UN environment programme

COVID-19

a Warning

Addressing Environmental Threats and the Risk of Future Pandemics in Asia and the Pacific

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ABBREVIATIONS

AIT
Asian Institute of Technology

BSE
Bovine Spongiform Encephalopathy

CBD
Convention on Biological Diversity

CDC
Centers for Disease Control [United States]

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

FAO
Food and Agriculture Organization

GAVI
The Vaccine Alliance

HPAI
highly pathogenic avian influenza

HTLV
human T-cell lymphotropic virus

ICIMOD
International Centre for Integrated Mountain Development

IGES
Institute for Global Environmental Strategies

ILRI
International Livestock Research Institute

IPBES
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

MERS
Middle East respiratory syndrome

NRI
Natural Resources Institute

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

PREZODE
Preventing ZOonotic Disease Emergence

RNA
ribonucleic acid

SADS CoV
Swine (porcine) acute diarrhoea syndrome coronavirus

SARS
Severe acute respiratory syndrome

SEEA-EEA
System of Environmental-Economic Accounting – Experimental Ecosystem Accounting

TEEB
The Economics of Ecosystems and Biodiversity

TERI
The Energy and Resources Institute

UNEP
United Nations Environment Programme

WHO
World Health Organization

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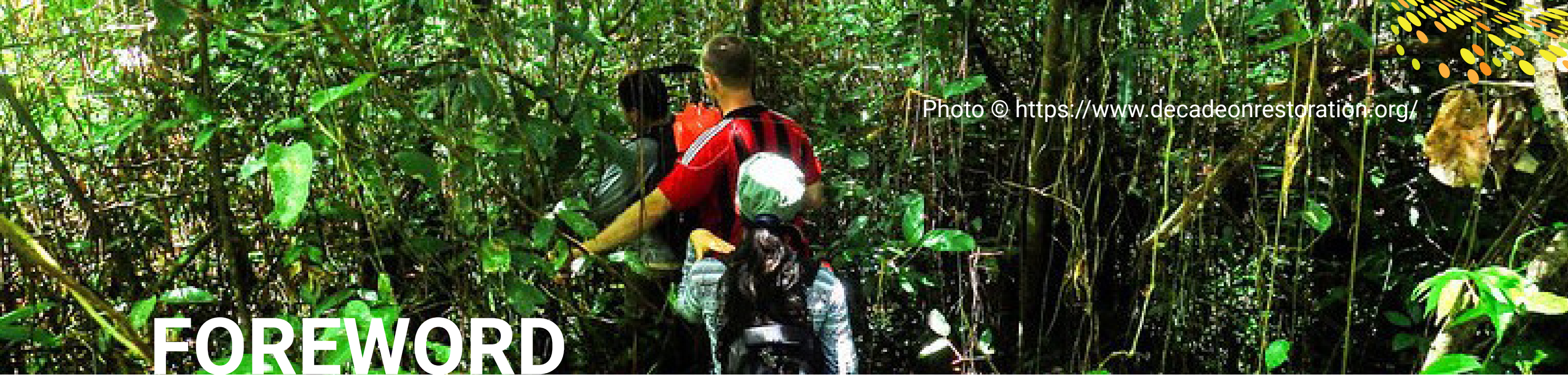

FOREWORD

Daily headlines inform us that the COVID-19 pandemic has infected more than 200 million people and taken more than 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 two of the three deepening, long-standing planetary crises of our time in addition to poverty and hunger— that is, climate change and biodiversity loss. And though, owing to the pandemic, air pollution improved in some regions, there is no evidence this will persist. What is certain is that these 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 and Goal 5, Gender Equality. Adverse outcomes from climate change and environmental degradation impact everyone. However, the burden on the poor and most disadvantaged, already vulnerable, is disproportionate—with women and children often over-represented in this category.

In this context, this UNEP report, *COVID-19, a Warning: Addressing Environmental Threats and the Risk of Future Pandemics in Asia and the Pacific*, presents a simple message—safeguarding nature is vital for avoiding future pandemics. In other words, natural habitat loss and degradation, over exploitation of plants and animals, climate change and unsustainable consumption of other natural resources 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, *COVID-19, a Warning* 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 authors and reviewers, and our colleagues in the UNEP Regional Office for Asia and the Pacific—for having made this timely report available at the Inaugural Session of the Asia-Pacific Science-Policy-Business Forum on the Environment. This report has undoubtedly informed dialogue at this meeting as well as at the Fourth Session of the 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

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, eventual fatalities of this pandemic may exceed that of HIV/AIDS.

The origin of the COVID-19 virus is unknown. The leading hypothesis to explain its origin is that the causal virus, SARS-CoV-2 (a coronavirus) has evolved naturally in an ecological milieu in which different species of farmed or smuggled animals, or both, exist in 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 escaped after evolving in a laboratory owing to experimentation. But what is certainly known is that a globally equitable distribution of effective vaccines is needed to control COVID-19 and its variants.

Looking forward, what tools do we have to confront future pandemics? A One Health approach is increasingly presented as a necessary strategy to restrict 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. Animal and plant domestication enabled 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.

The farming of long-domesticated (e.g. cattle, pigs and chickens) and "wild" animals (e.g. palm civets, raccoon dogs, bamboo rats) — for whatever purpose — creates opportunities to bring together species (either in farms or markets). In turn, this creates the potential for viral mixing that could generate novel zoonoses, perhaps even with global pandemic potential.

In Asia and the Pacific, demand for meat derived from farmed wildlife species (which possibly generates a higher risk of dangerous zoonoses than from wild-caught species) appears to be mainly driven by culturally shared 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 than farmed meat. Furthermore, for subsistence farmers and others who are very poor, the only possibility to ingest meat may be via animals that are hunted or trapped. Such meat is likely to be extremely valuable to them nutritionally.

However, for some, all forms of meat consumption are ethically problematic. If the global consumption of meat (especially non-aquatic) can be substantially reduced but concurrently made more equitable, then substantial benefits will accrue to many humans as well as to the environment. This change in consumption patterns will require courage and leadership—a change likely to be challenged by those who profit from the current situation, including 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 and other animal products may be a more important benefitreason than the ingestion of all essential amino acids. Furthermore, the absorption and tissue availability of iron will be enhanced for millions in the Asia Pacific by the improved treatment and prevention of intestinal parasites such as hookworm. These steps should reduce the need (and demand) for meat as may micronutrient food supplementation especially with zinc, iron and vitamin B12.

However, it is likely that consumers who are willing to pay a premium to consume wild animal species have lower levels of parasitic diseases. Better treatment of parasites may reduce the demand for wild meat from populations who hunt such species for food.

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 have been reduced by effective pandemic prevention measures.

Finally, owing to gender-differentiated roles, women and men participate in different activities in wildlife trade, whether legal or illegal. Understanding these differences in terms of access to and control over resources ought to be considered for effective policy formulation.

Finally, zoonoses can also enter human populations via laboratory accidents and errors. However, global warming, deforestation other forms of ecological alteration have also been implicated in the emergence of some zoonoses.

Irrespective of the true origin of the virus, COVID-19 can be interpreted as a profound warning to civilization—one that is intertwined with other interacting crises, including rising hunger and undernutrition, a record number of displaced persons, climate change, biodiversity loss and widespread pollution.

But the crisis caused by the current pandemic could possibly 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, increased gender equality, reduced poverty, reduced corruption—and most important, greater respect for nature.

COVID-19
A Warning

Addressing Environmental Threats and 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). The proximate cause of this pandemic is a newly discovered beta coronavirus,[1]1 officially referred to as "SARS-CoV-2" (Box 1 and Box 2).[2] The disease that results from infection with this coronavirus, COVID-19, is widely considered to be a zoonosis[3] (Box 3). The origin is believed, with high confidence (Haider *et al*. 2020), to have been the Rhinolophus bat genus before being introduced to humans via one or more "intermediary" or "bridging" vertebrate species (Andersen *et al*. 2020; Dobson *et al*. 2020; Sun *et al*. 2020). Although COVID-19 is spread chiefly by aerosols (Greenhalgh *et al*. 2021), fomite transmission, especially on frozen surfaces, is also considered possible (Jia *et al*. 2021).

