified under climatic conditions that stress the fungus (Camardo Leggieri et al., 2019). Studies show that the previous infection of F. graminearum benefits later infection with F. verticillioides. A shift in the composition of Fusarium species towards more F. graminearum could thus also have an effect on FB-producing species. Insect infestations with damaged corn kernels are another aspect that favours infection and FB formation (Dall'Asta and Battilani, 2016)(Kamle et al., 2019, Parikka et al., 2012)

In conclusion, it is likely that problems with fumonisins will increase in Sweden as our climate will be more similar to that prevailing in the Mediterranean regions and especially, if this leads to increased cultivation of maize.

Ochratoxin A

Foodborne infection — characteristics, sources and routes of transmission

Ochratoxins are a group of closely related toxins where ochratoxin A (OTA) is the most common and relevant (van der Fels-Klerx et al., 2016).

OTA is produced by some distinct groups within the genera Aspergillus and Penicillium: A. ochraceus and related species are xerophilic and often occur in dried products; black Aspergillus (A. carbonarius and A. niger, among others) are present in many types of foods and are common in fresh vegetables, especially grapes; P. verrucosum and P. nordicum occur in cool conditions, e.g. during the storage of cereals in the Nordic climate (Pitt et al., 2013).

Conditions that support the growth and production of OTA vary depending on the species involved but also between different strains and depending on the product on which the mould grows. In many cases the OTA concentrations increase with time, which means that high concentrations can be present in stored food even if they are not kept at optimal conditions for toxin production. The following are examples of growth requirements for OTA producing species (Paterson and Lima, 2010, Sanchis and Magan, 2004):

- A. ochraceus
  Optimal growth: 25-30°C and a_w 0.97, may grow down to a_w 0,80
  Optimal OTA production: 25-30°C and a_w 0,98
- A. carbonarius
  Optimal growth: 30-35°C and a_w 0.93-0.99, resistant to UV radiation
  Optimal OTA production: 15-20°C and a_w 0,85-90
- P. verrucosum
  Optimal growth: 15-25°C, possible between 0-35°C
  Optimal OTA production: 25°C and a_w 0,90-0.95. Toxin production can take place down to 5°C and a_w 0.83

Due to the variety of ecological niches, OTA is found in many different types of food (Malir et al., 2016, Ostry et al., 2013). For example, in vegetable foods, OTA occurs in wine, raisins, onions, maize, cereals, coffee, chocolate, many types of spices, liquorice, olives, beans, nuts, seeds, etc. In livestock, OTA occurs partly as a consequence of mould growth (P. nordicum) during maturation and ageing, in particular in hard cheese and pig meat products, and partly when animals are fed with OTA-contaminated feed. The highest concetrations are found in blood, and organs such as kidney and liver.

Importance of a changing climate

The many toxin producing species and widely varying conditions under which OTA can be produced mean that climate change can have varying effects on occurrence (Medina et al., 2017a).

For most Aspergillus species, overall growth rates and OTA production seem to remain unchanged or possibly be reduced due to climate change (Akbar et al., 2016, Perrone et al., 2020). However, in vitro studies on coffee beans and medium based on coffee and grapes have shown that A. westerdijkiae and A. carbonarius, produce more OTA at elevated concentrations of carbon dioxide. However, for several other Aspergillus species this effect was absent (Akbar et al., 2016, Cervini et al., 2019). Under certain conditions, drought and heat stress may lead to increased OTA production, e.g. for A. carbonarius and P. nordicum, while the same conditions may reduce toxin production in other species such as A. westerdijkiae and P. verrocosum (Magan et al., 2011, Medina et al., 2017a).

OTA levels in wine are often higher in products produced in the southern parts of Europe compared to wine from the northern regions (Paterson et al., 2018). As climate changes, these patterns may change. Some predictive studies have shown that in southern Europe, climate change will lead to an increase in A. flavus at the expense of A. carbonarius, resulting in a shift from OTA to aflatoxin (Perrone et al., 2020). In cereals, increased presence of insects during storage may create problems with moisture pockets, which increases the risk of OTA formation (Magan et al., 2011). More variable weather in connection with higher harves yieldsincreases the risk of high moisture levels in the cereals, which is also a risk factor for OTA formation.

