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Will the damage be done before we feel the heat? Infectious disease emergence and human response

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Abstract

The global political economy is facing extreme challenges against a backdrop of large-scale expansion of human and domestic animal populations and related impacts on the biosphere. Significant global socio-ecological changes have occurred in the period of a single lifetime, driven by increased technology and access to physical and biological resources through open markets and globalization. Current resource consumption rates are not sustainable and ecological tipping points are being reached and one of the indicators of these may be a changing balance between hosts and pathogens. A period of extraordinary progress in reducing infection risk and disease impact on humans and domestic animals in the 20th Century is reversing in the 21st, but not always and not everywhere. Drivers for this shift are discussed in terms of demographics, agroecology, biodiversity decline and loss of resilience in ecosystems, climate change and increasing interconnectedness between species globally. Causality of disease emergence remains highly speculative, but patterns and data are emerging to commend a precautionary approach, while reassessing our global political, social and economic systems.

Keywords: climate change and infectious disease, One Health, resilience, agroecology, disease emergence

Introduction

Despite general acceptance of climate change and its human origins, there remains extraordinary resistance to doing anything about it. This complacency is rooted in the short-termism of our political systems, our self-belief in human adaptive capacity, and the result of a long history of technological fixes that have brought us thus far. Climate change for most people remains in the future and has no immediacy. So what will shake human society into action to prevent the looming ecological crisis (Ewing *et al.*, 2010), if it is not the fear of the consequences of a warmer planet? History tells us fear is not enough and socio-economic change usually follows major technological innovations (e.g. agricultural and industrial revolutions) or major catastrophes (e.g. global conflict). In the absence of disaster, conservatism and confidence in the status quo, dominates. Meanwhile, we try to control perturbations that are common before a crisis and are oblivious to the increasing vulnerabilities that this policy environment creates (Holling and Meffe, 1996; Carpenter and Gunderson, 2001).

This paper explores the possibility that disease emergence is an early indicator of ecological tipping points, including those influenced by climate. To induce necessary socio-economic change and prevent global ecological catastrophe, health might be a more acceptable entry point to influence people than climate. Awareness of the decline in ecosystem, human and animal health, reversing the hitherto positive trends in human longevity, well-being and economy might be a more effective means of achieving a new political economy.

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Changing patterns in disease emergence

It is proposed that under rising temperatures, changing nitrogen and phosphorous cycles, pollution, change in land use (agriculture), biodiversity loss, ozone depletion, global fresh water (ab)use (Rockstrom, 2009) and rising human and domestic animal populations; new patterns of disease at the human, domestic animal and wildlife/ environment interface are emerging, but we are yet to understand all of the mechanisms (Taylor *et al.*, 2001; Roche and Guégan, 2011).

The evidence for rapidly changing patterns in disease emergence comes from observations and records on both non-communicable and communicable disease incidence over recent decades (WHO, 2009, 2012). In the so-called developed world, infectious disease as a contributor to disease burden declined significantly to about 4% over the 20th Century while in the less industrialized societies remained stubbornly about 40% of the burden (70% in Africa). This remarkable achievement, in reducing infectious disease risk, was ascribed to social and economic development, a result of modern medicines (treatments and vaccines), improved housing, clean and accessible water, better sanitation, hygienic food preparation and packaging, refrigeration and abundant fuel for cooking and cheap efficient cookers, chemical sterilizing agents and overall reduced contact with animal and environmental pathogens. However, this progress has been overshadowed by the increasing incidence of non-communicable diseases including cancers and numerous lifestyle-related disorders. Many of these are derived from relative inactivity, systemic pollution (smoking, industrial processes and combustion engines), an overabundance of cheap processed food and shifting dietary patterns. The result is a pandemic of lung disease, eco-toxicology, metabolic and immune-mediated disorders (allergies), obesity, diabetes, heart and liver disease, in both poor and wealthy societies. Many of the inciting factors are outside of an individual's control and most hardly realize it is happening to them until pathology is advanced. The drivers for these changing disease trends are many, but a good example is our loss of sovereignty over food and its production. The corporatization and globalization of food systems and loading of food with saturated fats, salt and sugars to stimulate demand and greater profits have had dramatic and unintended consequences on health. The focus on quantity of food over quality and for export and the promotion of industrial agribusiness is highly destructive to local communities and the environment (Wallace and Kock, 2012) and has resulted in persistent malnutrition among poor people despite investment and advanced production systems in their midst (Anon, 2012b; Galt, 2013).

