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Drivers for emerging issues in animal and plant health

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Abstract

The history of agriculture includes many animal and plant disease events that have had major consequences for the sector, as well as for humans. At the same time, human activities beyond agriculture have often driven the emergence of diseases. The more that humans expand the footprint of the global population, encroach into natural habitats, alter these habitats to extract resources and intensify food production, as well as move animals, people and commodities along with the pathogens they carry, the greater the potential for pathogens and pests to spread and for infection to emerge or re-emerge. While essential to human well-being, producing food also plays a major role in disease dynamics. The risk of emergence of pests and pathogens has increased as a consequence of global changes in the way food is produced, moved and consumed. Climate change is likely to increase pressure on the availability of food and provide newly suitable conditions for invasive pests and pathogens. Human population displacements due to economic, political and humanitarian crises represent another set of potential drivers for emerging issues. The overlapping drivers of plant, animal and human disease emergence and environmental changes point towards the concept of 'One Health'. This paradigm underlines the urgent need to understand the influence of human behaviour and incorporate this understanding into our approach to emerging risks. For this, we face two major challenges. One is cultural; the second is methodological. We have to look at systems not under the narrow view of specific hazards but with a wider approach to system dynamics, and consider a broad spectrum of potential outcomes in terms of risk. In addition, we have to make sense of the vast amounts of data that are available in the modern age. This paper aims to help in preparing for the cultural and methodological shifts needed in our approach to emerging risks.

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1. Introduction

An emerging risk to plant, animal and/or human health may be defined as a risk resulting from a newly identified hazard to which significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard (EFSA, 2007). The history of agriculture includes many developments related to plant and animal health, some of which have had a major impact on the sector. The successful identification of risks at their early inception is at the heart of public health and environmental protection (Robinson et al., 2012). Understanding the environmental, epidemiological and social factors that lead to emerging infectious diseases in plants and animals may help prevent future outbreaks.

The concept of drivers is used in different fields, including economics, social sciences, technology, health and environmental sciences (EFSA, 2014). They are defined as issues shaping the development of a society, organisation, industry, research area, technology, etc. They may act as facilitators or modifiers of effect on the onset of emerging risks. Namely, drivers can either amplify or attenuate the magnitude or frequency of risks arising from various sources.

Human activities have often driven the appearance of emerging issues. The more that humans expand the footprint of the global population, encroach into natural habitats (i.e. not previously inhabited or otherwise significantly altered by humans), alter these habitats to extract resources, intensify food production, as well as move animals, people, commodities and their pathogens, the greater the potential for infections to emerge or re-emerge and for pathogens and pests to spread (Jones et al., 2008; Bebbler et al., 2014).

Producing food creates and augments such drivers. Food production is a human activity, through which man is considered to have the largest environmental impact on the planet. As an example, food production uses twice the amount of water compared to all other human activities combined. The risk of emergence of new pathogens and the spread of existing ones has also increased as a consequence of deep and global changes in the way that food is produced and consumed, as well as many other factors that characterise the Anthropocene, an epoch that begins when human activities started to have a significant global impact. Rather than static practices, change is a key factor, with land-use change and agricultural industry changes being the two most commonly associated drivers of infectious disease emergence (Loh et al., 2013). These trends in changing land use and agricultural practice are likely to continue into the immediate and longer term future considering that, by 2050, the global population is expected to grow significantly, potentially reaching over 9 billion. The financial income of a substantial part of the global population is expected to increase to be nearly three times what it is today with expected changes in food habits such as an increased demand for meat. These new habits, and shifting demands, will result in an effort to increase food production, which will place a greater burden on the resources of the planet.

At the same time, climate change is likely to increase pressure on the availability of food because of a reduced reliability on seasons, and extreme climatic events such as droughts or heavy rains. Climate change will also provide new habitats for living organisms, including not only crops but also invasive species, as well as pests and pathogens.

