EUROPEAN CENTRE FOR DISEASE PREVENTION AND CONTROL

TECHNICAL REPORT

Assessing the potential impacts of climate change on food- and waterborne diseases in Europe

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This report was commissioned by the European Centre for Disease Prevention and Control (ECDC), coordinated by Jan Semenza, Bertrand Sudre and Jonathan Suk (Health Impact Section, Office of the Chief Scientist, ECDC), and produced by the Institute for Hygiene and Public Health at the University of Bonn, Germany.

Authors

Thomas Kistemann, Andrea Rechenburg, Christoph Höser, Christiane Schreiber, Tobias Frechen and Susanne Herbst (Institute for Hygiene and Public Health at the University of Bonn, Germany)

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Contents

Abbreviations

CDC	Center for Disease Control and Prevention (US)
ECDC	European Centre for Disease Prevention and Control (EU)
EEA	European Environment Agency
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
FWB	Food- and waterborne
GIS	Geographical information system
IHPH	Institute for Hygiene and Public Health (University of Bonn, Germany)
IPCC	Intergovernmental Panel on Climate Change
LOCODE	United Nations code for trade and transport locations
MeSH	Medical subject headings
MySQL	Relational database management system
NUTS	Nomenclature of territorial units for statistics in Europe
OECD	Organisation for Economic Co-operation and Development
WAR	Web application archive
WHO	World Health Organization
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

Executive summary

Background

Climate change has almost certainly had an impact on Europe, playing a role in the occurrence of severe weather events such as droughts, heat waves and flooding in recent years. Climate change projections for the coming decades make it likely that there will be a further increase in such extreme weather events. Additionally, water scarcity is expected to become an important challenge to EU Member States around the Mediterranean basin, particularly during summers; an increase in heavy rainfall events is predicted for much of central and northern Europe; and higher overall levels of precipitation are anticipated in northern Europe, particularly during winters. In addition, higher overall temperatures are projected for all of Europe.

These changes to Europe's climate will not only impact the European environment and ecosystems but also human health and well-being. Food- and waterborne (FWB) pathogens are known to be particularly sensitive to climatic conditions, and thus public health planning and preparedness activities need to be informed by the potential impacts that climate change could have on FWB disease transmission.

In this report, we present the findings of a comprehensive literature review, in which we identify the published links between six FWB pathogens (*Campylobacter* spp., *Cryptosporidium* spp., *Listeria* spp., *Norovirus*, *Salmonella* spp. and non-cholera *Vibrio* spp.) and meteorological and climate variables. The main objective was to assess and understand the potential impacts of climate change on FWB disease transmission in the EU.

Methodology

This assessment is based on a systematic literature review. For each pathogen (*Campylobacter*, *Cryptosporidium*, *Listeria*, *Norovirus*, *Salmonella* and non-cholera *Vibrio*), articles from the PubMed and ScienceDirect bibliographic databases were retrieved that also matched MeSH terms related to climate change and/or climate variability. Articles published between 2000 and 2009, published in English or German, were reviewed. For each identified article, teams of reviewers extracted 'key facts', thus linking a given pathogen with climatic information. Each 'key fact' was ranked according to the quality of its evidence and combined with a spatial attribute for mapping purposes. All information was entered into a relational database, which was used to analyse the results.

Results

A relational database was developed including data from 741 peer-reviewed publications, reports, and other scientific sources. From these sources, 1653 'key facts' linking the FWB pathogens of interest with a range of climatic variables were identified. Water temperature, seasonality, air temperature, heavy rainfall events, precipitation, and temperature changes were the variables associated with climate change most commonly attributed to the pathogens of interest in this study. Campylobacteriosis and salmonellosis were cited with the highest frequency in association with air temperature; campylobacteriosis and non-cholera vibrio infections were reported in association with water temperature; cryptosporidiosis followed by campylobacteriosis were related with highest frequency with precipitation; and cryptosporidiosis followed by non-cholera vibrio were found in association with precipitation events.

The most prevalent FWB disease in Europe is campylobacteriosis which exhibits strong seasonality and has been associated with a number of meteorological variables and specific weather events, which indicates that campylobacteriosis peaks may shift as a result of climate change in the future. Temperature has also a pronounced influence on salmonellosis and food poisoning notifications, which can be attributed to improper food storage and handling at the time of eating. Nonetheless, salmonellosis incidence has declined throughout Europe over the last ten years, in part due to public health measures. Therefore, carefully implemented health promotion and food safety policies should be able to counterbalance the probable negative impacts on public health. A large number of studies have examined the role of surface water, tap water and heavy rainfall events in the transmission of *Cryptosporidium*. Erratic precipitation events are predicted to increase cryptosporidiosis outbreaks, even though the strength of the association might vary by climatic region. *Listeria* sp. was not associated with temperature thresholds, extreme precipitation events, or temperature limits. Despite the lack of scientific data, it is not likely that climate change will directly influence listeriosis incidence, though it could result in more cases through indirect pathways. The association between climatic determinants and *Norovirus* is tenuous, in part due to the relative lack of published information. As such, no data are available on temperature extremes or thresholds, or on the after-effects of storms, droughts, or rain events. In contrast, there is documented evidence of a strong association between rising summer (water) temperatures, extended summer seasons and non-cholera *Vibrio* spp. infections. Nevertheless, any increase of the disease burden is projected to be modest due to low current incidence rates. However, an increase in absolute infection cases can be assumed for the future. Specifically the Baltic Sea is a habitat where minor changes in environmental conditions, e.g. temperature, will result in elevated *Vibrio* spp. populations.

Discussion/conclusion

Published climate change scenarios for Europe suggest that some regions will experience an increase in normal and extreme precipitation events, and that all areas will experience increases in air and water temperatures.

All FWB pathogens examined in this study were cited by the literature to have relationships with some form of environmental variable relevant to climate change. The risk of campylobacteriosis is associated with mean weekly temperatures, although this link is shown more strongly in the literature relating to salmonellosis. Irregular and severe rain events are associated with *Cryptosporidium sp.* outbreaks, while non-cholera *Vibrio sp.* displays increased growth rates in coastal waters during hot summers. In contrast, for *Norovirus* and *Listeria* sp. the association with climatic variables was relatively weak, yet much stronger for food determinants.