Progress in infectious disease control

This initial progress in resolving age-old infectious disease problems might well turn out to be a false dawn. If we take a broader view on disease at the ecosystem level, rather than human infection alone, the situation is not looking so promising. There are a growing number of diseases at the interface between humans, animals and the environment (including plants), which are having a significant impact on human well-being, mostly through food systems. For example, the USA has suffered a series of highly significant and costly disease epidemics in the last decade or so. The emergence of West Nile Virus (WNV) in New York City, which subsequently spread to all 48 States of the continental USA, caused mortalities and sickness in a wide range of domestic animals, wild birds and people (Kilpatrick, 2011). Although the costs are still being calculated, WNV showed how rapidly such disease events can occur and there was nothing that could be done to stop the epidemic. This was followed shortly after by another epidemic disease coined 'white nose syndrome' affecting bats (Blehert *et al.*, 2009). This is caused by a fungus *Geomyces destructans*, most probably introduced by travelers and cavers (Warnecke *et al.*, 2012), which, to date, has killed an estimated 6.5 million bats. The consequences are a conservation crisis and a multi-billion dollar cost to the agricultural industry from lost predation on agricultural pests, a significant ecosystem service provided by bats (Boyles *et al.*, 2011). Similarly, a global insidious spread of a fungal disease of amphibians is resulting in an unexpected and 'premature' extinction crisis, long before the planet heats up (Berger *et al.*, 1998; Rosenblum *et al.*, 2010). Over a third of amphibian species are expected to disappear in the coming years but these extinctions are not only a result of this disease (Heard *et al.*, 2011). These taxa have provided significant unappreciated benefits to humanity through the control of mosquitos and other vectors of serious infectious diseases. Moreover, if this is not enough, there are numerous tree diseases that are spreading globally, some fungal and others insect-based, which are devastating woodlands and individual tree species populations in North America and Europe with wide spread economic consequences. It seems the rapid increase in transportation networks and frequency of human and animal movements by air and sea, a consequence of free market capitalism and globalization, has created a 'perfect storm' for infectious disease emergence across ecosystems (Brown, 2004). It is rather like humans picking up Pandora's box, giving it a thorough shake, and then sending its contents to every corner of the earth. A massive experiment in human-assisted pathogen evolution and spread, gives every advantage to the microorganisms to gain access to immunologically naive hosts and for them to gain dominance over larger organisms, the latter too sluggish in their ability to respond immunologically and adapt. This physical reassortment and distribution of current pathogens alone could drive an era of plague and pestilence affecting most biological taxa.

Unfortunately the story does not stop here, human engineering of landscapes and biological systems are associated with pathogen evolution and disease emergence at the interface, but almost without exception the drivers are poorly researched (Jones *et al.*, 2013). These events are not all new but we are only just beginning to appreciate the extent of our influence on their occurrence. Wolfe *et al.*, 2007 elegantly described how several major human diseases, including smallpox, malaria, campylobacteriosis, rotavirus, measles, diphtheria, mumps, HIV-AIDS and influenza virus, are derived from our domestication of animals and/or harvesting of wild animals over the millennia. These diseases became firmly established in humans, no longer driven or dependent on zoonotic cycles. This is on top of approximately 900 zoonotic infections recorded; of which about 292 are significant pathogens, most associated with domestic animals but many originating from wildlife, sometimes directly (e.g. Ebola virus) (Cleaveland *et al.*, 2001). It seems that this process is accelerating, with the majority (75%) of emerging human pathogens being zoonotic (Taylor *et al.*, 2001).

