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SPECIAL ISSUE

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Introduction

With respect to the present pandemic, ecology is the key to understanding both the emergence of the SARS-CoV-2 virus and the control of COVID-19 disease. Emergence and control are linked, the context in which the virus emerged providing a framework for addressing the pandemic. Ecological thinking prioritizes the complex relationships that exist between organisms and their environments, situating these within interdependent, integrated systems (McMichael 2001). Humans are inherently situated within their ecological contexts, with profound implications for health and the mitigation and management of risk (Rayner and Lang 2012). This paper examines how the complex ecological origins of SARS-CoV-2 underscore the importance of more holistic approaches to the containment of epidemics and pandemics more broadly. The increasing interconnectedness of human worlds with non-human ones and the complex interplay between them provides fertile ground for new and emerging infectious disease outbreaks among humans. Thus, emerging infectious disease and its control poses one of the most critical and pressing challenges to public health in the 21st century. 'Ecological public health' (ibid.) is underscored here as a framework for seeing the connections between diverse ecologies in a way that can promote improved outbreak prevention and containment strategies. Given the complex social and political contexts in which the spread and control of infectious disease are played out, we argue that ecological thinking needs to go beyond public health when considering epidemics and pandemics in the future.

Ecology of the emergence of coronavirus

The emergence of new viruses that can infect humans must be situated within the ecological relationships of and between different species, since the emergence of infectious disease in humans is predominantly zoonotic, that is, caused by pathogens of animal origin (Engering et. al. 2013). Such pathogens emerge through processes of coevolution, or the reciprocal adaptive change of two species in response to selective pressures from each other, affecting each other's evolution (Gluckman et. al. 2016). Coronaviruses are a family of single-stranded RNA viruses that have infected animals for millennia (Ye et. al. 2020), their emergence in humans being the outcomes of such coevolutionary forces. Since the emergence of the SARS-CoV virus in 2002 and the ensuing Severe Acute Respiratory Syndrome epidemic, seven coronaviruses have been identified in humans, all of zoonotic origin in vertebrates, specifically domestic animals, mice and bats (ibid.). Bats are viewed as the evolutionary hosts of many of the coronaviruses identified in humans, suggesting that coronaviruses in bats are closely related ancestors to those found in humans and that bat-pathogen co-adaptation is strong (ibid.).

Before the current pandemic, Anthony et al. (2017) predicted that there are more than 3,000 types of coronavirus in 1,200 bat species and posited coevolution as a driving factor in producing this coronavirus diversity. Evidence to support the host–pathogen coevolution of bats and coronaviruses comes from the frequently limited virulence observed in co-evolved host-pathogen relationships; bats identified with coronavirus infections are either asymptomatic or present only mild symptoms of disease. Adaptations facilitating this include defects in the activation of pro-inflammatory responses in bats which efficiently reduce coronavirus pathology (Ye et. al. 2020). Bat–coronavirus coevolution has increased the genetic diversity of bat coronaviruses; geographically separated bat families have evolved distinctly and specifically in relation to their host coronavirus species (Joffrin et. al. 2020). The diversity of coronaviruses is also greater where there is a greater diversity of bats (Anthony et. al. 2017).

The epidemics of Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS) and the COVID-19 pandemic have shown how debilitating the emergence of coronaviruses in humans can be on health and on society at large. In addition to their role in increasing the diversity of coronaviruses, coevolutionary processes are involved in the emergence of coronavirus diseases in humans. This is due to the spill-over of pathogens from hosts, including bats, to humans. Pathogens can cross directly into humans from bats; although direct transmission is not confirmed in the case of coronaviruses, it is known to occur in the case of viruses such as rabies, Ebola and Nipah (Ye et. al. 2020). Upon transmission to humans, such viruses are likely to be very virulent and to reproduce very quickly (ibid.). Coronaviruses are thought to transfer into humans more often through intermediary hosts, as has been the case with MERS, whose ancestral host is known to be the bat. However, humans are thought to acquire the MERS coronavirus from dromedary camels, with which they have significantly more contact than bats, thus increasing the likelihood of spill-over. Are there similar effects in relation to SARS and the civet cat, or COVID-19 and the pangolin? Both are possible, and both possibilities are yet to be confirmed by research. Coevolutionary processes play a role in the emergence of disease, as with MERS when the pathogen transfers into the new camel host and is not well adapted to the new host environment

