Moving towards a new discipline - Health ecology

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Health is subject to a variety of hazards, especially climatic ones. The future management of health requires urgently the development of models that incorporate climatic variables and the characteristics of ecosystems where diseases develop...without forgetting the human aspect!

Climate and health are closely linked. Human health, but also plant and animal health are subject to seasonality. If the climate changes, disease seasonality is expected to also change. This raises the question of the consequences of climate change on health. Are they always negative, as certain articles or alarmist reports would lead us to believe? The situation is complex and therefore, naturally, much more nuanced. Clearly, weather extremes, such as heat waves, floods and violent storms will become more intense and more frequent in years to come, which could lead to increased mortality and decreased efficiency of health systems.

However, this impact is still difficult to estimate, as we are unable to predict the frequency of these events, while they will remain rare. Another expected consequence of climate change on health will concern modified environmental risks, through increased exposure to ultraviolet radiation or atmospheric pollutants such as ozone. Certain effects will be harmful, but others could prove to be positive by prompting, in some places, the disappearance of harmful viruses, bacteria or fungi. Here again, the general impact, of which we understand very little, remains uncertain.

Outbreak of epidemics

Over the past 20 years, research on the consequences of climate change on health has focused mainly on infectious diseases, due to the multiplicity of factors involved in an epidemic outbreak and to interest in the subject by ecologists, entomologists and zoologists.

As we have just pointed out, the systems are complex because they involve so many interactions. We can begin with the simple biological systems, in which two species interact, the host and the pathogen, developing in a natural ecosystem. We can simplify this further considering the hosts with non-regulating body temperatures - such as plants, insects, reptiles or fish - and who are, consequently, highly susceptible to ambient weather conditions and their changes.

In the case of sudden oak death, an infectious disease caused by a fungus, global warming appears to be responsible for the spatial progression of this disease in some tree species, for example, the red oak in America and the common oak in Europe. Using numerical simulations to model winter survival of the pathogen depending on the temperature of its microhabitat (phloem of infected trees, which is the vascular tissue in plants that conducts elaborate sap), the French National Institute for Agricultural Research (INRA) and Météo-France established that this fungus is expected to gradually move eastward in France, which will result in a potential increased spread of this disease throughout the majority of the territory by the end of the 21st century.

Conversely, positive effects of climate change have also been reported. This is the case for a study conducted in the framework of the CLIMATOR project (2007-2010) which focused on three diseases affecting annual crops: the Septoria leaf blotch for wheat, wheat stem rust and Botrytis (gray mold) affecting grape vines – all caused by fungal pathogens. Numerical models taking into account temperature change and air moisture content were used to estimate the duration of the time period over which water is present on the surface of the leaves, especially for wheat. Indeed, infection by the microorganism causing the wheat stem rust requires the presence of liquid water on the leaves for a minimum period, which is dependent on temperature. For the regions of Dijon and Colmar, simulations indicate that the duration of the periods when infection occurs are expected to decrease by roughly 30 percent by the end of the century, which would lead to lowered risk of stem rust infection of wheat. However, to know the precise duration of infection, we need to consider the influence of climate change on crop dynamics, as well as the effect of predicted earlier sowing dates, which has not yet been implemented. While these preliminary studies are encouraging, they need to be confirmed and expanded to include other crop fungal diseases.

Regarding animals, the case of the Virginia oyster on the Atlantic coast of North America is particularly demonstrative, confirming the simple and direct link that exists between climate change and the development

Immunization against influenza, which affects millions of people each winter, helped significantly to reduce the mortality of more vulnerable people.

The paradox of winter mortality

In France, the 2003 heat wave resulted in the death of roughly 15,000 people, not considering its consequences on the ecosystems and infrastructures. Despite this episode, the mortality rate in temperate regions in the northern hemisphere is surprisingly much higher in winter than during any other season.