Population displacements due to multiple and overlapping political and humanitarian crises which have occurred in several parts of the globe over the last few years will probably be a feature of the future and will also represent a potential for the spread of pests and pathogens, and the consequent emergence or re-emergence of infections outside their current zones of endemicity.

Change is not only a threat to plants and animals, but also may have direct and indirect consequences on public health, either because of the impact on livelihoods, including food shortage, or because of zoonotic impact of new pathogens on humans, or antimicrobial resistance (Greger, 2007; Liverani et al., 2013). Indeed, the overlapping drivers of diseases and environmental changes, as well as their interwoven implications, point towards the relevance of the concept of 'One Health', an integrated view and approach to human, animal and environmental health (Karesh and Cook, 2005).

The recent outbreak of Ebola virus disease affecting Western Africa is the largest ever documented Ebola outbreak, with reported cases and deaths that have exceeded any previous historical outbreaks. It is also the largest outbreak in terms of geographical spread. A legitimate question was raised about 'why there and why then?' (Bausch and Schwarz, 2014). In order to identify the drivers for this spillover of Ebola virus from animals to humans, which triggered the rapid spread of infection within a geographically dispersed population, a set of drivers was identified from the scientific literature. This corpus of papers (including original research and review papers) was then used to analyse the network of drivers and visualise their behaviour (EFSA, 2015). The analysis included 40 drivers, which were

found to be connected through 142 linkages. The visualisation of the driver network revealed a few central drivers involved in the spillover. Two main limitations were identified during the project. One of them was the limited number of documented spillover events from which scientific evidence was available. The second was the limited number of publications, which specifically, or explicitly, use the concept of drivers.

The example of Ebola virus disease in Western Africa and its dramatic consequences reminds us about the need for emergency preparedness and a response to detect the emergence of outbreaks in a timely manner for their rapid containment, mitigating their devastating effects on the society at large in the affected countries. Such events continue, as evidenced by the recent outbreak of Zika virus in the Americas. Emergency preparedness and timely detection are, however, distinct from the identification of emerging risks, which, in essence, is based on forecast. The lack of understanding of the drivers that lead to such an outbreak, their spatial and temporal heterogeneity, as well as their interconnections across the affected region and even beyond, may hamper our ability to prevent similar future outbreaks. It also reminds us about the urgent need to explicitly take into account the interactions between environmental, epidemiological and socio-economic factors.

Most drivers for emerging issues are common to human, veterinary, plant and ecosystem health. In order to avoid a dilution of efforts in identifying, describing and monitoring those drivers, such efforts should be developed collectively by the relevant communities. Several initiatives have engaged in fostering synergies and aim to bring together human and animal health, social development, ecology, economics, and other sectors to investigate connections between health and environmental change, thus generating scientific evidence and policy options to limit the impact of emerging diseases and, even more importantly, prevent them from occurring.

The challenge is to understand the influence of human behaviour and to incorporate this understanding into our approach to emerging risks. For this, we probably face two major obstacles. One is cultural; the second is methodological. We have to look at systems not from the standpoint of specific hazards but for the dynamics of the systems themselves, and a broad spectrum of possible outcomes. The second challenge is to make sense of the vast amounts of data that are available in our post-modern age.

2. How to prepare for the challenge ahead?

There is a need for a cultural and methodological shift in our approach to emerging risks for plant, animal, ecosystem and human health.

A cultural change is required in relation to our capacity to look at systems not from the narrow standpoint of a specific hazard but from the perspective of the dynamics of the system, and a spectrum of possible outcomes related to plant, animal, ecosystem or human health.

A methodological change is also required, which relates to our capacity to make sense of the vast amounts of data that are available in our digital era (Scherm et al., 2014). At the same time, much of the available data on animal, plant and human epidemics is still being collected using arbitrary administrative spatial units, which do not always correspond to the best resolution from an epidemiological and disease management perspective (Thompson et al., 2016).