Unlike SARS and the Middle East respiratory syndrome (MERS), both which can be considered as providing the world with an under-appreciated warning (Weiss and McLean 2004), COVID-19 rapidly affected almost every country (apart from a few isolated islands that have yet to record cases). In fact, as of year-end 2021, the COVID-19 pandemic has directly infected almost 275 million people and caused more than five million deaths at a global scale. In the Asia Pacific, more than 51.5 million cases and about 800,000 deaths were reported during this timeframe.

In addition to global health impacts, the COVID-19 pandemic has had a profound economic impact. The public health response, manifested especially as lockdowns, has resulted in wide-ranging disruptions, from social isolation to the cancellation of mass gatherings,[4] and ultimately, in increased unemployment around the world in many sectors, including tourism and education.

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1 Coronaviruses are divided into four groups, that is, alpha, beta, gamma and delta. To date, humans are infected only by alpha and beta coronaviruses, with the latter being SARS, MERS-CoV and SARS-CO-V-2. Of these, two alphacoronaviruses are widespread, and most illnesses they cause are forms of the so-called common cold (Marty and Jones 2020).

2 "CoV" is the abbreviation for "coronavirus", and while the number "2" refers to the similarity to the "strain" of coronavirus that caused SARS it also indicates differentiation

3 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, refer to the WHO's fact sheet, "Zoonoses."

4 For example, the Gavi Alliance (formerly the Global Alliance for Vaccines and Immunizations) interrupted all other vaccination programmes, including its planned vaccine investment strategy for cholera and rabies because of its engagement in co-ordinating the distribution of vaccines against SARS-Cov-2.

Box 1

What is the etymology of the term "pandemic"?

The term "pandemic" has been in occasional use for over three centuries (Morens, Folkers and Fauci 2009). 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 (Morens and Taubenberger 2018). For this cataclysm, "epidemic" seemed (and seems) too mild, and as a consequence, the term "pandemic" became temporarily commonplace (Morens, Folkers and Fauci 2009) 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 highlighted that the infectious agent must be able to infect humans and to spread easily from human to human (Porta *et al*. 2014).

Tedros Ghebreyesus, Director General of the World Health Organization, speaking in March 2020, stated that "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" (World Health Organization [WHO] 2020).

Box 2

What are the characteristics of a pandemic?

Morens, Folkers and Fauci (2009) identify several pandemic characteristics, in addition to the traceable movement of disease over a large region. These characteristics 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, that is, those with a potential for extraordinary mortality.

The decline in economic activity has itself had numerous adverse effects, including for health. Health systems in many countries have been greatly stressed not only by the substantial morbidity and mortality borne by infected health workers but also by the burnout of many of their colleagues; these workers have been overwhelmed by the huge influx of hospital patients compounded by inadequate resources such as 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. These constraints have magnified the number of deaths and overall morbidity for patients in need

Box 3

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 (Hubálek 2003). 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)[a] for their reproduction. They can also be non-living substances such as prions, although this is rare.

Zoonoses can be transmitted directly (such as an animal bite) or indirectly, such as via an insect vector or through the ingestion of uncooked, or undercooked food.

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

Box 4

What does the term “prion disease” refer to?

Prion diseases (originally thought to be caused by “slow viruses”) have long been known, especially kuru, a disease transmitted by ritual cannibalism in New Guinea (Gajdusek 1977), and scrapie, a disease of sheep. Prions are not viruses, and non-living; they lack any form of nucleic acid. They are modified proteins (Prusiner, 1997) that rarely occur spontaneously in mammalian brains, including humans, causing Creutzfeld-Jacob disease (CJD). They are transmissible to humans (and other species) if prion-containing tissue is ingested.[a]

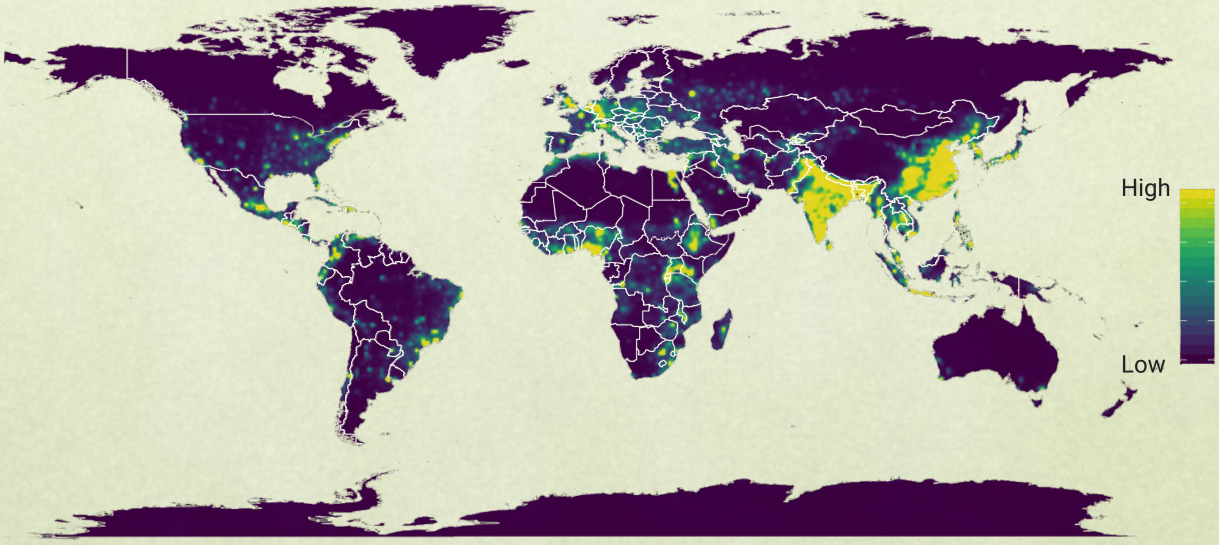
[a] In the case of kuru, the ingested body part appears to have been restricted to the brain. In contrast, in the case of bovine spongiform encephalopathy leading to variant-CJD, transmission appears to have occurred from eating muscle as well as, perhaps, brain and other neural tissue (see Box 8).

of care. Moreover, as a result, the financial equilibrium of these health care institutions has weakened, risking deterioration of the whole health system over the long term.

There are two leading alternative hypothesis for the origin of SARS-CoV-2, albeit each related to a laboratory route of transmission. The first leading hypothesis is that the virus may have been introduced to the human population—in unchanged form—via an accidentally infected laboratory worker after carriage of the pathogen from the external environment to a laboratory for research purposes. The second hypothesis is that the pathogen may have evolved during experimental laboratory work, and it then may have been accidentally introduced to the human population also possibly via an infected laboratory worker (Relman 2020; Bloom *et al*. 2021; Waxmen and Mallapaty 2021; van Helden *et al*. 2021; Van Kerkhove *et al*. 2021).

Figure 1 /

Estimated global risk of zoonotic disease emergence



Source: Allen *et al*. [20].
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

About this report

This scientific review begins with the history of humans and zoonoses and provides clarity on the issues of zoonoses and emerging infectious diseases. It then presents the seven anthropogenic drivers of zoonotic disease emergence as well as the concept of viral mixing. After providing rich context, this review continues to outline solutions that address the intricate link between nature and human health and strategies to prevent future zoonotic outbreaks.