Overall, several factors suggest that the incidence of OTA may increase due to climate change but the state of knowledge is uncertain. Impacts are likely to vary in different regions and for different foods. There is more data on OTA producing Aspergillus species than Penicillium, where there is a lack of data.

Patulin

Foodborne infection — characteristics, sources and routes of transmission

Patulin is formed by several species of the genus Penicillium, Byssochlamys and Aspergillus, which are found in fruit, berries (e.g. blueberries) and vegetables. The main producer, Penicillium expansum, is most common in apples and related fruits (Baert et al., 2007, Saleh and Goktepe, 2019).

Infection with P. expansum occurs most often when the apple has mechanical damage, e.g. by insects or during harvest and handling. The mould causes so-called blue mould rot. Patulin can also be formed in seemingly undamaged fruit when infection occurred during flowering (Zhong et al., 2018). The main source of exposure to patulin via food is processed apple products, such as apple juice (Saleh and Goktepe, 2019, Zhong et al., 2018). Fruit of poorer quality is often used for products and that patulin is water soluble and heat-stable and therefore remains in the products.

Growth and patulin production of P. expansum is highly influenced by external factors, especially temperature and water activity. The species is psycrotrophic and can grow down to about -2°C, however, the optimal growth temperature is about 20-25°C. The optimum temperature for toxin production varies between strains and depending, for example, on modified atmosphere, 4-20°C is mentioned in the literature (Baert et al., 2007, Medina et al., 2017a, Paterson and Lima, 2011). Optimal water activity for both growth and toxin production is 0.99 (Medina et al., 2017a).

Importance of a changing climate

There are suggestions that a warmer climate can help reduce patulin problems as conditions become too hot for P. expansum (Paterson and Lima, 2010). However, P. expansum and patulin today occur globally, even in countries with much warmer climates than in Sweden (Zhong et al., 2018). It is therefore uncertain whether this effect will have any significance. Heavy rain and insect infestations, which are likely to increase with climate change, have been shown to increase the production of patulin (Saleh and Goktepe, 2019, Zhong et al., 2018).

Overall, it is uncertain how climate change will affect the occurence of patulin.

Trichothecenes

Foodborne infection — characteristics, sources and routes of transmission

Trichotecenes are a large group of mycotoxins formed by species within the genus Fusarium, which can be divided into four groups, A-D. Types A and B are the most relevant in food. Trichothecenes occurs in many types of cereals, in Sweden, mainly T2 and HT2 (type A) and deoxynivalenol (DON) and nivalenol (NIV) (both type B) are common (Fredlund and Lindblad, 2014).

The species of Fusarium that form trichothecenes cause a plant disease called fusarium head blight in cereals which, in addition to the formation of mycotoxins, contributes to small, discoloured grain kernels and reduced yields. Fusarium head blight is often caused by several species at the same time, which makes the co-occurence of several fusarium toxins common (Fredlund and Lindblad, 2014).

T2 and HT2

T2 and HT2 toxin are formed by F. poae, F. sporotrichioides and F. langsethiae and others species. In Sweden, F. langsethiae is the most important toxin producer (Medina and Magan, 2011, Fredlund and Lindblad, 2014). T2 is rapidly metabolised to HT2 in vivo, which means that this form is often more common. The toxicity of the two substances cannot be differentiated, which means that T2 and HT2 are usually studied together (Medina and Magan, 2011)

T2 and HT2 are present in several types of cereals. In Sweden, the presence in oats is the most common and to a lesser extent in wheat (Fredlund and Lindblad, 2014)

Optimal conditions for the T2 and HT2 production of F. langsethiae are about 20-30 °C and a_w 0.98-0.995. However, T2 and HT2 production can take place under a wide range of temperatures (down to about 10 °C), while water activity is a significantly more limiting factor. Experimental studies have shown that Swedish strains of F. langsethiae had a narrower toxin production window than strains from other geographical areas. The Swedish strains showed virtually no production of T2 or HT2 at aw 0.95, while strains from England, Finland and Norway continued to produce toxin down to a_w 0.93 (Medina and Magan, 2011).

