Nested ecology and emergence in pandemics

The deep interconnectedness between humans, other species, and the environment has become very apparent as individual, organisational, and societal behaviours change in reaction to the COVID-19 pandemic. In complex systems thinking, whole-system characteristics are understood to emerge through processes of collective self-organisation, adaptation, and coevolution[1] (eg, the emergence of severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2]), and they are irreducible (ie, they cannot be understood from study of individual components or subsystems). The global extent of COVID-19 and our ability to respond to and prevent future pandemics will benefit from a complex systems perspective.

Within our global ecosystems, biodiversity is declining faster than at any point in human history and habitat removal is causing wildlife to move closer to human settlements.[2] Global growth in trade and consumption is enabling the mixing of wildlife, domestic animals, and other marketable natural products, which is increasing the risk of disease transmission from animals to humans. COVID-19 is the latest dangerous infectious disease facilitated by human behaviours that provide transmission opportunities from animals into humans, other examples include Zika, Hendra, Ebola virus disease, SARS, Middle East respiratory syndrome, and avian influenza.[3] Human-forced climate change exacerbates these risks. Shifting wildlife migration patterns can cause the emergence of novel diseases as new species-interactions occur. The increasing frequency of natural disasters, such as the 2019–20 Australian wildfires, increase respiratory vulnerability, and air pollution particles facilitate pathogen transport.[4] Other climate-related events, such as Tropical Cyclone Harold in the Pacific Islands (April, 2020) and Amphan in south Asia (May, 2020), have caused widespread flooding, damage to infrastructure (including water and sanitation facilities), and distress to people and animals who are crowded into evacuation centres while governments try to enforce social distancing and hygiene. Vulnerable populations and places—eg, with elevated levels of poverty, high prevalence of non-communicable diseases, or degraded natural systems—are at high risk of having poor health outcomes and being epicentres for the emergence of pathogens with pandemic potential.[5] The COVID-19 pandemic highlights our interdependence; however, it also highlights the consequences of widening social inequities and the misunderstood nature of disturbances in our natural systems.

With emerging infectious diseases, preventive programmes to minimise the risk of animal-to-human disease transmission are gaining momentum. Although preventive programmes are important, surveillance and linkage of data across the human–animal–environmental nexus are insufficient.[10] It is less evident how the interacting factors of climate change, poor land use, poor coverage of improved water and sanitation, poor hygiene practices, and rapid urbanisation could also be contributing to pathogen emergence. Public health reports and practice could benefit greatly from the use and development of ideas on systems thinking. A myriad of human and ecosystem health co-benefits could be realised by approaching pandemic preparedness and public health using nested systems approaches that recognise how subsystems ranging from genes, to individual behaviours, and the environment (inclusive of health care and surveillance systems) work together to regulate health.[6]

Preparing and responding to pandemics, such as COVID-19, is a complex system paradox because we are managing an emergent problem that is unpredictable. The COVID-19 pandemic might change policy on preparedness for future zoonotic infectious disease outbreaks—eg, enforcing constraints on the wildlife trade, being more circumspect about the interactions between domestic animals and wildlife, and regulating wildlife markets more carefully. The condition of the environments in which we live, another source of infectious diseases, requires a similar level of understanding with associated policy directives, such as restricting expansion of large-scale extractive uses in intact landscapes, planning infrastructure development to avoid habitat fragmentation, and avoiding disruption of natural fire and flood regimes. Seeing ourselves as part of ecosystems, with mutual relationships with our surroundings, recognises interdependencies not adequately addressed by the way we treat where we live. Policy consequences for pandemic preparedness in these contexts therefore adopt a value proposition of respecting ecosystems, acting accordingly, and

aligning public health data with environmental data at a variety of nested scales. Our nested existence in ecosystems demands: greater inclusion of ecologists as core members of pandemic preparedness teams, acknowledgment by public health practitioners of the crucial role of environmental management in disease risk reduction, and equitable consideration for the health and wellbeing of all people, entities, and systems.

We declare no competing interests.

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1 Tansley AG. The use and abuse of vegetational concepts and terms. *Ecology* 1935; **16:** 284–307.
2 Díaz S, Pascual U, Stenseke M, et al. Assessing nature's contributions to people. *Science* 2018; **359:** 270–72.
3 Murdoch DR, French NP. COVID-19: another infectious disease emerging at the animal-human interface. *N Z Med J* 2020; **133:** 12–15.
4 Hu W, Wang Z, Huang S, et al. Biological aerosol particles in polluted regions. *Curr Pollut Rep* 2020; **6:** 65–89.
5 Ahmed F, Ahmed N, Pissarides C, Stiglitz J. Why inequality could spread COVID-19. *Lancet Public Health* 2020; **5:** e240.
6 Pongsiri MJ, Bickersteth S, Colón C, et al. Planetary health: from concept to decisive action. *Lancet Planetary Health* 2019; **3:** e402–04.