The preliminary findings and conclusions of this scientific review were presented via a webinar organized by the UNEP Regional Office for Asia and the Pacific and its partners, which was based on the UNEP-ILRI (2020) report *Preventing the Next Pandemic–Zoonotic Diseases and How to Break the Chain of Transmission*. 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 this 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. It was also peer-reviewed by policymakers from Member countries and scientists in virology, public health and environmental sciences. A revised version of the preliminary report was used as a background document for the Inaugural Regional Session of UNEP Science-Policy-Business Forum on the Environment, held virtually on 5 October 2021.

In this context, Box 5 discusses the role and geographic span of the UNEP Regional Office for Asia and the Pacific Office.

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 feasible mitigation measures. While pre-existing disease, such as Type II diabetes, is an important factor influencing vulnerability to and outcomes of exposure to COVID-19 (Thakur, Ryan and Ghebreyesus 2021), limited evidence does exist on the significance of gender-based anatomical and physiological differences. Results are mixed: higher mortality has been reported for men in Europe, with higher rates reported for women in some parts of the Asia Pacific, namely, India and Viet Nam (Dehingia and Raj 2021).

Reflection on factors concerning disease emergence and mitigation measures 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 the heatmap (Figure 1) (Allen *et al*. 2017).

Box 5

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/subregional 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 subregional 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 the following 41 countries in 5 subregions:

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

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 (Weiss 2015). In fact, humans also carry a vast number[5] of microbes on the skin and internally in the gastro-intestinal tract (about 3 kg of the average person's weight).

Nonetheless, some microbes are infectious agents that cause periodic disease in all vertebrate animals as well as plants. The number of known infectious agents[6] 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" (Taylor, Latham and Woolhouse 2001).

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.[7] 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 likely to have infected some humans for perhaps 40,000 years, since the domestication of dogs (Pierotti and Fogg 2020). Forty millenniums is, of course, a brief period compared to our existence as a species; our species has been hunting and butchering animals for far longer. It is possible, indeed likely, that some zoonoses did infect human populations before canine domestication, but such infections are likely to have been rare and transient.

If a hunter killed or found an obviously diseased animal, disgust and perhaps fear,[8] may have inhibited the consumption of that animal as food and even contact with it, thus reducing disease-transmission risk.[9] In fact, such fear is innate to many if not all humans and has also been documented in several non-human animals (Curtis, de Barra and Aunger 2011; Weinstein, Buck and Young 2018; de Waal 2019) Even so, some ancient hunters are likely to have occasionally acquired a zoonotic infection, perhaps because hunger overrode caution or the disease in the dead or killed animal was not obvious. One possibility of a very early zoonosis is measles (related to the now extinct cattle disease rinderpest) (Furuse, Suzuki and Oshitani 2010). This may occasionally have entered

5 Over 10^{17} organisms, most of which are viruses (Weiss 2015).
6 Including, in addition to viruses, other "micro-parasites", that is, prions, bacteria, rickettsia, fungi, protozoa and helminths.
7 These include gamma-herpes viruses, the Epstein-Barr virus and the Kaposi's sarcoma-associated virus. These are typically transmitted from mother (or grandmother) to offspring via saliva, but they can also be transmitted sexually, including sexual kissing, later in life (Weiss 2015). These viruses have "stealth" characteristics, exist for many years in the host, rarely if ever killing an immune-competent host, and they 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 host's evolutionary distance (Weiss 2015).

8 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.
9 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?

Source: Weiss 2001; Kravetz and Federman 2002; Wolfe, Dunavan and Diamond 2007; Luis *et al*. 2013; Zhu, Zimmerman and Deem 2019.
Note: Numbers overlap as some infections are shared among multiple species.
Key: ? Denotes uncertainty.

human populations through the hunting of cattle before domestication.

However, current understanding is that any such zoonoses could not have persisted in human populations until long after the dawn of agriculture (and animal domestication), about 10,000 years ago (Diamond and Bellwood 2003). Before then, all human groups lived in small numbers, generally isolated from other humans, who also lived in

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			South-East Asia
Crimean-Congo haemorrhagic fever *		Tick		Pakistan
Japanese encephalitis		Mosquito		South-East, South, and East Asia
Leishmaniasis, visceral *	Cattle	Sandfly		Bangladesh, Nepal, Northern India
Leptospirosis *	Eodents			Widespread
Rabies *	Wild dogs			Widespread

Note: Animal reservoir and geographic locations are incomplete. More details of these conditions are in the glossary where marked with an asterisk (*).
Key: -, denotes item not applicable.

similarly small, isolated groups. Measles (unlike a disease such as haemorrhagic fever) was unlikely to have provoked extreme fear and avoidance of an infected ancient hunter; thus, 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 thus could only persist in human populations if a constantly replenished "supply" of non-immune people were have contact with someone who is infectious. Wolfe, Dunavan and Diamond (2007) 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).[10]

Although populations of this size are common today, they were unlikely until thousands of years after the development of agriculture,[11] 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.

Long after the development of agriculture, zoonoses are believed to have increasingly emerged for three reasons. Firstly, animal domestication increased the chance for diseases to spillover 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

10 Wolfe, Dunavan and Diamond (2007) summarise likely animal origins of 25 important zoonoses.

11 A recent study has found earlier dates for human cases of Hepatitis B (c5ky BP) and smallpox than previously known (Spinney 2020). By applying phylogenetics (the study of genetic relationships among different groups of organisms and their evolutionary development), these viruses have been each traced back to the first millennium BC). However, even if these earlier dates are correct, they occur well after the development of agriculture.

proximity with humans, even though peri-domestic (i.e. not domesticated), for reasons such as shelter or greater food availability. Thirdly, as mentioned, ongoing epidemics of zoonoses, or diseases that were originally zoonotic, require large human populations to persist.[12]

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

Fortunately, only very few diseases with high potential burdens of disease are currently considered to have this characteristic (Table 3, Section 3). SARS does not fall under this category (Gandhi, Yokoe and Havlir 2020); however, claims exist that the share of asymptomatic cases of MERS have increased, especially among children (Al-Tawfiq 2020).

Some forms of long-standing behavioural immunity (Box 6) have applied to zoonoses. In ancient Babylon, an edict imposed fines if a rabid dog attacked a man or slave (with rabies being another zoonosis) (Weiss 2001). Also, in Central Asia, nomads and marmot hunters recognized an association between diseased marmots and plague (a zoonosis), shunning sick animals and moving camp if any were observed (Lynteris 2013). For a final example, since ancient times, Judaism and Islam has imposed religious dietary restrictions on pork consumption (Rosenblum 2010), with their rationales grounded in the protection of public health (Weiss 2001).

12 Nomadic groups dependent on the husbandry of large animal herds also are vulnerable to epidemics.

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 (Curtis, de Barra and Aunger 2011).

Being a strong motivator of protective distancing from an obviously sick person,[a] disgust appears as an innate behaviour, for instance, when observing vomiting or haemorrhaging.[b] An extreme example is that sufferers of the contagious disease leprosy, a zoonosis, have been socially distanced by non-lepers for millenniums.

A range of less extreme forms of behavioural immunity activities are learned, from hand-washing, mask-wearing, 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 (Gensini, Yacoub and Conti 2004), where the Black Death is believed to have been the result of an infectious fever caused by the bacterium *Yersinia pestis*, the plague. In this case, infected fleas likely transmitted the bacterium from rodents to humans.

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

a To an extent, this reflex can be overcome by carers. However, such behaviour does place the carer at higher risk of becoming infected. Parents, especially mothers (and perhaps other family members) experience little if any aversion to infant faeces (and perhaps to other infant secretions) even if associated with sickness. This behaviour may have evolved being protective for the child.

b 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 (Peng, Chang and Zhou, R. 2013).

c Many diseases are likely to be transmissible with mild or early symptoms, including the "common" cold, which can be caused by alphacoronaviruses (Marty and Jones 2020). Several other viruses also cause similar symptoms, including rhinoviruses, enteroviruses, adenoviruses and most of the common paramyxoviruses. Several of these can transmitted by asymptomatic individuals as well.