For this to happen, it is important to learn the lessons from historical outbreaks, and to have systems in place so that we can learn from future incidents; understand how hosts, pathogens and their environment are interlinked; and, finally, use our knowledge about drivers to improve our capacity for preventing and detecting emergence. We need to explore how natural and social sciences can find synergies in systemic analysis of emerging issues providing better identification, description, monitoring and management of their drivers (Mills et al., 2011).

2.1. People, animals, plants, pests and pathogens: connections matter

With globalisation and international travel, disease movement is now rapid and what were once natural barriers to the spread of disease beyond its local point of origin are becoming immaterial (Banks et al., 2015). Significant proportions of natural or agriculturally based resources harvested or produced in developing countries are further processed or consumed in economically more advanced countries, providing regular routes for hitch-hiking organisms (Eschen et al., 2015). Similarly, developing countries often are not self-sufficient in various food commodities and need to import them, hence being at risk of importing new pests or pathogens. Nowhere in the world are the health impacts from infectious diseases more important than in developing countries, where daily work and

livelihoods are highly dependent on natural resources, plants and animals. Many developing countries have little to no capacity for the diagnosis of endemic diseases, nor for detecting disease emergence prior to their spread to crops, animals or humans. The linkages of human, animal, plant and environmental health are at the heart of the One Health approach, an increasingly important prism through which governments, non-governmental organisations and practitioners view the public good that is health. While the principles underlying the evolution and ecological principles of disease emergence have not changed, changes in human activities have shifted the playing field on which these natural laws act (Karesh et al., 2012).

2.2. Relations between pathogens, hosts and environments: joining the dots

Understanding the risks and drivers of emergence of pests and pathogens requires extensive knowledge of the types of microbes present in plants, animals and the environment, and their potential for cross-species/domain spread of disease-causing organisms, as well as the risk of commensals becoming pathogens. For example, human foodborne pathogens include microbes present in food-producing animals or the wider environment that we acquire by eating contaminated food. There is, however, a significant under-representation of plant, animal and environmental pathogens in the scientific literature compared to pathogens of human beings. Studies of pathogen diversity report over 40% more pathogen species known in humans alone than in up to 50 domestic animal species combined. A key research challenge is to identify the characteristics of pathogens that give them the propensity to be infectious, or be infectious to species or groups of species other than those already known to be susceptible. Considering the specific issue of zoonotic risk, key questions are: are some pathogen types (such as bacteria, viruses) more or less likely to spread from animals to humans? Are we humans most likely to acquire zoonotic pathogens from the animals that we eat (livestock), the ones we share our homes with (pets) or the ones we are most similar to genetically (primates)? And what about the few plant pathogens affecting humans (e.g. *Cryptococcus gattii*; Hagen et al., 2013)? And is the transmission route important? Are we more likely to share foodborne pathogens with animals, than those that are transmitted by direct contact, by aerosol or by sexual contact? Are we overlooking the consequences for human health of regional outbreaks of exotic plant pests and pathogens (e.g. emerald ash borer) (Donovan et al., 2013)? Data on pathogens and hosts can be acquired using automated procedures applied to online data sources, such as the metadata uploaded with gene sequences, and the abstracts of biomedical papers. Media monitoring and social media are also a source of unstructured data (Galaz et al., 2010; Daume et al., 2014; Alomar et al., 2015; Daume, 2016). A pathogen/host database, such as the Enhanced Infectious Disease Database (EID2) can be used to address questions about the relationships between pathogens, hosts and their environment. At present, for example, the EID2 database holds information on 1,606 human pathogens, of which half are zoonotic, and 1,038 pathogens of domestic animals. Using network analysis, the human and animal hosts (dots) can be joined by the pathogens that they share, with the strongest joins for those that share the most pathogens. Joining the dots creates pathogen networks that can then be used to assess which types of host are the major source of pathogens for humans; and the network properties can be compared for different types of pathogen and those with different properties, such as transmission route. Such an approach should be further expanded to include more plants and environmental isolates.