DON

DON is formed by F. graminearum, F. culmorum, F. sporotrichioides, F. roseum and others species. Previously, F. culmorum was the most important DON producing species in Sweden, but F. graminearum has become more common (since about 2010's) and is now the most important producer. DON occurs in cereals such as wheat, barley, oats, rye and maize. Oats and wheat are the crops in which DON poses the greatest problems in Sweden and DON is the Fusarium toxin that is most common in Swedish cereals (Fredlund and Lindblad, 2014, Parikka et al., 2012).

Optimal conditions for toxin production in F. culmorum and F. graminearum are approximately 25 °C and a_w 0.97-0.99 (Ksenija, 2018). Both high temperatures and high rainfall during the flowering phase of the cereals favor the formation of DON, however, the impact differs slightly between different types of cereals (Fredlund and Lindblad, 2014). For wheat, there is a clearer relationship with climatic factors than for oats. High levels of DON in Swedish cereals occur mainly in the western parts of the country and are linked to a higher incidence of F. graminearum. The reason for this is not entirely clear but may be due to the fact that there are often higher rainfall levels in these areas, which favours infection and toxin formation (Fredlund and Lindblad, 2014).

There are several so-called modified forms of DON, of which the acetylated derivatives (3-Ac-DON and 15-Ac-DON) are formed by the fungus itself and often make up a large proportion of the total content (Efsa, 2017). DON often coexist with ZEN because they are produced from the same Fusarium species (Parikka et al., 2012).

NIV

Nivalenol is produced by F. graminearum, F. culmorum and F. poae. Studies show that when high concentrations occur, this is usually linked to the presence of F. poae (Edwards, 2017).

NIV occurs in Sweden mainly in oats but also in wheat (Fredlund and Lindblad, 2014). The occurrence of NIV has been shown to correlate negatively to the presence of both DON and T2 HT2 (Edwards, 2017).

Importance of a changing climate

Trichothecen-producing species of Fusarium are all so-called field fungi and therefore their occurrence is greatly influenced by weather conditions during the growing season. However, optimal climatic conditions vary for different species of Fusarium and also the impact of weather vary in different cereals depending on the crop species, variety and stage of development (Parikka et al., 2012, van der Fels-Klerx et al., 2012).

T2 and HT2

Studies of cereal samples from Sweden, Finland, Norway and the Netherlands collected over a 20-year period (1999-2009) have shown that increased temperatures in June increased the incidence of HT2 in wheat. In oats, increased rainfall in May and increased temperatures at the end of the growing season correlated with increased concentrations (van der Fels-Klerx et al., 2012). A UK study has shown a correlation between precipitation in May and dry weather later in the growing season with increased concetrations of T2 and HT2 in oats. Experimental studies on oat kernels and oat-based culture medium have shown that a combination of so-called abiotic factors likely to occur in the future (high concetrations of carbon dioxide, high temperature and mild drought stress) resulted in high production of T2 and HT2 from F. langsethiae (Verheecke-Vaessen et al., 2019).

DON

In cereals samples collected in 1999-2009 (see above), increased temperatures, increased precipitation and higher relative humidity have been shown to increase DON levels in oats, maize, barley and wheat. However, the times when these conditions were critical varied and some deviations from the general pattern were shown. For example, DON in oats was negatively correlated with precipitation in April and increased temperatures in July did not affect DON levels in wheat (van der Fels-Klerx et al., 2012).

The occurrence of F. graminearum is expected to continue to increase in northern Europe with climate change. This species is a more virulent plant pathogen and can also produce DON in a wider temperature spectrum than F. culmorum, which means that the continued species shift is likely to lead to an increased presence of DON (Parikka et al., 2012, Hope et al., 2005).

The occurrence of DON in wheat grown in Northwest Europe in 2040 has been modelled in a project called Emtox. The project used climate data on humidity, temperature and precipitation from IPCC emissions scenario A1B together with phenological data on development phases in wheat (e.g. flowering and full maturity). The results showed that climate change was expected to result in an increasing occurrence of DON in basically all regions studied. In winter wheat, an increase a factor of 2-4 compared to today's concentrations was predicted, for spring wheat the increase was even greater. However, there was variation in the model results and in the outcome between regions, in some areas a decrease compared to today was predicted (van der Fels-Klerx et al., 2016).