2 EMERGING ZOONOSES AND INFECTIOUS DISEASES

In 2001 a comprehensive literature review identified 1,415 unique, potentially infectious microorganisms and prions (Taylor *et al*. 2001)—that is, 217 viruses and prions, 538 bacteria and rickettsia, 307 fungi, 66 protozoa and 287 helminths. Of these, 868 were classified as "zoonotic".[13] The review identified 176 pathogens and prions as "emerging", of which 132 (75 per cent) were zoonotic. These figures have since been very widely reported. Moreover, additional zoonoses have been discovered since 2001, including three highly pathogenic coronaviruses: one causing Middle East respiratory syndrome in addition to others causing SARS and COVID-19. 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).[14]

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 (Crutzen 2002). Most Anthropocene scholars date the initiation of this proposed epoch to the start of the Industrial Revolution in about 1750 (Crutzen and Steffen 2003), with a "great acceleration" since the end of World War II (McNeill and Engelke 2016). It is an epoch that can be characterized as one of ecological recklessness or even "environmental brinkmanship" (Butler 2016). The best recognized examples relate to climate change, the erosion of biodiversity and excessive pollution, including that of

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

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

Box 7

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

The term "emerging infectious disease" was used in the title of a review in a leading journal published back in 1971 (Spencer 1971), suggesting the association of "emerging" with "disease" goes back to those times or earlier.

the seas—with microplastic pollution being the latest environmental threat to be widely recognized.

Some examples of this environmental peril, however, transcend to epidemics: bovine spongiform encephalopathy (Box 8), the contamination of hundreds of millions of polio vaccines with simian virus 40 (Bookchin and Schumacher 2004) and the iatrogenic[15] epidemic of hepatitis C in Egypt (Strickland 2006).

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 (Weiss and McMichael 2004). 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 (Chin *et al*. 2020).

Socioeconomic factors continue to push interactions between humans and wildlife. Key factors influencing these interactions include unsustainable and illegal trade, inadequate tenure rights, poverty and food and livelihood insecurity. These all have significant gender dimensions that also need to be addressed.

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 millenniums, 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 virtually no antibiotics[16] and far fewer vaccines existed. 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 (Spellberg and Taylor-Blake 2013). Nonetheless, the statement widely attributed to him was, for some years, considered to be plausible.

The view that communicable diseases were disappearing, as a major health threat, was dispelled in the early 1980s by the emergence 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) (Hahn *et al*. 2000; Wolfe *et al*. 2000). HIV/AIDS spread worldwide, resulting in a pandemic 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 (Pépin 2013; Faria *et al*. 2014).

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 (Taubenberger and Morens 2006). Centuries earlier, repeated pandemics of the *Yersinia pestis* (plague, responsible for the Black Death) terrified millions of people 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 tuberculosis, to which indigenous populations had no immunity,

15 An "iatrogenic epidemic" 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 (Breman and Johnson 2014). 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 (UNAIDS 2002).

16 Many infected with the 1918 influenza virus (commonly known as the "Spanish flu") died from secondary bacterial infections, today treatable by antibiotics (Morris *et al*. 2017).

Box 8

What is "Variant Creutzfeld-Jacob disease"?

In the early 1990s an increasing number of cases of bovine spongiform encephalopathy (BSE) appeared in the UK. The cause of "mad cow disease," as it was initially known, was traced to the bovine ingestion of prions, contained in a nutrient powder manufactured from the ground-up remains of dead cattle. In this way, prion-infected cattle became comparatively common in the UK. V CJD is (hopefully "was") a tragic, degenerative and rapidly fatal neurological disease in humans, with no effective treatment. The disease arose in a mercifully small number of people, mainly British, who had unknowingly eaten beef from cattle afflicted by pre-symptomatic BSE. Most cases occurred in the 1990s. Hamburger eaters may have been at higher risk because hamburger beef is generally sourced from multiple animals. The practice of forcing naturally vegan cattle (i.e after being weaned) to not only be carnivores but also cannibals was banned, but not before a number of human cases occurred. Early in the epidemic, however, this possible transmission route was denied. Clearly, this bovine feeding practice violated basic ecological principles and would never have occurred without human intervention.

thus prematurely terminating the lives of millions (Diamond 1997).

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 CJD (Box 8).

3 SEVEN MAJOR ANTHROPOGENIC DRIVERS OF ZOONOTIC DISEASE EMERGENCE

Caused by humans and their activities, the seven major anthropogenic drivers of zoonotic disease emergence presented 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 such drivers, citing four articles (Jones *et al*. 2008; Perry *et al*. 2011; Jones *et al*. 2013; Hassell *et al*. 2017).

Driver 1: Changes in food value preferences

As income increases, many eat more expensive foods, including animal products, unless prohibited by religious or social, cultural or other popular beliefs (e.g. Hinduism or veganism).[17] This change in the food value preferences is partly based on the belief that eating "higher on the food value chain" will improve health and extend lifespan. An increased demand for animal protein[18] is commonly advanced as a main reason for eating more meat (Fu *et al*. 2012).

However, the assumption that animal protein is the primary driver for meat ingestion can be questioned. Noteworthy is that protein deficiency owing to undernutrition (*kwashiorkor*) is extremely rare in the Asia Pacific. In fact, if active, humans require, on average, about 60 g[19] of protein per day. Animal-based foods are the main source of complete proteins,[20] and such protein is more readily digested than plant protein unless the plant cell wall constituents are removed (Tomé 2014). However, for most people, even if ageing, sufficient protein can be readily obtained from a vegetarian diet, balanced to provide all essential amino acids even if such protein is not processed by having the cell walls removed. Furthermore, a largely vegetarian diet reduces exposure to many toxins found in animal foods, particularly red and processed meat (Potter 2017).

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

17 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. For instance, demand for wild meat is reported to have declined in China through a combination of fear (of illness) and the closure of markets.

18 Animal protein contains all essential amino acids unlike protein from most plants. Exceptions (among plants) are soy and the "pseudocereals" buckwheat, amaranth and quinoa (Tessari *et al*. 2016; Motta *et al*. 2019).

19 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 (Willett *et al*. 2019).

20 Containing all essential amino acids. In contrast, to obtain all essential amino acids, most plant-sourced foods need to be eaten in combination (e.g. rice and beans, corn and beans). Humans can synthesize other amino acids as well.

Table 3 Major drivers of zoonotic disease emergence: Current report compared with 2020 UNEP report

Driver	Rank	Closest equivalent	Rank
Current report (2022 UNEP)		**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 over exploitation and unsustainable, unregulated or illegal trading 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	Unsustainable utilization of natural resources accelerated by urbanization, land use change and extractive industries	4
Climate change as a driver of bat and rodent densities	5	Climate change	7
Increased global travel and transportation	6	Travel and transportation	5
Laboratory and medical procedures contributing to outbreaks and pandemics	7	*No equivalent*	
Viral mixing (see Section 4)	?	Changes in food supply chains	6

Source: 2022 UNEP analysis based on UNEP (2020)

a major cause of fatigue, poor learning, impaired mental health and weakened immunity (Black 2003; Kelkitli *et al*. 2016), 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. For instance, intestinal parasites, such as hookworm,[21] are a major reason for low levels of iron and, often, iron-deficient anaemia, conditions that may be further complicated in women of childbearing age.[22] These deficiencies are attributed to the fact 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[23] on soil contaminated by faeces. This is especially common in parts of South-East Asia, in regions with high levels of wildlife harvesting and consumption and remains a serious problem in the Asia Pacific, as shown in Figure 2 (Loukas *et al*. 2016).