(Banerjee et. al. 2019). As a result, the pathogen reproduces more quickly and is more virulent, which in turn increases the likelihood of it being transferred into a human host (Ye et. al. 2020). Coevolution has an impact on the emergence of new diseases such as those caused by coronaviruses through increasing pathogen diversity and by modulating the virulence, replication and transmissibility of a virus in a new host. Coevolution also highlights the vulnerability of human society to diseases from diverse species due to human embeddedness within complex networks of interdependent relationships.

Coevolution and ecological change

Ecological thinking is an important framework for understanding the emergence of disease in the context of unprecedented anthropogenic environmental change. The genetic diversity of pathogens and the risks to human health posed by zoonotic diseases are both compounded by the complex effects of ecological change on coevolution. Zhody and colleagues (2019) have proposed the 'coevolution effect hypothesis' to account for the increase in the emergence of infectious diseases in the context of habitat fragmentation, which increasingly separates vertebrate hosts from other, usually non-vertebrate, potential pathogen hosts. As a result, pathogens and their hosts coevolve along trajectories that are separate from those of other species. This increase in isolated pathogen hosts and pathogens has the overarching impact of increasing the genetic diversity of pathogens due to mutation and genetic drift, consequently increasing the probability of the emergence of new pathogens that can cross the species barrier into humans (ibid.). This 'coevolution effect hypothesis' is consistent with studies of spatial patterns of coevolution that assume that different spatial subpopulations coevolve differently, resulting in spatial variation in both pathogens and hosts (Woolhouse et. al. 2002). The context of ecological change, including habitat fragmentation, additionally increases the range of habitats in which disease vectors can come into contact with humans, increasing the risk of zoonotic diseases crossing species barriers into humans (Zhody et. al., 2019). Thus, rapid (?) ecological changes compound the risk of the emergence of zoonotic diseases in humans through coevolutionary processes that both increase pathogen diversity and human contact with pathogens. Zhody et al.'s hypothesis (ibid.) highlights the necessity for ecological thinking in approaching coevolution due to the complex, system-wide effects of habitat fragmentation they describe.

Ways forward: ecological thinking in public health and beyond

The compounding effects of environmental change on coevolutionary processes present novel challenges to health globally. The unprecedented environmental change that humans are currently facing is causing habitat fragmentation at increasing rates and is influencing patterns and rates of host-pathogen coevolution in ways that cannot be readily understood. This is largely because of the complexity of ecological systems, and also because of changing patterns of climatic seasonality, which in turn influence host–pathogen relationships. Changing patterns of human land-use and changing human relationships with the natural world further influence the rates and patterns of transmission of newly coevolved human pathogens. Simple awareness of such facts should provide an impetus to recalibrate public health systems to prepare for future outbreaks of infectious disease. It is imperative for public health discourse and practice to integrate ecological thinking to help build more resilient and robust health systems and responses for the containment of the present COVID-19 pandemic and for the future prevention and minimization of emerging infections that may infect humans in new and different ways.

The need for ecological thinking in public health is imperative. Along with the consideration of coevolutionary processes in the emergence of zoonotic disease, it offers a framework for the control of such diseases in human populations. Coevolutionary processes account for the genetic diversity of pathogens and their virulence in new host species. However, it is because of the complex ecological systems within which coevolutionary processes are situated that they pose risks to human health through the emergence of novel zoonotic diseases. There is a need for 'big thinking' beyond the public health arena, since the COVID-19 pandemic has exposed how deeply implicated political and economic systems are, especially with regard to the decisions they make to combat the spread of the virus. In the UK, the political inertia and simple prioritization of the economy that led to preventable disease and death have been termed 'failures of state' (Calvert and Arbuthnott 2021).