One limitation of the study is publication bias. The articles retrieved were not evenly distributed throughout Europe and show a north-south and a west-east gradient. This observation is in part due to the selective retrieval of published reports in English or German from bibliographic databases, but also due to underreporting. Lack of information on climate change and these food- and waterborne diseases could pose a risk to public health, particularly at times of financial recession, which could lead to the underfunding of surveillance and control programmes.

This study's approach to electronic data mining, and the way it assesses the impact of climate change on food- and waterborne diseases, assures a methodical appraisal of the field. The resulting climate change knowledge base offers information on national climate change vulnerability, potential impact, and adaptation assessments, and thus facilitates the management of future threats from infectious diseases. In the face of diminishing resources for public health, this approach can be helpful in assessing different public health strategies for responding to climate change.

Introduction

This report summarises the key findings of a project with the objectives:

- to conduct a structured and systematic review of published literature on food- and waterborne pathogens and how they are influenced by meteorological and climate variables; and
- to develop a computerised interface for stakeholders to easily access the findings of this literature review so as to further explore relationships between climatic and environmental variables and FWB pathogens.

This technical report was published with the sole intent of informing readers about the links between FWB pathogens and climatic variables, so as to inform any public health work addressing the potential impacts of climate change on FWB pathogen transmission.

This report is not designed to offer formal guidance or guidelines on the best strategies for adapting public health systems to climate change.

This report was written to present the findings of a project entitled 'Impact of climate change on food- and waterborne diseases in Europe', which was commissioned by ECDC, in accordance with its mandate to identify emerging threats to communicable disease control in the EU.

The project was financed solely by the European Centre for Disease Prevention and Control (ECDC), and the project was undertaken by the Institute for Hygiene and Public Health (IHPH), University of Bonn, Germany, in collaboration with ECDC technical staff.

This document has been prepared for public health institutions, public health policymakers, and other experts dedicated to the control of FWB pathogens. This report should be of particular relevance to those working within EU Member States, but it may also be relevant to a broader international audience.

The relational online database described in this report is accessible to any interested reader of this report. For further information, please contact Bertrand Sudre at ECDC (Bertrand.sudre@ecdc.europa.eu).

Background

Europe's climate is changing rapidly due to anthropogenic activity such as extensive fossil fuel combustion and widespread alterations in land use [1,2]. Conservative projections foresee global mean air temperatures increasing by 1.8 to 4.0 °C this century, while other models suggest a range of increase of 1.1 to 6.4 °C. The global average temperature is now 0.8 °C higher than between 1850 and 1919, while in Europe this average is 1.4 °C higher [3]. As to the rate of change, the last decade was the warmest on record, with 1998 and 2005 being historically extreme years. The most dramatic increase has been recorded in the Arctic region of Europe where the temperatures have risen by 3 °C over the last 90 years [4]. Northern Europe is also the geographical area with the biggest projected temperature increase according to climate change scenarios [5].

This change is particularly pronounced in the winter rather than the summer months, with projected increases as high as 8 to 10 °C in some European regions by 2080 [4]. In contrast, southern and central Europe are projected to experience temperature increases during the summer months of up to 6 °C [6,7]. Another aspect of rising temperatures is the seasonality of warming. In Europe, the spring and summer seasons have warmed the most, whereas autumn has warmed less. Observational studies in several areas of Europe have documented a lengthening of the time period between the last spring frost and the first autumn frost over recent decades [8,9]. The arrival of spring and summer phenological events, such as pollen season, the first flowering date of plant species, or the onset of animal breeding, advanced on average 2.5 days per decade between 1971 and 2000 [10].

Human contributions to greenhouse gas emissions have already played a role in flooding in northern Europe [11,12], and extreme precipitation events are projected to increase in western and northern Europe, but not in the south [13,14]. Over the last decade, Europe has recorded historically high ambient temperatures during the summer months, notably during the 2003 heat wave. Precipitation in northern Europe is projected to increase, particularly during the winter months, but to decrease further in the south, mainly during the summer months. Reductions in precipitation in parts of Mediterranean Europe may also be accompanied by longer periods of drought [15], which have increased in frequency and intensity, while the number of cold spells has fallen [16]. Mean annual precipitation in Europe has also changed significantly. During the last century, northern Europe has witnessed a 10 to 40% increase, while southern Europe has seen a 20% decrease in mean annual precipitation [16].

Climate change has far-reaching implications for public health. These include deaths and hospitalisation due to heat waves [17], injuries and death from flooding, and the emergence and re-emergence of communicable diseases and their shifting distribution [18]. Although vector-borne diseases have received attention in discussions about climate change, food- and waterborne diseases are also of particular interest because their incidence has been linked to ambient temperature and precipitation. Elevated temperatures accelerate the replication cycles of food-borne microorganisms, and extended summer seasons may increase the chance of mistakes in food handling. Extreme and erratic rain events can flush pathogens into water treatment and distribution systems, resulting in community outbreaks [19–22].

To further understand how climate change could influence FWB disease transmission, the complex relationships between FWB pathogens and climate variables need to be assessed. We conducted a systematic literature review and extracted key information into a relational database, which we used to document the relations and interactions between infectious diseases, meteorological variables and climate change.

Methods

Literature review

Original research articles were retrieved from PubMed and ScienceDirect bibliographic databases. The search strategy involved combining 'climate change' and climate-related subjects in various combinations with the FWB pathogens selected for this study (*Campylobacter*, *Cryptosporidium*, *Listeria*, *Norovirus*, *Salmonella* and non-cholera *Vibrio*). Key words and MeSH terms (when available) were used in three different searches (Table 1), which included all papers published between 1998 and 2009, in both English and German.

The number of citations was then expanded to include the titles listed in the bibliographies of the sources identified in the literature review.

Table 1. Keywords and MeSH terms used in the literature review

Search 1 (pathogens)	'climate change'	AND	Vibrio (excluding Vibrio cholera); Salmonell*; Cryptosporid*; Lister*; Enterovirus; Norovirus; Norwalk-like; Campylobacter*		
Search 2 (health aspects)	'climate change'	AND	human health; disease; risk assessment; diarrhoea; foodborne; food-borne; waterborne; water-borne		
Search 3 (pathogens and health aspects)	'climate change'	AND	rainfall OR moisture OR precipitation OR humidity	AND	Vibrio (excluding Vibrio cholera); Salmonell*; Cryptosporid*; Lister*; Enterovirus; Norovirus; Norwalk-like; Campylobacter*

Design of a relational database

A sophisticated relational database was developed to facilitate the analysis of the results of the literature review. The purpose of this online database was to enable users to explore relationships between climate variables and FWB pathogens. The database was designed such that data can be retrieved according to thematic or spatial attributes (i.e. geographic location), 'key facts', or through free text search. Thus, the database makes it possible to comprehensively and efficiently assess and evaluate the literature review.