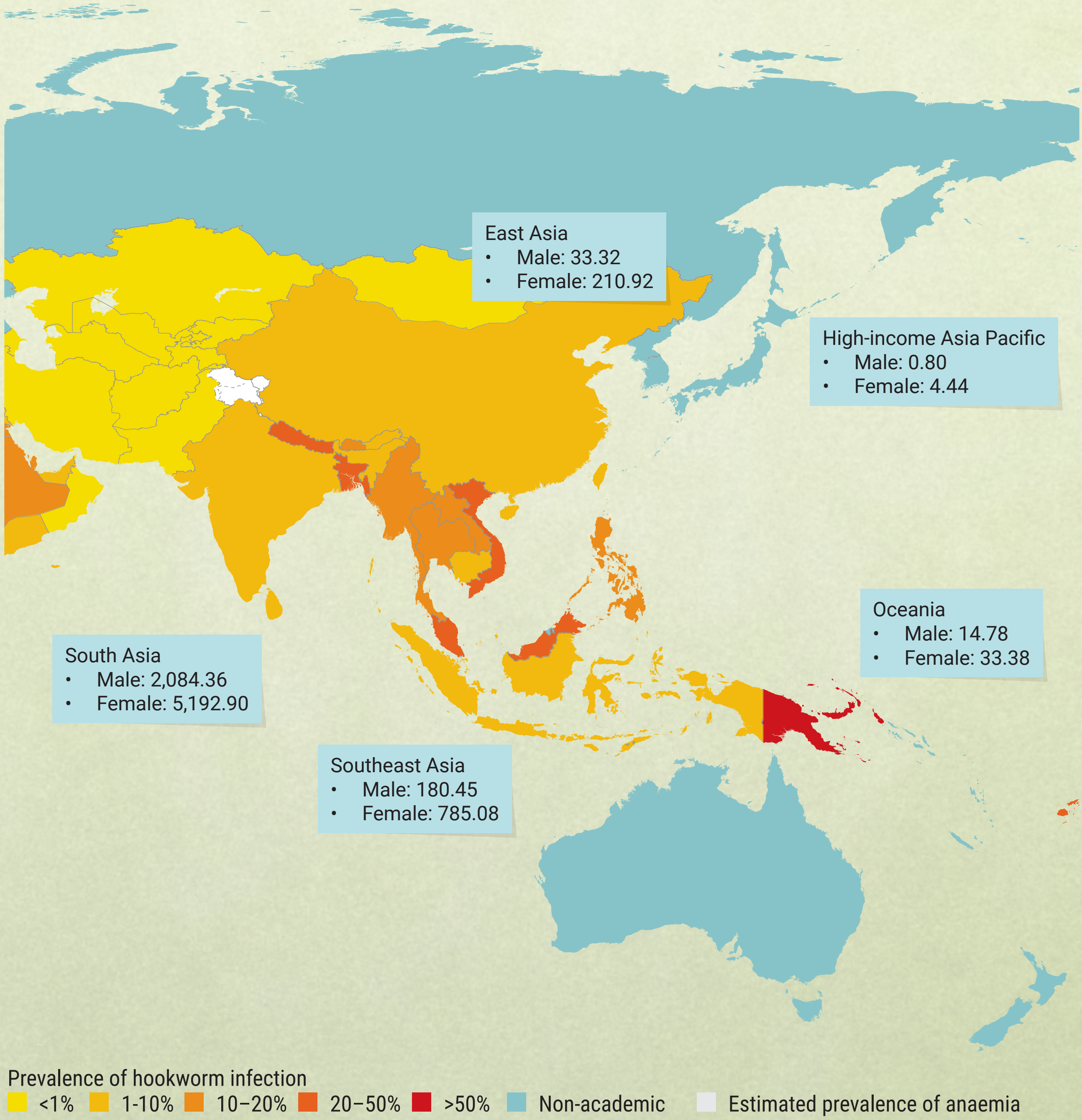
It may thus be possible to reduce the demand for meat and other animal products through improved treatment and prevention of parasitic infections. Judicious food supplementation with micronutrients, especially zinc, iron and vitamin B12 may have a role, among populations too poor to afford an adequate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

21 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.

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

23 Although footwear use has been promoted in WASH community engagement programmes to control hookworm infection, some studies suggest such use is not supported by robust evidence for a variety of reasons (Loukas *et al*. 2016). Improperly washed food, including 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 Loukas *et al.* (2016). Data for 2010, from Pullan *et al.* (2014).
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Butler 2012; Butler and Dixon 2011).[24] However, such supplementation is complex, difficult to implement among very poor populations and may cause unwanted effects, including inflammation (Ma *et al*. 2016). Furthermore, in populations with untreated parasites, supplementation with either meat or iron-enriched cereal may be ineffective in improving iron status.[25] Such interventions should not displace efforts to improve sanitation and should not be viewed as an inexpensive shortcut.

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 (Godfray *et al*. 2018). A study undertaken in the Lao People's Democratic Republic (PDR) found that the price of pig and chicken meat,[26] while far costlier than rice and beans, is considerably cheaper than a range of wild species (Figure 3) (Greatorex *et al*. 2016). 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, than by the ingestion of meat, from any source (Loukas *et al*. 2016).[27]

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. Nonetheless, 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 are associated with higher levels of chronic disease, including cardiovascular disease and cancer (Song *et al*. 2016; Godfray *et al*. 2018). Concerns about animal welfare[28] may also increase with higher levels of income (Frank 2008).

Finally, the intensive farming of chickens, pigs and cattle has been associated with many zoonoses, not only influenza (chickens and pigs) but also emerging infectious diseases, including Nipah and Ebola reston, (pigs) (Cantoni *et al*. 2016).[29] Swine (porcine) acute diarrhoea syndrome coronavirus (SADS-CoV) is nother known virus, albeit with no known transmission to humans (Zhou *et al*. 2019). Pangolins and some other species that may be associated with emerging zoonoses are believed to also have medicinal properties, though scientific evidence for such benefit is lacking (Still 2003).

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 from such sources 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[30]—and equally important, an unsubstantiated perception that eating such foods imparts vitality above that of dietary supplements, other sources of meat,[31] plant-based

24 Nutrients (such as iron) that are provided by meat-based diets are lost by populations infected with parasites (e.g. hookworm and schistosomiasis). Parasitic 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 "efficiency" of consumed animal products (Kovats and Butler 2012). In fact, a particularly valued health benefit of these products, especially red meat, is energy-facilitating iron, which occurs in a molecular form that is easier to absorb than plant-based iron. Organ meats and other offal, which were particularly consumed in ancient times, sometimes also confers highly valued, restorative health benefits (Butler and Dixon 2011).

25 One study by Ma *et al*. (2016) commented that although iron-fortified cereals improve iron status in some poor toddler populations, fortification may generate systemic inflammation, favouring enteric pathogen growth and slowing childhood growth. This study found no evidence that meat consumption improved iron status in this study population, but it did conclude that consuming meat-based complementary foods improved growth parameters.

26 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 hypothesized that culling may have increased human-wildlife contacts (Lytras *et al*. 2021).

27 Understanding the benefits of hookworm treatment led to the Rockefeller Sanitary Commission for the Eradication of Hookworm Disease, which was the first example of modern-day public health philanthropy (in this case, the Rockefeller Foundation) (Loukas *et al*. 2016; Rockefeller 2016).

28 There are increasing calls for conservation organizations and scientists to incorporate concerns for animal welfare into their campaigns (Sekar and Shiller 2020).

