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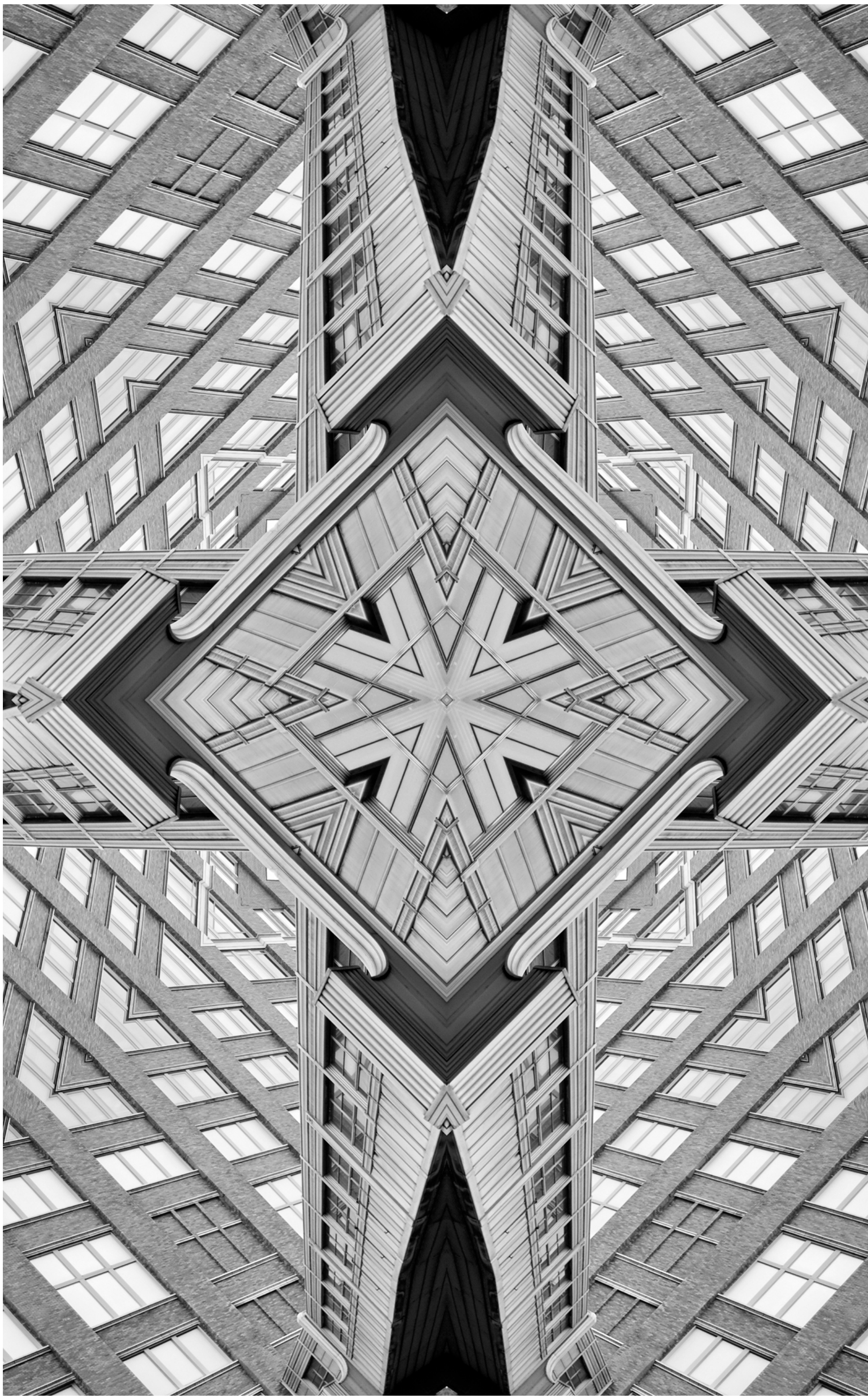

Lessons from COVID-19: Promoting Sustainability in Food Production to Limit Zoonotic Transmissions

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Abstract

COVID-19, which is a highly infectious disease of zoonotic origin, serves as a serious reminder that human-nature interactions need to be based on sustainable development pathways. The recent surge in zoonotic infections in different parts of the world—among them, H1N1, Nipah virus, Zika virus, and Lyme disease—can be attributed to the intensification of human-animal contact through wildlife trade and livestock production. Reducing the rates of zoonoses has become an imperative, and one that requires modifications to global food production systems. This brief makes a case for adopting a social-ecological framework for the intensification of sustainable food production systems across the world. Such systems must build resilience and adaptive capacity to environmental change, and account for the heightened risk of disease outbreaks.

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Introduction

Throughout contemporary history, it is when an environmental crisis of a massive scale emerges that the world is reminded of the unsustainable nature of human economy. As the crisis develops, the focus usually shifts from its origins, to mitigating its worst effects through mostly proximal measures. Biodiversity loss and climate change, for example, are world-wide calamities that have elicited global reaction and yet, for decades, have not been arrested, lacking responses to the key drivers of such changes.[1] Analysts have traced a wide range of environmental impacts—including heat waves and dust storms, droughts and extreme rainfall, landslides and soil loss, pest attacks and disease outbreaks—to the degradation of ecosystems and anthropogenic influence on the atmosphere and oceans.[2,3,4,5,6] Yet, the world is nowhere near redirecting economic and developmental activities to a sustainable path.[7,8]

No event in recent decades has been as hugely disruptive of almost every single human activity as COVID-19 has, and its economic, social, and humanitarian consequences will be felt for years to come. As a health hazard measured in morbidity and mortality rates, the impact of COVID-19 varies hugely among nations.[9,10,11,12]

> The world is nowhere near redirecting economic and developmental activities to a sustainable path.

