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Managing emerging infectious diseases needs global understanding of microbial ecology and evolution

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Abstract:

Globalization accelerates the mobilization of microorganisms via international trade and transport. Growth in population, increasing connectivity and rapid urbanization all exacerbate the consequent risk of zoonotic disease pandemics. Global problems require global solutions, particularly the co-ordination of international research in biomedical sciences, global ecology, and sustainability.

Globalization promotes pandemic disease

The COVID-19 pandemic is a clear example of how globalization speeds the planetary-scale mobilization of emerging infectious diseases (EIDs). The devastating impacts on human health and global economies arose as a consequence of a single novel virus transmission event, which was first reported on 31 December 2019 from Wuhan City of China[1]. Assisted by human transport, the virus spread to the entire globe in as little as three months, leading to the announcement of global pandemic by the World Health Organization (WHO) on 11 March 2020.

The COVID-19 pandemic is not an isolated event, viruses and microorganisms constantly move between humans, animals, plants and the environment (Fig. 1), and now they do so on a planetary scale at an increasing and unprecedented pace driven by international transport of goods and produce, ballast water, and exponentially growing human travel via air, sea and land[2]. The scale of global movement of people and potential spread of infectious diseases during outbreaks is exemplified by global airline passengers, a key factor in the rapid dissemination of viruses and microorganisms around the planet, that has increased by an order of magnitude in recent decades (Fig. 2).

The pace and scale of the current pandemic is not simply the result of this exponentially increased mobilization. It also results from other human-related risk factors, including population density, anthropogenic disturbance of ecosystems, and zoonotic transmission. Anthropogenic impacts can cascade via disturbance of ecosystems into the microbial world, changing pathogen hosts and transmission routes, and increasing the likelihood of disease outbreaks in humans. Understanding the complexities of these interactions is central to predicting and managing the continuously increasing number of EID events (Fig. 1).

Infectious diseases and sustainability

Historical data and modelling confirm the increasing incidence of EIDs being driven by deforestation, food production and climate change.[3,4] These risk factors will likely be exacerbated as the world's population is projected to increase by 2 billion by 2050, with nearly 70% then living in cities. Rapid urbanization and associated increases in population density provide fertile ground for rapid spread of novel pathogens in pathogen-naïve populations. Meanwhile, population growth and rising food demand drive agricultural expansion and intensification, and thus deforestation and habitat loss, both of which are associated with an increased incidence of EIDs[5]. The majority of recently emerged infectious diseases are zoonoses, and of these, 70% originate from wildlife[4] (Fig. 1). Hunting and widespread trading in wildlife are therefore also major drivers for the emergence and spread of infectious diseases.[4,6]

As discussed above, all these sustainability issues, such as rapid population growth, urbanization, increasing consumption of nature-derived commodities and land conversion are all interconnected and interact with each other to increase risks of pandemic disease at global scale. Novel pathogens, such as new coronaviruses, are often zoonotic[4], and consequently are likely to emerge and spread as human land use expands into the nature, food distribution and human traveling are globalized, and population density increases. Although sustainability issues have been included in large scale modeling of EID incidences, these issues have yet to be fully integrated into systems for managing and preventing infectious diseases. We therefore call for urgent consideration of EIDs in global sustainability agenda. We need to track the way that microorganisms cycle between the environment, animals and humans at various temporal and spatial scales. We can no longer afford to ignore the complex dynamics and ecology of the microbial world. Incorporation of ecological understanding, environmental management and disentangling of human-animal interactions will help inform decision-making and preventative actions around infectious disease.

Systems approaches to managing infectious diseases

Monitoring and assessment of microbial ecology should enlighten the complex multifactorial relationship between sustainable development, human health and microorganisms. Such understanding will make it possible to develop the required complex and integrated solutions to manage future emerging infectious diseases. One Health[7] is one such systems approach to global health security. One Health is dedicated to achieving optimal human and environmental health by linking research disciplines, sectors and public health organizations to advance a holistic view of the interconnections between humans, animals, plants, microbes and ecosystems as a single integrated system. It particularly examines the role of microbial dynamics in socio-ecological systems from local to global scales.

Realizing these aims and effectively mitigating emerging infectious diseases, however, still requires a shift in scientific research. We need improved collaboration between the biomedical sciences, global ecology, and sustainability. In general (although not universally), modern medicine is often practiced as though humans are separate from the natural world, and evolutionary processes are often ignored.[8] Efficient data sharing, and an appreciation of research that crosses traditional discipline boundaries would help in disease prevention and control by allowing faster and multi-pronged responses to outbreaks . An increased appreciation in medical circles of the importance of microbial ecology and evolution in disease dynamics will be critical to managing future pandemics. The evolutionary processes of mutation and selection, and the evolutionary dynamics between virulence and transmission are important for understanding how diseases spread and adapt to their hosts. The One Health approach[7] offers a platform for collaboration, but fundamental integration between biomedical science, global ecology and sustainability is still needed. Ecological and evolutionary disciplines have often been seen as irrelevant to human health, but they are central to understanding disease emergence and risk.