The trend in zoonotic disease emergence correlates with the expansion of domestic animal populations in parallel to that of human growth. This has fundamentally altered the epidemiological environment. Paradoxically, increasing animal production for human use, through industrialization of crop and animal agriculture, has resulted in an increasing opportunity for pathogen evolution (Arzt *et al.*, 2010; Jones *et al.*, 2013). These larger epidemiological units of plants and animals, with considerable homogeneity, when densely packed (ironically for reasons of biosecurity and production efficiency) are perfect pathogen factories. The recent 'bird flu' panzootic is an example of this. The emergence of the atypical, highly pathogenic influenza virus H5N1 was coincident with a massive expansion of the duck and poultry industry in South East Asia. Water birds are natural hosts of avian influenza viruses and are highly tolerant of infection (Alexander, 2007). However, the growth in domestic duck farms including exploitation of semi-domestic ducks in close proximity to both wild bird populations and densely packed chicken farms, created an opportunity for the rapid evolution of this highly virulent strain of avian influenza, its amplification and spread. H5N1 was first isolated in 1997 (Xu *et al.*, 1999) with epidemics recorded in Hong Kong in 1998 and with a significant wild bird epidemic between 2005 and 2007 (Chen *et al.*, 2006). The infection spread rapidly across Eurasia between poultry systems and as far as Egypt (Abdelwhab and Hafez, 2011) and Nigeria (Newman *et al.*, 2008). Wild bird cases reported appear to be mostly during epidemics or spillover cases from poultry epidemics (Feare and Yasué, 2006; Lebarbenchon *et al.*, 2010; Soliman *et al.*, 2012), and wild bird epidemics appear to have been largely independent of domestic bird disease. The infections burned out in wildlife with no evidence of a long-term reservoir and only rare cases based on circumstantial evidence of spillover from wild birds to poultry (Hars *et al.*, 2008), predators (Desvaux *et al.*, 2009; Globig *et al.*, 2009) and humans (bird hunters) (Newman *et al.*, 2008). The great fear has been that should this virus, which rarely infects humans, evolve into a form that is highly transmissible among humans, it will then cause a severe pandemic. Whilst the immediate threat has subsided, with apparent resilience in the wild bird populations to H5N1 increasing (Siembieda *et al.*, 2010) and with mass vaccination and slaughter of poultry providing temporary relief, endemic foci in domestic birds still persist. This strain of virus has been recently joined by a new, more sinister low pathogenic strain (in poultry) of H7N9, which is lethal in humans and can be transmitted more readily between humans than was the case with H5N1. The main reason for failure to stop the emergence of these diseases is the continued expansion of agroecological systems and industry, which cause the problem in the first place.

It is not always necessary to have a farm for these spillover events, other concentrations of mixed animal species in e.g. food markets has led to emergence, exemplified by the SARS epidemic. Here a bat virus was involved, most probably spilling into a market and replicating in (probably) a number of species, adapting and amplifying until it was established in humans and an epidemic ensued. Globally, the virus infected approximately 8000 people and caused several hundred deaths. The remarkable fact is that this pathogen jump probably only took a period of 2–3 years (Wang *et al.*, 2005; Zhao, 2007; Tang *et al.*, 2009).

Another important driver of disease at the interface has been changing landscapes, with increasing incursion into and modification of diverse habitats for settlement and exploitation of resources. An example is the creation of new vector niche habitats, mostly through urban development (Globig *et al.*, 2009) enabling persistence and emergence of significant problems e.g. dengue fever virus; once only found in primates (Mackenzie *et al.*, 2004). HIV is the most famous example, where frequent spillover of SIV to humans through their exploitation of chimpanzee and gorilla for food, resulted in the establishment of human infection and adaptation of the virus (Gao *et al.*, 1999). However, it was not until road networks were put into the Congo basin that the epidemic really took hold. There were probably a series of stuttering epidemics until the virus entered the urban environment and then the world. It is sobering to note that the African mortality statistics (WHO, 2012) indicate that, far from following the pattern in the Western world, the life expectancy from birth in two of the richest nations, South Africa and Botswana, has significantly *decreased* between 1990 and 2010; and this was from the impact of only one emerging disease, HIV–AIDS. What if we have ten novel diseases occurring simultaneously?