Data extraction

Figure 1 summarises the data extraction process. Once the relevant articles were identified through the literature review and the database was capable of extracting the salient data, the project could move on to the next phase – the extraction of data from each article and their addition to the knowledge base.

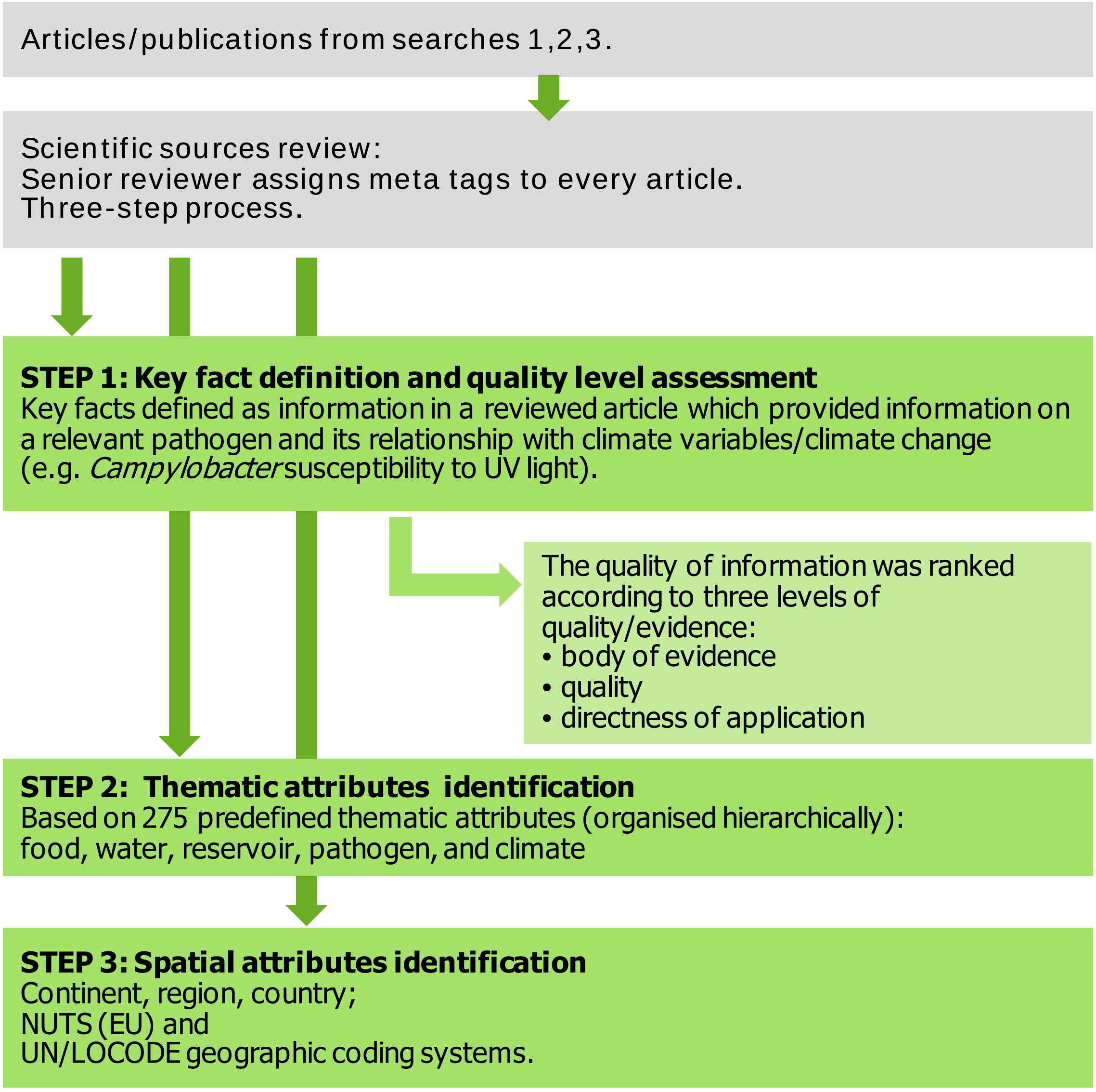
Each article was reviewed by at least one expert from the research team who tried to identify key facts. Reviewers evaluated information by assigning four categories:

- **Key facts** (step 1); defined as any information in a publication pertaining to a given study pathogen and its relationship with climate or climate change (e.g. *Cryptosporidium* and its association with extreme precipitation).
- **Quality of evidence** (step 1); categorised as 'body of evidence', 'quality of evidence', or 'directness of application'.
- **Thematic attributes** (step 2); used to classify 'key facts'. Thematic attributes are based on a predefined hierarchical set of more than 275 attributes across five groups: pathogens, food, water, climate/environment, and reservoirs. Pathogen attributes were categorised according to virus, bacteria,

protozoa, etc., whereas food attributes were classified in accordance with the Codex Alimentarius[1] (see Annex 1 for a complete set of attributes).

- **Spatial attributes** (step 3); i.e. geographic locations linking 'key facts' and/or 'thematic attributes' (e.g. country or region of study).

Figure 1: **Data extraction strategy**



No limit on key facts per source publication was imposed (multiple 'key facts' were possible). Irrelevant data sources were not attributed any 'key facts'. Interactive analyses of particular subject matters were made possible by structuring the collected information. Tags and attribute, for example, allowed for the retrieval of all key facts connected to a certain question (e.g. 'What do we know about "fresh poultry"?') or a certain combination of attributes (e.g. 'What do we know about "salmonella" AND "fresh poultry" AND "heavy rainfall events" IN "Germany"?').