Although the origin of this novel coronavirus is not yet established, what is known is that wet markets and animal farms have been the source of most viral diseases of pandemic potential in recent decades.[13] Zoonosis—or the natural transmission of a disease or infection from animals to humans—will only intensify as industrial-scale animal farming and contact with live animals in farms and markets increases.[14] It is expected that infectious diseases will spread easily in large and dense human populations, which includes most of the world's urban centres. The expansion and intensification of the modern food production systems of agriculture and animal farming has reciprocal feedbacks with technology-driven intensification of economies and urbanisation.[15] Agriculture and livestock production are historically the predominant cause of land transformation, which is a significant driver of biodiversity loss and climate change.[16] Conversion of natural ecosystems to food production systems remains a primary cause of natural habitat loss in many developing regions in the tropics.[17] Scholars link these crises to increasing human exploitation of natural resources driven by population growth, shifts in

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dietary preferences towards higher consumption of animal products, and rising demand for energy.[18,19]

As agriculture usually comes with poultry or meat production systems, there is a combined effect on environmental change and human health via the emergence of infectious diseases. With the world population likely to reach 9-10 billion by 2050, global food production is expected to grow between 60 and 110 percent.[20] Despite agriculture being crucial to achieving the UN Sustainable Development Goals (SDGs)[21] of eradicating hunger and securing food for the rising world population,[22] the interactions between agriculture, environmental change and human health is not adequately explored in planning for sustainable development. The emergence of novel infectious diseases of pandemic potential merits particular attention, as the impact of COVID-19 shows.

These insights provide a sound scientific basis for shifting the focus of agriculture development from improving productivity (with limited concern for sustainability or environmental impacts), to putting sustainability at the core.[23] The world should integrate sustainable practices to meet rising human needs and improve livelihoods, while minimising environmental impacts and containing the emergence of novel infectious diseases. The entire notion of "sustainable intensification" is based on increasing agricultural output without compromising ecological resilience and the functional integrity of ecosystems. Sustainability is about setting absolute biophysical limits; achieving higher productivity while remaining within planetary boundaries.[24]

This brief emphasises the need to adopt a social-ecological framework based on the core ideas of sustainability science for the intensification of world food production systems. Some simple remedies include dismantling the wildlife trade, which was already an important focus to prevent species extinctions but has assumed further urgency due to the link with zoonosis. Making food production systems both adaptive and resilient to future environmental changes would require efficient use of energy and land resources while ensuring the sustainable cycling of nutrients and other materials. Without developing alternatives to large-scale intensive animal farming for animal protein production, it is unclear how the problem of zoonosis can be kept in check. Laboratory-grown meat, and plant-based or vegan substitutes, while showing great promise are still far from the scale and cost considerations that would make them a practical alternative.

Transformation of Natural Ecosystems and the Emergence of Zoonotic Pathogens

The world is more vulnerable today than ever before to novel infectious diseases.[25] Advances in medical science and improvements in disaster management notwithstanding, almost all of the changes to the economy, environment, and societies seem to favour the microbe in the co-evolutionary arms race between microbial pathogens and human beings. In theory, the world has better mechanisms for global cooperation today. However, a wide range of conflicts and hostile geopolitical alliances persist, while numerous countries across different regions suffer from corruption, poor governance, and collapsing economies. These problems can in themselves accentuate a public health crisis when a novel pathogen emerges. When governance fails, the most immediate casualty is usually the environment.

Today, the greatest threat in the emergence of novel pathogens may be the transformation of natural ecosystems and the loss of biodiversity, which increases contact between humans and wild animal species. Wild animals are reservoirs of major groups of pathogens such as coronaviruses, influenza viruses, and immunodeficiency viruses, which have serious pathogenic potential for humans. Recent studies point to multiple pathways for a heightened risk of human disease caused by deforestation and degradation. Defaunation, resulting from the loss or departure of large animal species following habitat destruction or degradation, leaves a void that may be filled by small animals. These are often rodents that take swift advantage of the resources and attain high population densities, while their range seamlessly encompass human habitation. Rodents are common reservoir hosts for a wide range of zoonotic pathogens, and many recent outbreaks of known and novel pathogens may be traced to increased contact with rodents.[a] The flea vectors borne by rodents are seldom associated with large mammals. When livestock is bred and raised in proximity to degraded forest-fringe sites, the transmission from small animals to human via the livestock becomes a highly probable pathway.[26] Another link between loss of biodiversity and human disease comes from a rather unexpected source.