2.3. Discovering novel pathways of cross-species pathogen transmission

Emerging methods in epidemiology have the potential to inform a comprehensive assessment of how pathogens might move from natural settings into agricultural areas and human habitations and vice versa pathogen spill over from agricultural areas into natural or semi-natural environments (Freer-Smith and Webber, 2015). The search for new disease transmission pathways could be independent of the pathogens themselves, which may be unknown, lurking undiscovered in reservoirs, or not yet even evolved. An organism in its native environment might not be pathogenic, but can become so when introduced into a new setting; as shown, for example, by *Hymenoscyphus fraxineus*, an Ascomycete fungus causing ash dieback, a chronic fungal disease of ash trees (*Fraxinus excelsior*) in Europe characterised by leaf loss and crown dieback in infected trees, subsequent to its introduction in Poland at the beginning of the 1990s. The fungus appears to

live endophytically without causing symptoms on *Fraxinus mandshurica* commonly called Manchurian ash, a medium to large deciduous tree, native to wooded slopes and open valleys of northeast Asia and Japan. Moreover, multiple pathogens traverse common transmission pathways, such that disrupting these pathways would have wide-ranging health impacts beyond individual diseases. The expected benefit would be at a level not fully attainable by any other approaches. A caveat to this would be that these pathways could also be important for microorganisms conferring health benefits, such as improving nutrient/vitamin availability or beneficial immune modulatory effects. Taking the example of zoonotic risk, many undiscovered transmission pathways involve human cultural practices that bring people into contact with reservoirs or vectors at times in places that are especially suitable for subsequent human-to-human transmission. Some pathways may not presently be traversed by any known pathogens, making them invisible to traditional epidemiological approaches. To discover them would require a re-focusing of efforts by epidemiologists and social scientists working together to better understand pathways of transmission among plants, animals and humans.

2.4. Understanding disease drivers, ecology and pathogen evolution

With pests and pathogens posing growing concerns with regard to plant, veterinary and human health, the disentangling of the underlying ecological disease dynamics has become a matter of attention. A historical perspective on agriculture, and more particularly livestock, shows that the long-term evolutionary pull is towards an ever increasing intimacy with the host, for pathogenic viruses, endoviruses and commensals. In animals, intimate pathogenic viruses may circumvent the outer defence lines, cause subclinical infection and yet infiltrate inner-body organs and vital systems, resulting in life-long infections that are vertically transmitted, selecting for greater host specificity. Host radiation thus appears more of a feature typical for opportunistic myxoviruses. However, given the enhanced ecological perturbation at the interfaces of the livestock, wildlife and human host domains, long-term interdomain and interspecies barriers are breaking down, permitting spillover and species jumps by pathogenic viruses. Livestock bacteria reside chiefly on the skin and mucosal tracts, supporting the host health rather than being harmful. Novel forms of clinical disease may appear when a bacterium succeeds in infiltrating inner-body environments, as seen recently in the Netherlands with the emergence of virulent Q fever in intensive goat dairy systems. Arguably more important is the evolution of new strains and toxins in the enteric tract environment of fast growing food animals. In particular, the use of antibiotics as growth promoters interferes with the functioning of the enteric tract microbiome, metabolism and immune system. Indeed, most modern livestock diseases and food safety challenges appear to be the result of an intensification process that has been driven too far.