[1] http://www.codexalimentarius.net/web/index_en.jsp

Results

Literature review

A total of 862 references were identified in the first round of the literature review, of which 453 were excluded. The second literature review, based on the references of the initial set of publications, led to an additional 401 references being added to the relational database. In total, 810 references were identified through the literature review; sources included journal articles, surveillance reports, grey literature, and various other publications (Table 2).

Table 2: Summary of references transferred to the knowledge base

Literature search	Number of sources
Number of references after one-line request	862
Excluded	453
Sub-total	409
Additional references *	401
Total	**810**

Types of sources				
Journal articles			*Institutional reports*	
Cryptosporidium	128		WHO	24
Campylobacter	61		ECDC	4
Vibrio	24		CDC	3
Salmonella	24		OECD	1
Virus	49		EEA	1
Listeria	10		EFSA	1
Microbiology/pathogens	123		FAO	1
Climate	63		IPCC	1
Other	16		WMO	1
Surveillance reports			WWF	1
Outbreak report in Eurosurveillance	88		*Other sources*	
German surveillance	37		Book/book section	68
US surveillance	8		Web sources	20
Governmental documents			Proceedings	13
Germany	27		Research reports	2
Switzerland	2		Thesis	1
United States	2		Miscellaneous	4
Canada	1			
UK	1			
			Total	**810**
Excluded (no key fact related to climate and selected pathogens)				69
Total				**741**

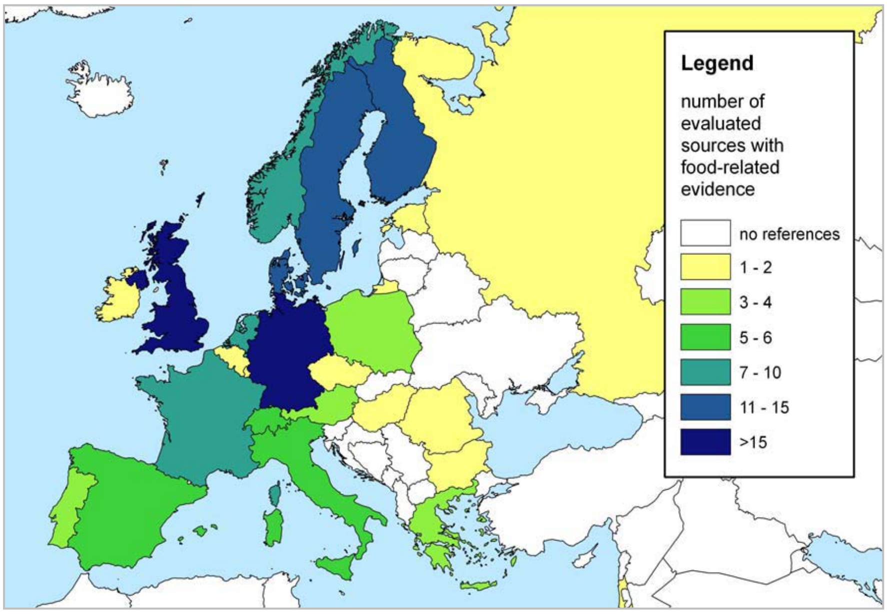
** Retrieved from full-text articles*

Geographic distribution of references

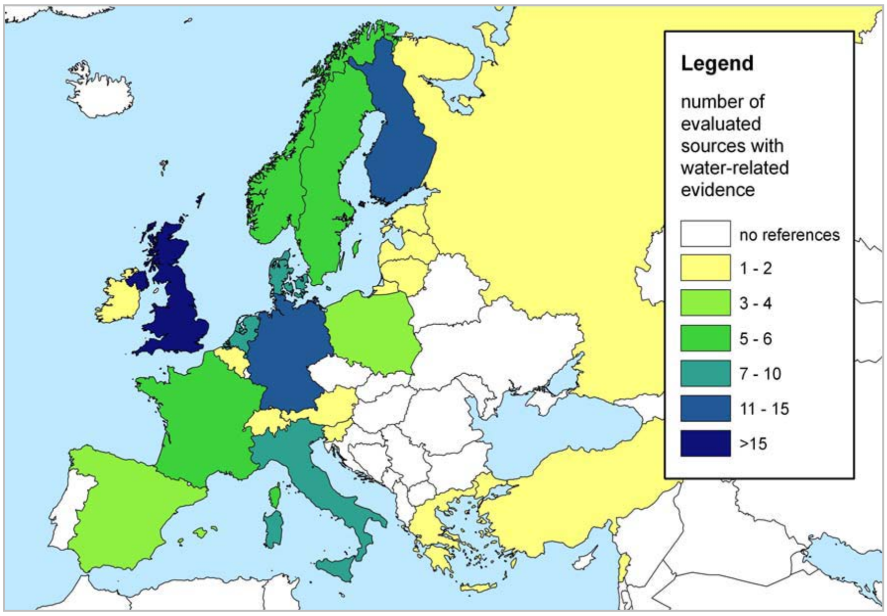
The literature review sought references from across the European Union. Although findings may be slightly biased because only two search languages (English and German) were included, a clear trend can be seen for references addressing both food- and waterborne diseases. A majority of publications described these diseases in the northern and western parts of Europe (Figure 2).

Figure 2: Number of references to food- and waterborne diseases in the knowledge base, according to country of origin

a) Food-related references, by country



b) Water-related references, by country



Key facts overview

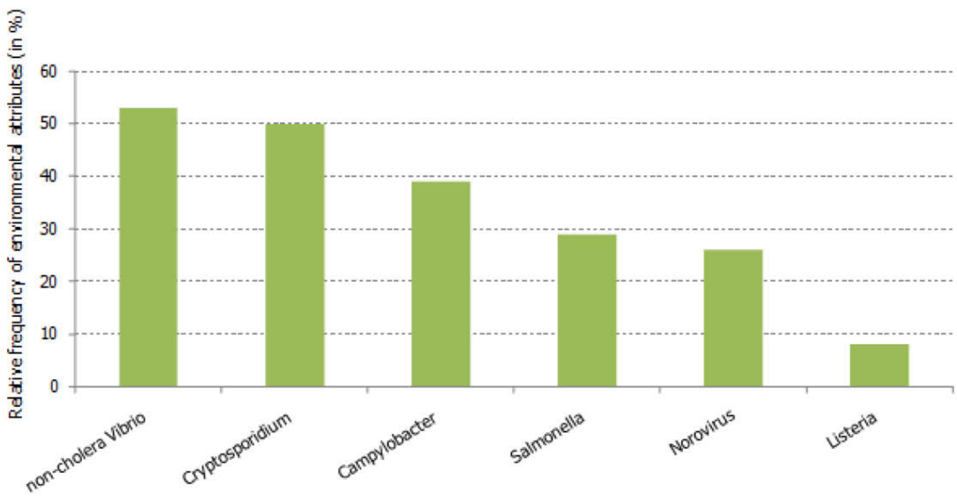
A total of 1653 key facts were extracted from the literature review and classified. Of these key facts, 1643 were given thematic attributes and 1109 were given spatial attributes. The distribution of key facts by pathogen is listed in Table 3.