Along with plants and animals, a large component of the biodiversity lies in microorganisms – mainly bacteria, viruses and fungi. These microorganisms are necessary not only for the healthy functioning of ecosystems through their influence on biogeochemical cycling and biotic interactions, but they constitute the second genome and the inner ecosystem within individual organisms. The microbiome within plants and animals are critical for numerous metabolic and physiological functions including immunity and stress tolerance. The microbe-higher organism symbiotic associations have co-evolved from the earliest stages of life on earth, forming an enduring partnership. This partnership has become so ubiquitous and successful, that the bacterium is perhaps the only

a Examples include the Hantavirus Pulmonary Syndrome (HPS), Lymphocytic Choriomeningitis (LCM), both viral diseases and even the Bubonic Plague, a bacterial disease, which killed millions of people.

organism that can survive entirely on its own. All higher organisms depend on microbiota for the performance of vital metabolic functions. The human gut alone hosts over a 100 trillion microbes, which vastly outnumbers human cells. The microflora contributes to a wide range of biological functions, including bolstering the immune system. The loss of microbial biodiversity from human-dominated environments will deprive humans of 'old friend' microbes that provide protection from a whole range of diseases.[27]

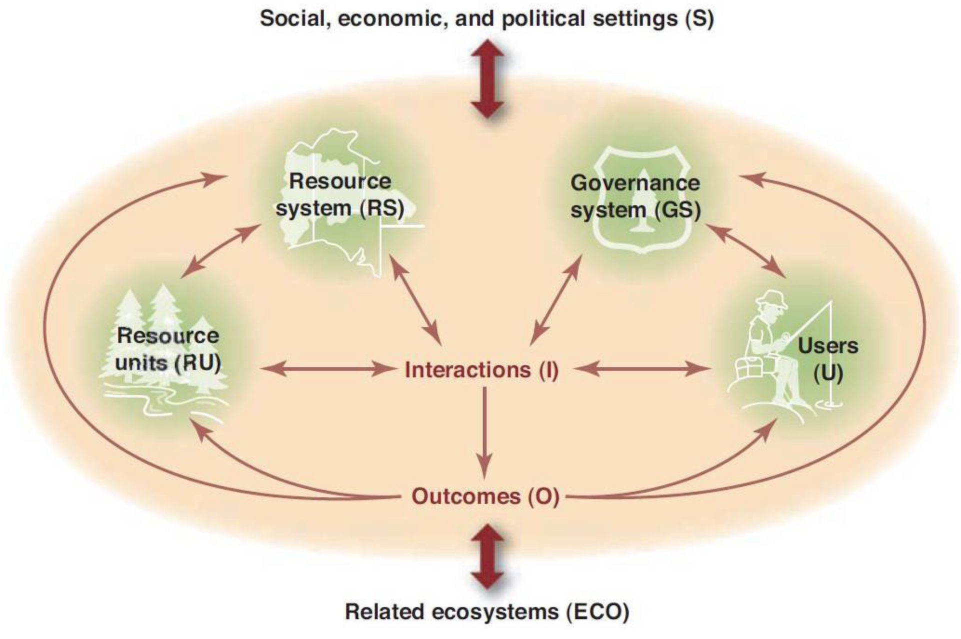
The linkages among biodiversity, environmental change, and infectious disease burden illustrate the connectedness of nature and human societies. What the world faces today at an increasing scale and rate are the consequences of humans' own success as a species—[28] consequences brought upon by a disregard of boundaries set by the finite earth, and regulated and maintained by intricate biotic relationships. Restoring and maintaining the natural capital and processes will require fundamental transformations in the way human beings produce food, generate energy, consume resources, and transfer goods and services across the globe. While humans seek to understand the fundamental character of interactions between nature and societies, the imperative is for a remodelling of human economies to follow sustainable development pathways.

Indeed, the notion of "sustainable development"—which first became popular in the 1980s—emerged from the broad global environmental crises at that time; since then it has become the leading aspiration of humankind in the 21st century. *Development* indicates growth, not only in quantity, but primarily in quality; and *sustainable* refers to something that can or should last. With a finite earth and the expanding human population that uses it as a source of resources and a sink for waste, humanity's shared goals and global vision should converge towards a sustainable development path. Although the origin of sustainability thinking may be located in the natural sciences, prompted by observations of human-induced changes at the planetary scale, a sustainable development trajectory cannot be codified purely on ecological-environmental criteria. Rather, economic and social aspects are integral components and infuse welfare economics and societal cost-benefit analyses into the comprehension of sustainability.[29] Among the first definitions of sustainable development was given in the UN's World Commission on Environment and Development report, Our Common Future:[30] "Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." This definition has endured the test of time and remains the favoured rationale today. It emphasises sustainability while leaving open the specifics of development itself to the subjective needs of societies—needs which may evolve with time.

Sustainable Development as a Complex Social-Ecological System

An analytical and management framework to achieve sustainable development lies in the concept of the coupled social-ecological system (SES).[31] There are synergies to be exploited and trade-offs to be minimised in the achievement of SDGs which can be done by considering the interconnectedness between human societies and nature. Figure 1 presents an overview of the framework for analysing social-ecological systems. It shows the relationships among four first-level core subsystems of an SES that affect each other, as well as linked social, economic, and political settings and related ecosystems.