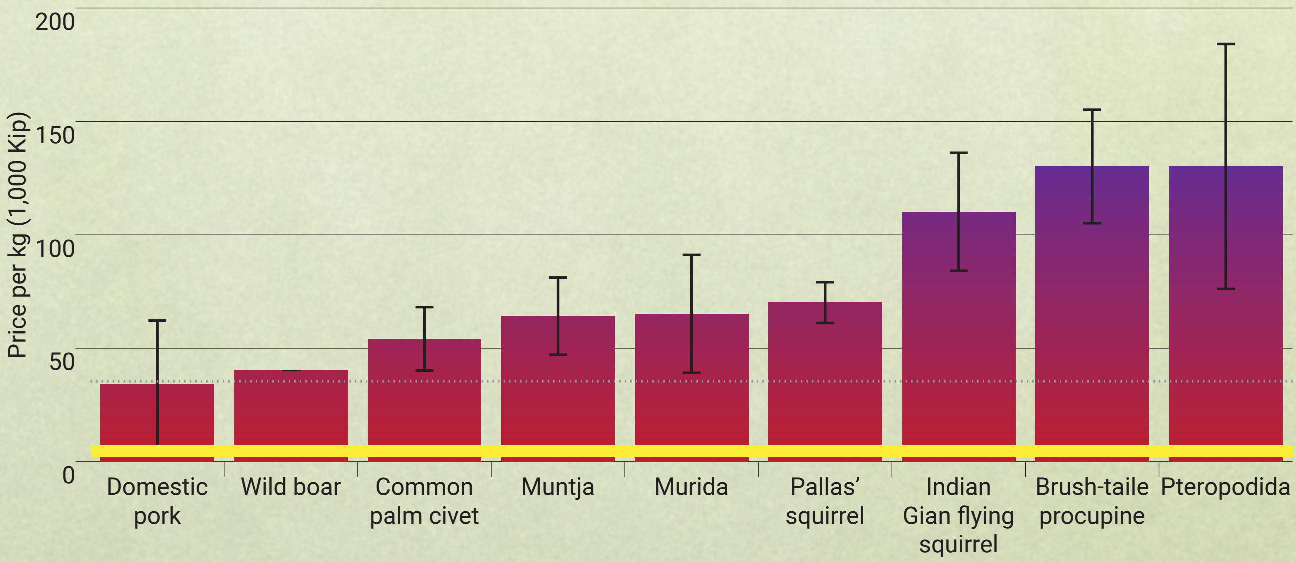
29 The Reston ebolavirus, known to exist in the Philippines, is currently considered to be benign for humans (Cantoni *et al*. 2016).

30 Although occasionally for cultural reasons, bushmeat is sought in urban areas as a luxury, status-symbol item even though diverse protein options exist (Dobson *et al*. 2020)

31 According to Field (2009), "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". In fact, some wildlife (e.g. kangaroos) are more nutritious, with lower exposure to pesticides and reduced saturated-fat levels, although some populations gain an important fraction of their fat from wildlife.

Figure 3 /

Average price of fresh dead wildlife versus domestic pork in Lao People's Democratic Republic, 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 Greatorex *et al*. (2016).

sources of micronutrients and the treatment and prevention of parasitic infections.

Driver 2: Intensification of livestock farming

One factor in the emergence of SARS was the intensification of livestock farming, including cultivating "novel"[32] species of wildlife such as palm civets and raccoon dogs.[33] This trend has been postulated as a factor in the emergence of COVID-19 insofar as it has increased opportunities for viral mixing. Farming of wild-caught civets and, potentially, other animals may introduce a coronavirus risk, but this risk is likely to be magnified (i) if there are a multitude of such animals, 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 the highly pathogenic avian influenza, swine flu and African swine fever. For instance, the outbreak of Nipah disease in Malaysia and Singapore in 1998 was related to intensive pig farming and its interaction with bats (Pulliam *et al*. 2012), as detailed in Box 9. 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 over exploitation and unsustainable, unregulated or illegal trading of wildlife

The increase in unsustainable, unregulated and illegal trading of wildlife and its over exploitation is generally hypothesized as important in the genesis of COVID-19 and other emerging zoonoses, some with pandemic potential (Table 3). This may be attributed to the fact that the range of animals now either kept in captivity or, otherwise, captured and traded, often illegally, is continuing to expand, including in South-East Asia (Bell, Roberton and Hunter 2004; Shepherd *et al*. 2020). Increased human contact with relatively novel species has expanded the suite of zoonoses with which humans and science have little familiarity, notwithstanding the fact that these are considered as high-status foods or claimed to have medicinal uses.

Despite attempts to criminalize some forms of wildlife trade, in some cases with severe penalties,[34] substantial illegal trade still occurs. Examples include pangolins between China and Myanmar (Nijman, Zhang and Shepherd 2016). 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 (Nijman, Zhang and Shepherd 2016; Shepherd *et al*. 2020). Importantly, despite this focus on illegally traded animal products, it must be noted that legally traded animals may also introduce the risk of zoonotic emergence.

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

Vast areas of Earth have been transformed by human activity, with steep declines in biodiversity (UNEP 2019). Worldwide, including in South-East Asia, most of this transformation has been driven, directly or indirectly, by the wish to produce more natural products, such as timber, as well as food products, including significant quantities of wild meat (Bell, Roberton and Hunter 2004) to satisfy

32 All farmed animals were once wildlife.
33 According to IPBES (2021), "wildlife farming has expanded substantially, particularly in China prior to COVID-19, where 'non-traditional animal' farming generated US$77 billion dollars and employed 14 million people in 2016."

34 In China, smuggling pangolin parts valued over RMB 200,000 (about US$290,000) carries a penalty of life imprisonment or death (Nijman, Zhang and Shepherd 2016). 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 equivalent to only US$10,000 (Yang *et al*. 2020).

human wants and needs and to feed an increasing human population.

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 have denied the long-term value to humans of keeping a sufficient "buffer"[35] of nature (Ripple *et al*. 2017). In turn, most humans have either benefited from this transgression (at least during the short term), ignored it or participated in it (e.g. whether wielding a chainsaw or participating as shareholders in companies that excessively 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, agricultural intensification and deforestation[36] (often facilitated by fires with consequent pervasive haze) (White and Razgour 2020). New roads and plantations, such as for palm oil, are often involved, increasing the opportunities for novel human-animal interactions.[37]

A study undertaken in Sabah (Malaysian Borneo) found that land-use changes can influence mosquito vector populations and thus malaria transmission, including human cases of the zoonotic malaria *Plasmodium knowlesi* (Byrne *et al*. 2021). One mechanism is that these changes help enable the over exploitation of wildlife, and they also make human contact more likely with bats and other wildlife, which may harbour unknown pathogens.

35 That is, reserve, or spare capacity.
36 An early outbreak of Ebola was reported in 1996 at a logging camp in Gabon (Tucker *et al*. 2002).
37 Palm oil plantations have been suggested as a factor for Chagas disease in South America (Rendón *et al*. 2015) and for Ebola in West Africa (Wallace *et al*. 2014). Palm oil plantations were speculated as a cause for the Nipah virus in Malaysia, but this hypothesis is now rarely supported (Field 2009). 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.

Another mechanism is that human-modified landscapes can be conceptualized as "attracting" species (beyond bats and rodents) that can host zoonotic diseases (McFarlane *et al*. 2012).

In other words, 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 (Gibb *et al*. 2020). Many populations of bats (a long-lived species) are affected by habitat loss, tourism[38] 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 (Plowright *et al*. 2008; Banerjee *et al*. 2020). 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 (Arunkumar *et al*. 2019) (see also Box 9).

Moreover, 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 (Xu 2013). Investigations later revealed a previously unknown henipavirus,[39] isolated from a rodent (Wu *et al*. 2014). 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" (Ge *et al*. 2016).

38 Including the bats of the Cat Ba Biosphere Reserve in Viet Nam, which has the highest species diversity for bats of any mangrove area in mainland Southeast Asia (Thong *et al*. 2021).
39 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.

Driver 5: Climate change as a driver of bat and rodent densities

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[40] (Jones and Rebelo 2014). Thus, climate change may alter not only bat flyways and behaviour but also bat population densities around the world, including those in South-East Asia (Beyer, Manica and Mora 2021). Whether via increased temperature extremes or altered food availability, climate change—may play a role in reducing bat immunity. For instance, bats in flight can tolerate body temperatures of over 41°C; however, like all species, their thermal limits are lower when humidity is high. Not only has heat stress resulted in an increasing number of bats deaths (Ratnayake *et al*. 2019), but also notably, it has also been speculated to be an underlying driver of viral spillover[41] (Butler 2020c).

