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Environmental Change and COVID-19

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Environmental Change and COVID-19

The Risk of Future Pandemics in Asia and the Pacific

Preview edition

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Contents

Figures

Boxes

Tables

ABBREVIATIONS

AIT
Asian Institute of Technology

CITES
Convention on International Trade in Endangered Species of Wild Fauna and Flora

EID
emerging infectious disease

FAO
Food and Agriculture Organization

HPAI
highly pathogenic avian influenza

HTLV
human T-cell lymphotropic virus

ICIMOD
International Centre for Integrated Mountain Development

IGES
Institute for Global Environmental Strategies

MERS
Middle East respiratory syndrome

OIE
World Organisation for Animal Health (*formerly Office International des Epizooties*)

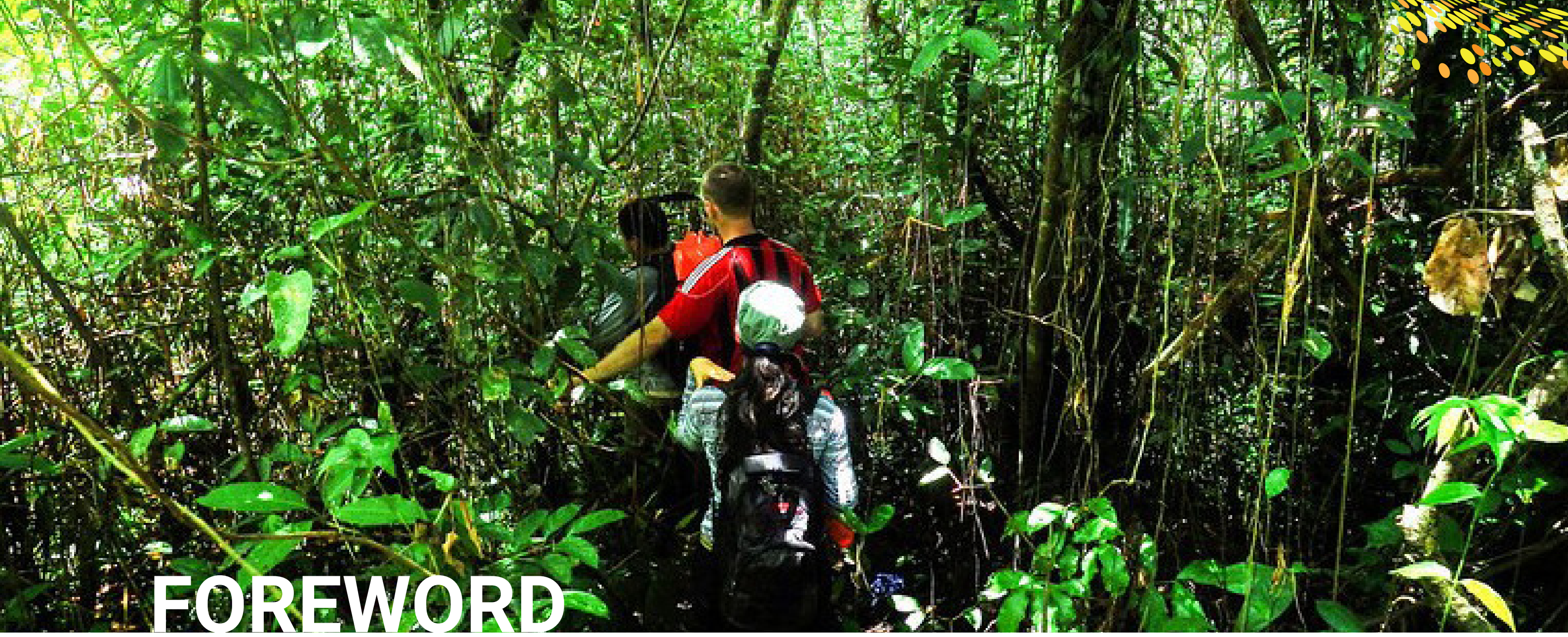
SARS
Severe acute respiratory syndrome

TEEB
The Economics of Ecosystems and Biodiversity

TERI
The Energy and Resources Institute

UNEP
United Nations Environment Programme

WHO
World Health Organization



FOREWORD

Daily headlines inform us that the COVID-19 pandemic has infected more than 200 million people and taken more than 4.5 million lives globally. The headlines also make us aware of the current socioeconomic crisis that has been spurred by shutdowns and job layoffs worldwide, including Asia and the Pacific, where about 80 million have been pushed into extreme poverty.

But perhaps, a lesser-known story is that the COVID-19 pandemic is also significantly compounding the three deepening, long-standing planetary crises of our time in addition to poverty and hunger— that is, climate change, biodiversity loss and pollution. The planetary crises are reinforcing each other and driving further damage to the environment and our health. In fact, this pandemic complicates multilevel actions to address these planetary crises and opportunities as outlined by the 2030 Agenda for Sustainable Development, including Goal 3, Good Health and Well-being.

In this context, this UNEP report, Environmental Change and COVID-19: The Risk of Future Pandemics in Asia and the Pacific, presents a simple message—safeguarding nature is vital for avoiding future pandemics. Or in other words, natural habitat loss and wildlife exploitation are critical drivers of zoonotic disease emergence. This message is crucial for the Asia Pacific region, a hotspot of zoonotic disease outbreaks resulting in recent public health crises—avian influenza, viruses such as Nipah and Zika, and SARS, the severe acute respiratory syndrome.

Thus, Environmental Change and COVID-19 provides an in-depth analysis of the intricate links between human infectious diseases and nature, highlighting the role of wildlife and habitat management. It also reviews the experience and lessons learned, over past decades, from Asia and the Pacific in managing these zoonotic diseases. In doing so, this report presents rich knowledge, critical analytics and sharp conclusions on the drivers and causal factors that heighten the risk for zoonoses and pandemics. And finally, it illustrates how human pressure on nature can influence the emergence and distribution of infectious diseases.

We appreciate the inspirational collaboration—from our regional partners, the report's authors and reviewers, and our colleagues in the UNEP Regional Office for Asia and the Pacific—for making this timely report available at the Inaugural Session of Asia-Pacific Science-Policy-Business Forum on the Environment. This report will also undoubtedly inform dialogue at this meeting as well as at the Fourth Session of Forum for Ministers and Environment Authorities of Asia Pacific, held on 5 to 7 October 2021.

We strongly hope that the report will inspire and generate innovative policies, regional and national surveillance frameworks to monitor, prevent and early detect future zoonotic diseases for generations to come.

Dechen Tsering
Regional Director and Representative for Asia and the Pacific

Image from https://www.decadeonrestoration.org/

KEY MESSAGES

COVID-19 is the worst pandemic of the twenty-first century and the third worst since 1900. Despite the rapid development of effective vaccinations, the eventual impact of this pandemic may exceed that of HIV/AIDS.

The origin of the COVID-19 virus is unknown. The currently dominant hypothesis to explain its aetiology is that the causal virus, SARS-CoV-2, a coronavirus has evolved naturally as a result of viral mixing in an ecological milieu in which different species of farmed or smuggled animals, or both, exist in close proximity. A more speculative hypothesis is that the causal virus either escaped from a laboratory after either being brought there for purposes of study or, otherwise, escaped after evolving in a laboratory due to experimentation. In either case, the laboratory pathway, if true, may have unfolded owing to a well-intended attempt to better understand potential viral capacities—with the goal of preventing an epidemic.

Irrespective of the true origin of the virus, COVID-19 must be recognized as signifying a profound warning to civilization, which faces other interacting crises, including rising hunger and undernutrition, a record number of displaced persons, climate change, biodiversity loss and widespread pollution.

It is possible that the crisis caused by the current pandemic will lead to a fundamental awakening to the danger of humanity's recent trajectory, energizing reforms such as improved governance and cooperation, a new economic system, reduced corruption—and most important, greater respect for nature.

From a health perspective, what is required for the COVID-19 pandemic is a globally equitable distribution of effective vaccinations, with persisting immunity. But looking forward, what tools do we have to confront future pandemics? A One Health approach is increasingly presented as one such necessary strategy to prevent the emergence of future zoonoses, epidemic and pandemics. Such approaches call for greater disciplinary integration. But unfortunately, advocates for One Health will need to overcome formidable barriers to achieve its genuine implementation on a large scale.

Defined as diseases transmitted from non-human animals to humans, "zoonoses" are an inadvertent consequence of the domestication, farming, hunting and fishing of animals, enabling (with plant domestication), large human populations and ongoing close contact between different species of animals and between humans and animals, including peri-domestically. These animals are captured and bred not only for human food but also for the fur and pet trade and for products of claimed medicinal value (and even to impart a unique flavour to coffee).

Zoonoses can also enter human populations owing to laboratory accidents and errors. Deforestation, climate change and palm oil plantations have also been implicated in the emergence of some zoonoses.

Most emerging infectious diseases are zoonotic, but only a very small number of them (including SARS-CoV-2) have the potential to cause a genuinely global pandemic. Several properties of SARS-CoV-2 make this possible, including its airborne transmission. However, it is here postulated that the most important relevant property may be its capacity for significant transmission by carriers who have subclinical or asymptomatic infection. Such properties have been characterized as "stealth" transmission. It is stressed, however, that while this property may be necessary (at least for the widespread infection of diseases that do not involve an arthropod vector), it is not sufficient.

Influenza, HIV/AIDS and SARS-CoV-2 each have significant stealth transmission. Asymptomatic carriage and transmission of MERS-CoV is documented, but such transmission is far less important, thus limiting its pandemic potential.

The farming of domesticated and "wild" animals for whatever purpose creates opportunities to bring together species (either in farms or markets)—and in turn, this creates the potential for viral mixing that could generate novel zoonoses, perhaps even with global pandemic potential.

In the Asia Pacific, demand for meat derived from wildlife species (including if farmed) is mainly driven by perceptions of increased status and vitality gained from its consumption, rather than by evidence of health benefits. However, in some settings, wild meat is cheaper, more available and more nutritious. All meat consumption is ethically problematic for some people. If the global consumption of meat (especially non-aquatic) can be substantially reduced, but made more equitable, then substantial benefits will accrue to many humans as well as to the environment. This will require courage and leadership, challenging the global meat and livestock industry.

Although the health benefits from eating meat and other animal products, such as eggs and dairy, are commonly attributed to increased protein intake, the absorption of micronutrients (especially zinc, iron and vitamin B12) from meat may be a more important reason. Nonetheless, the absorption and nutritional level of iron may be enhanced by better treatment and prevention of intestinal parasites such as hookworm. Thus, it should be possible to reduce the demand for meat, including, in some cases, by judicious micronutrient food supplementation, especially zinc, iron and vitamin B12.

However, it is likely that consumers who pay a premium for wild animal species have higher levels of micronutrients, in association with their higher living standards. Thus, while better treatment of parasites (and supplements) may reduce the demand for meat, it may have minor impact on the demand for wild species.

The farming of wild animal species generates income for farmers and for those involved in the legal and illegal wildlife trade. Alternative livelihoods need to be found for people whose incomes are reduced by effective pandemic prevention measures.

Environmental Change and COVID-19

The Risk of Future Pandemics in Asia and the Pacific

INTRODUCTION

> “If there is any conceivable way a germ can travel from one species to another, some microbe will find it”.
>
> William H. McNeill (1976) [1]

COVID-19 was first reported in the Asia Pacific region, just like its predecessor, severe acute respiratory syndrome (SARS). Unlike SARS and the Middle East respiratory syndrome (MERS), both which can be considered as providing the world with an under-appreciated warning [3], COVID-19 rapidly affected almost every country in the world (apart from a few isolated islands that have yet to record cases).

In fact, as of September 2021, the COVID-19 pandemic has directly infected more than 225 million people and caused more than 4.6 million deaths at a global scale. In the Asia-Pacific countries alone, more than 51.5 million cases and about 800,000 deaths were reported as of September 2021. More than 10 countries in Asia-Pacific confirmed more than 2,000 new cases daily.

In this context, Box 1 discusses the role and geographic span of the UNEP Regional Office for Asia and the Pacific Office.

Box 1

What is the role and geographic span of UNEP in the Asia Pacific region?

The United Nations Environment Programme (UNEP) assesses environmental conditions and trends at the global, regional/sub-regional and national levels; fosters the development of international agreements and national environmental instruments; and strengthens institutions for sound environmental management.

To enhance the effectiveness of programme development and delivery, UNEP aims to strengthen partnerships at the regional and sub-regional levels with other UN bodies, development banks and other institutions, including Major Groups and Stakeholders.

To this end, the UNEP Regional Office for Asia and the Pacific fosters this partnership by engaging with 41 countries in 5 subregions as follows:

- Australia and New Zealand
- *Northeast Asia*: China, Democratic People’s Republic of Korea, Japan, Mongolia and the Republic of Korea
- *South Asia*: Afghanistan, Bangladesh, Bhutan, India, Iran (Islamic Republic of), the Maldives, Nepal, Pakistan and Sri Lanka
- *Southeast Asia*: Brunei Darussalam, Cambodia, Indonesia, Lao People’s Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste and Viet Nam
- *The Pacific*: Cook Islands, Fiji, Kiribati, the Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu

Box 2
What is the etymology of the term “pandemic”?

The term “pandemic” has been in occasional use for over three centuries [4]. Clemow (1894) described the gradual progression of influenza (circa 1889–1892) as a pandemic, but without defining it and without seeking to distinguish it from “epidemic”, a term he also used frequently in the same article.

However, starting near the end of World War I the catastrophe of the 1918 influenza pandemic (also known as the “Spanish” flu) killed as many as 100 million people, including millions of young adults [6] For this cataclysm, “epidemic” seemed (and seems) too mild, and as a consequence, the term “pandemic” became temporarily commonplace [4] as it is, again, today.

In 2014 the fifth edition of *A Dictionary of Epidemiology* defined “pandemic” as an “epidemic occurring over a very wide area, crossing international boundaries, and usually affecting a large number of people”. The definition pointed out that the infectious agent must be able to infect humans and to spread easily from human to human [7].

WHO Director General Tedros Ghebreyesus, speaking in March 2020, said “pandemic is not a word to use lightly or carelessly. It is a word that, if misused, can cause unreasonable fear, or unjustified acceptance that the fight is over, leading to unnecessary suffering and death” [203].

Box 3
What are the characteristics of a pandemic?

Morens *et al.* (2009) identify several pandemic characteristics, in addition to the traceable disease movement over a large region [4]. These include (i) high attack rates and “explosive” spread; (ii) the capability to be transmissible by an infectious agent (rather than a spreading set of social determinants, thus excluding conditions like obesity) and (iii) comparative novelty.

Although waves of plague, cholera, influenza and dengue have occurred repeatedly, their high crests are at sufficient intervals (often a generation or longer) to qualify as novel, unlike more perennial conditions, such as tuberculosis. As WHO Director-General Ghebreyesus and others seemed to recognize, the term “pandemic” should be reserved for the most severe conditions, with a potential for extraordinary mortality.

In addition to health impacts, the COVID-19 pandemic has had a profound economic impact globally, reflected by increased unemployment in many sectors, including tourism and education. The public health response, manifested especially as lockdowns, has resulted in wide-ranging disruptions, from social isolation to the cancellation of mass gatherings.[1]

The decline in economic activity has itself had numerous adverse effects, including for health. Health systems in many countries have been greatly

1 For example, the Gavi, the Vaccine Alliance interrupted all other vaccination programmes, specifically the planned vaccine investment strategy for cholera and rabies because of its engagement in the co-ordination of the distribution of vaccines against SARS-Cov-2.

stressed not only by the substantial morbidity and mortality borne by infected health workers but also because many health workers have been overwhelmed by the huge influx of patients in hospitals, compounded by inadequate resources such as of personal protective equipment. In addition, under-resourced hospitals in many countries have had to not only triage COVID-19 patients but also suspend much of their routine medical procedures. This has greatly magnified the number of deaths and overall morbidity for patients in need of care. Moreover, these constraints have also weakened the financial equilibrium of these health care institutions, risking the long term of deterioration of the health system as a whole.