Figure 1: Framework for analysing social-ecological systems



Source: Ostrom, 2009[32]

The key notion is that SES is defined as an integrated human-nature system with reciprocal feedbacks and interdependencies. Such a definition of SES lends itself to modelling and analyses based on well-developed *systems theory* and *complex systems science*. Today, it forms the basis of a formal transdisciplinary framework for scientific investigation. The framework acknowledges that the world is a more integrated and complex entity than what is suggested by analyses using individual disciplines. It provides the foundations for, and the essential concepts and methods for sustainability science, which is the basis to aspire for and realise sustainable development through scientific knowledge. Although sustainability science is problem-driven, the key goal is to develop a fundamental understanding of the interactions between the resource system (earth/life sciences), and its users—the governance system (social sciences). It provides the processes and mechanisms to manage complex SES and make the systems deliver what people value. It allows human beings to choose the trajectory, the time-path and the target with reference to some ecological, environmental, and socio-economic desires.[33]

In a complex social-ecological system like the one studied in this brief, transmission of zoonotic (which represents connectedness of nature and human societies) subsystems are relatively separable but interact to produce outcomes at the SES level: resource system (e.g., food production system comprising agriculture and natural systems); resource units (livestock, wildlife); users (mainly for human consumption); and governance systems (organisations and rules, norms that govern the extraction of natural resources, conservation of endangered species, biodiversity, habitat loss). This in turn gives feedback and affects these subsystems and their components, as well as other larger or smaller SESs. The framework helps to identify relevant variables and their subcomponents for studying an SES.

Systems theory and complex systems science is the favoured approach for modelling, analyses, and management of SES.[34] A system is simply an interconnected set of elements that is coherently organised around a certain purpose. Therefore, the three key components of a system are: *elements*; *(inter)connections*; and *purpose*, given a defined system boundary. Armed with a system where the constituent elements are linked by interconnections or relationships, one can potentially study the dynamics and response concerning any particular purpose or goal. Inanimate systems in physics or chemistry typically do not include a purpose or goal, but natural systems, particularly those that involve decisions by societies are always goal-driven. The interconnections capture the processes and fluxes that govern the dynamics of the system, while the rates of the processes and fluxes are the parameters that can be optimised to achieve defined goals.

It is only when such complexity is harnessed and diagnosed that efforts to sustain SESs can be enhanced. The identification and analysis of relationships among multiple levels of these complex systems are likely to ensure sustainable social-ecological systems.

Sustainable Food Production Systems Amidst Zoonotic Pandemics

The emergence of SARS-CoV-2, the novel coronavirus that causes COVID-19, is pinned to the unabated trade and consumption of wild animals.[35] Exotic wild meat is not considered part of the conventional food production system, is illegal in most countries, and is restricted as a trade item by international laws and treaties. Yet wet markets for wildlife meat thrive in many parts of East Asia, Africa, and Latin America. Recent zoonotic viral infections such as Ebola, SARS, MERS, Nipah, Zika, and Lyme disease, and even HIV-AIDS[36] exemplify the problem caused by increased direct or indirect human contact with wild animal reservoir host species such as bats, civets, pangolins, and rodents, at both the supply side and demand side of the trade. Domesticated animals—mainly pigs and poultry—may share the same space and serve as intermediate hosts, but direct transmission through multiple wild species (bat to pangolin/civet to human) is a probable route. While only a handful of domesticated mammal and bird species are reared for food, the global wildlife trade for luxury foods, medicine, and amusement, involves thousands of species.

A comprehensive global study reveals that of the more than 31,500 species of terrestrial bird, mammal, amphibian, and reptile species considered, an estimated 18 percent (5,579) are traded globally in one form or another.[37] The extraction of animals from wild habitat has become so intense that wildlife trade is now the prominent driver of global vertebrate species extinction. It is also a significant interface where pathogens jump across species, combine, and mutate, with devastating potential for novel diseases in humans. The trade itself is driven by criminal syndicates, much like the drug trade, and controlling or eradicating it presents significant challenges. Imposing bans and strict law enforcement on the demand-side is an important first step; what should follow are other equally urgent measures such as improving the livelihood options of forest-fringe communities to resist the temptation to get involved in the wildlife trade. Wildlife forensics is increasing in sophistication and capabilities and can assist law enforcement in identifying the sources and trade routes. Dismantling the wildlife trade should be an important goal for both biodiversity conservation and for preventing zoonosis.[38]

> “Wildlife trade is a significant interface where pathogens jump across species, combine, and mutate, with potential for novel diseases in humans.”

The bigger challenge for sustainable development is in organising food production systems. Climate change-induced changes in temperature, rainfall, extreme climatic events (droughts, heatwaves, floods), increased incidence of pest attack, crop and livestock diseases, are among the stress factors that are increasing in severity. Soil erosion, salinity, diseases, and crop pests are already significant stressors. What is needed is a system that is both adaptive and resilient to future environmental changes, prudent in the use of soil resources and water, comprehensive in terms of the diversity and values of the products generated, and optimal in the use of energy and materials.[39] From the social and economic perspectives, the system should minimally provide meaningful livelihood in terms of income and quality of life to the communities, and generate wealth through the production of goods that can contribute to overall development in other sectors.