Table 3: Number of key facts per FWB pathogen

Type	Pathogen	Number of key facts
Bacteria	*Campylobacter*	461
	Salmonella	372
	Listeria	121
	Non-cholera *Vibrio*	126
	non specific	50
	Total	**1080 (71%)**
Viruses	Norovirus	212
	Enterovirus	16
	non specific	31
	Total	**228 (15%)**
Parasites	*Cryptosporidium*	198
	non specific	10
	Total	**208 (14%)**

The relative frequency of association between environmental attributes and each pathogen was assessed also (Figure 3).

Figure 3: Proportion of climate/environmental thematic aspects relative to all key facts, per pathogen



The frequency with which thematic attributes were assigned to key facts and the distribution of these attributes for each pathogen were analysed. The environmental aspect of the literature review is prominent: the top-three thematic attributes relate to water (surface water, tap water, and water temperature); air temperature, heavy rainfall, and seasonality all figure among the most common attributes classified in the knowledge base (Table 4).

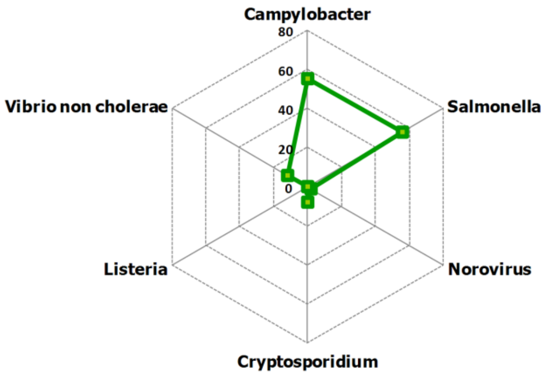
Table 4: Frequency of the 20 most common attributes in the knowledge base

Thematic attribute with 20 or more key facts	Key fact	
	Number	Relative percentage
Surface water	191	9.9
Water temperature	128	6.6
Tap water	117	6.0
Food	116	6.0
Seasonality	112	5.8
Sea	89	4.6
Air temperature	83	4.3
Water	76	3.9
Heavy rainfall event	74	3.8
Molluscs, crustaceans, echinoderms	64	3.3
Precipitation	60	3.1
Winter	60	3.1
Fresh poultry	58	3.0
Summer	56	2.9
Faeces	51	2.6
Contamination	50	2.6
Wastewater	48	2.5
Change in temperature (increase/decrease)	47	2.4
Groundwater	46	2.4
UV light	37	1.9
Climate/environment	35	1.8
Fish and fish products	34	1.8
Water salinity	30	1.5
Stormwater/sewer overflow	29	1.5
Relative humidity	26	1.3
Vegetables	25	1.3
Processed meat	24	1.2
Processed poultry	22	1.1
Fresh vegetables	22	1.1
Dairy products	22	1.1
Change in average temperature (increase/decrease)	22	1.1
Eggs and egg products	21	1.1
Fruit	21	1.1
Diffusion (in water)	21	1.1
Chicken	20	1.0

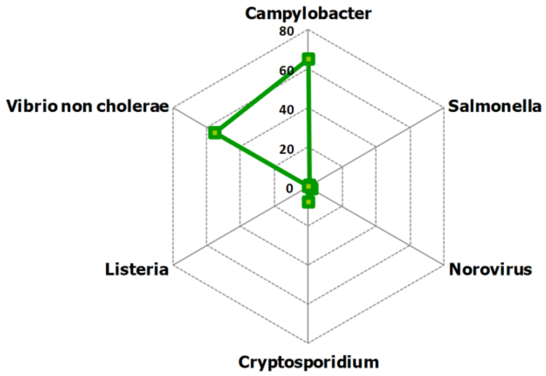
In addition, the number of associations between each FWB disease and four key variables related to climate change (air temperature, water temperature, precipitation, and extreme precipitation) was assessed. Campylobacteriosis and salmonellosis were cited most frequently in association with air temperature; campylobacteriosis and non-cholera vibrio were cited most frequently in association with water temperature; cryptosporidiosis (followed by campylobacteriosis) was cited most frequently in association with precipitation; and cryptosporidiosis was cited most frequently in association with precipitation. The pattern of association of FWB pathogens with four climate-related variables is presented in Figure 4.

Figure 4: Radar diagram showing climate-related key facts and their association with six FWB pathogens according to reviewed literature