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The changing climate of pathogen transmission

Lastly for consideration are the much publicized rising atmospheric CO_2 levels and global mean temperatures, the impact of which is becoming increasingly evident from growing numbers of weather-linked disasters. In more subtle ways, these changes are affecting disease. Vectors, whose life cycles are closely linked to seasonal temperature changes, are on the move as are parasite abundance patterns that benefit from this trend, but the biological and ecological impacts are difficult to predict precisely (Randolph, 2008). It should also be remembered that climate change is only one factor in the area of global change, which can affect vectors, parasites and pathogens and their persistence and emergence (Patz *et al.*, 2000, 2008; Campbell-Lendrum and Woodruff, 2006; George, 2008; Rosenthal, 2009; Gauly *et al.*, 2013). Some examples of specific, climate-related disease epidemiologies include distemper outbreaks in lions in the Serengeti ecosystem. Such outbreaks were at first believed to be due to a simple spillover infection from dogs but with long-term datasets it was possible to show that climate might have had a key role to play through increasing of vector abundance and blood parasite loads (Roelke-Parker *et al.*, 1996; Munson *et al.*, 2008). Other examples are the spread of bluetongue virus (Roche and Guégan, 2011) and introduction of Schmallenberg virus into Western Europe and the UK (Anon, 2012a). What can Europe expect next from mosquito invasions? Perhaps WNV and Crimean Congo Hemorragic Fever and, from ticks, possibly Tick-Borne Encephalitis and African Swine Fever? The irony of these named viruses is that they were often discovered in remote geographical locations, and these names create the illusion of an exotic disease, far apart from contemporary life. These diseases were named at a very different time in history when there was a risk for the immunologically naive 'explorer' to contract these serious and fatal illnesses but now, the mountain has come to Mohammed.

Conclusions

There are acute research gaps in this evolving scenario that need to be addressed; the priority must be to confirm cause and effect of the actions humans are taking in driving disease emergence and then, designing innovative preventive measures (Jones *et al.*, 2013). Rather like climate change, this will take time but we need a body of evidence as large as that of the Intergovernmental Panel on Climate Change (IPCC) to convince governments and society alike, to shake them into taking necessary interventions and transformations. This is not an easy path for scientists or human society. It is not enough to just talk about pending catastrophe: we need solutions now. If we begin to seriously test the theory of complex systems, which advocates socio-ecological diversity, which in turn enhances resilience (Gunderson *et al.*, 1995), we will be on what I believe to be the right path. This will most likely mean increasing experimentation in agriculture, a reappraisal of our monotypic fossil fuel-driven industrial agricultural, a move to more integrated diverse semi-natural production of diverse food crops, agroforestry and other production systems, enhancement of biodiversity and subsequent sustainable harvest, and all this within our now very human landscapes. We will need to develop disease prevention, not through a fortress mentality and indiscriminate destruction of microorganisms and parasites, but through a One Health approach, adaptation, a return to co-existence and identifying and stopping behaviors and practices that drive pathogen evolution. We will become a paradox to our current nature, closer to our environment, to the animals, plants and other diverse life that we share the planet with, and return to an evolutionary process that we have so recently stepped out of; different, yes, but still benefiting from its effects. It will require first a capping of food production (which underpins any residual growth in population), a change in landscape design, social infrastructure and transportation systems, and most important checks on globalization, which is very much at the root of the pandemic risk.

Human decisions influencing global ecology are neither predetermined nor inevitable, but a matter of our choosing. There is also no certainty in the direction societies will take, current pathways will and must change or human beings will most certainly go extinct, perhaps even before climate change has its full effects (Matheny, 2007).

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