To create and manage such a system would first require the definition of system boundaries. Here the logical starting point is the agroclimatic zone, which is demarcated by the macroclimatic conditions, soils, topography, and broad hydrological regimes.[40] The agroclimatic zone would determine appropriate cropping patterns and animal husbandry options. This has to be refined further, depending on land-use patterns, forest cover, population density, levels of urbanisation, access to markets, indigenous cultural practices, traditional rights, and the presence of any stress factors. An SES that is maximally bounded by physical-climatic zonation and further limited by ecological, environmental, social and cultural dimensions should be amenable for modelling and analyses with reference to a negotiated set of goals or purpose. The elements, the interconnections that embody the links, processes and fluxes among elements, and the interactions between the resource components and governance components, can then be modelled and managed to deliver on the purpose.[41]

Such models that optimise coupled processes and linkages to achieve desired goals are known even outside the domain of systems modelling. For example, Dobson, Bradshaw, and Baker (1997) took a known compartmental epidemiological model based on coupled differential equations and used it to understand how ecological restoration and biodiversity conservation can be realised in a landscape characterised by human population growth and changing agricultural practices.[42] The impact on land use, forest cover types, and landscape configuration and composition could be understood as functions of human population growth rates, agricultural practices, and restoration efforts. Coupling of process equations is meant to model interconnections among components/elements as is the case in systems dynamics models.

The first step in creating sustainable SES out of landscapes that are primarily devoted to food production is to analyse why they may be on the path of unsustainable development.[43] To identify the climatic, biophysical, and social stress factors that undermine sustainability, both under present conditions and future scenarios of environmental and social change. To identify thresholds beyond which the equilibrium dynamics of systems are radically altered.[44] To locate tipping points, which function as points of no return to original conditions, implying that the old regulating mechanisms would no longer work.[45] It is likely that responses of system components are non-linear and difficult to predict. Time lags and scale dependence further make it difficult to identify trajectories and changes before it is too late. Biodiversity loss, ecosystem degradation and the diminishing of ecosystem services, all occur with unknown time lags and spatial variability.[46] Recognising and quantifying these key attributes of SES would demand extensive research to identify generalisable relationships and the mechanisms that govern system dynamics.[47]

> "The first step in creating socio-ecological systems out of landscapes that are devoted to food production is to analyse why they are unsustainable."

In particular, if the landscape also hosts areas of ecological importance such as forests, grasslands, and wetlands, conservation imperatives have to be integrated with production goals. Human population growth, urbanisation, industry and infrastructure development, may also influence land transformation and the local economy and induce dynamism.[48] The goals of SES cannot be viewed as static and will evolve with changing scenarios of the environment and the economy, to be negotiated and renegotiated by the stakeholders. The systems approach, therefore, provides a framework to identify all the relevant elements (from resources to governance) and interconnections in SES defined by clear boundaries.[49]

It is in understanding the interactions and dynamics of the systems where new science is needed. For example, will diversification of the system to produce a wide range of goods and services lead to greater resilience and adaptive capacity to climatic changes?[50] Will the diversity, say from mixed cropping patterns and less intensive livestock or aquatic production, confer biotic protection from pests and diseases, while decreasing input costs and health risks to humans? These questions arise precisely because they have been articulated as goals or benchmarks to achieve sustainability.[51]

There is support for the general idea that diversification of crops and small-scale animal farming reduce the epidemiological burden and help containment in the case of outbreaks.[52] If the incidence of zoonoses is to be reduced, there is a need to move away from high-intensity large-scale farming.[53] When livestock is raised near forest boundaries or even inside forest patches, as happened in the case of the Nipah virus outbreak, the chances of pathogens jumping from wild species to humans through an intermediate domestic animal host is extremely high.[54] Numerous outbreaks of bird flu, swine flu, and the recent swine fever that blazed through the Chinese pig farms[55] is sufficient testimony to the unsustainability of these farming systems. Millions of birds and pigs had to be culled within a short time using extreme methods, raising serious moral and ethical concerns, and putting to question the international community's commitment to animal rights.

Meanwhile, the global demand for animal protein continues to increase with rising incomes across many developing countries. The domestic chicken population has grown from about 3 billion in 1960 to a staggering 23 billion today.[56] The numbers of chickens processed per year are much greater (66 billion in 2016), as fast-growing breeds birth 6-12 generations in a single year, and each bird that is raised represents a veritable 'test-tube' for the evolution of new viruses and bacteria. The global pig stock may exceed 800 million,[b] and hundreds of millions are slaughtered each year for meat.[57] Both these species are in close contact with humans, and share the same breathing and living space with the people who care for them. Chickens, pigs, and humans have become an operative mixing bowl for new, unstable, and easily-mutated viruses with great pathogenic potential. Intensive farming of animals in monocultures requires the heavy use of antibiotics, which transmit to humans as regular doses in consumed meat. The resulting antibiotic resistance is only amplified by the indiscriminate or improper administration of antibiotics to treat human ailments. Although chicken and pig farming remain the most serious threats, other species like domesticated cattle and camels have also been sources of novel pathogens. Thus, a wide range of species with which humans have high levels of contact act as intermediary hosts for deadly pathogens that emerge from wild animals.

"Diversification of crops and small-scale animal farming can reduce the epidemiological burden."

b China accounts for half this number.