According to a review published in 2012 by Patrick Kinney and his colleagues at Columbia University in New York, death rates are generally higher in winter in temperate countries, like Western Europe. In a context of rising global temperatures, this winter mortality rate could increase even further for populations living in hot countries. Cardiovascular or inflammatory complications from respiratory infections, as in the case of flu, are among the possible causes of this still not well understood phenomenon.

Before any generalizations can be made, it should be noted that there are important local and global geographical disparities in winter mortality occurrence. Furthermore, reliable ecological and epidemiological data are scarce although they would be necessary to predict the impacts of climate change on human health, to identify the most vulnerable populations, and to define appropriate preventive and adaptive measures.

of epidemics. In this case, rising surface water temperatures supported the winter survival of the parasite responsible for an infectious disease, perkinsosis, which affects the Virginia oyster: since late 1940's, the range of this disease has progressed more than 500 kilometers to the North.

The role of temperature

In terms of impacts of climate change, experts agree that mean temperature variations will play an important role in the development of infectious diseases. By influencing metabolism levels of parasites and host organisms, these variations influence the speed microbial agents develop and, as a result, the expansion or reduction of the range of the disease they cause.

Temperature is easier to use than other physical variables to test climate change scenarios. This state variable does not depend on the size or range of the system being considered and experiences much slower fluctuations than rain, a cumulative flux variable. In addition, temperature affects the speed of all biological processes, while rain affects more specifically, for example, fungal infections for plants and the dispersion of spores and bacteria.

Even if we accept the fact that the frequency of extreme events is going to increase, for example the frequency of long-term rainy periods, the intermittent nature of rain and uncertainty in data collected on a daily scale; make it difficult to determine hourly distribution. This is a challenge for meteorological research as it is occasionally necessary to work with data taken on a time scale shorter than one day. Longer lasting summer droughts present another form of extreme event that could limit, or even stop, the spread of fungal disease, which is transmitted both through the air and within soils, particularly among drought resistant host plants.

Diseases and their vectors

Now consider the case of human vector-transmitted diseases, such as malaria, dengue and yellow fever. These more complex infectious systems spread from one host to another via vectors - small arthropods that feed on blood, like for these three diseases spread by mosquitoes. In humans, vector-borne diseases are responsible for close to a quarter of emerging epidemics identified worldwide. As vectors do not regulate their internal temperature, their development is weather-dependent, which consequently affects their survival, fertility and dispersal. Weather conditions also determine the growth of the parasite and, to a lesser extent, the interactions between the vector and its pathogen, and interactions between the vector and the host.

In the current context of climate change, vector-borne diseases are being closely observed by epidemiologists. In the northern hemisphere, the distribution of certain vectors, such as the *Ixodes ricinus* tick, has already changed. This vector for a number of diseases, particularly Lyme disease and tick-borne encephalitis, has progressed to the north of Sweden. In 16 years, the area in which this tick is present has doubled *(see illustration on opposite page)*.

Climate change also influences the distribution of "reservoir" species which may host pathogens. This can be seen in North America where the range of the white-footed mouse, the principal breeding reservoir of the bacterium *Borrelia burgdorferi* responsible for Lyme disease, expanded yearly by 10 kilometers to the North.

Since the early 2000s, predicting changes in vector distribution has become an active field of research, due to developments in modeling of ecological niches described by a set of biological parameters and physico-chemical factors. However, while essential for the dissemination of these types of diseases, the presence of a vector is not a solely sufficient condition to cause the development of an epidemic. Even if climate change plays an influential role in the shift of distribution areas for certain vectors, it is difficult to determine precisely how it influences the increased occurrence of


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Caused by a fungal pathogen, the wheat stem rust disease manifests on the surface of the leaves as small orange pustules containing spores.