2.5. Horizon scanning for emergence of new viruses in animal and public health

Horizon scanning is the approach to predict the next pathogen to emerge in animals, plants and/or being a threat for public health, both in terms of its route(s) of transmission and its origins (i.e. country and source reservoir). The emergence of a pathogen generally involves a combination of events together with a change in key drivers, typically socio-economic, environmental, climatic and/or zoological factors. Central to horizon scanning, therefore, is the construction of 'complex scenarios'. In a novel approach developed at a European Science Foundation-funded workshop in 2010, complex scenarios in the form of 'spidergrams' were produced by randomly linking factors, which may directly or indirectly affect the emergence of pathogens. The focus of the exercise was on viruses. The factors were chosen from a database under eight header categories (as defined by the workshop participants). Many thousands of scenario chains can be produced by this method and most may be irrational. However, the approach enables the testing of combinations not previously considered but which would be tested in nature. While it may not be possible to develop quantitative risk assessments for each combination, the approach provides a discussion focus for scientists of different disciplines and may help address identification of 'unknown-knowns' and even 'unknown-unknowns'. A problem with relying on such complex webs of putative drivers for prediction and management is that slight variation in the initial conditions will result in substantial impacts on the outcome of simulations based on those webs of drivers. An additional problem may be that both researchers and policy-makers might not be aware of such an issue.

2.6. Mapping complexity: visualising a world of change

Controversy mapping is a formal teaching and research methodology developed in the field of science and technology studies to deal with the growing intricacy of socio-technical debates. The aim of controversy mapping is to open up the assumptions, sometimes undeclared (the 'black boxes'), of science and technology and expose the complexity of their construction; not to debunk them, but with the objective to show the amazing amount of work required to build them and to associate more and more actors with such a work. The political aim of controversy mapping is to provide innovative methods to approach scientific and technical disputes. Instead of being concerned that the public is exposed to a disagreement, controversy mapping questions what advantages can be drawn by rendering controversies more 'readable' by the public. Instead of focusing on how science might be contaminated by political interference and lamenting the fragmentation of society, controversy mapping questions under what conditions public intervention enhances scientific discussion, as well as what tools can be harnessed to help citizens navigate controversies. The metaphoric use of the word 'mapping' is by itself controversial. Although few of these projects resemble standard geographical maps, controversy atlases have the same objective of classic travel atlases and they struggle with the same difficulties. They aim at providing as much detail as possible on a region while remaining compact and legible. They also aim at respecting the unique characteristics that define a territory, while translating them into a standard visual language; only these atlases display issues or matters of concern. In this sense, the words 'atlas' and 'map' should be taken somewhat metaphorically (in the same way as one can talk about botanical or medical atlas). Not so much because our territories are discursive more than geographical, but because the quality and the standardisation of our maps are still far from that of proper atlases. Developing such maps, and the standards required to ensure their universality and comprehensibility, requires the collaboration of experts from different camps in the debate, and the exploitation of digital data and computation to follow the weaving of techno-scientific discourses, with the design of making such complexity readable for a larger public. As mentioned earlier, this methodological approach has been applied to studying drivers for spillover events of Ebola virus. This methodology allows visualisations, or maps, of proposed interactions between drivers potentially leading to a spillover. It is considered that such maps, and their dynamics with time and data, may inform on risk of emergence.

2.7. A global operations room

The need and the expectation that control and prevention will involve coordinated action across scientific, organisational, geographical and political boundaries are greater today than at any time before. It is now possible for a person to travel from one side of the globe to the other in less than the time that it takes for most infectious diseases to become symptomatic following exposure to a source of infection. The experience of severe acute respiratory syndrome (SARS), the 2009 influenza pandemic, Middle East respiratory syndrome coronavirus (MERS-CoV) and gastrointestinal outbreaks such as that associated with sprouting fenugreek seeds in Germany demonstrates the need for rapid and coordinated international action to control outbreaks and emerging infections. A similar need has become clear after several plant health emergencies, including *Xylella fastidiosa*, ash dieback and *Phytophthora ramorum* (Pautasso et al., 2015). International legislation and agreements, such as the EU Decision on Serious Cross-Border Threats to Health (2013) and the International Health Regulations (2005), reflect the need for formalised threat detection and response coordination arrangements at the international level. Coordination could be delivered at the global level, through a global operations room. The purpose of a global operations room, whether it be virtual or a single physical entity, would be to ensure that appropriate decisions are made and appropriate actions taken in response to emerging threats. The function would be to bring together the appropriate information and the appropriate expertise, and to provide the technical and organisational infrastructure to support threat detection and response coordination. There are many questions and challenges that need to be addressed in the setting up of such an operations room, including the establishment of the political mandate and mutual trust required to ensure effective coordination between national and supra-national authorities; creating the network of expertise required to enable the operations room to deal with the full range of threats requiring global coordination; developing the technical infrastructure for threat detection and communication, and for coordination of the response; and establishing standard operating procedures for escalation and de-escalation of the threat response, and for command and control arrangements in risk management.