Fundamental innovations will also be required to prevent disease outbreaks at their sources. Agile surveillance and warning systems are now within practical reach, since the cost of DNA sequencing analysis is rapidly dropping, and we can effectively screen wild animal populations to understand viral composition, evolution and dynamics[9] before animal viruses become a danger to human populations. Indeed, pandemic risk should be explicitly considered within the overall framework of global ecology and sustainable development[10], and research teams should be assembled to monitor and understand viral dynamics in natural ecosystems.

In the longer term, understanding the impact of consumption-driven changes in ecosystems could also help to inform fundamental changes in policy. For example, it is estimated that about 20% of the malaria risk is driven by the international trade of commodities implicated in defeorestation, such as timber, wood products, tobacco, cocoa, coffee and cotton[11]. This linking of EID risk to the final consumers of commodities strongly justifies demand-side policy measures with important co-benefits for reducing deforestation and forest disturbance[11]. Demand-side measures can be established by engaging consumers, legislating certification and other producer standards, or/and establishing fiscal instruments to thus reduce deforestation and EID risk at the same time.

With our increasing awareness of pandemics, preparedness should become a priority for the global health agenda. Preparedness for disease outbreaks will require expanded reserves in diagnostic infrastructure, in the population of medical personnel, and in healthcare consumables. But preparedness will also require full consideration of the nexus between social and ecological systems. Thus, greater public literacy about infectious diseases and their dynamics is also warranted, such as awareness of the interconnections between pandemics, population growth, urbanization and consumption. We therefore strongly propose that the dynamics of the planet’s microorganisms be incorporated as a key issue in the United Nations Sustainable Development Goals. Currently the issue of infectious disease is included in SDG3 (Good health and well-being). However, since the emergence and spread of infectious diseases are the integral outcome of intricate interactions between human and natural ecosystems, SDG3 must promote a strong co-ordination of international research in biomedical sciences, global ecology, and sustainability and strongly interact with the other SDGs: Climate action, Sustainable cities, Life on land, Sustainable consumption and production, Food, Poverty …, for example in the frame of a cross action platform (see: https://sustainabledevelopment.un.org/sdgactions).

Long-term preparedness will ultimately rely on advances in our fundamental understanding of the composition, dynamics and functions of the microbial world, in which pathogens co-exist and interplay with beneficial microorganisms. Such advances will assist rapid and rational monitoring of microbial cycling between humans and the environment using molecular and big data approaches. Better understanding of the Earth's microbial inhabitants will help to predict likely sources of pandemics and novel disease agents and facilitate vaccine development in a timely and targeted manner. For example, spatially explicit models can be developed to diagnose and predict the regions where humans are more exposed to wildlife and their associated microbiomes[12]. We urgently need to assess what species (e.g. those with highest viral loads), locations (e.g. regions projected to experience rapid urbanization by 2050) and practices (e.g. wildlife traffic) pose the greatest risk for zoonotics, and plan or act accordingly [13,14].

Concluding remarks

Despite our attempts to insulate ourselves from disease agents, we are living in an ever more tightly connected microbial world, regardless of wealth or location. Human activity has caused dramatic changes in the world, potentially to the point of irreversibility. These changes extend into the microbial world, much of which is yet to be explored or understood. This understanding can only be achieved through a strong co-ordination of international research in biomedical sciences, global ecology, and sustainability.

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DECLARATION OF INTERESTS

Authors declare no competing interests.

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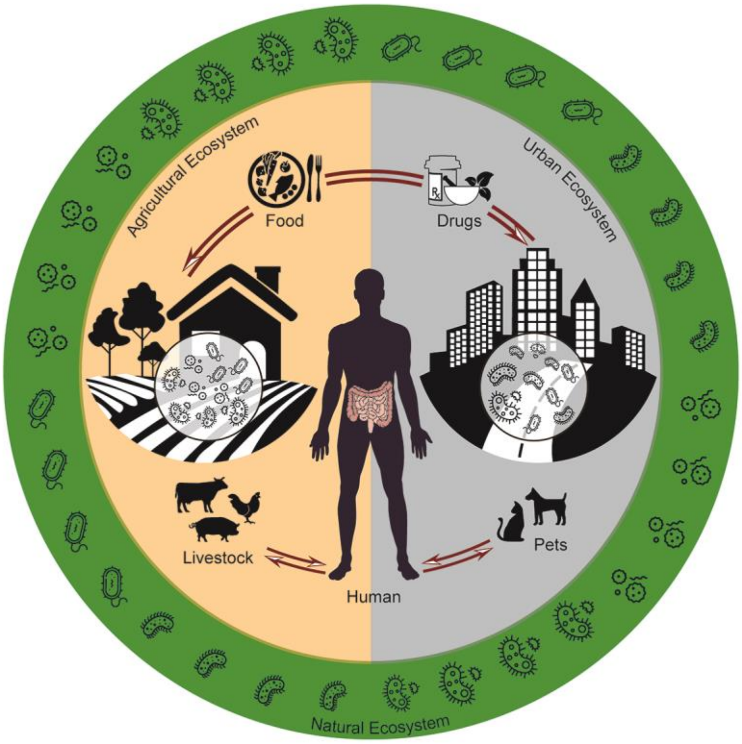
Figure 1. Human and emerging infectious diseases (EIDs). (A) Human, animals and the environment share the complex microbial world. (B) The cumulative EIDs and zoonotic EIDs of humans since 1940, in which non-wildlife and wildlife represent the zoonotic EID event caused by a pathogen with no known and known wildlife origin, respectively. (C) Effects of food- and drug-drivers on number of EID events per decade. For (B) and (C), data were collected from Jones et al.[4] database.