Climate change may also be a factor in infection disease risk via what were once routine human activities. For instance, rapid climate change in the arctic and subarctic regions is being manifested as rapid permafrost. In turn, permafrost degradation may expose historic burial grounds in Russia, for example, enabling the revival of deadly infections from the past; these infections include anthrax, which generates spores that are very resistant to degradation. These spores can be spread in the wind and 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 (Stella *et al*. 2020). This is but one illustration of the threat to human health by climate change.

40 One study reported that Ebola outbreaks from 1994–1996 were associated with a change to wetter conditions (Tucker *et al*. 2002).

41 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 (Kafetzopoulou *et al*. 2019).

Driver 6: Increased global travel and transportation

Travel and transportation, especially by air, are conducive to accelerating the rate of spread of pandemics; this is particularly the case for "mass events", including festivals, sporting events and pilgrimages. The 2002–2004 SARS outbreak had spread to several countries before it was contained by social distancing and hygiene. In contrast, COVID-19 and its variants, also transmitted by aerosols, has spread much further to all continents of the world, despite intense containment efforts, partly owing to its highly developed "stealth" characteristics.

Driver 7: Laboratory and medical procedures contributing to outbreaks and pandemics

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] (Heymann, Aylward and Wolff 2004); anthrax (1979 [former Soviet Union]) (Meselson *et al*. 1994); *Yersinia pestis* (2009 [United States]); Ebola (2004 [Russia] and 2009 [Germany]); Marburg, *Neisseria* meningitis (Silver 2014); Venezuelan equine encephalitis (Brault *et al*. 2001); foot and mouth disease (2009 [United Kingdom]) (Enserink 2007); H5N1 influenza (2014 [United States]) (Branswell 2014); and H1N1 influenza (about 1976 [China or former Soviet Union]) (Silver 2014).

Even standard medical procedures have contributed to outbreaks. For instance, the reuse of medical needles 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 (Pépin 2013). 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 (Editorial 2001). The reuse of unsterile needles contributed to the early spread of HIV/AIDS in Sub-Saharan Africa (Pépin 2013) and to the spread of hepatitis C in Egypt (Strickland 2006).

Deliberately searching for wildlife viruses could paradoxically increase the possibility of accidentally generating an outbreak or even a pandemic, via accidental escape (as is the case of PREDICT[42] and the Global Virome Project [Carroll *et al*. 2018]). Gain of function experiments, intended to investigate disease-transmission characteristics, could inadvertently generate problems (Wain-Hobson 2013). Furthermore, trust is undermined when scientists overstate the benefits of disease prevention (Holmes, Rambaut and Andersen 2018). 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 (Holmes, Rambaut and Andersen 2018).

42 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 in the previous chapter, 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.[43] As a 2020 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report on biodiversity and pandemics noted, "the industrialization of the wildlife trade provides substantial opportunity for cross-species microbial transmission when diverse wildlife species and livestock are held in close confinement for significant periods of time, with often little surveillance, a poor regulatory framework and poor law enforcement" (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] 2020).

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 (Bell, Roberton and Hunter 2004). These species include pangolins (Nijman Nijman, Zhang and Shepherd 2016; Lam *et al*. 2020), 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.[44] 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.[45]

However, a search for evidence of coronavirus (and four other viral families) in 334 pangolins confiscated and rescued in Malaysia over a 10-year period was entirely negative (Lee *et al*. 2020). 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.[46]

As mentioned, viral mixing may have contributed to the SARS outbreak of 2002-2003, 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 (Guan *et al*.

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

44 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, 74 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 chevrotain were also sold. Up to 364 kg of various species of civet meat was served monthly in just five restaurants (Bell, Roberton and Hunter 2004).

45 Concerns also exist that viruses with human affinity may have been engineered in laboratories (Sirotkin and Sirotkin 2020).

46 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 (Lee *et al*. 2020).

2003), while SARS antibodies were also found in a third species, the Chinese ferret badger (Guan *et al*. 2003). In the article "What have we learned from SARS?", published soon after the epidemic, Weiss and McLean (2004) write, "the importation, holding together and rearing of so many species[47] of viverrids[48] and also one canid and one must have allowed its (i.e. SARS) amplification and transfer to humans to occur".[49]

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 during the winter of 2003-04, following a second outbreak (Normile 2004). 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 (Kan *et al*. 2005). 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.[50] However, in February 2020, the Standing Committee of the National People's Congress announced a ban on wildlife consumption for food and related trade (Dobson *et al*. 2020). There were also reports of ongoing discussions on phasing out this industry (Dobson *et al*. 2020).

Nevertheless, since the SARS outbreak and despite considerable expansion of the wildlife farming industry in China[51] (Dobson *et al*. 2020), 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[52] 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 had declined in recent years, especially in the United States (Cameron 2020).

Factors enabling a zoonosis to potentially unfold into a global pandemic

Over 100 viral zoonoses are rarely if ever transmitted from human to human (Woolhouse *et al*. 2016). But although about 40 viruses do circulate between and among humans, they usually cause self-limited outbreaks (epidemics).[53] The Nipah virus is one such example (Box 9).

Only a tiny fraction of zoonoses have genuinely global pandemic potential. These are the most concerning from a public health perspective. COVID-19 is one such zoonosis. Looking back, 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

47 A description of a market in Xinyuan (Guangzhou, Guangdong Province, 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" (Kan *et al*. 2005).

48 There are at least 36 species of viverrids, which include civets (Bell, Roberton and Hunter 2004).

49 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 (Guan *et al*. 2003).

50 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.

51 The wildlife farming industry has been reported to have been worth about US$20 billion in 2020, employing about 15 million workers (Dobson *et al*. 2020).

52 MERS (Middle East respiratory syndrome) did emerge during this time frame albeit from the Middle East. Its bridging species is the camel. Like COVID-19, it is transmissible by asymptomatic humans, though much less frequently. An outbreak of MERS occurred in South Korea in 2015 (Cho *et al*. 2016).

53 According to Wolfe, Dunavan and Diamond (2007), human-to-human transmission of Ebola and Marburg quickly fades out owing to the rapid onset and severity of symptoms, which, in turn, make identification and containment feasible.

Box 9

How did the 1998 Nipah virus outbreaks in Malaysia, Singapore and (later) parts of South Asia evolve, and what are the positive lessons learned?

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, the Philippines 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.

Primarily in Bangladesh and India, limited outbreaks of Nipah (over 20) 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 health-care settings (Centers for Disease Control [CDC] [United States] 2020). 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, and the Philippines, which involved horses. 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 via contact from bodily fluids more so than respiratory droplets. In fact, though the high case-fatality rate of 40–70 per cent (Centers for Disease Control [United States] 2020) 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 been developed although progress has been reported. Thus, it is recommended that "gain of function of concern" research studies, and other experiments to explore the potential of Nipah for wider transmission be strictly regulated—or even banned altogether.

Malaysia and Singapore. Until the September 1998 outbreak in the northern peninsula of Malaysia (Pulliam *et al.* 2012) and the ensuing March 1999 outbreak in Singapore, Nipah was a then-unknown henipavirus. Initially mis-diagnosed as Japanese encephalitis, the Malaysian Government conducted a vigorous vector control programme for what they believed was a mosquito-borne disease. Chemical-based foggers were used on over 18,500 pig farms and 400,000 houses in their vicinity. Also, the Malaysian Ministry of Health purchased over 640,000 doses of Japanese encephalitis vaccines for mass vaccination.