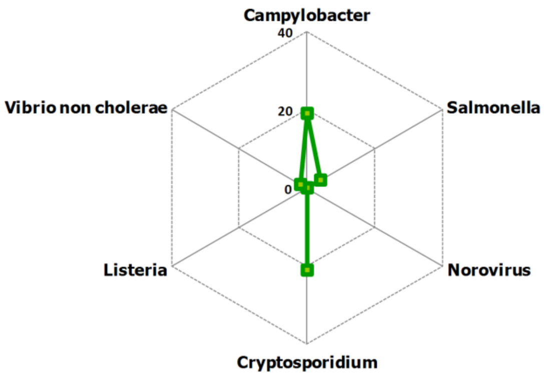
Air temperature



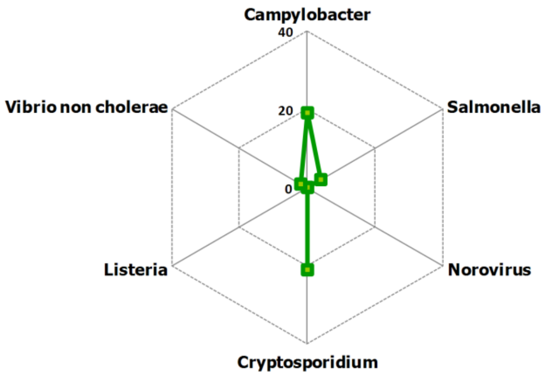
Water temperature



Precipitation



Extreme precipitation events

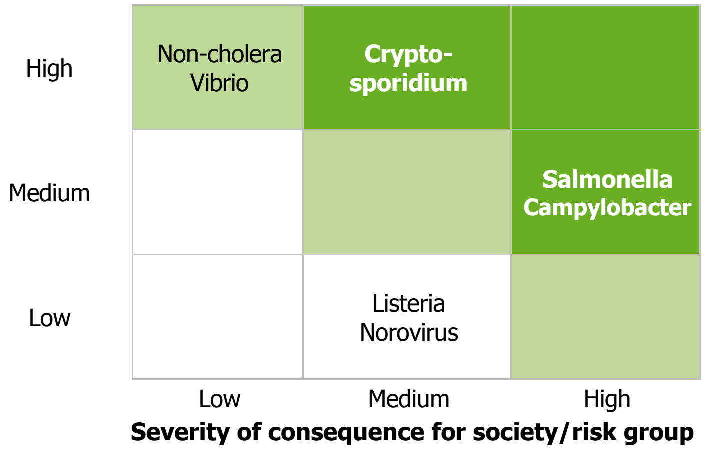


Discussion

Climate change will result in a shift in the distribution of communicable diseases in Europe, yet the multi-factorial nature of disease transmission and the challenge of attributing single events to climate change complicates analysis. An assessment of the potential impacts of climate change on FWB disease transmission must necessarily begin with a careful review of the literature in order to find links between environmental variables relevant to climate change and FWB pathogens. The systematic review described in this report makes it possible to examine such associations by using the available qualitative and quantitative information.

It is difficult to evaluate the strength of the association between study pathogens and climatic variables without having to resort to quantitative modelling, which lies beyond the scope of this study. However, the frequency of association between climate variables and FWB pathogens was measured and can be viewed as a possible, albeit imperfect, proxy for strength of association. The frequency of association was plotted against our assessment of the relative severity of these pathogens from a public health perspective (Figure 5). Pathogens toward the top right corner of this figure may be considered to be priorities for climate change adaptation planning because they appear to have strong climate-pathogen associations and are known to have significant public health impacts [18,23].

Figure 5: Qualitative summary



Study pathogens are plotted according to strength of association with climatic variables and according to relative public health importance.

In this study, cryptosporidiosis demonstrated strong associations with precipitation and heavy precipitation, based on the frequency of associations identified in our literature review. Irregular and/or severe rainfall events can challenge the capacities of water treatment facilities, leading to *Cryptosporidium* spp. contamination and associated waterborne outbreaks.

Campylobacteriosis and salmonellosis are responsible for a high disease burden in Europe. The risk of campylobacteriosis was frequently cited to be positively associated with mean weekly temperatures, but the strength of the association is not consistent in all studies, despite the fact that this association is supported by a high number of key facts that link air and water temperatures to *Campylobacter* spp. Some sources link campylobacteriosis to precipitation. Salmonellosis, meanwhile, was frequently cited alongside air temperature (Figure 4); in fact, some studies have suggested that one third of salmonellosis cases can be attributed to temperature influences.

For non-cholera *Vibrio* spp., which contribute far less to the overall EU disease burden than the other FWB diseases assessed in this study, the relative influence of environmental and climatic factors appears to be very strong. For example, *Vibrio* bacteria, which can infiltrate skin lesions that can cause local infections and septicaemia, are indigenous to the Baltic, North Sea, and Mediterranean. They have been cited to display increased growth rates during hot summers.

For *Norovirus* infections and listeriosis, the link to climatic determinants appears to be relatively weak.

One limitation of the study is publication bias. The articles retrieved were not evenly distributed throughout Europe, and displayed a north-south and a west-east gradient (Figure 2). This observation is in part due to the selective retrieval of published reports in English or German from bibliographic databases, but also to underreporting. Lack of information on climate change and food- and waterborne diseases could pose a risk to public health, particularly at times of financial recession, which could lead to the underfunding of surveillance and control programmes.

Another limitation relates to the multi-dimensional pathways of disease transmission and the uncertainties inherent in climate modelling. The latter is addressed because our study only looks at published links with climate and meteorological variables, rather than models. The former makes the study subject to potentially confounding variables. Some have argued, for example, that the links between temperature and salmonellosis are confounding, supporting the counter hypothesis that more people eat outdoors during warmer temperatures and thus expose themselves to a greater risk of salmonellosis. Yet the breadth of our study and the number of key facts linking the two variables does lend credence to the links between behavioural factors and salmonellosis.

Conclusion

The literature review and the knowledge base developed for this study reveal a complex web of relationships between climatic and environmental determinants and food- and waterborne diseases. For each pathogen and variable examined, significant differences are observed in regard to weight of evidence, connectivity, and the proportion of climatic and environmental determinants relative to all key facts. Even so, given the breadth of evidence collected in this review, and given the projected climate changes for Europe, some conclusions can be made.

All FWB pathogens examined in this study were cited by the literature to have associations with some form of environmental variable relevant to climate change. The risk of campylobacteriosis is associated with mean weekly temperatures, although this link is shown more strongly in the literature relating to salmonellosis. Irregular and severe rain events are associated with *Cryptosporidium* spp. outbreaks, while non-cholera *Vibrio sp.* displays increased growth rates in coastal waters during hot summers. In contrast, Norovirus and *Listeria* spp. show only a relatively weak association with climatic variables, but a much stronger one with food determinants.

Whether the potentially increased transmission of *Cryptosporidium* spp., non-cholera *Vibrio* spp., *Salmonella* spp. and *Campylobacter* spp. will manifest as a greater public health risk in the future depends not only on the accuracy of climate predictions but also on:

- any new data re-assessing the strength of the associations examined in this study; the study was limited by its restriction to studies published in English and German, as well as underreporting of disease data;
- the current and future state of disease prevention and control infrastructures;
- the baseline resilience and health status of exposed populations; and
- the extent to which climate change adaptation strategies specifically designed to address FWB diseases have been devised and implemented.