Conclusion

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Human population growth and increasing consumption have led to the concomitant expansion and intensification of animal farming systems. The resulting deforestation, biodiversity loss, and the elevated risk of zoonotic infections must be immediately addressed, through campaigns to change both consumption patterns and production systems. Measures that will help include integrating and diversifying production within SES along with proper regulation of production and export, the introduction of safeguards like immunisation and regular screening of animals and people, creating barriers to transmission between animal populations, and creating buffer zones in forest-fringe sites to limit contact with wildlife. It is this interface between forest and farms that may serve as hotspots for the future emergence of highly infectious diseases with pandemic potential.

> "Deforestation, biodiversity loss, and the elevated risk of zoonotic infections must be addressed by changes in both consumption patterns and production systems."

Sustainability science and the notion of sustainable development precedes the recognition of the elevated risk of pandemic outbreaks and their disruptive influence on the economy and society. The original motivations remain, but are now strengthened by this emergent biotic challenge to human life. Global responses need only to build on the already articulated sustainable development goals using more rigorous application of sustainability science through models, analyses, observations, and experimentation. There is also a need to develop indicators of sustainability, tools for translating concepts and ideas to deliverable outputs, and the democratic mechanisms to negotiate and renegotiate the diverse and evolving set of goals in multi-use socio-ecological systems.

Endnotes

1 Michael R. W. Rands, William M. Adams, Leon Bennun, Stuart H. M. Butchart, Andrew Clements, David Coomes, Abigail Entwistle, et al., "Biodiversity Conservation: Challenges Beyond 2010," *Science* 329, 5997(2010): 1298–1303, https://doi.org/10.1126/science.1189138

2 George Luber and Michael McGeehin, "Climate Change and Extreme Heat Events," *American Journal of Preventive Medicine*, Theme Issue: Climate Change and the Health of the Public, 35, no. 5(2008): 429–35. https://doi.org/10.1016/j.amepre.2008.08.021

3 Madhavan Nair Rajeevan, Jyoti Bhate, and A. K. Jaswal, "Analysis of Variability and Trends of Extreme Rainfall Events over India Using 104 Years of Gridded Daily Rainfall Data," *Geophysical Research Letters* 35, L18707 (2008), https://doi.org/10.1029/2008GL035143

4 Shou-Hao Chiang and Kang-Tsung Chang, "The Potential Impact of Climate Change on Typhoon-Triggered Landslides in Taiwan, 2010–2099." *Geomorphology* 133, no.3-4 (2011): 143–151, https://doi.org/10.1016/j.geomorph.2010.12.028

5 Fay Newbery, Aiming Qi, and Bruce DL Fitt, "Modelling Impacts of Climate Change on Arable Crop Diseases: Progress, Challenges and Applications." *Current Opinion in Plant Biology*, Biotic interactions 32 August (2016): 101–109, https://doi.org/10.1016/j.pbi.2016.07.002

6 Soodabeh Namdari, Neamat Karimi, Armin Sorooshian, Gholam Hasan Mohammadi, and Saviz Sehatkashani, "Impacts of Climate and Synoptic Fluctuations on Dust Storm Activity over the Middle East." *Atmospheric Environment* 173 January (2018): 265–76, https://doi.org/10.1016/j.atmosenv.2017.11.016

7 Jeffrey D. Sachs, Guido Schmidt-Traub, Mariana Mazzucato, Dirk Messner, Nebojsa Nakicenovic, and Johan Rockström, "Six Transformations to Achieve the Sustainable Development Goals." *Nature Sustainability* 2, no. 9 (2019): 805–814. https://doi.org/10.1038/s41893-019-0352-9

8 Melissa Leach, Belinda Reyers, Xuemei Bai, Eduardo S. Brondizio, Christina Cook, Sandra Díaz, GiovanaEspindola, Michelle Scobie, Mark Stafford-Smith, and Suneetha M. Subramanian, "Equity and Sustainability in the Anthropocene: A Social–Ecological Systems Perspective on Their Intertwined Futures." *Global Sustainability* 1 (2018), https://doi.org/10.1017/sus.2018.12

9 Warwick J. McKibbin and Roshen Fernando, "The Global Macroeconomic Impacts of COVID-19: Seven Scenarios." SSRN Scholarly Paper ID 3547729. Rochester, NY: Social Science Research Network (2020), https://doi.org/10.2139/ssrn.3547729

10 Jean-Louis Vincent and Fabio S. Taccone, "Understanding Pathways to Death in Patients with COVID-19." *The Lancet Respiratory Medicine* 8, no.5 (2020): 430–432. https://doi.org/10.1016/S2213-2600(20)30165-X

11 Siddhartha Mukherjee, "Why Does the Pandemic Seem to Be Hitting Some Countries Harder Than Others?" *The New Yorker*, February 22, 2021, https://www.newyorker.com/magazine/2021/03/01/.

12 Hugo Zeberg and Svante Pääbo, "A Genomic Region Associated with Protection against Severe COVID-19 Is Inherited from Neandertals," *Proceedings of the National Academy of Sciences* 118, no. 9 (2021). https://doi.org/10.1073/pnas.2026309118.