The proximate cause of the COVID-19 pandemic is a newly discovered beta coronavirus,2 officially referred to as "SARS-CoV-2".[3] The disease that results from SARS-CoV-2 infection, COVID-19, is widely considered to be a zoonosis[4] (Box 4) that is believed, with high confidence [9], to have originated in the *Rhinolophus* bat genus before being introduced to humans. This might have occurred via one or more "intermediary" or "bridging" vertebrate species [11–13]. Although COVID-19 is spread chiefly by aerosols [14], fomite transmission, especially on frozen surfaces, is also possible [15].

There are two leading hypotheses for the origin of SARS-CoV-2. The first is that the virus may have been accidentally introduced to the human population, in unchanged form, via an accidentally infected laboratory

Box 4

What is the definition of "zoonoses"?

While definitions vary slightly, "zoonoses" (Greek "zôon" = animal, "nosos" = disease) are generally defined as human diseases or infections caused by pathogens whose original source is a non-human vertebrate animal, almost always warm-blooded [21]. It should be noted, however, that this term excludes infections that humans have lived with since our species diverged from other primates, as discussed briefly in Section 1.

Zoonotic agents might be living microorganisms capable of independent existence (e.g. bacteria, protozoa, rickettsia, fungi and helminths). Or they might be viruses that require the "cellular machinery" of a host species (vertebrate or invertebrate)[5] for their reproduction. They can also be non-living substances such as prions, although this is rare.

2 Coronaviruses are divided into four groups – alpha, beta, gamma and delta. To date, only alpha and beta forms are known to infect humans. SARS, MERS-CoV and SARS-CO-V-2 are all betacoronaviruses. Of these, two alphacoronaviruses are widespread; most illnesses they cause are forms of the so-called common cold [8].

3 While "CoV" is the abbreviation for "coronavirus", the number "2" refers to the similarity to the "strain" of coronavirus that caused SARS but also indicates differentiation.

4 The causal pathogen is thus generally considered a zoonotic agent. However, somewhat ambiguously, the World Health Organization defines "zoonosis" as "any disease or infection that is naturally transmissible from vertebrate animals to humans". For more information, visit the WHO's fact sheet, "**Zoonoses**."

5 Unlike all other organisms, which carry their genetic information only as DNA, some viruses can carry their genetic information as RNA only.

Box 5

What does the term “prion disease” refer to?

Prion diseases (originally thought to be caused by “slow viruses” were already known, especially kuru, a disease transmitted by ritual cannibalism in New Guinea [60]. Prions can occasionally occur spontaneously in mammalian brains, but they are only transmissible if flesh “infected” with prions is ingested.[5] For several years, however, the possibility that prion-infected cattle could infect humans was denied.

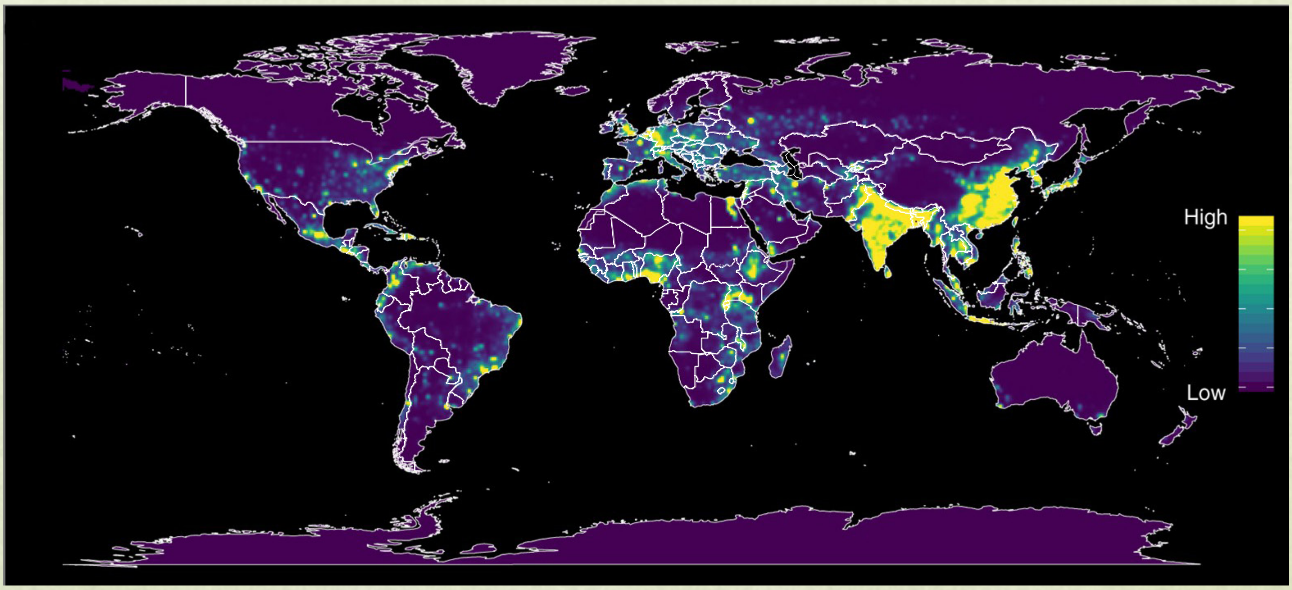
worker, after carriage of the pathogen from the external environment to a laboratory for research purposes. The second leading alternative hypotheses is that the pathogen may have evolved in a laboratory, resulting from experimental work, and then been accidentally introduced to the human population, probably via an infected laboratory worker. Variants of these hypotheses are plausible but have less support [16-19].

The loss of human life and livelihood that has resulted from the ongoing COVID-19 pandemic, as well as the frequency of emerging zoonoses, make it essential to reflect on the factors that contribute to their emergence as well as on the possible mitigation measures. This is especially important in the context of the Asia and Pacific region, which has been identified as home to potential hotspots for emerging zoonotic disease risk, as shown in Figure 1 [20].[6]

6 In the case of kuru, the ingested body part appears to have been restricted to the brain. In the case of bovine spongiform encephalopathy leading to v-CJD, transmission appears to have occurred from eating muscle as well, perhaps, as brain and other neural tissue.

Figure 1 /

Estimated global risk of zoonotic disease emergence



Source: Allen *et al*. [20].

About this report

The preliminary findings and conclusions of this scientific review were presented via a UNEP webinar based on the UNEP-ILRI report *Preventing the Next Pandemic – Zoonotic Diseases and How to Break the Chain of Transmission*, organized by the UNEP Regional Office for Asia and the Pacific and its partners. The webinar focused on the themes of the interconnectedness of nature and human health, options and actions to ensure green recovery responses to build back better, and practical solutions to prevent future zoonotic outbreaks, including examples of the application of a One Health approach that integrates human, animal and environmental health science and policy frameworks.

Registered for the October 2020 webinar were more than 200 participants from governments of Member countries, the academic community, civil society organizations and regional partners. The discussions and exchanges were incorporated into this report. The report has been peer-reviewed by stakeholders from Member countries and scientists in virology, public health and environmental sciences. Based on review comments, this report has been revised substantively and used as a background document for the Inaugural Regional Session of UNEP Science-Policy-Business Forum on the Environment, held on 5 October 2021, virtually.

1 A HISTORY OF **HUMANS** AND **ZOONOSES**

Just like all vertebrate animals, humans live in proximity to an enormous number and variety of microbes. Although little is known about these organisms, more than 99 per cent are considered harmless, and many are beneficial [22]. In fact, humans also carry a vast number[7] of microbes internally; about 3 kg of the weight of the average person is comprised of microbes, and they are found particularly on the skin and in the gastro-intestinal tract.

Nonetheless, all vertebrate animals (and plants) suffer periodic disease, including that from infectious agents. The number of known infectious agents[8] that humans are potentially exposed to is fewer than 1,500. Although a few new ones have been identified over the past 20 years, including SARS, MERS and COVID-19, of these, fewer than 900 are classified as "zoonotic" [23]. A small number of viral pathogens, such as the Herpes zoster and Epstein-Barr viruses, are thought to have been present since the time that humans diverged from the great apes.[9] While these pathogens were once shared with other animal species, they are not usually considered zoonotic because they have adapted to humans and no longer need non-human animals to persist in nature.

Some zoonoses are thought to have infected some humans for perhaps 40,000 years, since the domestication of dogs [24]. Forty millenniums is, of course, a brief period compared to our existence as a species; in fact, our species has been hunting and butchering animals for far longer. It is possible, indeed likely, that some zoonoses did infect human populations before dog domestication, but any infections are likely to have been rare and transient. If a hunter killed or found an obviously diseased animal, disgust (and perhaps fear,[10] which is innate to many if not all humans and has also been documented in several non-human animals) [25–27] may have inhibited the consumption of that animal as food, thus reducing disease-transmission risk.[11] Even so, some ancient hunters are likely to have acquired a zoonotic infection, perhaps because either hunger overrode caution or the disease in the dead or killed animal was not obvious.

It is believed that zoonoses could not have persisted in human populations until long after the dawn of agriculture (and animal domestication), about

7 Over 10^{17} organisms, most of which are viruses [22].
8 Including, in addition to viruses, other "micro-parasites": prions, bacteria, rickettsia, fungi, protozoa and helminths.
9 These include gamma-herpesviruses, the Epstein-Barr virus and the Kaposi's sarcoma-associated virus. These are typically transmitted from mother or grandmother to offspring via saliva, but can also be transmitted sexually or by sexual kissing later in life [22]. These viruses have "stealth" characteristics, exist for many years in the host, rarely if ever kill an immuno-competent host, and do not require large numbers of people to remain indefinitely established in human populations. Our closest extant relative, the chimpanzee, carries a virus closely related to the Epstein-Barr virus, while other apes and monkeys harbour more distant relatives of this virus in parallel with the evolutionary distance of the host [22].
10 Likely, these responses vary in populations and can be repressed or suppressed in some people, including health and other caregivers and in individuals or groups compelled to perform work considered "unclean" by others.
11 Disgust and fear also act to reduce secondary infection, that is, from the index case into the wider group. Other examples of behavioural immunity include washing hands after contact with animals; disgust for animal faeces; fear of vermin and rodents, such as mice and rats, especially near food; and traditional and contemporary forms of meat inspection.

Table 1 Animal infections transmissible to humans, ranked by estimated human contact

Animal	Infections shared with humans	Millenniums of close human contact
Dog	65	20–40
Cattle	50	10–11
Rat, mouse	68	10?
Sheep, goat	46	9–10
Cat	28 (circa)	8?
Pig	42	8
Llama	few if any	6–7
Horse	36	6
Camel	39	5?
Poultry	25	4.5?
Bat	61	Uncertain but likely thousands
Palm civet	1? (SARS)	<50 years?
Raccoon dog	1? (SARS)	<50 years?
Bamboo rat	1? (SARS)	<50 years?

Abbreviations: Question mark (?), uncertainty.
Source: [30, 32–35].
Note: Numbers overlap as some infections are shared among multiple species.

10,000 years ago [28]. Before then, all human groups lived in small numbers, generally isolated from other humans, who also lived in similarly small, isolated groups. For example, the zoonosis measles (related to the now extinct cattle disease rinderpest [29]) may occasionally have entered human populations through the hunting of cattle before domestication.

Measles (unlike a disease such as a haemorrhagic fever) was unlikely to have provoked extreme fear and avoidance of an infected ancient hunter; thus,

Table 2 Selected key zoonoses in the Asia Pacific not detailed in this report

	Animal reservoir	Vector (if applicable)		Geographical areas of transmission
Anthrax *	Cattle			South Asia
Brucellosis *				South-East and South Asia
Chikungunya	Primates	Mosquito		South-East and South Asia
Cysticercosis *	Pigs			SE Asia
Crimean-Congo haemorrhagic fever *		Tick		Pakistan
Japanese encephalitis		Mosquito		South-East, South, East Asia
Leishmaniasis, visceral *	Cattle	Sandfly		Bangladesh, Nepal, Northern India
Leptospirosis *	Eodents			Widespread
Rabies *	Wild dogs			Widespread

Source: Animal reservoir and geographic locations are incomplete. More details of these conditions are shown in the glossary and marked with an asterisk (*).

this disease could have plausibly more easily infected most or all of the human group to which the index case of measles belonged. However, after that, measles would die out in that early human band. Measles (unlike the Epstein-Barr virus and some others) does not persist in individual humans for years, and it also provokes enduring immunity in survivors. It could only persist in human populations if a constantly replenished “supply” of non-immune people come into contact with someone who is infectious. Wolfe *et al.* (2007) [30] cite studies that conclude that human populations of at least several hundred thousand are needed to sustain measles, German measles (rubella) and whooping cough (pertussis).

Although populations of this size are common today, they were unlikely until thousands of years after the development of agriculture[12] (even though some pre-agricultural populations occasionally did come together in the hundreds or perhaps thousands, at least briefly, when food resources were particularly abundant at a particular time). This remains a practice, for example, of some Australian indigenous peoples.

Long after the development of agriculture, zoonoses increasingly emerged for three reasons. Firstly, animal domestication increased the chance for diseases to spill over from animals to humans (and vice versa) (Table 1). Secondly, as human habitats became more complex, animals such as rodents found it advantageous to be in proximity with humans, even though peri-domestic (i.e. not domesticated), for reasons such as shelter or

12 A recent study, using phylogenetics (the study of genetic relationships among different groups of organisms and their evolutionary development) has found earlier dates for human cases of Hepatitis B (c5ky BP) and smallpox (each in the first millennium BC) than previously known [31]. However, even if these earlier dates are correct, they are well after the development of agriculture.

Box 6

What types of behaviours inhibit disease transmission?

The term "behavioural immunity" refers to individual and collective behaviour that reduces the risk of infection, particularly in humans [25]. Being a strong motivator of protective distancing from an obviously sick person,2 disgust appears innate in many people.[14]

A range of less extreme forms of behavioural immunity activities are learned, from hand-washing, mask-wearing and mouth-covering when coughing to engaging in lockdowns.

The term "quarantine", originally meaning 40 days of enforced social distancing, dates to late fourteenth century Italy [37]. Sufferers of the contagious disease leprosy, a zoonosis, have been socially distanced by non-lepers for millenniums.

Importantly, not only disgust, but learned causes of social avoidance cannot completely inhibit disease transmission if infection is possible from completely[15] asymptomatic people.

greater food availability. Thirdly, as mentioned, ongoing epidemics of zoonoses, or diseases that were originally zoonotic, require large human populations to persist.[13]

Some important zoonoses in the Asia Pacific, not discussed in more detail in this report, are shown in Table 2.

Fortunately, only a very few diseases with high potential burdens of disease are currently considered to have this characteristic (Table 4, Section 4). SARS does not fall under this category; [39] however, there are claims that the proportion of asymptomatic cases of MERS have increased, especially among children [40].

Some forms of long-standing behavioural immunity have applied to zoonoses. An edict from ancient Babylon imposed fines if a rabid dog attacked a man or slave (with rabies being another zoonosis) [32]. Nomads and marmot hunters in Central Asia recognized an association between diseased marmots and plague (a zoonotic), shunning sick animals and moving camp if any were observed [41]. For a final example, religious dietary restrictions on the consumption of pork in Judaism and Islam, among peoples, are ancient [42], and their rationales grounded in the protection of public health [32].