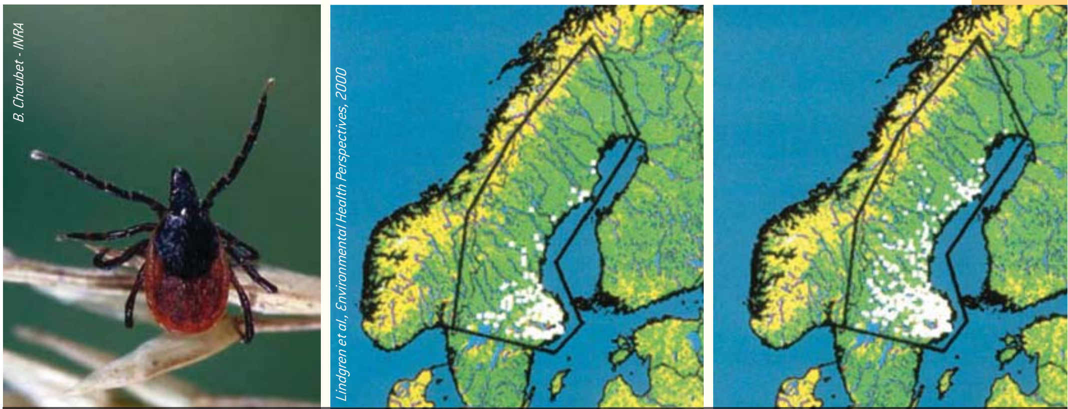
these diseases in regions where they were already present.

The role of humans

The situation complicates further when we take into account human activities. Bluetongue disease (or also named catarrhal fever), illustrates the complex and sometimes misleading links between climate change and the spread of an epidemic. Bluetongue disease affects ruminants but not humans. This vector-borne disease is caused by a virus, which is itself transmitted by small midges of the *Culicoides* genus. Bluetongue disease epidemics were identified in North Africa where the virus was transmitted by a species of midge *(Culicoides imicola)*, whose presence had never been recorded on the European continent. However, in the 1980's and 1990's, this species was detected in its northernmost range ever recorded: in Italy, Sardinia, Corsica and soon after in the South of France. In Europe, it was feared that this epizootic disease (an epidemic outbreak in an animal population) would come from the south. But it was in the Netherlands where the outbreak occurred in August 2006. Over several years, the epidemic spread at a speed of five kilometer per day in all directions, causing important economic damage to sheep and cattle farms across Western Europe: livestock abortions, a decline in milk and meat production, mass vaccination campaigns, trade restrictions, etc.

Due to the location of its origin, the directions of its spread and the responsible virus (BTV8, a different viral form than the one that is present in North Africa), this epidemic presents a spatial dynamic that cannot be directly linked to climate change. Subsequently, it was also observed that the biting midges involved in transmitting BTV8 did not correspond to *Culicoides imicola*, but to other native species, which had previously not been considered as effective vectors. Genetic studies have also established that these midges detected in Southern Europe had been there for a long time. Thus, the apparent progress of *Culicoides imicola* to Northern Europe can mostly be attributable to augmented efforts in monitoring its presence and tracking its biogeographical distribution.

However, climate change cannot totally be exonerated. A cross-analysis of changing weather conditions in the 1960's and a model describing the population dynamics of vectors and host organisms for this disease showed that the summer of 2006 corresponded to a period of high risk for an outbreak in Northwestern Europe. And, beyond climatic factors facilitating the transmission of the virus, every indication suggests that its introduction was linked to human activities such as importation (illegal or accidental) of livestock animals or vectors. This example shows how it is sometimes difficult to identify the role of climate changes, or any other types of changes, when human activities play a central role: transporting populations or goods of animal or plant origin, land-use changes, introducing biological control agents, decreasing biodiversity affecting host reservoir species and predators, etc.



The tick Ixodes ricinus (left), *the main vector species for vector-borne diseases affecting humans in Europe, should continue to spread northward in the 21st century. In Sweden, its distribution range* (white points) *doubled between the early 1980's* (center image) *and 1990's* (right image).