13 Kristian G. Andersen, Andrew Rambaut, W. Ian Lipkin, Edward C. Holmes, and Robert F. Garry, "The Proximal Origin of SARS-CoV-2." *Nature Medicine* 26, no.4 (2020): 450–52, https://doi.org/10.1038/s41591-020-0820-9

Endnotes

14 Kate E. Jones, Nikkita G. Patel, Marc A. Levy, Adam Storeygard, Deborah Balk, John L. Gittleman, and Peter Daszak, "Global Trends in Emerging Infectious Diseases." *Nature* 451, (7181) (2008): 990–93, https://doi.org/10.1038/nature06536

15 Nathan D. Wolfe, Claire Panosian Dunavan, and Jared Diamond, "Origins of Major Human Infectious Diseases." *Nature* 447 (7142) (2007): 279–83, https://doi.org/10.1038/nature05775

16 M. C. Hansen, P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, et al., "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160) (2013): 850–53, https://doi.org/10.1126/science.1244693

17 M. C. Hansen, Stephen V. Stehman, Peter V. Potapov, Thomas R. Loveland, John R. G. Townshend, Ruth S. DeFries, Kyle W. Pittman, et al., "Humid Tropical Forest Clearing from 2000 to 2005 Quantified by Using Multitemporal and Multiresolution Remotely Sensed Data." *Proceedings of the National Academy of Sciences* 105 (27) (2008): 9439–44, https://doi.org/10.1073/pnas.0804042105

18 Moreno Di Marco, Michelle L. Baker, Peter Daszak, Paul De Barro, Evan A. Eskew, Cecile M. Godde, Tom D. Harwood, et al., "Opinion: Sustainable Development Must Account for Pandemic Risk," *Proceedings of the National Academy of Sciences* 117, no.8 (2020): 3888–92. https://doi.org/10.1073/pnas.2001655117

19 Kate E. Jones, Nikkita G. Patel, Marc A. Levy, Adam Storeygard, Deborah Balk, John L. Gittleman, and Peter Daszak, "Global Trends in Emerging Infectious Diseases"

20 Johan Rockström, John Williams, Gretchen Daily, Andrew Noble, Nathanial Matthews, Line Gordon, Hanna Wetterstrand, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability," *Ambio* 46, no.1 (2017): 4–17, https://doi.org/10.1007/s13280-016-0793-6

21 UNDP, "Sustainable Development Goals," United Nations Development Programme. 2015, https://www.undp.org/content/undp/en/home/sustainable-development-goals.html

22 Johan Rockström, John Williams, Gretchen Daily, Andrew Noble, Nathanial Matthews, Line Gordon, Hanna Wetterstrand, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability"

23 Johan Rockström, John Williams, Gretchen Daily, Andrew Noble, Nathanial Matthews, Line Gordon, Hanna Wetterstrand, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability"

24 Johan Rockström, John Williams, Gretchen Daily, Andrew Noble, Nathanial Matthews, Line Gordon, Hanna Wetterstrand, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability"

25 Michael T. Osterholm and Mark. Olshaker, *Deadliest Enemy: Our War Against Killer Germs*. Updated edition. (USA: Little, Brown and Company, 2020)

26 Hillary S. Young, Rodolfo Dirzo, Kristofer M. Helgen, Douglas J. McCauley, Sarah A. Billeter, Michael Y. Kosoy, Lynn M. Osikowicz, Daniel J. Salkeld, Truman P. Young, and Katharina Dittmar, "Declines in Large Wildlife Increase Landscape-Level Prevalence of Rodent-Borne Disease in Africa." *Proceedings of the National Academy of Sciences* 111 (19) (2014): 7036–41. https://doi.org/10.1073/pnas.1404958111

27 Jake M. Robinson,"Biodiversity Loss Could Be Making Us Sick – Here's Why." *The Conversation,* August 2020, http://theconversation.com/biodiversity-loss-could-be-making-us-sick-heres-why-143627

28 Bert J. M. de Vries, *Sustainability Science*. 1 edition. (New York, NY: Cambridge University Press, 2012)

29 Bert J. M. de Vries, *Sustainability Science*

30 WCED, *Our Common Future*. World Commission on Environment and Development. (Oxford ; New York: OUP Oxford, 1987).

31 Elinor Ostrom, "A General Framework for Analyzing Sustainability of Social-Ecological Systems," *Science* 325 (5939) (2009): 419–22. https://doi.org/10.1126/science.1172133

32 Elinor Ostrom, "A General Framework for Analyzing Sustainability of Social-Ecological Systems"

33 Bert J. M. de Vries, *Sustainability Science*

34 Simon Levin, TasosXepapadeas, Anne-Sophie Crépin, Jon Norberg, Aart de Zeeuw, Carl Folke, Terry Hughes, et al., "Social-Ecological Systems as Complex Adaptive Systems: Modeling and Policy Implications." *Environment and Development Economics* 18 (2) (2013): 111–32.