13 Nomadic groups dependent on the husbandry of large animal herds an also experience epidemics.
14 This is illustrated when most people decline to eat food that is rancid or putrid; most also try to avoid contact with faeces, human and non-human. [36].
15 Many diseases are likely to be transmissible with mild or early symptoms, including the "common" cold, which can be caused by alphacoronaviruses [8]. Several other viruses also cause similar symptoms, including rhinoviruses, enteroviruses, adenoviruses and most of the common paramyxoviruses. Several of these also can transmitted by asymptomatic individuals.

2 EMERGING ZOONOSES AND INFECTIOUS DISEASES

In 2001 a comprehensive literature review identified 1,415 unique microorganisms and prions capable of causing infections [23]—that is, 217 viruses and prions, 538 bacteria and rickettsia, 307 fungi, 66 protozoa and 287 helminths. Of these, 868 were classified as "zoonotic".[16] The review identified 176 pathogens and prions as "emerging", of which 132 (75%) were zoonotic. This estimate has since been very widely reported. Moreover, additional zoonoses have been discovered since 2001, including three highly pathogenic coronaviruses.[17] Thus, using the same definitions and methodology, the percentage of "emerging zoonoses" would be currently slightly higher than 75 per cent,.

In this context, noteworthy is the source of confusion arising from the fact that the definitions of "zoonosis" and "emerging infectious disease" are not standardized (Box 7).[18]

Box 7

What is the etymology and meaning of the term "emerging disease"?

The term "emerging diseases" was used in the title of a review in a leading journal published in 1971 [43], suggesting the association of "emerging" with "disease" goes back to those times. That review focused exclusively on infectious diseases; however, some non-infectious diseases (e.g. an increasing risk of myopia in children owing in part to excessive screen watching [44]) can also be considered as emerging.

While there is no universally accepted definition of an "emerging infectious disease" (EID), it is generally interpreted to mean either a disease arising from a newly detected pathogen or a marked increase in a disease whose association with a pathogen is long-established.

Some experts interpret EIDs to also include antimicrobial resistance, including, sometimes, distinct kinds of antimicrobial resistance of the same organism as separate EIDs. In fact, Allen *et al.* (2017) use the term "zoonotic EID" [20].

16 Although this report classifies vector-borne diseases as zoonotic, HIV was considered an anthroponosis, a disease well-established in humans, no longer requiring a non-human animal to survive.

17 Causing Middle East respiratory syndrome, in addition to SARS and COVID-19.

18 Some definitions of "emerging infectious diseases" include multiple varieties of antimicrobial-resistant micro-organisms, thus counting one species multiple times.

The Anthropocene, zoonoses, pandemics and ecological recklessness

The "Anthropocene" is increasingly recognized as the best term for our current geologic epoch, recognizing that our species, humans, are akin to a geological force operating on a planetary scale [45]. Most Anthropocene scholars date the initiation of this proposed epoch to the start of the industrial revolution in about 1750 [50], with a "great acceleration" since the end of World War II [51]. It is an epoch that can be characterized as one of ecological recklessness or even "environmental brinkmanship". The best recognized examples of this relate to climate change, the erosion of biodiversity and excessive pollution, including that of the seas—with microplastics pollution being the latest environmental threat.

However, some examples of this environmental peril are also relevant to epidemics: bovine spongiform encephalopathy (Box 6), the contamination of hundreds of millions of polio vaccines with simian virus 40 [46] and the iatrogenic[19] epidemic of hepatitis C, in Egypt [49].

As many experts have observed, the extent and velocity of global travel and trade increase the risk of new diseases (and vectors) spreading rapidly to other parts of the world [52]. Some scholars have suggested that the concept of the "great acceleration" also applies to the number of disease outbreaks and their propensity for widespread distribution [53].

However, while industrialization, globalization, food production and population growth have increased enormously since 1945, there may be a risk of oversimplification and, perhaps, even despair if this correlation is accepted automatically or uncritically. Not all infectious disease risks are equal. Not all have pandemic potential. Many have been discovered in recent decades, such as Ebola, but are likely to have existed in nature for millennia, occasionally infecting human beings. In this modern age of generally adequate food supply (though not to the poorest billion) and widespread antibiotic use, it is possible to under-estimate the exposure to and risk from infectious diseases faced by many previous human generations.

But even if the number of outbreaks of emerging infectious diseases of zoonotic origin is increasing (more than can be explained by ascertainment bias), it is worth recalling that a century ago, there were virtually no antibiotics[20] and far fewer vaccines. It has been said, at least among public health workers, that former U.S. Surgeon General William H. Stewart is reputed to have declared the end of the age of infectious diseases in the 1970s. It is less well-known that this is an urban myth [55]. But even if Stewart did not say this, the statement widely attributed to him, was, for some years, considered plausible.

The spell was broken in the early 1980s by the emergence of the pandemic of HIV/AIDS, a zoonosis thought to be transmitted via contact with "wild meat" in the African forest, such as through deliberate hunting or from an incidental bite or scratch, or in other words, a similar pathway to Ebola. HIV/AIDS spread worldwide, facilitated by the spiked increase in tourism, travel and trade that characterizes the so-called great acceleration. Medical procedures, such as blood transfusions and injections with non-sterile needles, were involved in its amplification [56, 57].

By far, the worst pandemic of recent centuries occurred at the close of World War I, decades before the great acceleration, when a new subtype of influenza A may have killed 100 million, many of them young adults [58]. Centuries earlier, repeated pandemics of the *Yersinia pestis* (plague, responsible for the Black Death) terrified millions and contracted human populations in Europe and parts of Asia. In addition, the European invasion and conquest of the New World and the Pacific introduced diseases such as smallpox, measles and

19 Refers to an epidemic caused by medical treatment. There are many other examples, including the initial outbreak of Ebola, spread in 1976 by the use of Ebola in the Yambuku Mission Hospital in Zaire [47]. A tragic example from the Asia Pacific is the pooling of plasma and the re-injection of pooled red blood cells to plasma donors, in this way inadvertently spreading HIV to as many as hundreds of thousands of poor Chinese, mostly villagers [48].

20 Many infected with the 1918 influenza virus (commonly known as the "Spanish flu") died from secondary bacterial infections, today treatable by antibiotics [54].

Box 8

What is "Variant Creutzfeld-Jacob disease"?

Variant Creutzfeld-Jacob disease is (and hopefully "was") a tragic, degenerative and rapidly fatal neurological disease, with no effective treatment. The disease arose in a mercifully small number of people, mainly British, who had unknowingly eaten beef from cattle infected with bovine spongiform encephalopathy, commonly known as "mad cow disease". Hamburger eaters may have been at higher risk because the beef is generally sourced from multiple animals. Bovine spongiform encephalopathy occurred because of the practice, since banned, of feeding cattle with a nutrient powder manufactured from the remains of dead cattle. That is to say, mammals, who are naturally vegan (after being weaned), were inadvertently forced to not only be carnivores but also cannibals. Clearly, this practice violated basic ecological principles and would never have occurred without human intervention.

tuberculosis, to which indigenous populations had no immunity, thus prematurely terminating the lives of millions [59].

Therefore, even though the factors that create and shape the great acceleration are facilitating the discovery and probably the emergence of new zoonoses, this does not necessarily mean that humanity is destined to again endure a heavy burden of infectious diseases, though it could. This risk can be greatly reduced by learning from our mistakes, including those that led to the outbreak of one of the most economically expensive emerging infectious diseases of recent time, variant Creutzfeld-Jacob disease (v-CJD) (Box 7).

3 SEVEN MAJOR ANTHROPOGENIC DRIVERS OF ZOONOTIC DISEASE EMERGENCE

The seven drivers in this section are adapted from the previous UNEP report on the current pandemic, that is, *Preventing the Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission* **(United Nations Environment Programme [UNEP] and International Livestock Research Institute [ILRI] 2020)]. The 2020 report listed seven drivers citing four articles [62-65].**

However, no universally accepted hierarchy or categorization exists for drivers for this current report; several were amended with some changes to their order.

Aspects of one (changes in food supply chains) were promoted to their own section (Table 3).

Table 3 **Major drivers of zoonotic disease emergence compared to previous UNEP report on zoonotic disease emergence**

Driver	Rank	Closest equivalent	Rank
2021 UNEP report		**2020 UNEP report**	
Changes in food value preferences	1	Increasing demand for animal protein	1
Intensification of livestock raising	2	Unsustainable agricultural intensification	2
Increased use and exploitation of wildlife	3	Increased use and exploitation of wildlife	3
Unsustainable use of natural resources accelerated by urbanization, land-use change and extractive industries	4	Titles unchanged	4
Climate change	5		7
Travel and transportation	6		5
Laboratory and medical procedures	7	No equivalent	
Viral mixing	Section 4	Changes in food supply chains	6

Driver 1: Changes in food value preferences

As income increases, many eat more expensive foods, including animal products, unless prohibited by religious or other beliefs (e.g. Hinduism or veganism).[21] This change in the food value chain is partly based on the belief that eating "higher on the food value chain" will improve health and extend lifespan. Social and cultural factors also play a role. An increased demand for animal protein is commonly advanced as a main reason for eating more meat [66].

However, this assumption can be questioned. Humans require, on average, about 60 g[22] of protein per day, if active. Animal-based foods are the main source of complete proteins,[23] and such protein is more readily digested than plant protein unless the plant cell wall constituents are removed [68]B. However, for most, even ageing adults, sufficient protein can be readily obtained from a vegetarian diet, balanced to provide all essential amino acids, that is, even if such protein is not processed by having the cell walls removed. Protein deficiency owing to undernutrition (kwashiorkor) is extremely rare in the Asia Pacific. A vegetarian diet avoids exposure to many toxins found in animal foods, particularly red and processed meat [69].

Despite the common opinion that animal foods are primarily sought for their protein, alleviation of unrecognized micronutrient deficiency may be a more important reason. Micronutrient deficiency, especially of iodine, iron, zinc and vitamin B12, is common in low-income settings; moreover, it is a major cause of fatigue, poor learning, impaired mental health and weakened immunity [70, 71], especially among vegetarians. These forms of ill-health are each major determinants of reduced lifetime income, but they can be improved by the regular consumption of modest quantities of animal products, in some cases leading to noticeable boosts in health and vitality.

However, the lack of eating meat and other animal products (e.g. eggs, dairy) is not the main reason for at least some of these forms of micronutrient deficiency. Intestinal parasites, such as hookworm[24], are a major reason for low levels of iron and, often, iron-deficient anaemia, especially in women of childbearing age.[25] The underlying reason is that hookworms can reside in the small intestine for many years, from where they suck blood.

Hookworm, an important soil-transmitted helminth, is associated with poor sanitation and walking barefoot[26] on soil contaminated by faeces. This is especially common in parts of South-East Asia, in regions with high levels of wildlife consumption (Figure 2) [72].

It may thus be possible to reduce the demand for meat and other animal products through improved treatment and prevention of parasitic infections. Judicious food supplementation with micronutrients, especially zinc, iron and vitamin B12 may have a role, among populations

21 Hinduism permits the consumption of dairy products (and sometimes, eggs) but prohibits meat consumption. In some societies, dietary customs can also be shaped by legal means, such as rationing during scarcity, or by religious laws, when they exist. It also is possible to reduce the consumption of some species, such as by regulation or by consumer embarrassment. Demand for wild meat is reported to have declined in China through a combination of fear (of illness) and the closure of markets.

22 The recommended dietary allowance of protein for a healthy adult with minimal physical activity is currently 0.8 g protein per kg body weight per day [67].

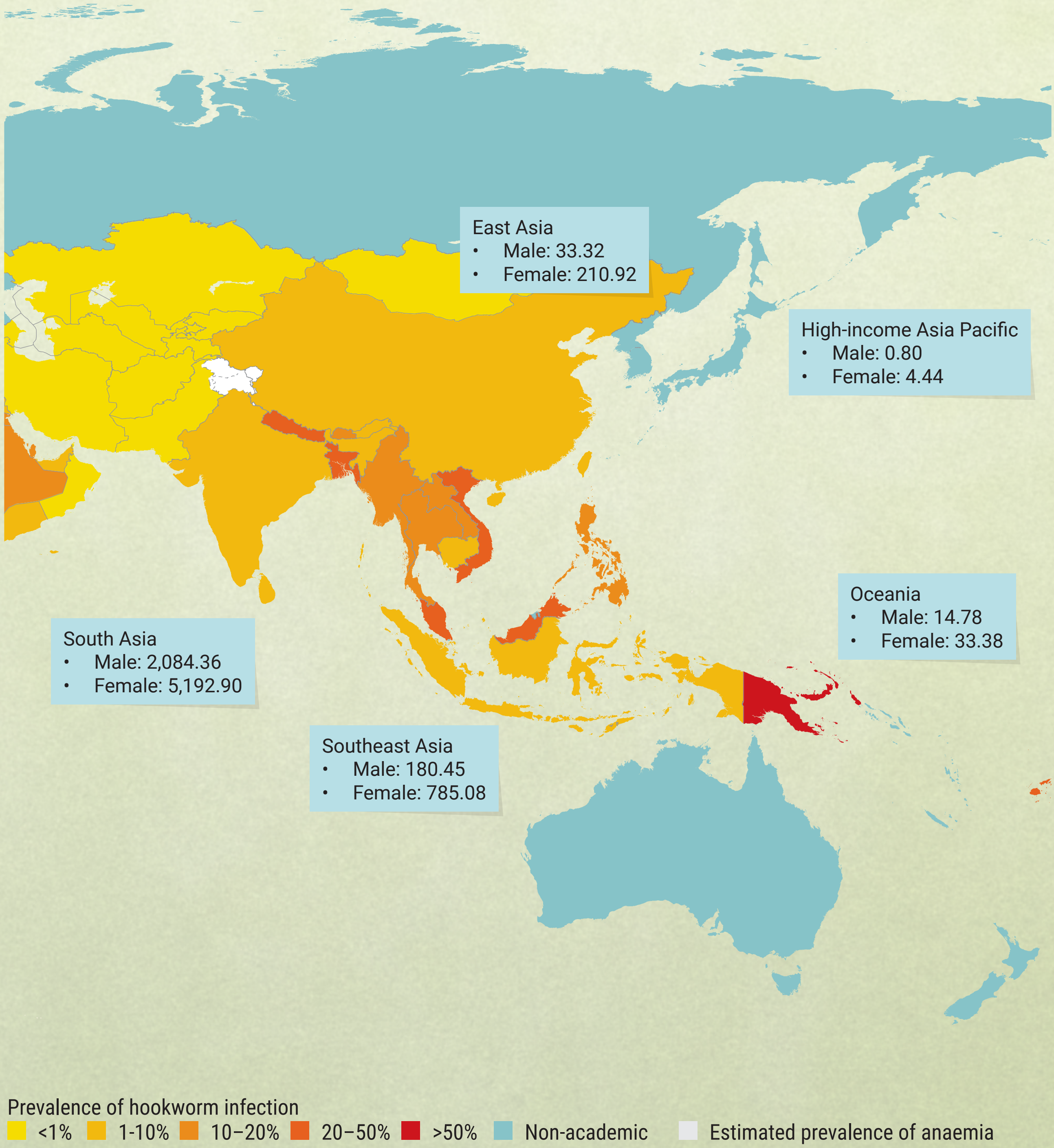
23 Containing all essential amino acids. In contrast, plant-sourced foods need to be eaten in combination (e.g. rice and beans, corn and beans) to obtain all essential amino acids. Other amino acids can be synthesised by humans.

24 Other important parasites that harm nutrition include the roundworm, whipworm and schistosomiasis. All common in parts of the Asia Pacific, they are also associated with poor sanitation.