This study's approach to electronic data mining and the way it assesses the impact of climate change on food- and waterborne diseases assures a methodical appraisal of the field. The resulting climate change knowledge base offers information on national climate change vulnerability, potential impact, and adaptation assessments, and thus facilitates the management of future threats from infectious diseases. ECDC has produced a handbook for Member States to assist with the assessment of climate change vulnerability and impact and to consider various adaptation options [23]. The database used in this analysis is available for use by interested stakeholders – please contact us should you be interested.

Annex: Spatial and thematic and attributes

Thematic attributes

All key facts in the database were assigned thematic attributes. The thematic attribute states that there is knowledge linking a given attribute to a key fact. Key facts related to food items were classified in accordance with the Codex Alimentarius.

Linking key facts to attributes ensures rapid access to the relevant aspects of the reviewed articles. For instance, attributes make it possible to retrieve all key facts related to a specific question (e.g. 'What do we know about "fresh poultry"?') or a combination of attributes (e.g. 'What do we know about "salmonella" AND "fresh poultry" AND "heavy rainfall events" IN "Germany"?').

The thematic attributes are organised in four groups:

- pathogens
- climate
- aspects of food
- aspects of water

The exhaustive list of attributes used is presented in Tables 7, 8 and 9.

Spatial attributes

Spatial attributes are variants of the thematic attributes and describe geographical information. The hierarchical list of spatial attributes has been taken from two different sources:

- European classification: NUTS levels[2] cover European countries from major socio-economic regions to small regions for specific diagnoses
- International classification: United Nations/LOCODE[3] assigns codes to locations used in trade and transport. The 2008 version contains codes for about 60 000 locations.

By employing thematic and spatial attributes, it is possible to search the knowledge base for information on specific research questions.

Table 7: List of thematic attributes (1/3)

Attributes	Level of detail*			
	1	**2**	**3**	**4**
Food	1	0	0	0
meat and meat products	1	1	0	0
fresh meat	1	1	1	0
beef	1	1	1	1
pork	1	1	1	2
veal	1	1	1	3
processed meat	1	1	2	0
non-heated processed	1	1	2	1
cured non-heated	1	1	2	2
cured and dried	1	1	2	3
fermented non-heat treated	1	1	2	4
heat treated	1	1	2	5
frozen	1	1	2	6
fresh poultry	1	1	3	0
processed poultry	1	1	4	0
non-heated processed	1	1	4	1
cured non-heated	1	1	4	3
cured and dried	1	1	4	4
fermented non-heat treated	1	1	4	5

Attributes	Level of detail*			
	1	**2**	**3**	**4**
Food	1	0	0	0
fruit	1	6	0	0
fresh fruit	1	6	1	0
untreated	1	6	1	1
surface treated	1	6	1	2
peeled or cut	1	6	1	3
processed fruits	1	6	2	0
frozen	1	6	2	1
dried	1	6	2	2
canned	1	6	2	3
cooked	1	6	2	4
jams, jellies, marmalades	1	6	2	5
candied	1	6	2	6
fermented	1	6	2	7
vegetables	1	7	0	0
fresh vegetables	1	7	1	0
untreated	1	7	1	1
surface treated	1	7	1	2
peeled or shredded	1	7	1	3

[2] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/reference and http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

[3] http://www.unece.org/cefact/codesfortrade/codes_index.htm and http://en.wikipedia.org/wiki/UN/LOCODE

Attributes	Level of detail*			
heat treated	1	1	4	6
frozen	1	1	4	7
fresh game	1	1	5	0
processed game	1	1	6	0
non-heated processed	1	1	6	1
cured non-heated	1	1	6	2
cured and dried	1	1	6	3
fermented non-heat treated	1	1	6	4
heat treated	1	1	6	5
frozen	1	1	6	6
fish and fish products	1	2	0	0
fresh fish	1	2	1	0
processed fish and fish products	1	2	2	0
frozen	1	2	2	1
frozen battered	1	2	2	2
frozen minced	1	2	2	3
cooked or fried	1	2	2	4
smoked, dried, fermented, salted	1	2	2	5
semi-preserved	1	2	2	6
fully preserved	1	2	2	7
molluscs, crustaceans, echinoderms	1	3	0	0
fresh	1	3	1	0
processed	1	3	2	0
frozen	1	3	2	1
frozen battered	1	3	2	2
frozen minced	1	3	2	3
cooked or fried	1	3	2	4
smoked, dried, fermented, salted	1	3	2	5
semi-preserved	1	3	2	6
fully preserved	1	3	2	7
eggs and egg products	1	4	0	0
fresh eggs	1	4	1	0
preserved eggs	1	4	2	0
egg-based deserts	1	4	3	0
egg products	1	4	4	0
liquid	1	4	4	1
frozen	1	4	4	2
dried and/or heat coagulated	1	4	4	3
sauces, salads, spices	1	5	0	0
sauces and similar products	1	5	1	0
salads	1	5	2	0
mayonnaise	1	5	3	0
herbs	1	5	4	0
vinegars	1	5	5	0
mustards	1	5	6	0
soups and broth	1	5	7	0
yeast and like products	1	5	8	0
soybean products fermented/ non-fermented	1	5	9	0

Attributes	Level of detail*			
processed vegetables	1	7	2	0
frozen	1	7	2	1
dried	1	7	2	2
canned	1	7	2	3
cooked or fried	1	7	2	4
in vinegar (pickled)	1	7	2	5
vegetable spread	1	7	2	6
fermented	1	7	2	7
confectionery	1	8	0	0
cocoa products	1	8	1	0
cocoa mixes	1	8	1	1
cocoa spreads	1	8	1	2
chocolate products	1	8	1	3
chocolate substitutes	1	8	1	4
candies and nougats	1	8	2	0
candies	1	8	2	1
nougat	1	8	2	2
marzipan	1	8	2	3
decorations	1	8	3	0
cereals	1	9	0	0
whole, ground, or flaked grains, including rice	1	9	1	0
breakfast cereals	1	9	2	0
pre-cooked cereal products	1	9	3	0
soybean products	1	9	4	0
bakery items	1	10	0	0
breads and rolls	1	10	1	0
crackers	1	10	2	0
fine bakery items	1	10	3	0
sweeteners	1	11	0	0
honey	1	11	1	0
sugar	1	11	2	0
syrups	1	11	3	0