35 Michael T. Klare, "Is the Covid-19 Pandemic Mother Nature's Response to Human Transgression?" *Common Dreams*. April 2, 2020. https://www.commondreams.org/views/2020/04/02/covid-19-pandemic-mother-natures-response-human-transgression

36 Ping-Ing Lee and Po-Ren Hsueh, "Emerging Threats from Zoonotic Coronaviruses-from SARS and MERS to 2019-NCoV," *Journal of Microbiology, Immunology, and Infection* 53, no.3 (2020): 365–367, https://doi.org/10.1016/j.jmii.2020.02.001

37 Brett R. Scheffers, Brunno F. Oliveira, Ieuan Lamb, and David P. Edwards, "Global Wildlife Trade across the Tree of Life," *Science* 366 (6461) (2019): 71–76. https://doi.org/10.1126/science.aav5327

38 William B. Karesh, Robert A. Cook, Elizabeth L. Bennett, and James Newcomb, "Wildlife Trade and Global Disease Emergence," *Emerging Infectious Diseases* 11, no.7 (2005): 1000. https://doi.org/10.3201/eid1107.050194

39 Johan Rockström, John Williams, Gretchen Daily, Andrew Noble, Nathanial Matthews, Line Gordon, Hanna Wetterstrand, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability"

40 Günther Fischer, Harrij van Velthuizen, and Freddy. O. Nachtergaele, "Global Agro-Ecological Zones Assessment: Methodology and Results," Monograph. IIASA, Laxenburg, Austria: IR-00-064. November 2000. http://pure.iiasa.ac.at/id/eprint/6182/

41 Bert J. M. de Vries, *Sustainability Science*

42 Andy P. Dobson, A. D. Bradshaw, and A. J. M. Baker, "Hopes for the Future: Restoration Ecology and Conservation Biology," *Science* 277 (5325) (1997): 515–22. https://doi.org/10.1126/science.277.5325.515

Endnotes

43 Johan Rockström, et al., "Sustainable Intensification of Agriculture for Human Prosperity and Global Sustainability"

44 Richard D. Horan, Eli P. Fenichel, Kevin L. S. Drury, and David M. Lodge, "Managing Ecological Thresholds in Coupled Environmental–Human Systems," *Proceedings of the National Academy of Sciences* 108 (18) (2011): 7333–7338, https://doi.org/10.1073/pnas.1005431108

45 Vasilis Dakos, Blake Matthews, Andrew P. Hendry, Jonathan Levine, Nicolas Loeuille, Jon Norberg, PatrikNosil, Marten Scheffer, and Luc De Meester, "Ecosystem Tipping Points in an Evolving World." *Nature Ecology & Evolution* 3, no.3 (2019): 355–62. https://doi.org/10.1038/s41559-019-0797-2

46 DonghaiWu, Xiang Zhao, Shunlin Liang, Tao Zhou, Kaicheng Huang, Bijian Tang, and Wenqian Zhao, "Time-Lag Effects of Global Vegetation Responses to Climate Change," *Global Change Biology* 21, no. 9(2015): 3520–31, https://doi.org/10.1111/gcb.12945

47 Bert J. M. de Vries, *Sustainability Science*

48 Andy P. Dobson, A. D. Bradshaw, and A. J. M. Baker, "Hopes for the Future: Restoration Ecology and Conservation Biology"

49 Elinor Ostrom, "A General Framework for Analyzing Sustainability of Social-Ecological Systems"

50 Per Olsson, Carl Folke, and Fikret Berkes, "Adaptive Comanagement for Building Resilience in Social-Ecological Systems," *Environmental Management* 34, no.1(2004): 75–90. https://doi.org/10.1007/s00267-003-0101-7

51 Thomas Allen, Paolo Prosperi, Bruce Cogill, and Guillermo Flichman,"Agricultural Biodiversity, Social–Ecological Systems and Sustainable Diets," *Proceedings of the Nutrition Society* 73, no.4 (2014): 498–508. https://doi.org/10.1017/S002966511400069X

52 Joseph M. Krupinsky, Karen L. Bailey, Marcia P. McMullen, Bruce D. Gossen, and T. Kelly Turkington, "Managing Plant Disease Risk in Diversified Cropping Systems," *Agronomy Journal* 94, no.2 (2002): 198–209. https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronj2002.1980

53 Fiona M. Tomley and Martin W. Shirley, "Livestock Infectious Diseases and Zoonoses," *Philosophical Transactions of the Royal Society B: Biological Sciences* 364 (1530) (2009): 2637–42, https://doi.org/10.1098/rstb.2009.0133

54 Ping-Ing Lee and Po-Ren Hsueh, "Emerging Threats from Zoonotic Coronaviruses-from SARS and MERS to 2019-NCoV"

55 Xintao Zhou, Nan Li, Yuzi Luo, Ye Liu, Faming Miao, Teng Chen, Shoufeng Zhang, et al., "Emergence of African Swine Fever in China, 2018," *Transboundary and Emerging Diseases* 65, no.6 (2018): 1482–84, https://doi.org/10.1111/tbed.12989

56 Darrin Qualman, comment on "Earth's Dominant Bird: A Look at 100 Years of Chicken Production," Darrin Qualman Blog, comment posted January 24, 2018, https://www.darrinqualman.com/100-years-chicken-production/ (accessed February 5, 2021).

57 Keith Bradsher and Ailin Tang, "China Responds Slowly, and a Pig Disease Becomes a Lethal Epidemic," *The New York Times*, December 17, 2019, https://www.nytimes.com/2019/12/17/business/china-pigs-african-swine-fever.html

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