25 Women of child-bearing age are more vulnerable than men, owing not only to their menstrual cycle but also to gender-based discrimination in some settings.

26 Although the use of footwear has been promoted in WASH community engagement programmes to control hookworm infection, some studies suggest such use of footwear is not supported by robust evidence for a variety of reasons [72]. Improperly washed food, including of vegetables grown in faecally contaminated soil, is another risk, especially if food is eaten raw.

Figure 2 / Prevalence of hookworm infection in the Asia-Pacific region



Note: Figure adapted from [72]. Data for 2010, from [76].

too poor to afford an adequate diet [73, 74].[27] However, such supplementation is complex, difficult to implement among very poor populations, and may cause unwanted effects, including inflammation [75]. Furthermore, in populations with untreated parasites, supplementation with either meat or iron-enriched cereal may be ineffective at improving iron status.[28] Such interventions should not displace efforts to improve sanitation and should not be viewed as an inexpensive shortcut.

Hookworm infection remains a serious problem in the Asia Pacific, including in areas where wild animals are harvested and eaten.

In recent decades, intensified farming of animal species, especially chickens and pigs, has led to large decreases in the price of meat, in areas that include many parts of the Asia Pacific [77]. A study undertaken in Lao PDR found that the price of pig and chicken meat,[29] while far costlier than rice and beans, is considerably cheaper than a range of wild species (Figure 3) [79]. However, the health of such populations is likely to be improved as much, or even more, by treatment of parasites and by adaptations in lifestyle (especially safe toilets) that reduce parasite reinfection [72].[30]

In several high-income settings, an inverted "U" shaped relationship exists between income and animal product consumption. As incomes increase, animal product consumption also increases, but at higher income levels, the consumption of animal products often declines because such populations tend to have higher health literacy and are aware that diets high in meat and animal fat (e.g. butter) are associated with higher levels of chronic disease, including cardiovascular disease and cancer [77, 81]. Concerns about animal welfare[31] may also increase with higher levels of income [83].

Finally, the intensive farming of chickens, pigs and cattle has been associated with many zoonoses, not only influenza (chickens and pigs) but also EIDS, including Nipah and *Ebola reston,* (pigs) [84].[32] Swine (porcine) acute diarrhoea syndrome coronavirus (SADS-CoV) is also a known virus, but with no known transmission to humans [85]. Pangolins and some other species that may be involved with emerging zoonoses are also believed to have medicinal properties, though scientific evidence for such benefit is lacking [86].

In conclusion, although the total quantity of meat derived from wildlife (e.g. viverrids, including palm civets, and other species) is significant, demand for meat is not objectively driven by a need for better nutrition. More important is a search for novelty, a belief that such foods confer higher social status[33]—and equally important, an unsubstantiated perception that eating such foods imparts vitality above that of dietary supplements, other sources of meat,[34] plant-based sources of micronutrients and the treatment and prevention of parasitic infections.

27 Nutrients (such as iron) that are provided by meat-based diets are lost by populations infected with parasites, e.g. hookworm and schistosomiasis. These diseases are associated with poverty, and poverty-reinforcing consequences such as cognitive impairment. Efforts to reduce their burden of disease could disproportionately benefit development and improve nutrient-improving 'efficiency' of consumed animal products [73]. A particularly valued trait, especially of red meat, is energy-facilitating iron, which occurs in a molecular form that is easier to absorb than from plant foods. Ancient consumption of animal parts may sometimes have had a highly valued restorative effect [74].

28 One study commented that although iron-fortified cereals improve toddler iron status in some poor populations it may generate systemic inflammation, favouring enteric pathogen growth, slowing childhood growth. This study found no evidence that the meat intervention improved the iron status in this study population, but it did conclude that consuming meat-based complementary foods improved growth parameters [75].

29 The African swine fever virus pandemic (2019) led to ~150 million pigs being culled in China, resulting in a pork shortfall of ~11.5 million metric tons. It has been hypothesised that this may have increased wildlife–human contacts [78].

30 Understanding the benefits of hookworm treatment led to the Rockefeller Foundation-funded human hookworm eradication commission, the first example of modern-day public health philanthropy [72, 80].

31 There are increasing calls for conservation organizations and scientists to incorporate concerns for animal welfare into their campaigns [82].

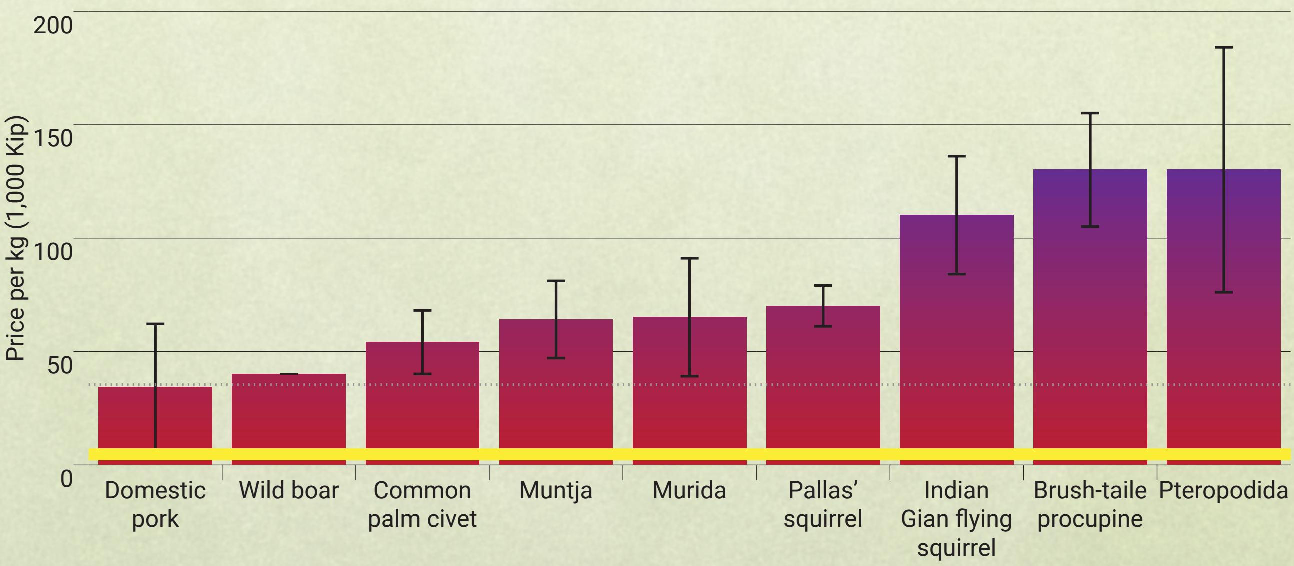
32 The Reston ebolavirus, known to exist in the Philippines, is currently considered benign for humans [84].

33 Although occasionally for cultural reasons, bushmeat is sought in urban area as a luxury to show status even though diverse protein options exists [12].

34 Field (2009) writes: "Many people, particularly in southern China still seek *ye wei* (the wild taste) and believe that it endows added social status, prosperity, health benefits etc derived from the traits of the animal, or from specific parts of the animal" [87]. Some wildlife (e.g. kangaroos) are more nutritious, with lower exposure to pesticides and reduced saturated fat levels. In fact, some populations gain an important fraction of their fat from wildlife.

Figure 3 /

Average price of fresh dead wildlife versus domestic pork in Lao PDR, 2012



Note: Bars represent standard deviation. The price of rice (yellow line) is far cheaper than pork, less than 5,000 Kip/kg. Adapted from [79].

Driver 2: Intensification of livestock farming

One factor in the emergence of SARS was the intensification of livestock farming, including cultivating "novel"[35] species of wildlife such as palm civets and raccoon dogs. This animal farming practice has been postulated as a factor in the emergence of COVID-19 in so far as it has increased opportunities for viral mixing. Wild-caught civets introduce a coronavirus risk, but this risk is likely to be magnified (i) if there are a multitude of civets, especially from different regions and probably (ii) if in proximity to other wildlife species.

Intensively farmed pigs, poultry and ruminants also risk human and animal diseases, including highly pathogenic avian influenza, swine flu and African swine fever. The outbreak of Nipah disease in Malaysia and Singapore in 1998 was also related to intensive pig farming and its interaction with bats [88]. However, diseases from these species are generally better understood than those from viverrids and other animals with a shorter history of farming.

Driver 3: Increased trading and exploitation of wildlife

The increased trading and exploitation of wildlife is generally hypothesized as very important in the genesis of COVID-19 and other emerging zoonoses, some with pandemic potential (Table 4). Increased human contact with relatively novel species has expanded the suite of zoonoses with which humans and science have little familiarity. The range of animals now either kept in captivity or, otherwise, captured and traded, often illegally, for high-status foods or claimed medicinal uses is continuing to expand, including in South-East Asia [89, 90].

Despite attempts to criminalize some forms of wildlife trade, in some cases with severe penalties,[36] substantial trade still occurs, such as between China and Myanmar [91]. The budget for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[37] is only US$6 million [12]. Moreover, zoonotic diseases are outside of CITES's mandate [12]. In several parts of South-East Asia, smuggling appears to have remained common; this practice has involved multiple species, including the smuggling of pangolins into China, at least until the current pandemic [90, 91].

Driver 4: Unsustainable use of natural resources accelerated by urbanization, land-use change and extractive industries

Vast areas of Earth have been transformed by human activity, with steep declines in biodiversity [94]. Worldwide, including in South-East Asia, most of this transformation has been driven, directly or indirectly, by the wish to provide more food and other natural products (not only timber, but significant quantities of wild meat [89]) to feed an increasing human population and to satisfy human wants and needs.

Moreover, another driver is the fact that the conversion of "natural capital" has been lucrative to some individuals, corporations and governments. For decades, these practices have been assisted by the majority of economists and other social scientists who have, on the whole, failed to recognize, or who have denied, the long-term value to humans of keeping a sufficient "buffer" of nature [95]. In turn, most humans have either benefited from this transgression (at least in the

35 All farmed animals were once wildlife.

36 In China, smuggling pangolin parts valued over RMB 200,000 (about US$290,000) carries a penalty of life imprisonment or death [91]. However, a man who in 2018 poached about 8,000 birds in China, including the critically endangered yellow-breasted bunting (*Emberiza aureola*), received a fine of only $10,000 [92].

37 The members of CITES are required to adopt national domestic legislation and to be compliant with the Convention, including the banning or limiting trade of species listed in one of its three appendices [93].

short term), ignored it or participated in it (e.g. whether wielding a chainsaw or participating as shareholders in companies that exploit nature). Those who have sought fundamental reform have been greatly outnumbered and overwhelmed by forces supporting the status quo or even by more aggressive forms of change.

Yet another driver is land-use changes, which include urbanization, deforestation[38] (often facilitated by fires with consequent pervasive haze) and agricultural intensification [97]. New roads and plantations, such as for palm oil, are often involved.[39] A study undertaken in Sabah (Malaysian Borneo) found that land-use changes can influence mosquito vector populations and malaria transmission, including human cases of the zoonotic malaria *Plasmodium knowlesi* [100]. These processes help enable the exploitation of wildlife, and they also make human contact more likely with bats and other wildlife, which may harbour unknown pathogens. Human modified landscapes can also be conceptualized as "attracting" species (beyond bats and rodents) that can host zoonotic diseases [101].

Global changes in the mode and the intensity of land use are creating or expanding hazardous interfaces between people, livestock and wildlife reservoirs of zoonotic disease [102]. Many populations of bats (a long-lived species) are affected by habitat loss, tourism[40] and unusual flooding and by deliberate attempts to relocate them. Some studies have suggested that viral shedding from bats, leading to an enhanced risk of zoonoses (in other species), may be increased by pregnancy and nutritional stress [104, 105]. Other zoonosis- harbouring species may also be more infectious owing to nutritional stress. The index case for the 2018 outbreak of Nipah virus in Kerala, India, is thought to have been an animal lover who perhaps came into contact with a juvenile bat that he rescued [106].

Extractive industries, such as mining, also drive new roads and opportunities to facilitate wildlife capture, exposure and trading. In 2012 six workers, who were clearing bat guano from a mineshaft in Mojiang Hani Autonomous County, Yunnan, China, acquired pneumonia of unknown cause. Three died of a suspected viral infection [107]. Investigations later revealed a previously unknown henipavirus,[41] isolated from a rodent [108]. Apparently in the same mineshaft, a separate investigation detected coronavirus co-infection in six bat species, a phenomenon that "fosters recombination and promotes the emergence of novel virus strains" [109].

Driver 5: Travel and transportation

Travel and transportation, especially by air, are conducive to accelerating the rate of spread of pandemics, particularly, for "mass events", including festivals, sporting events and pilgrimages. SARS spread to several countries before it was contained by social distancing and hygiene. COVID-19, also transmitted by aerosols, has spread much further, despite intense containment efforts, in part because of its highly developed "stealth" characteristics.

Driver 6: Climate change

Climate change may contribute to nutritional stress for bats and rodents, over and beyond that caused by deforestation—for example, by altering flowering time or through floods[42] [110]. Climate change may

38 An early outbreak of Ebola was reported in 1996 at a logging camp in Gabon [96].

39 Palm oil plantations have been suggested as a factor for Chagas disease in South America [98] and for Ebola in West Africa [99]. Palm oil plantations were speculated as a cause for the Nipah virus in Malaysia, but this hypothesis is now rarely supported [87]. Bats migrate to oil palm for food and shelter from the heat, while the plantations' wide trails permit easy movement between roosting and foraging sites. Field (2009) noted that deforestation, including that from oil palm planting, changes foraging behaviour of the flying fox, which now fixates on horticulture crops, and expands the interfaces among bats, humans and livestock [87].

40 Including the bats of the Cat Ba Biosphere Reserve in Vietnam, which has the highest species diversity for bats of any mangrove area in mainland Southeast Asia [103].

41 This genus (family Paramyxoviridae) contains 3 established viral species (Hendra, Nipah and Cedar) and 19 newly identified species, including 1 full-length sequenced virus, Bat Paramyxovirus.

42 One study reports that Ebola outbreaks from 1994–1996 were associated with a change to wetter conditions [96].

alter not only bat flyways and behaviour but also bat population densities around the world, including in South-East Asia [111]. Climate change—via increased temperature extremes as well as altered food availability—may play a role in reducing bat immunity. For instance, bats in flight can tolerate body temperatures of over 41oC; however, like all species, their thermal limits are lower when humidity is high. An increasing number of bats are dying from heat stress [112], and notably, heat stress has also been speculated to be an underlying driver of viral spillover[43] [114].

Climate change may also be a factor in infection disease risk via what were once routine human activities. For instance, the arctic and subarctic regions are experiencing rapid climate change—with one manifestation being rapid permafrost. In turn, permafrost degradation may expose historic burial grounds in Russia, enabling the revival of deadly infections from the past; these infections include anthrax, which generates spores that are very resistant to degradation. Spores can spread in the wind and be ingested by grazing animals. In fact, a 2016 outbreak of anthrax in Russian Siberia caused the death of one person and over 2,000 reindeer [115]. This is but one illustration of the threat to human health by climate change.

Driver 7: Laboratory and medical procedures

Laboratory and medical procedures, including those for biowarfare, must also be considered as important, legitimate elements of the Anthropocene, relevant to epidemics and even to possible pandemics. Documented, accidental pathogen escapes from laboratories include those of smallpox (in 1966, 1972 and 1978 [United Kingdom]), SARS (2003 [Singapore] and 2004 (China and Taiwan, Province of China) [116], anthrax (1979 [former Soviet Union]) [117], *Yersinia pestis* (2009 [United States]), Ebola (2004 [Russia] and 2009 [Germany]), Marburg, *Neisseria meningitis* [118], Venezuelan equine encephalitis [119], foot and mouth disease (2009 [United Kingdom]) [120], H5N1 influenza (2014 [United States]) [121] and H1N1 influenza (about 1976 [China or former Soviet Union]) [118].