NIV

The occurrence of NIV in oats and wheat has been shown to be negatively correlated with factors such as rain, relative humidity and higher temperature. However, a period of high humidity in June led to increased levels in wheat (van der Fels-Klerx et al., 2012).

Overall, the occurense and concentrations of trichothecenes in cereals produced in northern Europe are expected to increase with climate change mainly due to increasing rainfall and milder climates. DON is today the most common trichothecen in Sweden and is also the trichothecen where the increase is expected to be greatest in the future.

Zearalenone

Foodborne infection — characteristics, sources and routes of transmission

Zearalenone (ZEN) is produced by F. graminearum and closely related species such as F. culmorum and F. crookwellense and is mainly associated with various types of cereals (Perrone et al., 2020, Edwards, 2011). The most frequent and highest concetrations of ZEN are normally found in maize and maize products, but also occur in, for example, wheat, oats and vegetable oils. (Efsa, 2011, van der Fels-Klerx et al., 2012, Marroquín-Cardona et al., 2014)

ZEN occurs globally and is common for example in Central and South America, Asia and Central Europe. In Europe, ZEN and DON is often present in the same raw material because the two mycotoxins are formed by the same mould species and optimal conditions of production are largely overlapping (Perrone et al., 2020, van der Fels-Klerx et al., 2016, van der Fels-Klerx et al., 2012). Several modified forms of ZEN have been identified and characterised; α- and β-zearalenol, zearalanone, α- and β-zearalanol and their glucosidic, sulphate and glucuronide forms. Some of the forms are considered to have a significantly higher relative potency factor (i.e. toxicity) than the parent substance (Efsa, 2016).

F. graminearum and related species occur mainly in temperate conditions and high levels of ZEN in cereals are mainly associated with wet weather and improper storage at too high moisture content. Optimal conditions for ZEN production are 25-30°C and aw of 0.98 (Marroquín-Cardona et al., 2014, Ksenija, 2018)

Importance of a changing climate

The presence of ZEN in cereals has been shown to be strongly linked to weather conditions during cultivation, but the results vary slightly depending on the crop. High rainfall and humid weather and mild temperatures during the flowering phase resulted in high levels of ZEN in maize and wheat grown in Central and Southern Europe in 2014 (Ksenija, 2018, Perrone et al., 2020). Also humid weather during the harvest period has been shown to correlate positively to high concentrations of ZEN in maize. Rain and/or humid weather during cultivation also led to increased concentrations in wheat and oats while higher temperatures were negatively correlated with the ZEN concentrations in oats and positively correlated to increased concentrations in wheat. Experimental studies have shown that increased concentrations of carbon dioxide in combination with high temperatures lead to high concentrations of ZEN in wheat (Bencze et al., 2017).

Data suggest that climate change may lead to an increased occurrence of ZEN in several types of cereals, notably wheat, oats and maize.

Annex 3. Drinking water

Below is a background to the assessments on drinking water in the main text based on the pathogens listed in Table 5 in connection with climate change in Sweden (WHO, 2017).

Pathogens spread via drinking water

Bacteria

Pathogens that may be relevant for transmission via drinking water include bacteria such as Campylobacter spp., various groups of pathogenic E. coli, and Francisella tularensis. Burkolderia pseudomallei can also be present in raw water and there is some support for transmission via non-chlorinated drinking water in Australia. Atypical mycobacterium (Mycobacterium avium complex) survives and grow in biofilms, can be spread via inhalation, contact and consumption of contaminated water, but it is unclear how important drinking water consumption as a route of transmission is. Salmonella, in particular Typhi and Paratyphi, have been major problems related to drinking water-borne outbreaks. Drinking-water-borne outbreaks due to non-typhoidal salmonella is less common but have occurred. Domestic transmission of Typhi/Paratyphi is currently not normally occurring in Sweden. For shigella, domestic cases, irrespective of source of infection, are rare today, usually less than 100 reported cases per year. Vibrio cholerae is the only vibrio species relevant to drinking water. There are no reported cases of native cholera at least since 1980. The toxigenic types O1 and O139 cause cholera with abundant, watery diarrhoea, but other V. cholera types (non O1/O139) are also pathogenic. Non-toxigenic variants of O1 have been detected in areas without disease. Toxigenic V. cholera has been detected in copepods and other aquatic animals, often in higher numbers than in the water. The occurrence of V. cholera decreases at temperatures below 20 °C.