** Hierarchy of attribute classification*

Table 8: List of thematic attributes (2/3)

Attributes	Level of detail			
	1	**2**	**3**	**4**
Food				
dairy products	1	12	0	0
milk and dairy-based drinks	1	12	1	0
fresh pasteurised	1	12	1	1
fresh non-pasteurized	1	12	1	2
sterilized	1	12	1	3
skimmed milk	1	12	1	4
buttermilk	1	12	1	5
yoghurt drinks	1	12	1	6
flavoured milk	1	12	1	7
whey	1	12	2	0
plain whey	1	12	2	1
whey drinks	1	12	2	2
renneted milk products	1	12	3	0
fluid fermented milk	1	12	3	1
plain yoghurt	1	12	3	2
curdled milk	1	12	3	3
condensed milk products	1	12	4	0
sweetened condensed milk	1	12	4	1
evaporated milk	1	12	4	2
beverage whiteners	1	12	4	3
dehydrated milk	1	12	4	4
cream and similar products	1	12	5	0
pasteurised cream	1	12	5	1
clotted cream	1	12	5	2
milk powder	1	12	6	0
cheese	1	12	7	0
raw milk cheese	1	12	7	1
unripened cheese	1	12	7	2
ripened cheese	1	12	7	3
dairy-based deserts	1	12	8	0
pudding	1	12	8	1
fruit yoghurt	1	12	8	2
ice cream	1	12	8	3
iced milk	1	12	8	4
jellied milk	1	12	8	5
Butter, milk fat, ghee	1	12	9	0

Attributes	Level of detail			
	1	**2**	**3**	**4**
Water	2	0	0	0
usage	2	1	0	0
tap water	2	1	1	0
groundwater	2	1	1	1
surface water	2	1	1	2
carbonised at home	2	1	1	3
bottled water	2	1	2	0
carbonated	2	1	2	1
still (not carbonated)	2	1	2	2
recreational water	2	1	3	0
sea water	2	1	3	1
swimming pool/spa	2	1	3	2
river	2	1	3	3
reservoir, lake, pond	2	1	3	4
food production	2	1	4	0
ground water	2	1	4	1
surface water	2	1	4	2
irrigation	2	1	5	0
groundwater	2	1	5	1
surface water	2	1	5	2
water body	2	2	0	0
groundwater	2	2	1	0
surface water	2	2	2	0
sea	2	2	3	0
rain	2	2	4	0
glacier	2	2	5	0
wastewater	2	2	6	0
contamination	2	3	0	0
wastewater	2	3	1	0
faeces	2	3	2	0
diffuse	2	3	3	0
stormwater/sewer overflow	2	3	4	0
Pathogens	3	0	0	0
bacteria	3	1	0	0
Campylobacter spp.	3	1	1	0
Salmonella spp.	3	1	2	0
Listeria spp.	3	1	3	0
Non-cholera *Vibrio* spp.	3	1	4	0
viruses	3	2	0	0
Norovirus	3	2	1	0
Enterovirus	3	2	2	0
parasites	3	3	0	0
Cryptosporidium spp.	3	3	1	0

** Hierarchy of attribute classification*

Table 9: List of thematic attributes (3/3)

Attributes	Level of detail			
	1	2	3	4
Climate/environment	4	0	0	0
air temperature	4	1	0	0
change in temperature (increase/decrease)	4	1	1	0
change in maximum temperature (increase/decrease)	4	1	2	0
change in minimum temperature (increase/decrease)	4	1	3	0
change in average temperature (increase/decrease)	4	1	4	0
water temperature	4	2	0	0
change in increase of temperature (increase/decrease)	4	2	1	0
change in decrease of temperature (increase/decrease)	4	2	2	0
change in maximum temperature (increase/decrease)	4	2	3	0
change in minimum temperature (increase/decrease)	4	2	4	0
change in average temperature (increase/decrease)	4	2	5	0
precipitation	4	3	0	0
change in precipitation (increase/decrease)	4	3	1	0
change in precipitation pattern	4	3	3	0
(extreme) event	4	4	0	0
flood	4	4	1	0
drought	4	4	2	0
storm	4	4	3	0
heavy rainfall event	4	4	4	0
snow melt	4	4	5	0
relative humidity	4	5	0	0
increase	4	5	1	0
decrease	4	5	2	0
sunshine hours	4	6	0	0
increase	4	6	1	0
decrease	4	6	2	0
UV light	4	7	0	0
change in intensity	4	7	1	0
change in exposure	4	7	2	0
wind	4	8	0	0
change in wind strength	4	8	1	0
change in wind direction	4	8	2	0
change in frequency	4	8	3	0
cloud coverage	4	9	0	0
change in cloud coverage	4	9	1	0
seasonality	4	10	0	0
rainy season	4	10	1	0
dry season	4	10	2	0
summer	4	10	3	0
winter	4	10	4	0
change in seasonal pattern	4	10	5	0
time	4	11	0	0
time span between air temperature abnormality and event	4	11	1	0
time span between water temperature abnormality and event	4	11	2	0
time span between precipitation abnormality and event	4	11	3	0
time span between extreme weather event and pathogen/disease/outbreak	4	11	4	0
water salinity	4	12	0	0

Attributes	Level of detail			
	1	2	3	4
Reservoirs	5	0	0	0
fowl	5	1	0	0
poultry	5	1	1	0
chicken	5	1	1	1
domesticated ducks	5	1	1	2
domesticated geese	5	1	1	3
turkey	5	1	1	4
wild birds	5	1	2	0
wild ducks	5	1	2	1
wild geese	5	1	2	2
ruminants	5	2	0	0
cattle	5	2	1	0
calve	5	2	2	0
sheep	5	2	3	0
fish	5	3	0	0
salmon	5	3	1	0
trout	5	3	2	0
molluscs	5	4	0	0
clams	5	4	1	0
oysters	5	4	2	0
reptiles	5	5	0	0
crocodiles	5	5	1	0
snakes	5	5	2	0
rodents	5	6	0	0
mice, rats,	5	6	1	0
rabbits, beaver, etc.	5	6	2	0
pigs	5	7	0	0
pets	5	8	0	0
cats	5	8	1	0
dogs	5	8	2	0
reptiles	5	8	3	0

** Hierarchy of attribute classification*

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