The main causes of outbreaks

Among the multitude of existing scientific and institutional publications who have aimed to highlight the impact of climate change on human health, the work of Mark Woolhouse and Sonya Gowtage-Sequeria, from the Centre of Infectious Diseases at the University of Edinburgh, Scotland, is particularly interesting. By compiling a fully comprehensive database, they classified the main causes for the emergence and dispersion of 177 infectious agents that have emerged since the 1960's. Their conclusions dispelled a misperception: they determined that climate change does not play a key role in the emergence of new infectious diseases, but quite the opposite. In the classification that these epidemiologists have established, it appears that it is the least important factor, at least in 2005 when this study was published. The natural genetic evolution of microorganism comes in fifth place. A good example is the mutation of the Chikungunya virus that occurred in September 2005 on Réunion Island, which triggered a large-scale epidemic that struck more than 300,000 inhabitants of the islands in the Indian Ocean. Demographic, societal and behavioral (particularly high risk practices) changes place second. Using ecological niche models, a recent study on the transmission of dengue fever also showed that its spread was mainly due to high population density, unsanitary conditions and human transportation networks. Finally, in first place, come changes in land uses and agricultural and agronomical practices. Through their activities, via behaviors and socio-economical organization, humans are the most responsible for the emergence and spread of new pathogens.

The case of the vector-borne diseases transmitted by ticks illustrates the role that changing socio-economic conditions play on the prevalence of certain diseases. The prevalence of tick-borne encephalitis has increased in the Baltic since the early 1990's. Unlike Lyme disease, which has never been the subject of a systematic census, tick-borne encephalitis has been well characterized for over forty years, yielding in high quality data. However, in each of the Baltic countries studied (Lithuania, Latvia, Estonia), significant variability among regions from one year to another has been observed. This suggests that climate change - which occurs relatively homogenously over large areas - is not the sole cause at work. Sarah Randolph and Dana Sumilo, from the University of Oxford, showed that climate change - with an average annual increase of maximum temperatures (from 10° to 11°C) between 1988 and 1990 - is one of the causal factors, but cannot explain the spatial and temporal heterogeneity in observed cases. They suggest that the resurgence of tick encephalitis observed during this period would be the result of socio-economic transition experienced in the Baltic countries in the early 1990's with the collapse of communism and the former Soviet Union. At that time, many inhabitants of these countries increased their risk of exposure to the vector for this disease by frequenting forests: the poorest populations in search of revenue sources or additional resources collected mushrooms and berries in these areas; but also the wealthiest populations as their leisure activities increased, particularly in the countryside. Abandoned collective farms also lead to changes in land use (lands left fallow, for example), which would have promoted the spread of ticks and so the disease agents they can host in areas where wild and domestic fauna closely interact.

Through all of these examples, we can see that the impact of climate change on infectious diseases is at once complex, highly variable and difficult to study. On one hand, it involves several actors: pathogens, host reservoir and/or vector species as well as human interventions. On the other hand, several physical variables are acting such as temperature, humidity, wind and precipitation, whose changes are estimated by analyzing their average values as well as their extreme values, and more generally, their variability around the mean during a given period.

All of these parameters are often interdependent and their relationships to the prevalence of infectious diseases are not always linear (i.e., parameters and prevalence do not vary in the same proportions). Relevant spatial and temporal scales to analyze these processes are also highly variable: from a few square centimeters for spore dispersal caused by rain, to the global scale for climate change. This poses serious problems when identifying the relevant level of observation, as certain emerging properties are observable only at higher levels of integration. Such properties will appear at the population or ecosystem level, for example, but are not perceptible at the individual level.

Finally, the systems responsible for disease occurrence are neither fixed nor constant over time, as each actor evolves according to changes in the population genetic composition, prompted by various selection pressures in interactions between hosts and pathogens, or by the environment, for which climate is only one factor.