Virus

There is more uncertainty identifying which viruses are relevant for drinking water transmission. The presence of adenovirus in high concentrations is common in raw water. Such viruses are relatively resistant to chlorine treatment but above all to UV light. This makes them important organisms when deciding on the capacity of treatment methods in water treatment plants. Contaminated drinking water is considered a likely but unconfirmed source of human adenovirus infections. The symptoms are often not the traditional ones from the gastrointestinal tract, such symptoms are often caused by virus subgroups that are important in developing countries (serotypes 40 and 41), but instead involve symptoms in the respiratory system, urinary tract, and eyes. Astroviruses have been detected in treated drinking water and transmission via drinking water is likely but has not been confirmed. For calicivirus (norovirus and sapovirus), there is support for transmission via drinking water. For Picornaviridae/HAV, there is support for transmission via drinking water. HEV is excreted in faeces of infected persons and has been detected in treated waste water and contaminated water associated with major outbreaks. It may be different types that are relevant for water and food with different transmission routes and clinical symptoms. HEV is the only enteric virus that has an important animal reservoir, especially pigs and wild boars, in addition to humans. Rotavirus, excreted in large quantities from infected persons at high concentrations and has been detected in various water sources including treated drinking water. The transmission via drinking water has been identified, which poses a risk to public health, but person to person transmission and inhalation of airborne viruses or aerosols appear to be more important than the consumption of contaminated food or drinking water (WHO, 2017).

Protozoa

Among protozoa there are some with clear relevance for transmission via drinking water. The importance of drinking water as a transmission route for cryptosporidium is well established, not least in two major outbreaks in Sweden in 2010 (Rehn et al., 2015). Cyclospora cayetanensis has humans as the only host and transmission via contaminated water and food is the main route. Cyclospora is reported from many countries but is most common in tropical and subtropical areas including South and Central America, South and Southeast Asia, Middle East and Africa (ECDC, 2020). The occurrence is to some extent seasonal, but no clear link to climate variables is reported (CDC, 2020). Entamoeba histolytica is one of the most common intestinal protozoa and human beings are the main hosts. Asymptomatic infections are common but severe symptoms may also develop. Cysts can survive in suitable aquatic environments for extended periods, months, at low temperature, but waterborne transmission is greater in the tropics than in temperate areas, mainly due to a greater proportion of infected human people in the tropics. Person to person and contamination of food via infected people are the most common transmission routes, but contaminated water is also an important route, due, among other things, to some resistance to chlorine treatment. In the last five years, fewer than 10 domestic cases have been reported annually in Sweden. For giardia, person-to-person transmission is the most common route, especially among children, but drinking water and other sources of water have been associated with outbreaks for a long time. For Toxoplasma gondii (a protozoa not included in Table 5), transmission via contaminated drinking water is unusual, but water has been demonstrated as a source of toxoplasmosis outbreaks. One example is from Canada in 1995, with over 100 cases where the infection was spread via municipal water in connection with heavy rains and where there were infected cats around the lake, which was used as a source of raw water (Folkhälsomyndigheten, 2021). There is relatively scarce data on how the processes in the water treatment affect the occurrence of toxoplasma.

Pathogens with weak evidence for transmission via drinking water

Table 7.2 in (WHO, 2017) presents a summary of pathogenic microorganisms where evidence for spreading via drinking water is missing or weaker.

Bacteria

Among the bacteria with weaker evidence, common food-borne pathogens such as Staphylococcus aureus and Yersinia enterocolitica can be mentioned. There is some evidence that Y. entercolitica and Y. pseudotuberculosis have caused disease but via consumption of untreated drinking water. According to the WHO (WHO, 2017), there is no evidence that the bacterium aeromonas causes disease via drinking water. It has often been detected in drinking water, but other types than those that cause gastroenteritis. Aeromonas is common and can survive and grow in raw water and distribution systems but is considered more a nuisance than a health problem. Pathogens that for various reasons are considered less relevant in the present context are described below.