Even standard medical procedures have contributed to outbreaks. For instance, the reuse of needles, used for different medical interventions, has increased the number of cases of the hepatitis C virus, human T-cell lymphotropic virus (HTLV-1), and both the human immunodeficiency (HIV)-1 and HIV-2 viruses [57]. Blood transfusions and organ transplants have also caused the inadvertent spread of several viruses, including hepatitis C, HIV, and rabies. The commercial harvesting of blood products in China, in the 1990s, led to over 1 million cases of HIV/AIDS [122]. The reuse of unsterile needles contributed to the early spread of HIV/AIDS in Sub-Saharan Africa [57] and to the spread of Hepatitis C in Egypt [49].

Deliberately searching for wildlife viruses (as is the case by PREDICT[44] and the Global Virome Project [123]) could paradoxically increase the possibility of accidentally generating an outbreak or even a pandemic, via accidental escape. Gain of function experiments, intended to investigate disease-transmission characteristics, could inadvertently generate problems [124] Furthermore, trust is undermined when scientists overstate the benefits of disease prevention [125]. Some experts have argued, instead, for greater attention to surveillance, including that of animal die-offs; for example, in 2015, that of the bar-headed geese (*Anser indicus*) at Lake Qinghai, China, was caused by the H5N1 influenza virus [125].

43 In 2018 there was a large increase in Lassa Fever (a rodent-sourced zoonosis), shown to arise from increased rodent-to-human transmission for reasons that are unclear [113].

44 PREDICT's work illuminates both the threat posed by emerging viruses as well as the impact on rapid disease detection and response of strategic investments in strengthening pre-emptive capacity for virus surveillance .

4 VIRAL MIXING: A NEW PROMOTER OF ZOONOSES IN THE ANTHROPOCENE

As explained above, zoonoses are chiefly a consequence of the domestication and farming of animals and the existence of sufficiently large human populations, which among other things, provide a habitat for rodents. However, both SARS and COVID-19 may have evolved, in part, from viral mixing that arises by keeping, trading and butchering multiple animal species in proximity.[45]

Some species thought to act as bridges between humans and bats (the "reservoir" of coronaviruses) are raised in captivity, but many are captured and trafficked illegally [89]. These species include pangolins [91, 126], which rarely, if ever, are successfully bred. They can be sourced from widely different areas and brought together in ways that could never happen naturally.[46] Via this mechanism, coronaviruses from different parts of South-East Asia (or even Africa or elsewhere) may thus have been brought together, inadvertently creating "living laboratories" that have led to the evolution of viral strains with new characteristics, perhaps including a high affinity to humans, with airborne transmission.[47]

A search for evidence of the coronavirus in 334 pangolins confiscated and rescued in Malaysia over a 10-year period was entirely negative [128]. Possibly, infection of captured pangolins with corona and other viruses may have occurred further "downstream" in the process, that is, via cross-infection from other captured animals with whom they are housed together.[48]

As mentioned, viral mixing may have contributed to the SARS outbreak of 2002/03, emanating in Guangdong Province, China. The intermediary species is generally thought to have been palm civet cats, but viruses of high similarity to SARS were also detected in raccoon dogs [129], while SARS antibodies were also found in a third species, the Chinese ferret badger [129]. According to the article "What have we learned from SARS?" [203], published soon after the epidemic, "the importation, holding together and rearing of so many species[49] of viverrids[50] and also one canid and one mustelid

45 Viral mixing has also been suggested as a factor involving novel reassortments of influenza.

46 A survey, conducted soon after the SARS outbreak of the Vietnamese wildlife trade, found that civets, snakes, wild pig, muntjac, sambar, turtles, porcupine and pangolin are the most heavily traded animal groups. In this survey, seventy-four restaurants were found selling wildlife meat: the most common species found were wild pig, civet, porcupine, sambar, muntjac and soft-shelled turtles,although small quantities of bamboo rats, squirrels, pangolin, small cats, serow, langur and chevrotainwere also sold. Up to 364 kg of various species of civet meat was served monthly in just five restaurants [89].

47 Concerns also exist that viruses with human affinity may have been engineered in laboratories [127].

48 Smuggled animals often include movement through other Southeast Asian countries in a manner that fosters opportunity for viral transmission both within and among species: often in these countries, animals are housed in groups from disparate geographic regions and with other species.[128].

49 A description of a market in Xinyuan (Guangzhou, Guangdong, China) states the following: "The zoological biodiversity of the animal market was large, including live donkeys, calves, goats, sheep, piglets, American minks, raccoon dogs, farmed foxes, hog badgers, porcupines, nutria, guinea pigs, rabbits, and birds. Animals were presented in small wire cages piled atop one another, which highly favours the transmission of any pathogens present" [130].

50 There are at least 36 species of viverrids, include civets [89].

allowed its (i.e. SARS) amplification and transfer to humans to occur" [3].[51]

Initially, authorities responded vigorously and appropriately to SARS. This action led to the culling of an estimated 10,000 civets and some other species in China in the winter of 2003/04, following a second outbreak [131]. A study conducted later in 2004 was reported as failing to detect any SARS-like viruses in farmed civets (i.e. 1,107 sampled animals) in 12 Chinese provinces [130]. It has been suggested that once in the market, where farm-bred civets came into contact with wild-caught civets, the farm-bred ones quickly became infected with SARS.

There is no information of any subsequent, systematic screening for the SARS virus undertaken in civets and other potential intermediary hosts. Most likely, at least until 2020, trade in wild civets continued even though civets can be bred in captivity.52 However, in February 2020, the Standing Committee of the National People's Congress announced a ban on wildlife consumption for food and related trade in China [12]. There were also reports of ongoing discussions on phasing out this industry [12].

Nevertheless, since the SARS outbreak, and despite considerable expansion of the wildlife farming industry in China[53] [12], no subsequent cases of SARS have been reported (apart from three known laboratory associated cases, two in Beijing and one in Singapore). This hiatus in identifying highly threatening zoonoses emerging from the Asia Pacific[54] probably contributed to a relaxation in concern, shared by some public health authorities. Despite repeated warnings by a few infectious disease experts, global preparedness for a major new zoonosis has declined in recent years, especially in the United States [133].

Factors enabling a zoonosis to potentially unfold into a global pandemic

Over 100 viral zoonoses are rarely if ever transmitted from human to human [134]. About 40 viruses do circulate between and among humans, but they usually cause self-limited outbreaks (epidemics).[55] The Nipah virus is one such example (Box 8).

Only a tiny fraction of zoonoses have genuine global pandemic potential. These are the most terrifying from a public health perspective. COVID-19 is one such zoonosis. Another was an H1N1 virus with genes of avian origin responsible for the 1918 influenza pandemic (known as the "Spanish" flu) that killed 50–100 million after World War I. And finally, the third is HIV/AIDs.

What do these three zoonoses have in common? The elements they share are (i) a well-developed "stealth[56] phase"; (ii) the capacity to be transmitted, at least sometimes, before carriers are symptomatic; and (iii) a non-trivial capacity to cause death or prolonged illness in a share of those who are infected [22, 134, 140-142]. The term "stealth phase", though introduced in the literature in 2012 [140], builds on past literature that recognizes the importance of asymptomatic transmission for disease-transmission dynamics.[57] In some cases, COVID-19 infections have spread

51 An investigation conducted in Guangdong Province, China, compared the seroprevalence of SARS-CoV IgG antibody in workers in live animal markets with that of persons in control groups. The results found IgG antibodies to SARS-CoV in 13 per cent of the animal traders, none of whom had been diagnosed with SARS, compared with 1–3 per cent of persons in three control groups [129].

52 Field (2009) reported that in China, wild-caught civets attract a price premium because people believe they are more healthful (and taste better) than their grain-fed, farmed counterparts [87].

53 The wildlife farming industry has been reported to have employed 15 million workers and been worth about US$20 billion in 2020 [12].

54 MERS (Middle East respiratory syndrome) did emerge in this time, but from the Middle East. Its bridging species is the camel. Like COVID-19, it is transmissible by asymptomatic people, though much less frequently. An outbreak of MERS occurred in South Korea in 2015 [132]

55 Authors have commented that human-to-human transmission of Ebola and Marburg quickly fades out, due the rapid onset and severity of symptoms, which in turn make identification and containment feasible [30].

56 The word "stealth" (coined in relation to pathogen transmission in 2012) is not intended to convey properties of malevolence, consciousness or intent to the pathogen [140].

57 This study sought to identify general properties of infectious agents that determine the likely success of two simple public health measures in controlling outbreaks, namely (i) isolating symptomatic individuals and (ii) tracing and quarantining their contacts. The success of these control measures was determined as much by the proportion of transmission occurring before the onset of overt clinical symptoms (or via asymptomatic infection) as the inherent transmissibility of the etiological agent [143].

Box 9

The Nipah virus in South and South East Asia

The Nipah virus, a genus of RNA viruses, is naturally harboured by pteropid fruit bats and several microbat species that are widely distributed from Indonesia to India—and perhaps, even further west. The virus causes severe, often fatal respiratory and neurological diseases in humans.

So far, cases have been recorded only in Bangladesh, India, Malaysia and Singapore, with the latter two countries experiencing the first known outbreak in 1998/1999. Fortunately, no other known human outbreaks have since been reported in Malaysia and Singapore. However, though the Nipah virus is endemic to and widely distributed in fruit bats in Southeast Asia, including in Indonesia, Myanmar and Thailand, all countries in which the disease has never been identified in humans, some scientists are concerned that future transmission could occur in other countries.

But primarily in Bangladesh and India, limited outbreaks of Nipah have been since recorded almost yearly. Though person-to-person transmission has not been recorded in the first outbreak in Malaysia and Singapore, such transmission has been reported in Bangladesh and India albeit primarily in healthcare settings [206]. And as we will see below, local, limited-transmission cases in Bangladesh and India did not involve a bridging species—unlike Malaysia and Singapore, which involved pigs. Over and beyond various interventions by governmental entities, these transmissions have also been contained by international and local partners, to understand the mechanics of Nipah virus transmission and prevent these small outbreaks from spreading.

Unlike COVID-19, Nipah might have low genuine pandemic potential (See Table 4) because it lacks asymptomatic transmission (i.e. transmission occurs when infected persons are obviously ill). Also, Nipah is highly contagious from contact via bodily fluids more so than respiratory droplets. In fact, though the high case fatality rate of 40-70 per cent [206] is of concern to scientists, ongoing transmission is rare—provided that personal protective equipment is used and that other infection control procedures are followed, including stringent mortuary procedures.

To date, no vaccine for Nipah has yet been developed, although progress has been reported. Thus, it is recommended that “gain of function” studies, and other experiments to explore Nipah’s potential for wider transmission, be strictly regulated—or even banned altogether.

Malaysia and Singapore. Until the September 1998 outbreak in the northern peninsula of Malaysia [88] and the ensuing March 1999 outbreak in Singapore, Nipah was a then-unknown henipavirus. Thus, the manifestation of this virus was initially mis-diagnosed as Japanese encephalitis, and the Malaysian government conducted a vigorous vector control programme for such mosquito-borne disease. Consequently, chemical-based foggers were used on over 18,500 pig farms and 400,000 houses in their vicinity. Moreover, the Malaysian Ministry of Health purchased over 640,000 doses of Japanese encephalitis vaccines for mass vaccination.

As such, early control measures did not address this novel aetiological agent, and the outbreak spread by February 1999 to both pigs and pig farmers in the southern peninsula, a finding associated with the southward movement of pigs. Moreover, by March 1999, 11 cases of respiratory illness and encephalitis (resulting in one death) were reported among abattoir workers in Singapore who had had contact with pigs imported from Malaysia.

It was only soon after the Nipah virus was isolated from a victim's cerebrospinal fluid that the Government of Malaysia was able to engage in outbreak control. Nonetheless, Nipah eventually caused 294 known human cases with 110 fatalities [135, 136], with some survivors enduring chronic neurological illness.

Regarding the genesis of this epidemic, varied ecological factors were speculated as having stressed the bats that transmitted the Nipah virus to its intermediate host—that is, pigs housed in commercial farm enclosures adjacent to cultivated fruit orchards. One such stressor might have been the forced relocation from forest cleared for the then-new airport in Kuala Lumpur [32] or from elsewhere in South-East Asia. Another might have been the forced fleeing from the especially intense 1998 forest fires, deliberately lit to enable palm oil plantations but exacerbated by the strong El Niño that year [137]. In other words, nature has struck back.

Bats feeding on fruit (mangoes, durian and rambutan) are thought to have excreted the Nipah virus (via either faeces, saliva, urine or all three). In turn, the pigs developed a respiratory infection after eating fruit that fell to the ground. Also, some pigs may have gotten infected while drinking rainwater in which bats had urinated [137]. Other pig farm transmission occurred via other farming activities, including the transport of infected pigs, the sharing of boar semen and the reuse of unsterilized needles [136].

After the Malaysian government identified Nipah as the true aetiological agent of the outbreak, it switched focus on a new virus control. In March 1999, the government established the Cabinet Task Force Committee, chaired by the Deputy Prime Minister who oversaw 10 ministries: Health, Agriculture, Transport, Primary Industry, Public Works, Housing and Local Government, Finance, Information, Defence and Home Affairs.

In this context, the Department of Veterinary Services was empowered to cull all pigs who were either diseased or had been in contact with diseased pigs. All in all, between October 1998 and September 1999, over 13,000 pig farms were inspected. Slaughtered pigs were immediately buried in deep pits, using alkaline quick lime. Between February and May 1999 alone, over 900,000 pigs from about 900 farms were initially destroyed. Soon after, another 50 pig farms were targeted—and in total, about 1.1 million pigs were culled [136]. Further, during this time, Singapore responded by banning the import of Malaysian pigs.

During the outbreak, the government engaged in extensive surveillance for Nipah, some of which was innovative. The outbreak was effectively brought under control following the discovery of the virus and institution of correct control measures through a combined effort of multi-ministerial and multidisciplinary teams working in close co-operation and collaboration with other international agencies [136]. Surveillance involved three categories—humans, animals and the suspected reservoir host. The focus was on animal populations, including swine and peri-domestic animals (birds, rats and other rodents) and domestic animals (horses, dogs, cats, goats and poultry). This operation involved local medical epidemiologists, veterinary epidemiologists, wildlife researchers, medical and veterinary virologists, physicians, army personnel, biostatisticians and state epidemiologists in collaboration with WHO and international experts of the respective disciplines.

In addition to field operations, the Malaysian government engaged in a public information campaign, disseminating extensive educational materials to pig farm workers and the population in the vicinity—for example, guidelines on personal hygiene and Japanese encephalitis control and prevention. National radio and television were also actively engaged in this regard [136].

However, despite public anxiety [138] and intense actions by countries and international cooperation, the Nipah virus has never developed into a pandemic. Since that time, no further outbreaks of Nipah have been reported in Malaysia or Singapore. To this end, a plausible explanation is that the Malaysian government implemented and enforced rules that not only (i) limit the exposure of pigs to bat secretions but also (ii) require the surveillance of pigs and human beings for unusual respiratory or encephalitic illnesses.

Over and beyond illustrating a classic case of "stamping out" in response to animal epidemics, the case of the Nipah virus outbreak in Malaysia shows that wildlife, including bats, can coexist with agriculture in a way that keeps disease to a manageable risk.