Principal causes of the emergence of new infectious agents

Rank	Emergence Factors	Examples
1	Changes in land use, agricultural and agronomical practices	Nipah Virus in Southeast Asia
2	Demographic, societal and behavioral changes	Pertussis, HIV, syphilis
3	Precarious sanitary conditions	Cholera, Tuberculosis
4	Related to hospitals (nosocomial) or health care errors.	*Staphylococcus aureus*, *Pseudomonas aeruginosa*
5	Evolving pathogens (i.e., Chikungunya, antibioresistant forms, mutations)	A/H1N1 virus, H5N1 virus
6	Food or water contamination	*E. coli*, BSE, *Salmonella*
7	Travel or intercontinental exchanges	Dengue fever, seasonal influenza, H5N1 virus
8	Unorganized health and monitoring systems	Central Africa sleeping sickness, tick diseases and tuberculosis in the former USSR
9	Transportation of goods and animals	*Monkeypox* Virus, H5N1 virus, *Salmonella*
10	Climate change	Malaria in East Africa, Dengue fever in Southeast Asia, visceral leishmaniasis in Southern Europe (strong suspicion)

This ranking was realized on the basis of 177 infectious agents, responsible for emergent infectious diseases affecting human populations since the 1960's.

Health ecology

This is why a broader framework, combining ecology and evolutionary biology, has been proposed to address these complex issues. In addition to the One Health/One World approach, which is less concerned with the environment, we also have the EcoHealth approach which highlights "sharing responsibilities and coordinated global actions for managing heath risks at the animal-human-ecosystem interface levels" and the importance of "strengthening collaborations between human health, animal health and environmental management". It is about broadening the scope of analysis, traditionally centered on the health of individuals, by considering changes in ecosystems, the influence of planetary changes (particularly climatic) and the loss of biological diversity, with each of their direct and indirect interactions.

Health ecology reflects awareness of shared responsibilities and the need to strengthen actions concerning human, animal and plant health, and the management of the environment. This integrative approach should help to avoid the error of artificially isolating the effects of climate change from other changes caused by humans, which are involved in developing epidemics (land use changes or the introduction of invasive species related to human movement or transportation of goods, for example).

In the animal and plant health domain, the consequences of climate change are still largely unexplored, which explains the launch in 2014 by the French National Agency of Research (ANR) and the European Commission of new research programs. In this framework, increasing resilience of ecosystems, the role of biodiversity and the development of a transdisciplinary and participatory approach (involving researchers, businesses, farmers, managers, etc.) are included among the themes put forward for several major research programs.

Anticipating the changes

In the plant health domain, the main objectives relate to reducing the use of pesticides and facing global warming. Another important problem has emerged: the feedback of plant health on climate. Strongly affected, or even destroyed, crops or forests will release higher levels of carbon dioxide into the atmosphere, caused by plant dieback and higher mineralization of soil organic matter.

Given the complexity of the considered phenomena, modeling is a crucial tool. It gives the opportunity to project into the future and create likely scenarios in order to anticipate and better manage expected changes. However, for modeling tools to be relevant, accurate and informative, they require high quality data collected over long timeframes and wide spatial dimensions are needed, which is currently lacking in French research.

For human infectious diseases, for which the pathogen can persist for years or decades in the environment in the absence of its host (such as tetanus, anthrax and legionnaire's disease, for example), it is impossible to definitively conclude to the total absence of the infectious agent in a given location. Therefore, health surveillance does not permit - or makes it very difficult - to respond to questions concerning the influence of climate change in particular, for this requires a comparison of situations where the disease is present with others where it is absent.

In this context, long-term observatory systems, such as the Long Term Ecological Research Network, are particularly valuable. They should soon be able to integrate epidemiological research related to the effects of climate change on diseases affecting humans, animals and plants, which will improve the accuracy of numerical models.

Lastly, it is crucial that emphasis is given to the fact that identifying and quantifying the effects of global changes on health is a challenge that can only be met if climatologists, epidemiologists, modelers, ecologists, entomologists, microbiologists, parasitologists, immunologists, socioeconomists - among others - work together on one integrated project.

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Mosquitoes of the Aedes *genus spread the Chikungunya virus from one human individual to another by stinging them. This tropical disease is also called "disease of bent humans" because it causes strong joint pain associated with muscle stiffness.*

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