The case for 'ecological public health' (EPH) has been well-made by Lang and Rayner (2012), who, almost a decade before the emergence of Sars-CoV2 and COVID-19, advocated a rethink of the public health paradigm and the development of a 'new environmental conception of health' (ibid.: 52). The Ecological Public Health model acknowledges that human health is embedded in complex networks of relationships that are currently undergoing unprecedented anthropogenic change. Human health depends on the health of eco-systems, and while these may interact in myriad ways and sometimes exist in tension, they are ultimately inseparable (ibid.). For Rayner and Lang, 'big thinking' in public health should involve a move from single-dimensional thinking towards complex thinking, to enable 'people and societal systems to live within biological and natural processes and to fuse human and planetary health' (ibid.: 55). The scale and range of the structural issues that are driving the key challenges to health in the 21st century, several of which involve environmental and social vulnerabilities, are too vast and interconnected to rely any more on one-dimensional thinking. These basic tenets render Ecological Public Health a useful framework for illuminating areas of understanding and intervention that may protect against and mitigate contemporary and future disease outbreaks. The COVID-19 pandemic has shown how a disease outbreak can spread globally through a 'web of causality', where the interfacing of biology and the environment, along with cultural and social factors, engenders outbreaks.

However, ecological thinking should go beyond public health, since the damning analysis of the political response to COVID-19 in the UK by Calvert and Arbuthnott (2021) shows how easy it is for a government to ignore public health advice while at the same time saying that it is 'following the science'. Public health, however good and however ecological, must be enacted by the politicians and the people if it is to have an impact on this pandemic and on the spread of emerging infectious diseases in the future. Adopting mask-wearing, social-distancing and isolation, the people of the UK largely acted appropriately, while the government often did not. In the early days, the UK government gambled greatly on the idea of 'herd immunity' without much understanding of what that might mean in terms of additional disease and deaths due to inaction. Much was also gambled on the development of a vaccine, which thus far has helped drive down the prevalence of infection and the number of deaths, but is not without controversy and debate.

Beyond health, politics and economics, COVID-19 has exposed the complex and interdependent systems of everyday life, where technology, the environment, education, policing, engineering, transport, food systems, communication and more all intersect with politics and economics in the form of complex expert systems (McLennan et al. 2020), and where any health intervention shapes, and is shaped by, other parts of these systems. Humans live in a nexus of ecosystems, collective interventions which will eventually stabilize as the 'new normal' that we will inhabit in the future. Ecological systems never go back to an 'old normal', and ecological thinking in public health and beyond offers a way of thinking which allows us to go beyond dealing with the COVID-19 pandemic to imagine post-COVID-19 futures in transformational ways. There will be new infectious disease challenges for humanity, and this will also be part of the 'new normal'.

Ecological Public Health helps to identify key challenges and related goals within the context of new and emerging infectious disease. The unfolding of COVID-19 does not eliminate the threat of Disease X. Rather, it poses a stark warning and offers a blueprint for analysis of the impacts of rapid, drastic environmental change that increase the risk of zoonotic diseases by driving ever more rapid coevolution and increasing the chances of a spill-over into humans. Ecological Public Health is vital, but it is equally vital that ecological thinking goes beyond public health into politics and economics especially, because the survival of the human species depends on it.

Ecological thinking is essential for understanding coevolutionary processes and the emergence of zoonotic diseases, especially in relation to epidemics present and future. It is just as important that ecological thinking extends beyond public health into politics and economics especially. It is necessary to deploy 'big thinking', that is, paying attention to complexity, to construct more robust public-health systems that can more easily absorb and resist future challenges to human health.

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