Figure 2. Air passengers carried include both domestic and international aircraft passengers of air carriers registered in the country, unit: $\times 10^{12}$ passengers. (A) 1970, (B) 2018, (C) 1970-2018: world, (D) Global spread of MERS-CoV across 26 countries[15].

Data source for A, B and C:

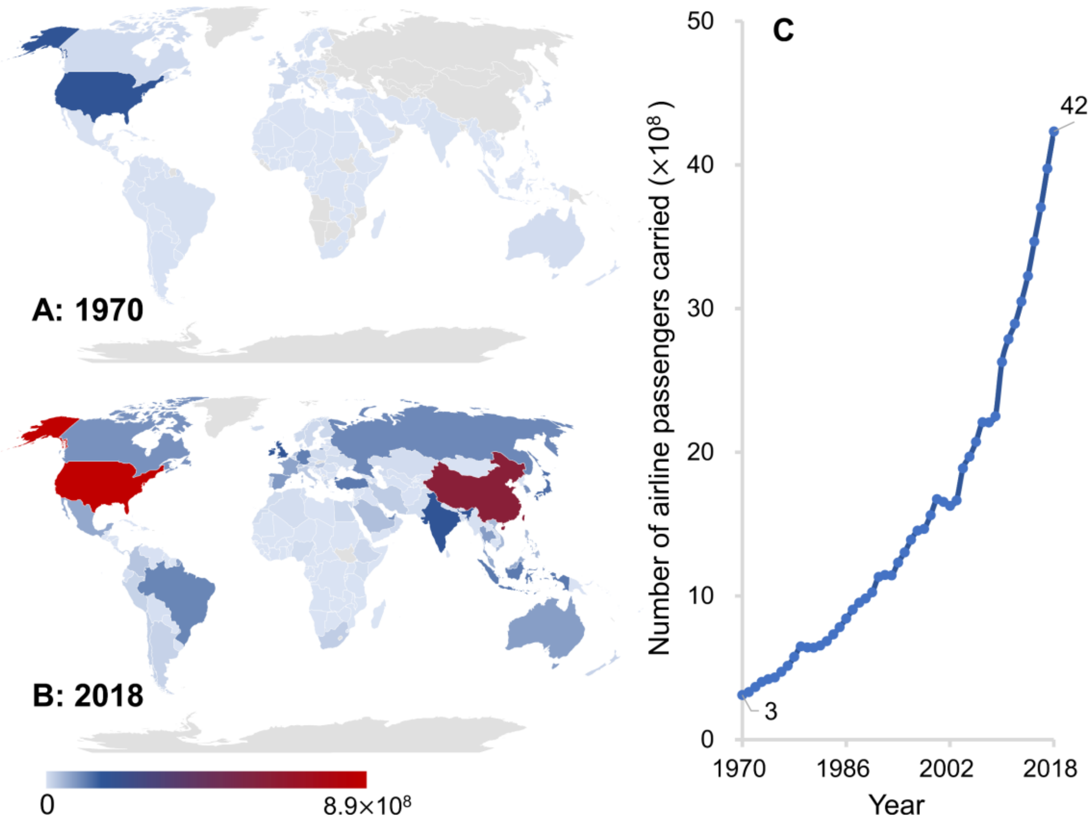
https://www.indexmundi.com/facts/indicators/IS.AIR.PSGR
https://data.worldbank.org/indicator/IS.AIR.PSGR

Figure 1



Agricultural Ecosystem
Urban Ecosystem
Food
Drugs
Livestock
Human
Pets
Natural Ecosystem

Figure 2


A: 1970
B: 2018
0
8.9×10⁸
C
50
40
30
20
10
0
42
3
Number of airline passengers carried (×10⁸)
1970
1986
2002
2018
Year