Bangladesh and the State of West Bengal (India). Sporadic cases of Nipah have been reported since 2001 in both Bangladesh and West Bengal [198, 199]. While 248 cases were reported in Bangladesh in 79 separate outbreaks from 2001 to 2014 [152], only 2 outbreaks were reported, 6 years apart, in 2001 and 2007).

The epidemiology of Nipah virus transmission is distinctly different to that of Malaysia and Singapore: no intermediary species are involved; instead, bats are the primary reservoir for Nipah in Bangladesh. The primary mode of transmission is human consumption of raw date palm sap contaminated with bat saliva, urine or faecal droppings [200] (though other observed modes have included person-to-person transmission as well as contact with sick animals).

In this context, a randomized control in Bangladesh has shown it is possible to reduce contact between the bats and the sap via a modified sap collection method. This modification entails inserting a barrier (i.e., a “skirt” made of bamboo, jute stick, polythene or a herb known as “dhaincha”) [200] over the sap-producing areas of the tree. Recommendations have ensued for the adoption of such community interventions. But to date, no evidence has been found on the extent to which they have been developed and applied in either Bangladesh or West Bengal.

Systematic hospital-based investigation of Nipah virus cases and their contacts in Bangladesh has been implemented since 2006 [152].

State of Kerala (India). The first recognized outbreak of Nipah in the southern Indian State of Kerala [106] occurred during bat breeding season—after two prior outbreaks in West Bengal in 2001 and 2007. While the 2001 outbreak resulted a higher fatality count, this 2018 outbreak of 18 cases resulted in 17 deaths [207]. The index case was thought to be an animal lover, most likely, a bat rescuer. Although the outbreak was initially unrecognized, it was controlled quickly. In September 2021, new cases were reported in Kerala [208].

The timing with the breeding season is noteworthy because bat antibody levels to Nipah are likely to vary by season and may be reduced when bats are pregnant. Moreover speculation also exists that children playing under trees in which bats roost may also become infected, that is, via direct exposure to bat secretions and waste. Regarding this mechanism, it is likely that education campaigns could be devised to try to reduce exposure of children especially during seasons of increased risk.

The positive stories confirmed the need for sharing information of any unusual illnesses in animals and humans, an open-minded approach and close co-ordination among the medical professions, veterinarians and wildlife experts in the investigation of such illnesses. Environmental mismanagement (such as deforestation and habitat fragmentation) has far-reaching effects, including encroachment of wildlife into human habitats and the introduction of zoonotic infections into domestic animals and humans.

from people who never develop symptoms, possibly including young children [144]. COVID-19 also appears remarkably well-adapted for human-to-human transmission [127]: so much so, that some experts argue that SARS-CoV-2 may have occurred through a recombination event that occurred inadvertently or consciously in a laboratory working with coronaviruses, leading to its accidental release into the local human population [127].

Moreover, the impact of a pandemic depends on the degree of contagiousness as well as on the morbidity and mortality in those who are infected. COVID-19 features airborne transmission; it lacks a highly effective treatment; and until recently, no effective vaccine existed. Another feature is the virus' high fatality rate in the elderly and those with existing co-morbidities. It is easily transmissible—not only from symptomatic but (as mentioned) from some asymptomatic cases as well. This combination of features is of special concern,[58] though the 1918 influenza pandemic was even

58 Past pandemics include smallpox and *Yersinia pestis,* a plague bacterium. Nowadays, an effective vaccine exists for smallpox, while the plague is easily treatable by antibiotics. Multiple drug-resistant tuberculosis lacks effective treatment, as it is well-known, it is transmissible by aerosols.

Table 4 **"Stealth" transmission and global pandemic risk of key current or past zoonotic infectious diseases**

Infectious disease	"Stealth" transmission	Global pandemic risk
Crimean-Congo haemorrhagic fever * #	Not observed [145]	▼ Low
Ebola virus disease *	Sexual transmission observed rarely [146, 147]	▼ Low
Marburg virus disease *	Not observed [148]	▼ Low
Lassa fever *	Sexual transmission reported [149]	▼ Low
COVID-19 *	Common [39, 144, 150]	▲ Occurred
MERS *	Reported as increasing [40]	▶ Moderate
SARS *	Not observed [39]	▼ Low
Zika * #	Sexual transmission observed [151]	▼ Low
Nipah and other henipaviral diseases *	Not observed [152]	▼ Low
"Disease X" *	Unspecified	Possibly high
HIV/AIDS	Sexual transmission, occasionally with very mild symptoms in early cases	▲ Occurred
Influenza	Generally considered common [153]	▲ Has occurred (vaccine of limited effectiveness)
Pertussis	Reported after vaccination [154]	▼ Low (vaccine)
Smallpox	Reported [155]	▼ Low (vaccine)
Tuberculosis	Not observed; however, multiple types of drug resistance have emerged and could worsen	▶ Moderate

Source: Key: *, WHO priority disease; #, vector-borne

worse because it disproportionately killed young adults in large numbers.[59]

Table 4 compares the global pandemic potential of some key infectious diseases (all known diseases listed are, or were, zoonotic). In this context, airborne transmission for Ebola has been alleged [156], but is generally unaccepted. The pandemic potential of vector-borne diseases can be lowered, in many regions, using insecticides.

Pre-existing health conditions and environmental factors

It is known that COVID-19 has a higher level of morbidity and mortality in older adults and in those with pre-existing disease (co-morbidity), including hypertension and lung disease. But it needs to be

59 Influenza pandemics have occurred since then, but with far less morbidity and mortality, in part owing to better treatment (including for bacterial pneumonia) and the existence of vaccines. While the pandemics of 1957 and 1968, collectively, killed over a million people, their toll is only about 2 per cent of fatalities from the 1918 flu pandemic , in a much smaller global population.

understood that air and other forms of pollution are key contributors to causing or intensifying many chronic diseases, both infectious and non-infectious, including COVID-19 [157–159].

In fact, a study by the World Bank, undertaken in the Netherlands, found that atmospheric particulate matter (less than 2.5 μg) is a highly significant predictor of hospital admission for COVID-19 cases. COVID-19 cases increased by nearly 100 per cent when pollution concentrations rose by 20 per cent [160]. This study supported the view that severe air pollution damages lungs, thus creating vulnerability to respiratory infections, asthma, and chronic obstructive pulmonary disease [158].

This World Bank study has also supported the conclusion that air pollution is thus likely to be an important cofactor in the extraordinarily high level of COVID-19 morbidity and mortality observed in 2021 in India [157]. The lockdowns in India, in an attempt to reduce the burden of COVID-19, led to a temporary reduction in air pollution [161] and likely conferred health benefits that would partially compensate for the associated socioeconomic harm [162].

5 TOWARDS **SOLUTIONS**

Climate change and other damage to planetary life-support" [163][60] mechanisms threaten the stability of civilisation [165], placing it on a perilous trajectory. Human capacity to modify the global environment has generated abundance for many but also notable risk, especially for future generations. In fact, no one can be completely protected from an airborne zoonosis with a highly developed stealth capacity.

Thus, implementation of the following recommendations requires genuine support by policymakers, governments and opinion leaders. It also requires the development of alternative livelihoods to compensate for diminishing employment in sectors that are currently destroying natural capital[61] and increasing pandemic risk.

Recommendation 1: **Develop new economic systems and better measures of progress**

The first recognition that the world will eventually need to evolve a "steady-state economy"[62] is attributed to the leading nineteenth century philosopher and economist John Stuart Mill. Some indigenous peoples[63] also recognized the importance of preserving a minimum suite of ecosystem services at a regional level, sufficient to ensure human well-being that could endure for many generations [167]. However, such sustainable cultures had levels of material consumption that were far lower than is today widely acceptable.

As technology evolved, many populations improved their material living standards, not only by invention but by appropriating resources originally claimed by other peoples. In the mid-twentieth century, measures of "economic growth" evolved, particularly associated with the theories of Nobel Laureate Simon Kuznets [168]. However, such measures completely excluded the change in the value of natural capital (and other "externalities"), as long pointed out by "ecological" economists such as Kenneth Boulding and Herman Daly. Thus, for

60 This phrase dates at least to 1972, when human ecologist Sargent [163] wrote "interventions in and manipulations of the processes of the planetary life support-system (ecosystem) have produced a set of complex problems, problems that constitute the essence of human ecology." Despite increasing use, the term should not be taken literally; life is unlikely to vanish owing to human effects, even via nuclear winter [164].

61 For example, the oil, gas and coal industries, fuel-driven cars, the global meat industry, fossil-fuelled aviation, palm oil and bitcoin mining.

62 The leading ecological economist Herman E. Daly defined the key characteristic of such an economy as having "constant stocks of physical wealth and a constant population, each maintained at some chosen, desirable level" [166].

63 For example, in arid Australia and the San in Botswana. Neither of these peoples practiced agriculture as we now know it.

decades, the dominant measure of progress has been misleading [169] .

Recognizing these problems issues, UNEP launched a global initiative in 2007 focused on "making nature's values visible", that is, **The Economics of Ecosystems and Biodiversity (TEEB)**. Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels.

To date, however, such attempts remain marginal. Policymakers and the populations they serve need to understand that many forms of planetary limit exist. Successful humans cannot perpetually steal resources from vulnerable people as well as from future generations. Ignoring such limits will ultimately lead to a great crisis, for all of humanity.

Recommendation 2: Promote a One Health strategy to reduce pandemic risk

The recognition that humans and other vertebrate animals exchange pathogens, together with similarities in their anatomy, physiology and emotions, is the foundation of the One Medicine movement, the predecessor of One Health. Rudolf Virchow, one of the founders of this concept is credited with coining the term "zoonosis" in 1855 [170]. In 2004, the concept of One Health emerged, as the field of investigation and science that links human, animal and, in some conceptualizations, environmental health [171, 172]. Many call for One Health approaches to reduce pandemic risks. Supporters of One Health have argued that such an approach "ensures that human, animal, and environmental health questions are evaluated in an integrated and holistic manner to provide a more comprehensive understanding of the problem and potential solutions than would be possible with siloed approaches" [173].

However, as with changing the measurement of economic systems, such aspirations are far easier to express than to achieve, partly owing to institutional structures and practices. Substantial cultural change is very often resisted if it is viewed to originate from outside. For instance, the UN system is itself largely siloed: it is, for example, difficult to find publications by the United Nations Population Fund that comment on biodiversity, while it is similarly difficult for UNEP to comment on human population size. Likewise, ministries of environment, health and agriculture around the world are all relevant to One Health and may have more influence if they cooperate better. However, vested interests, including those representing other ministries, are often more powerful.

An integrated approach requires the cooperation of those with different worldviews and different incentives. In fact, the willingness to change behaviour may be enhanced by a shared perception of threat. In this context, education campaigns (including in schools) that highlight the risk of pandemics from the prolific wildlife trade, whether legal or illegal, may gradually alter behaviour, especially among younger people and build support for risk reduction.

Recommendation 3: Promote greater respect for nature, including for animals

Humans, an animal species, are part of nature. While many indigenous peoples today recognize the deep dependence of humans on nature[64] [176–178] a dominant view is that nature can be managed indefinitely [179], even beyond planetary boundaries [180]. Furthermore, the once-popular belief that it is unscientific to ascribe emotions or thoughts to vertebrate species, ranging from fish to mammals, is inconsistent with evolutionary theory,

64 Not all, however. Many examples exist of "ecological overshoot," as a result of unsustainable indigenous practices [174, 175].

experimental evidence and any reasonable burden of proof[65] [82].

Humans are likely to continue to harm other species. However, the scale and cruelty of this behaviour may be altered if more of our species understand that our "war on nature" ultimately damages human well-being, including that for future generations [181]. Greater respect for nature would manifest in behaviour to (i) reduce deforestation and the abuse of non-human animals and (ii) adopt "full-cost" accounting, to include that of social and environmental harm [182]. Also, the integrated management of landscapes and seascapes that enhance the sustainable co-existence of agriculture and wildlife can be improved, including by finding ways to reduce zoonotic disease-transmission risk. Further destruction and fragmentation of wildlife habitat can be reduced by strengthening the implementation of existing commitments on habitat conservation and restoration and by maintaining ecological connectivity and reduction of habitat loss. Further harm can also be reduced by incorporating biodiversity values in the governmental and private sector decision-making and planning processes.

Recommendation 4: Reduce the global average consumption of meat, especially exotic wildlife

Though the consumption of exotic wildlife is considered prestigious and healthy in some cultures, it is unnecessary for optimal human nutrition. Indeed, the consumption of farmed meat, at least for most of the human lifespan, is not needed for optimal nutrition. Ample protein can be obtained, for most, via a vegan or vegetarian diet. Excessive protein[66] may be oncogenic (cancer-promoting), and diets low in meat can be associated with lower mortality, provided the plant-based foods are of sufficient quantity, quality and variety[67] [67]. Diets low in red meat (especially from digastric sources such as cattle, sheep and goats) are associated with significantly lower carbon emissions as well as with reduced rates of cancer and heart disease [67, 69]. However dietary supplementation, especially with iron and zinc is probably beneficial for many vegetarians, especially where diets are high in phytates, or when soil levels of zinc are low [183]. The benefit of micronutrient supplements is likely to be enhanced among populations with gastro-intestinal and other parasites if these cannot be reduced or eradicated. A small amount of animal products is nutritionally desirable for many people, but it does not require the consumption of wildlife. Instead, this can easily be supplied by the farming of pigs, poultry and ruminants.

However, intensified farming, even of these species, increases the risk of zoonotic infections, especially influenza. Nevertheless, health risks arising via the intensive farming of pigs, poultry and ruminants are better understood than those arising from minor species such as palm civets and raccoon dogs. While existing influenza vaccines and anti-virals are imperfect, they also reduce public health concern about influenza. If wildlife species are farmed, they should not be mixed with wild-caught species, especially those with long supply chains and from various locations, because such practices could increase the risk of viral mixing.

Finally, efforts should be made to provide livelihoods for populations who otherwise may turn to wildlife smuggling for support.

65 Many animal species are cognitively sophisticated; findings including tool use (diverse taxa), spontaneous insight, innovative behaviour, self-recognition, collaboration to solve unfamiliar tasks, planning for the future, political strategy, empathy, and ability to recognize hundreds of human words [82].

66 High-quality protein is important for growth of infants and young children, and possibly in older people losing muscle mass. However, one study noted that a mix of amino acids that maximally stimulate cell replication and growth can increase the risk of cancer and may be sub-optimal for most of adult life. [67].

67 A review (2015) by the US Dietary Guidelines Advisory Committee concluded that for people older than 2 years, a balanced vegetarian diet can be a healthy. They also found, in the largest prospective study of its kind, that people following vegan, vegetarian, pescatarian, or semi-vegetarian diets had 12% lower overall mortality risk than did omnivores; the lowest risk was among pescatarian diets [67].

Recommendation 5: Reduce other practices that drive wildlife farming

Several factors, other than supplying meat for human consumption, influence intensive wildlife farming. These include the global pet trade [184]; fur farming, including of mink [185], red foxes and raccoon dogs [78]; and traditional medicines [186].

Recommendation 6: Promote good governance by tackling corruption and promoting transparency

Huge profits, breeding temptation and corruption are all factors that can and have been made from natural resources. Examples include the conversion of habitats (e.g. for plantations or prawn farming), the burning of fossil fuel and the smuggling of wildlife. Penalties for violating environmental laws are comparatively light in many countries, including for smuggling wildlife [92].