Legionella is a pathogen but transmission is primarily not via consumption of drinking water but by aerosols or by inhalation of water (aspiration). Legionella can grow in the temperature range of 25-

50 °C and in biofilms in the water distribution system. Thus, control strategies should focus on temperature control and on minimising the occurrence of biofilms. Cases of disease have occurred in particular in risk groups and in connection with cooling systems, hot water showers, humidifiers and spa facilities. Legionella, like some other pathogens such as campylobacter, can be taken up by amoebas such as Acanthamoeba, and Naegleria, which increases the ability of legionellas to survive in the aquatic environment (e.g. (Greub and Raoult, 2004)). For pseudomonas, there is no evidence of safety concerns via the consumption of drinking water under normal conditions, but it may, however, be a source of quality problems, especially in packaged water. Burkholderia pseudomallei occurs mainly in tropical regions and has been associated with two waterborne outbreaks in Australia and may become more of a problem in the longer term.

Virus

Among the viruses considered less relevant from a drinking water consumption perspective are Picornaviridae/enteroviruses (poliovirus, coxsackie virus type A and type B, echovirus, respectively). These viruses are excreted in faeces by infected persons and are among the most commonly detected in sewers and various water sources. These viruses can also be detected in food. Drinking water is a possible transmission route, but the most important route is person-person and inhalation of viruses or virus drops.

Protozoa and other organisms

Less relevant protozoa include Acanthamoeba. They occur in many types of aquatic and terrestrial environments and tap water is a possible source but has only been linked to disease via "keratitis" acquired via home-made saline solution for contact lenses. One life stage can grow in water with optimum temperature around 30 °C, but perhaps more important is its role, together with some other protozoa and crustaceans, to accommodate some bacterial pathogens, thereby increasing their resistance and survival. The ciliate Balantidium coli is one of the largest protozoa and infections are rare and often asymptomatic, but symptoms may range from gastrointestinal symptoms to headaches and weight-loss. Their presence in tap water is unknown and humans and especially pigs are reservoirs. An outbreak from 1971 is known when a raw water source was contaminated with water containing porcine faeces subsequent to very heavy rain weather, but drinking water does not normally seem to be an important route of transmission. Blastocystis spp. can also be transmitted via drinking water but this has not been confirmed. In environments where this protozoa is present, it occurs in drains and water springs. For Cystoisospora belli (formerly Isospora belli) and microsporida (monocellular fungi), the situation is unclear, with drinking water as possible but not confirmed route of transmission (WHO, 2017). Naegleria fowleri is a thermophilic protozoa that can grow at temperatures up to 45 °C and occurs naturally in fresh water at suitable temperatures. It causes severe encephalitis/meningitis by passing through the nose and olfactorial nerve to the brain. It has been detected mainly in contaminated warmer water sources such as geothermal water or heated swimming pools, but has also been detected in raw water sources especially when the water exceeds 25-30 °C. The transmission route is almost exclusively via exposure to contaminated water in the nose. Dracunculus medinensis (Guinea worm), is a parasitic worm with transmission via drinking water (WHO, 2017). The only cause of infection is consumption of water containing infected small crustaceans (various species of Cyclops). The disease is limited to sub-Saharan regions. For the Fasciola hepatica flatworm (liver fluke), waterborne infection has been confirmed after consumption of untreated drinking water, but transmission via vegetables grown or irrigated with contaminated water is a more important transmission route.

This risk profile presents a scientific overview on how climate change can affect microbiological food safety. The report describes which pathogenic microorganisms and toxins that may become more important and affect the safety of food and drinking water consumed in Sweden. The overview also describes how the different stages of the food chain may be affected and which microbiological hazards that are most relevant to different groups of food.

The risk profile is intended as a basis for the agency's continued work on climate adaptation, but can also serve as a basis for further and more detailed studies and various activities in the food sector. The report should be seen as an initial and very general overview.

The Swedish Food Agency is the competent authority in the food sector. We work towards the following goals; safe food and drinking water, healthy dietary habits and fair practices in the food trade. Our tools are regulations, recommendations and communication.

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