3. Conclusions

Emerging disease risk for plant and animal health is in essence a local issue with a global dimension, both in terms of impact and the necessary response. Different parts of the world may be involved differently and subject to different levels of risk. While there will always be pockets remaining unaffected or only tangentially affected by some development, including epidemics, there is no place that exists in absolute isolation from the rest of the world.

The emergence of a pathogen involves a combination of changes in key drivers, typically described as socio-economic, environmental, technological and political factors. Drivers can be used effectively in inductive scenario building and to focus discussions between the disciplines of natural and social sciences.

To improve preparedness for emerging risk, there should be a common understanding of the important role of drivers and a joint endeavour to systematically analyse the risk of emerging issues based on a better identification, description and monitoring of their drivers. Such efforts should be based not only on retrospective studies of drivers of past disease emergence events but also on prospective, predictive models of future drivers and pathways based on anticipated patterns of global change.

Most drivers are not specific to either to public, plant or animal health: there are few, if any, drivers specific to a given hazard. Therefore, driver analysis should be conducted jointly across the fields of human, animal and plant health. However, drivers may need to be considered differently depending on the compartment (crop agriculture, livestock, human, environment) and the timescale. An agile iterative spiral approach for working with multidisciplinary teams on complex scenarios is therefore needed.

Network models in a data-rich environment and spidergrams for identifying and assessing unknowns are powerful tools for investigating drivers and interactions. The analysis of drivers and pathways could give preventative insights for pathway disruption in order to move away from a traditional 'bug hunting' approach. Measuring drivers is essential and the selection of the scale (from local to global, including assessment performed at various resolutions) is important to obtain the required results in terms of informing the decision-making process.

While pathogen discovery remains an important component of preparedness, 'pathway discovery' complements this approach by revealing the human practices that cause pathogens to move from their natural settings into and throughout other compartments of the systems, be they plants or animals. The monitoring of such pathways can help in determining not only their transmission and emergence but also their evolutionary trajectory (from benign coexistence to endemic pathogen), as well as providing points of entry for prevention and intervention.

Considering the inherent connections between people, animals, plants and their pathogens, one of the key challenges is to identify the characteristics of those pathogens that give them the propensity to become infectious to plants, animals and humans. Implicit in the concepts of natural settings and evolution is the concept of ever-changing relationships between hosts, their pathogens and their environments.

Big data sets may help in tackling the challenges of connecting the dots; addressing complexity requires developing our capacity to produce representations and visualisations of this complexity in the form of maps and atlases.

These considerations provide some technical foundation for a global operations room. Integration of existing organisations, such as the WHO, OIE (World Organization for Animal Health), EPPO (European and Mediterranean Plant Protection Organization) and FAO, with global operations rooms is desirable, using a hub and spoke model. Driver-based methodology would be central to such a global operations room, with the aim of estimating and describing changes in drivers' networks to inform the risk analysis process.

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Abbreviations

EID2	Enhanced Infectious Disease Database
EPPO	Efficacy Evaluation of Plant Protection Products
FAO	Food and Agriculture Organization
MERS-CoV	Middle East respiratory syndrome coronavirus
OIE	World Organization for Animal Health
SARS	severe acute respiratory syndrome
WHO	World Health Organization