If governments seriously wish to reduce the risk of pandemic emergence, then the penalties and enforcement for illegal wildlife trade must be increased and enforced. Also, funding for CITES and National Biodiversity Strategies and Action Plans under the Convention on Biological Diversity must be substantially raised, and the mandate of CITES should also be broadened to include the lowering of zoonosis risk [12]. However, a major challenge to reducing wildlife trafficking is that such crimes sit within corrupt frames and systems of governance that facilitate many types of crime.[68]

In this context, structures have been proposed to include those addressing the criminal justice system, the political environment and the economic environment [93]. These larger social structures thus also need to be reformed. Investigations of zoonotic outbreaks need to be rapid and transparent, with high levels of cooperation and trust. In many settings, the capacities of health systems and other health stakeholders need to be strengthened to better participate in the exploration, management and prevention of such outbreaks, including their One Health dimension.

Recommendation 7: Strengthen monitoring and surveillance of zoonotic diseases

Effective monitoring and surveillance for zoonotic diseases remain essential at the local, national and regional levels. Elements leading to effectiveness include:

- Enhancing human-based surveillance and international notification to provide an early-warning system;
- Ensuring surveillance and control of zoonotic agents before disease detection in humans;
- Using artificial intelligence tools to predict where, when and from which animal species zoonotic pathogens may arise in the future;
- Improving sanitation and food safety systems; and
- Overcoming possible barriers to timely reporting and surveillance, notably trust and transparency.

Recent studies and scientific reviews raised a critical question that the scientific community must address now: how did SARS-CoV-2 jump from non-human animals to humans [204, 205]? To prevent another tragedy like COVID-19, the careful, transparent collection of scientific information is essential to this and other related questions. This fact calls on humanity to co-operate—and even to overcome barriers that might otherwise block co-operation during wartime [205]. This noble aim might seem idealistic, but if all nations can put aside their mistrust and fear of embarrassment, then progress can be made.

68 For example, many Governments and Heads of State have institutionalized corruption. Courts and legal processes, in many settings, lack transparency and sufficient accountability.

Recommendation 8: Promote gender equality, reproductive health and family planning

Investing in human capital, including the education of women and girls, is likely to postpone marriage, lower fertility and increase child spacing [187]. This investment will benefit biodiversity [188] and, in some settings, accelerate human development.[69] Many determinants of lower fertility will be promoted if the Sustainable Development Goals can be realized, especially those relating to gender, health and education [190]. *Global Biodiversity Outlook 5* [191] acknowledges a relationship between human population growth and declining biodiversity. However, such strategies also require greater trust between stakeholder groups with rival views [192].

Recommendation 9: Better regulate or ban dangerous "gain of function" pathogen studies

Gain of function studies involve the manipulation of pathogens in attempts to explore characteristics, including transmission between species, that might not exist in nature.[70] Although such studies are undertaken in laboratories with high security, the accidental escape of highly virulent pathogens has occurred many times from "secure" settings and could reoccur. Supporters of such studies justify them as generating scientific insight, but others highlight risks. Critics note that while the risk of accidents might be acceptable if the consequences (of escape) are limited to the originally exposed individual, the risk is unacceptable if the potential consequences include the extensive or even global spread of a potential pandemic pathogen [195, 196].

Recommendation 10: Reduce academic silos, including those within the United Nations system

Increased interdisciplinary approaches are required, not only with One Health perspectives, but by the strengthened integration of environmental and related considerations within the United Nations system. One example is the Tripartite Collaboration, involving the World Health Organization (WHO), the Food and Agriculture Organization (FAO) and the World Organisation for Animal Health (OIE).[71] Scientific enquiry into the complex social, economic and ecological dimensions of emerging diseases, including zoonoses should be expanded; this is required to assess risks and develop interventions at the interface of the environment, animal health and human health. Economists can learn from ecological approaches and improve their cost-benefit analyses of interventions to limit emerging diseases.

69 Claims that low population growth in high-income settings is harmful [189] need to be challenged.

70 Potential pandemic pathogens are potentially highly contagious, potentially highly deadly and not currently present in the human population [193]. A 2012 report found 42 facilities engaged in researching live potential pandemic pathogens (also referred to as "PPPs") [194].

71 Another example is PREZODE (Preventing ZOonotic Disease Emergence). This international initiative aims to understand the risks of emergence of zoonotic infectious diseases, to develop and implement innovative methods to improve prevention, early detection, and resilience—in order to ensure rapid response to the risks of emerging infectious diseases of animal origin. For more information, visit the **PREZODE website**.

6 CONCLUSION

As of September 2021, over 5.5 billion doses of COVID-19 vaccines have been administered,[72] but full, equitable global vaccine access is still a distant goal [197]. At least 13 different COVID-19 vaccines are currently in use, and the fight against COVID-19 depends on the success of the overall global vaccination effort. The eventual burden of disease of COVID-19 may exceed that of HIV/AIDS, another fairly recent infectious disease, also resulting from contact with wildlife. In such case, the COVID-19 pandemic will prove to be the world's greatest infectious disease crisis since the 1918 influenza pandemic, over 100 years ago. During the past century, extraordinary scientific advances have occurred, including the development of antibiotics, genomics and many effective vaccines. But these developments have fuelled hubris, a fallacy that humans are a truly exceptional animal species.

In May 2020, the identification of the "zoonotic source" of the virus and its route of introduction to the human population was requested of the WHO Director-General by the World Health Assembly in conjunction with other countries and organizations. Consequently, a report, jointly organized by WHO and China, was released on 30 March 2021. This detailed report (120 pages plus 193-page annex section) did not reach a definite conclusion on the origin of the pandemic; however, the report presented the argument that the origin was most likely introduced to humans from bats via an intermediate host.[73] On the day of the report's release, Director-General Tedros Adhanom Ghebreyesus released a statement, advising that "as far as WHO is concerned, all hypotheses remain on the table. This report is an especially important beginning, but it is not the end. We have not yet found the source of the virus, and we must continue to follow the science and leave no stone unturned as we do".[74]

This report on future pandemics has not speculated where, in the Asia Pacific, a future pandemic may originate or be detected. However, known and unknown pathogens with zoonotic potential exist in all countries in the Asia Pacific. Noteworthy, factors such as wildlife smuggling, deforestation and climate change increase the risk of new outbreaks. Poverty is also a factor because it provides incentives for poor persons to engage in practices that erode natural capital: deforestation and wildlife trapping and smuggling. Solutions to these problems require whole of government approaches. In particular, the long-dominant practice of transforming natural capital into goods, services, money and power for some must be reformed, not only for the benefit of the poor, but even to improve the security of the wealthy. Greater transparency is

72 Visit the **WHO Coronavirus (COVID-19) Dashboard** for an up-to-date tally of vaccines administered as well cases and fatalities.

73 Visit "**WHO-convened global study of origins of SARS-CoV-2: China Part**" - Joint WHO-China Study Team report - 14 January-10 February 2021

74 **WHO calls for further studies, data on origin of SARS-CoV-2 virus, reiterates that all hypotheses remain open**, 30 March 2021 News release

also required, particularly concerning the ethics of gain of function research.

Irrespective of the origin of this pandemic, its emergence should be recognized as signifying a profound warning to civilization, which faces other interacting crises, including rising hunger and undernutrition, a record number of displaced persons, biodiversity loss, widespread pollution and climate change. But it is possible that the crisis caused by the current pandemic will lead to a fundamental awakening to the danger of humanity's recent trajectory, energizing reforms such as improved governance and co-operation, a new economic system, greater respect for nature and reduced corruption. Also required is a globally equitable distribution of effective vaccinations, with persisting immunity.

UNEP was formed in 1972 at the time of the first global environmental conference. Almost 50 years later, environmental challenges have intensified. Although some positivity can help persuade listeners to change their behaviours, messages from UNEP need to plainly state the peril in which that humanity now finds itself [114].

GLOSSARY

Aerosol transmission A recent editorial in the BMJ [201] argues that terminology introduced in the last century has led to confusion, by creating a poorly defined division between "droplet", "airborne", and "droplet nuclei" transmission, leading to misunderstandings over the physical behaviour of airborne particles. People infected with SARS-CoV-2 "produce many small respiratory particles" laden with virus as they exhale. Some of these will be inhaled almost immediately by those within a typical conversational "short range" distance (<1 m), while the remainder disperse over longer distances to be inhaled by others further away (>2 m).

Traditionalists will refer to the larger short-range particles as droplets and the smaller long-range particles as droplet nuclei, but they are all aerosols because they can be inhaled directly from the air. However, they accept that the tiniest suspended particles can remain airborne for hours, constituting an important route of transmission, pointing out that this necessitates additional effort in creating adequate ventilation to improve indoor air quality. **Tang** *et al.* **(2021)**

Agricultural intensification An increase in agricultural production (both of crops, livestock and farmed fish) per unit of inputs (e.g. labour, land, time, fertilizer, seed, feed, cash). This intensification is considered a prerequisite to support the size of the current human population. Increased production is critical for expanding food supply; intensification that makes efficient use of inputs is critical for maintaining the health of agricultural environments. **FAO**

Anthropogenic Caused by humans or their activities. **Cambridge Dictionary**

Anthrax An ancient zoonotic disease that continues to cause serious illness in livestock, posing a particular threat to cattle and small ruminants like sheep and goats. The disease can affect all warm-blooded animals, including humans. Treatment is possible with early diagnosis, but often, there are no symptoms and infected animals die swiftly. Humans generally acquire the disease directly or indirectly from infected animals or occupational exposure to infected or contaminated animal products. Although many countries have confirmed cases, this is not, in the main, a disease of wealthy countries. Incidences of both animal and human anthrax are frequently associated with conflict. **FAO**

Arthropod An invertebrate animal having an exoskeleton, a segmented body and paired jointed appendages. Arthropods include insects, arachnids (such as ticks and spiders), myriapods and crustaceans. **Biologydictionary.net**

Asymptomatic carriers Also known as "passive" or "healthy" disease carriers: Individuals who, while infected with a pathogen, neither report nor appear to have any symptoms or signs of illness. **WHO**

Avian influenza A severe, often fatal, type of influenza that affects birds, especially poultry, and that can also be transmitted to humans. Known informally as "avian flu" or "bird flu", the type with the greatest risk is highly pathogenic avian influenza (HPAI). Of three types of influenza viruses (A, B and C), influenza A virus is a zoonotic infection with a natural reservoir found almost entirely in birds. "Avian influenza", for most purposes, refers to the influenza A virus. Though influenza A is adapted to birds, it can sometimes also stably adapt and sustain person-to-person transmission. **WHO**

Behavioural immunity This refers to individual and collective behaviour that reduces the risk of infection. Examples include quarantine, physical distancing, washing hands or covering one's mouth and nose when coughing or sneezing. Forms of disgust appear to be innate, as well as learned. Some forms of behavioural immunity are also exhibited by non-human animals.

Biodiversity The variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems, as well as the ecological complexes of which they are part. Biodiversity includes diversity within species, between species and of ecosystems. **CBD**

Bovine spongiform encephalopathy (BSE) Commonly known as "mad cow disease", BSE is a progressive, fatal disease of the nervous system of cattle caused by the accumulation of "prion", an abnormal protein in nervous tissue. First detected in 1986, the implementation of appropriate control measures resulted in the decline of classical BSE cases worldwide. BSE is considered zoonotic owing to its assumed link with the emergence of variant Creutzfeldt-Jakob disease in humans. **OIE**

Co-morbidities More than one disease orcondition present in an individual at the same time. Also referred to as "co-existing" or "co-occurring" conditions and "multimorbidity" or "multiple chronic conditions". **US CDC**

Coronavirus disease 2019 Illness caused by a novel coronavirus, "severe acute respiratory syndrome coronavirus 2" (SARS-CoV-2), first identified amid an outbreak of respiratory illness cases in East Asia. The outbreak was first reported to WHO on 31 December 2019. On 30 January 2020, WHO declared the COVID-19 outbreak a global health emergency, and the following March, a global pandemic. This was WHO's first such designation since declaring H1N1 influenza a pandemic in 2009. **WHO**

Coronavirus Human coronaviruses (named for the crown-like spikes on their surface) were first identified in the mid-1960s. Seven coronaviruses can infect humans, of which four are common human coronaviruses, that is, 229E, NL63, OC43 and HKU1; these usually cause mild to moderate upper-respiratory tract illnesses like the common cold. But three of the seven coronaviruses—MERS-CoV, SARS-CoV and SARS-CoV-2—are novel, lethal coronaviruses that originated in animals and evolved in ways thatcan cause serious human illness and death. **US CDC**

Crimean-Congo haemorrhagic fever (CCHF) A viral haemorrhagic fever usually transmitted by ticks. It can also be contracted through contact with animal tissue; in such case, the virus has entered the bloodstream during and immediately post-slaughter of animals. Outbreaks of the disease can lead to epidemics, have a high case fatality ratio (10–40 per cent) and are difficult to prevent and treat. First described in the Crimea in 1944, the disease is endemic in all of Africa, Asia, the Balkans and the Middle East. **WHO**

Cysticercosis A parasitic tissue infection caused by larval cysts of Taenia solium, the pork tapeworm. These larval cysts infect brain, muscle or other tissue and are a major cause of adult- onset seizures in most low-income countries. Infection occurs by swallowing eggs found in the faeces of a person with intestinal tapeworm. People do not get cysticercosis by eating undercooked pork, which can result in intestinal tapeworm if the pork contains larval cysts. Pigs become infected by eating tapeworm eggs in the faeces of a human infected with a tapeworm. Both the tapeworm infection, also known as taeniasis, and cysticercosis occur globally. The highest rates of infection are found in areas of Asia, Africa and Latin America that have poor sanitation and free-ranging pigs that have access to human faeces. **US CDC**. **Aung and Spelman (2016)**

DNA virus A virus containing DNA as its genetic material and using a DNA-dependent DNA polymerase during replication. Most of these viruses must enter the host nucleus before they can replicate because they need the host cell's DNA polymerases when replicating their viral genome. **Biology Online**

Ebola virus disease (EVD) A rare, deadly disease in human and non-human primates. Though the viruses that cause Ebola are found mainly in Sub-Saharan Africa, Ebola Reston is found in The Philippines. Humans can get Ebola through direct contact with an infected animal (bat or non-human primate) or, otherwise, a sick or dead person infected with Ebolavirus. **WHO**

EcoHealth An emerging field that examines the complex relationships among humans, animals and the environment, and how these relationships affect the health of each of these domains. One Health places greater emphasis on zoonoses and, arguably, less on inequalities, even though one of its pioneers was also a "father" of social medicine. In contrast, the EcoHealth concept is defined as an "ecosystem" approach to health, initially framed by disease ecologists working in the field of public health and biodiversity conservation. **EcoHealth International**

Ecosystem A dynamic complex of vegetable, animal and microorganism communities and their non-living environment that interact as a functional unit. Ecosystems may be small and simple, like an isolated pond, or large and complex, like a specific tropical rainforest or a coral reef in tropical seas. **IUCN**

Ecosystem degradation A long-term reduction in an ecosystem's structure, functionality, or capacity to provide benefits to people. **IPBES**

Epidemic The occurrence in a community or region of cases of an illness, specific health-related behaviour, or other health-related events that are clearly in excess of normal expectancy. The community or region and the period in which the cases occur are specified precisely. **US CDC**

FAO, OIE, WHO Tripartite Alliance A collaboration between the Food and Agriculture Organization (FAO), the World Organisation for Animal Health (OIE) and the World Health Organization (WHO) to address risks from zoonoses and other public health threats existing and emerging at the human-animal-ecosystems interface and to provide guidance on how to reduce these risks. These three organizations have worked together for many years to prevent, detect, control and eliminate health threats to humans, originating—directly or indirectly—from animals. Putting the One Health vision into practice has been facilitated by a formal alliance of the three organizations established in 2010, acknowledging their respective responsibilities in combating diseases that have a severe impact on health and the economy, particularly zoonoses. **FAO; OIE; WHO**

Fomite transmission Refers to the transmission of infectious diseases by objects. It occurs when an inanimate object contaminated with or exposed to infectious agents (such as pathogenic bacteria, viruses or fungi) serve as a mechanism for transfer to a new host. **US CDC**

Food value chains Comprise all the stakeholders who participate in the coordinated production and value adding activities needed to make food products. **FAO**

Guano The excrement of seabirds and bats, used as fertilizer. **Lexico**

Habitat The natural home or environment of an animal, plant or other organism. **Lexico**

Habitat fragmentation A general term describing the set of processes by which habitat loss results in the division of continuous habitats into a greater number of smaller patches of lesser total and isolated from each other by a matrix of dissimilar habitats. Habitat fragmentation may occur through natural processes (e.g., forest and grassland fires, flooding) and through human activities (forestry, agriculture, urbanization). Habitat loss and fragmentation, to feed and satisfy a growing human population that is increasingly affluent have long been considered the primary cause for biodiversity loss and ecosystem degradation worldwide. Habitat fragmentation often refers to the reduction of continuous tracts of habitat to smaller, spatially distinct remnant patches. Although some habitats are naturally patchy in terms of abiotic and biotic conditions, human actions have profoundly fragmented landscapes across the world, altering the quality and connectivity of habitats. **IPBES**

Highly pathogenic avian influenza (HPAI) A highly contagious disease caused by viruses that occur mainly in birds and that can be deadly, especially in domestic poultry. Since 2003, an Asian HPAI H5N1 virus has resulted in high mortality in poultry and wild birds in Asia, the Middle East, Europe and Africa and has become endemic in some countries. **US CDC**

Hookworm An important soil transmitted helminth, associated with loss of iron. All soil transmitted helminths can increase nutrient malabsorption. **WHO**

Host An organism infected with or fed upon by a parasitic or pathogenic organism (for example, a virus, nematode, fungus). An animal or plant that nourishes and supports a parasite; the host does not benefit and is often harmed by the association. **Biology Online**

Host plasticity The ability of a virus to infect a diverse range of hosts, such as bats, rodents, and primates. **One Health Institute at the University of California, Davis**

Human T-cell lymphotropic virus (HTLV) HTLV is a type of retrovirus that infects a type of white blood cell called a T-lymphocyte. HTLV can cause cancer. Simian T-cell leukaemia viruses (STLVs) that infect Old World monkeys are the simian counterparts of HTLV, and these viruses are collectively called primate T-cell leukaemia viruses (PTLVs). The close relationship between HTLV type 1 and STLV type 1 suggests a simian origin for HTLV type 1 as a result of multiple interspecies transmissions between primates and humans and between different primate species. **Courgnaud** *et al*. **(2004)**

Japanese encephalitis virus (JEV) A flavivirus related to dengue, yellow fever, and West Nile viruses and spread by mosquitoes. It is found principally in Asia and the Western

Pacific and is the main cause of viral encephalitis in many countries of Asia, with an estimated 68,000 clinical cases every year. There is no cure for the disease. **WHO**

Leishmaniasis A disease caused by the protozoan Leishmania parasites which are transmitted by the bite of infected sandflies. There are three main forms of leishmaniases—visceral (also known as kala-azar, which is usually fatal if untreated), cutaneous (the most common) and mucocutaneous. The disease affects some of the poorest people on Earth and is associated with undernutrition, population displacement, poor housing and a weak immune system. Leishmaniasis is linked to environmental changes such as deforestation, building of dams, irrigation schemes and urbanization. An estimated 700,000 to 1 million new cases occur annually. **WHO**

Leptospirosis A bacterial disease affecting humans and animals caused by bacteria of the genus Leptospira. In humans, it can cause a wide range of symptoms such as fever, headache, diarrhoea, muscle ache. Without treatment, Leptospirosis can lead to kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, respiratory distress, and even death. The bacteria that cause leptospirosis are spread through the urine of infected animals, which can get into water or soil and can survive there for weeks to months. Many species of wild and domestic animals carry the bacterium. **US CDC**

Lockdown A state of isolation or restricted access instituted as a security measure. **Lexico**

Middle East respiratory syndrome (MERS) A viral respiratory disease caused by a novel coronavirus (Middle East respiratory syndrome coronavirus, or MERS-CoV) that was first identified in Saudi Arabia in 2012. Typical MERS symptoms include fever, cough and shortness of breath. About 35 per cent of reported patients with MERS have died. The virus does not seem to pass easily from person to person and most human cases of MERS have been attributed to human-to-human infections in health care settings. The largest outbreaks have occurred in Saudi Arabia, United Arab Emirates and the Republic of Korea. Current scientific evidence suggests that dromedary camels are a major reservoir host for MERS-CoV and an animal source of MERS infection in humans. **WHO**

Middle East respiratory syndrome coronavirus (MERS-CoV) A coronavirus causing Middle East respiratory syndrome (MERS). **WHO**

Neglected zoonotic diseases Zoonoses that include anthrax, brucellosis, foodborne trematodiases, human African trypanosomosis, leishmaniasis, leptospirosis, non-malarial febrile illnesses, schistosomiasis, rabies and taeniasis/cysticercosis. These neglected zoonoses are found in communities in low-resource settings across the world, where they impose a dual burden on people's health and that of the livestock they depend upon. Their management requires collaborative, cross-sectoral efforts of human and animal health systems and a multidisciplinary approach that considers the complexities of the ecosystems where humans and animals coexist. Where feasible, preventing and mitigating their occurrence in humans requires their elimination in their animal reservoirs. National governments are increasingly implementing control programmes to address these burdens. These initiatives have been strongly endorsed by the Food and Agriculture Organization of the United Nations, the World Organization for Animal Health and World Health Organization Tripartite and financially supported the international community, including the Bill & Melinda Gates Foundation, the UK Department for International Development, the European Union, the International Development Research Centre and CGIAR. **WHO**

Oncogenic Cancer or tumour causing **Dictionary.com**

One Health A collaborative, multisectoral, and transdisciplinary approach—working at local, regional, national and global levels—to achieve optimal health and well-being outcomes recognizing the interconnections between people, animals, plants and their shared environments. **One Health Commission**

Pandemic An epidemic occurring over a very wide area, crossing international boundaries, and usually affecting a multitude. The infectious agent must be able to infect humans and to spread easily from human to human" **Dictionary of Epidemiology** (2014) [7].

Pathogen Any microorganism able to cause disease in a host organism. **British Society for Immunology**

Pathogenic capable of causing disease. **Dictionary.com**

Pathogenicity The absolute ability of an infectious agent to cause disease/damage in a host—an infectious agent is either pathogenic or not. **ScienceDirect**

Peri-domestic Pertaining to living in and around human habitations. The rat is a peri-domestic animal. **WordSense Dictionary**

Permafrost A thick subsurface layer of soil that remains frozen throughout the year, occurring chiefly in polar regions. **Lexico**

Phylogenetic analysis Phylogeny is the relationship between all the organisms on Earth that have descended from a common ancestor, whether they are extinct or extant. Phylogenetics is the science of studying the evolutionary relatedness among biological groups and a phylogenetic tree is used to graphically represent this evolutionary relation related to the species of interest. **ScienceDirect**

Planetary boundaries Earth system processes, modifiable by human actions, whose boundaries, if not exceeded, constitute a "safe operating space for humanity". This term, first published in 2009, is conceptually linked to the Limits to Growth framework. SRC

Planetary health Defined as "the achievement of the highest attainable standard of health, well-being, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity and the earth's natural systems that define the safe environmental limits within which humanity can flourish. Put simply, planetary health is the health of human civilization and the state of the natural systems on which it depends". In 2014 the Rockefeller Foundation and The Lancet jointly formed the Commission on Planetary Health to review the scientific basis for linking human health to the underlying integrity of the earth's natural system. **The Rockefeller Foundation–Lancet Commission on Planetary Health**

Rabies A vaccine-preventable, zoonotic, viral disease. Once clinical symptoms appear, rabies is virtually 100 per cent fatal. It can spread to people and pets if they are bitten or scratched by a rabid animal. In up to 99 per cent of cases, domestic dogs are responsible for rabies virus transmission to humans, but it can affect both domestic and wild animals. The virus can cause disease in the brain, ultimately resulting in death. Rabies is present on all continents, except Antarctica, with over 95 per cent of human deaths occurring in the Asian and African regions. Rabies is one of the 'neglected tropical diseases' that predominantly affects poor and vulnerable populations who live in remote rural locations. Although effective human vaccines and immunoglobulins exist for rabies, they are not readily available or accessible to those in need. **WHO**

Reservoir The habitat in which the agent normally lives, grows, and multiplies. Reservoirs include humans, animals, and the environment. The reservoir may or may not be the source from which an agent is transferred to a host. **US CDC**

Reservoir host A primary host that harbours a pathogen but shows no ill effects and serves as a source of infection. Once discovered, natural reservoirs elucidate the complete life cycle of infectious diseases, providing effective prevention and control. **Biology Online**

RNA viruses Those that containing RNA as its genetic material. The RNA may be single stranded or double stranded. Examples of RNA viruses include Reoviruses, Picornaviruses, Togaviruses, Orthomyxoviruses, Rhabdoviruses, etc. The RNA may be single stranded or double stranded. Examples of RNA viruses include Reoviruses, Picornaviruses, Togaviruses, Orthomyxoviruses and Rhabdoviruses. Most RNA viruses replicate in the cytoplasm of the host cells. Examples of human diseases caused by RNA viruses are SARS, influenza and hepatitis C. **Biology Online**

Severe acute respiratory syndrome (SARS) A viral respiratory illness caused by a coronavirus, the SARS-associated coronavirus (SARS-CoV). First reported in East Asia in 2002, the illness spread to more than two dozen countries in North America, South America, Europe and Asia before the SARS global outbreak of 2003 was contained. The last outbreaks occurred in association with laboratory accidents, in 2004. **CDC**

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) A novel coronavirus causing the 2019–2020 coronavirus 2019 (COVID-19) pandemic. On 11 February 2020, WHO named the new virus SARS-CoV-2 because the virus is genetically related to the coronavirus responsible for the SARS outbreak of 2003. While related, the two viruses are different. WHO announced "COVID-19" as the name of this new disease on the same

day, following guidelines previously developed with the World Organisation for Animal Health (OIE) and the Food and Agriculture Organization of the United Nations. **WHO**

Simian Relating to, resembling, or affecting apes or monkeys. **Lexico**

Simian virus 40 A virus, sometimes oncogenic, that contaminated hundreds of millions of polio vaccines, both Salk (administered by injection, using a killed polio virus) and Sabin (administered orally, using an attenuated polio virus). **Butel (2000)**

Social distancing A form of behavioural immunity, also called 'physical distancing', means keeping six feet (two metres) of space between yourself and other people outside of your home, not gathering in groups, staying out of crowded places and avoiding mass gatherings. Adapted from **US CDC**

Steady-state economy An economy with constant stocks of physical wealth and a constant population, each maintained at some chosen, desirable level. **Daly (1974)**

Stealth transmission Disease transmission that it is virtually impossible to detect, except retrospectively, such as from a person who is completely asymptomatic, or has a sexually transmissible disease without any obvious signs. **Butler (2012)**

Swine (porcine) epidemic diarrhoea A non-zoonotic viral disease of pigs caused by a coronavirus and characterized by watery diarrhoea and weight loss. First identified and reported in 1971, it affects pigs of all ages, but most severely neonatal piglets, reaching a morbidity and mortality of up to 100 per cent, with mortality decreasing as age increases. It is a contagious disease transmissible mainly by the faecal-oral route. The prevention and management control are focused on strict biosecurity and early detection. There is no specific treatment for the disease. **OIE**

Triage The process of quickly examining patients who are taken to a hospital with the aim to decide which ones are the most seriously ill and must be treated first. In some cases of assessing suitability for coronavirus treatment the only criterion considered is the patient's age, for example for eligibility to be placed on a ventilator. **Cambridge Dictionary**

Vector An organism or vehicle that transmits the causative agent or disease-causing organism from the reservoir to the host. Often thought of as a biting insect or tick, it can also be an animal or inanimate object. Many living vectors are bloodsucking insects and ticks, which ingest disease-producing microorganisms during a blood meal from an infected host (human or animal) and later transmit it into a new host, after the pathogen has replicated. Often, once a vector becomes infectious, they can transmit the pathogen for the rest of their life during each subsequent bite/blood meal. **Biology Online**

Vector-borne diseases Human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors. Vector-borne diseases account for more than 17 per cent of all infectious diseases, causing more than 700,000 deaths annually. **WHO**

Virus An infectious agent of small size and simple composition, not observable by light microscopy that can multiply only in living cells of animals, plants or bacteria. The name is from a Latin word meaning "slimy liquid" or "poison". **Encyclopaedia Britannica**

Sustainable agricultural intensification A concept that challenges global agriculture (crops, livestock, forests, fisheries) to achieve a major increase (probably short of a doubling) in world food production while sustaining the environment in which we live. Food production efficiency needs to improve in order to feed a growing global population, using only currently available land while protecting our living environment and conserving natural and agricultural biodiversity. Sustainable agricultural intensification provides the means to do this with limited available resources, which are unlikely to increase. This ambition is highlighted in the Sustainable Development Goals, so the efficiency with which they are used will have to be enhanced to ensure ecosystems services are maintained. Sustainability also requires ensuring social equity in the productive and environmental benefits from sustainable agricultural intensification, otherwise the poorer sections of the farming population and women farmers risk being left behind or displaced by the promotion of intensification. **NRI**

Wild meat More commonly called "bushmeat" (but in this report, "wild meat"). Wildlife makes an important contribution to food security for many people, especially in low-income settings and for Indigenous people. For some in the Asia Pacific, wild meat may be the main type of meat available, an important component of food diversity or a food that contributes to cultural identity. Wild meat may have a better profile of fat and pesticides than farmed animals and fish although (as with domestic stock) its use may carry health risks related to zoonoses— diseases transmitted to humans through the handling or consumption of animals. Declines in wildlife due to over-hunting or other causes, whether direct (e.g. habitat degradation) or indirect (e.g. weak governance or climate change) could significantly affect many people's food security and nutritional health. Furthermore, an increasing number of vertebrate species are being hunted to dangerously low levels as a result of increased commercial demand for meat and medicines, with many now in danger of extinction. **FAO**

Vermin Wild animals that are believed to be harmful to crops, farm animals, or game, or that carry disease, for example, rodents. **Lexico**

Zika virus A mosquito-borne flavivirus first identified in Uganda in 1947 in monkeys. Zika virus disease is caused by a virus transmitted primarily by Aedes mosquitoes, which bite during the day. Most people infected with the Zika virus do not develop symptoms, and those that do suffer mild symptoms (fever, rash, conjunctivitis, muscle and joint pain, malaise or headache) for 2–7 days. Zika virus infection during pregnancy can cause infants to be born with microcephaly and other congenital malformations, known as congenital Zika syndrome, and is associated with other complications of pregnancy, including preterm birth and miscarriage. Outbreaks of Zika virus disease have been reported in Africa, Asia Pacific and the Americas. **WHO**

Zoonoses Diseases that can spread between animals and people, moving from wild and domesticated animals to humans and from humans to animals. Every year, nearly 60,000 people die from rabies, and other zoonotic diseases such as avian influenza. These diseases affect not only human health but also animal health and welfare by causing lowered productivity (e.g. in terms of milk or egg quality and safety) or death, with significant harm to farmer livelihoods and national economies. **WHO**

Zoonotic agent Pathogens that cause zoonoses. **Encyclopedia of Insects (2nd Edition, 2009)**

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