These control measures did not address this novel aetiological agent, and the outbreak of Nipah had spread by February 1999 to both pigs and pig

(continued)

Box 9 (continued)

farmers in the southern peninsula, caused by the southward transport of infected pigs. By March 1999, 11 cases of respiratory illness and encephalitis (resulting in only one death) were reported among abattoir workers in Singapore who had had contact with pigs imported from Malaysia (Paton *et al*. 1999).

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 (Chua, Chua and Wang 2002; Chua 2010), with some survivors enduring chronic neurological illness.

Several ecological factors were speculated as having stressed the bats that resulted in the first transmission of Nipah virus to its intermediate hosts—that is, pigs housed in commercial farm enclosures adjacent to cultivated fruit orchards. One such speculated stressor was forced relocation of bats from forest cleared in response to the construction of the new airport for Kuala Lumpur (Weiss 2001). Another hypothesized factor may have been the displacement of bats from the especially intense 1998 forest fires, many of them deliberately lit to enable farming, including those on palm oil plantations, and exacerbated by the strong El Niño that year (Chua, Chua and Wang 2002).

It is thought that bats feeding on fruit (mangoes, durian and rambutan) 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 contaminated with bat urine (Chua, Chua and Wang 2002). 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 medical needles (Chua 2003).

After the Malaysian Government identified Nipah as the true aetiological agent of the outbreak, it switched focus new virus control measures. 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 (Chua, Chua and Wang 2002). 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 cooperation and collaboration with other international agencies (Chua, Chua and Wang 2002). 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 prevention and control. National radio and television were also actively engaged in this regard (Chua, Chua and Wang 2002).

However, despite public anxiety (Fraser *et al*. 2004) 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.

(continued)

Box 9 (continued)

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 (Arankalle *et al*. 2011; Khan *et al*. 2012). Speculation exists that children playing under trees in which bats roost may also become infected, that is, via direct exposure to bat secretions and waste. Antibody levels to Nipah in bats are likely to vary by season and may be reduced when bats are pregnant. 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.

Systematic hospital-based investigation of Nipah virus cases and their contacts in Bangladesh has been implemented since 2006 (Nikolay *et al*. 2019). While 248 cases were reported in Bangladesh in 79 separate outbreaks from 2001 to 2014 (Nikolay *et al*. 2019), only 2 outbreaks were reported, 6 years apart, in 2001 and 2007, in West Bengal.

The epidemiology of Nipah virus transmission in this part of South Asia is distinctly different to that of Malaysia and Singapore in that 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 (though other observed modes have included person-to-person transmission as well as contact with sick animals).

A randomized control experiment 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") (Khan *et al*. 2012) 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.

State of Kerala (India). There have been three recognized outbreaks of Nipah in the southern Indian State of Kerala (WHO 2021). All have occurred in coastal cities. The first occurred during the May 2018 bat breeding season. Initially unrecognized, the outbreak resulted in 17 deaths from 23 cases, 18 of which were laboratory-confirmed. The index case was thought to be an animal lover, possibly a bat rescuer. In May 2019, another case in Kerala was reported. Notably, no proven secondary cases were detected, despite intense surveillance (Warrier and Wilson 2020). In August 2021, a new case was reported, also in coastal Kerala. Almost 200 primary and secondary contacts were quarantined, and although a few cases developed fever, there were no fatalities.

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 coordination 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.

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

Note: Also see the glossary Disease X and vector-borne.
Abbreviations: *, WHO priority disease (see Simpson *et al*. 2020); #, vector-borne.

"stealth[54] 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 (Fraser *et al*. 2004; Butler 2012; Weiss 2015; Woolhouse *et al*. 2016; Butler 2020b). The term "stealth phase", though introduced in 2012 (Butler 2012), builds on past literature that recognizes the importance of asymptomatic transmission for disease-transmission dynamics.[55]

In some cases, COVID-19 infections have spread from people who never develop symptoms, possibly including young children (Heald-Sargent *et al*. 2020). COVID-19 also appears remarkably well-adapted for human-to-human transmission (Sirotkin and Sirotkin 2020): 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 (Sirotkin and Sirotkin 2020).

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, effective vaccines. 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,[56] though the 1918 influenza pandemic was even worse because it disproportionately killed young adults in large numbers.[57]

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 (Judson, Prescott and Munster 2015) 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 co-morbidities (pre-existing disease), including hypertension and lung disease.

But it needs to be 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 (Zhang, Xue and Jin 2020; Gupta *et al*. 2021; Zhou *et al*. 2021). In fact, a World Bank study, undertaken in the Netherlands, found that atmospheric particulate matter (less than 2.5 µg) is a significant predictor of hospital admission for COVID-19. Cases increased by nearly 100 per cent when pollution concentrations rose by 20 per cent (Andrée 2020). This study supported the view that severe air pollution damages lungs, thus creating vulnerability to respiratory infections, asthma, and chronic obstructive pulmonary disease (Zhang, Xue and Jin 2020).

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 (Gupta *et al*. 2021). The lockdowns in India,

54 The word "stealth" is not intended to imply the pathogen has properties of malevolence, consciousness or intent (Butler 2012).

55 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 (Fraser *et al*. 2004).

56 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 an effective treatment, as it is well-known that it is transmissible by aerosols.

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

in an attempt to reduce the burden of COVID-19, led to a temporary reduction in air pollution and likely conferred health benefits that would partially compensate for the associated socioeconomic harm (Bera *et al*. 2021).

The differences in risks of infection, morbidity and mortality related to COVID-19 reflect pre-existing economic and social disparities. These include inequalities in working, living, health and social conditions, all of which have a gender dimension.

In fact, gender-related morbidity and mortality data from COVID-19 are complex.[58] Generally, pregnant women and their unborn children are likely to be at increased risk, from the pandemic, including where antenatal services are disrupted (Gausman and Langer 2020). Noteworthy is that in India and Viet Nam, while women have been reported as dying at a rate higher than men, the reverse effect has been reported in many other countries (Dehingia and Raj 2021). A study from Delhi, India, found that, among wage earners, women experienced greater job losses than men owing to lockdowns in response to the pandemic. The predicted probability of employment for women declined by 72 per cent compared to 40 per cent for men (Desai, Deshmukh and Pramanik 2021).

58 For morbidity and mortality data, refer to the COVID-19 Sex-Disaggregated Data Tracker website.

5 TOWARDS **SOLUTIONS**

Climate change and other damage to planetary life-support (Sargent 1972)[59] mechanisms threaten the stability of civilisation (Keen 2020), 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 below 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 would be regulated to prevent declines in natural capital[60] and to better reduce the risks of future pandemics.

59 The phrase "planetary life-support" dates at least to 1972, when human ecologist Sargent 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" (Sargent 1972). Despite increasing use, the term should not be taken literally; life is unlikely to vanish owing to human effects, even via nuclear winter (Butler 2020a).

60 For example, palm oil, bitcoin mining, fossil-fuelled aviation and automobiles, the global meat industry and the oil, gas and coal industries.

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"[61] is attributed to the leading nineteenth century philosopher and economist John Stuart Mill. Some indigenous peoples[62] also recognized the importance of preserving a minimum suite of ecosystem services at the regional level, sufficient to ensure human well-being that could endure for many generations (Sahlins 1972). 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 (Kuznets 1973). 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 decades, the dominant measure of progress has been misleading (Daly 1996). Therefore, there exists

61 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" (Daly 1974).

62 For example, in arid Australia and the San in Botswana. People living in neither of these areas practiced agriculture as we now know it.

a need for more comprehensive macroeconomic indicators such as the Inclusive Wealth Index, as discussed in the UNEP report *Making Peace with Nature*. Natural capital accounting (guided by the System of Environmental-Economic Accounting Experimental Ecosystem Accounting [SEEA-EEA) framework) is another tool and approach governments can use to measure and monitor the impacts of major economic sectors on the state of natural capital.

Recognizing this challenge and opportunity, 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. The TEEB is one of several initiatives that support governments and other stakeholders in measuring and recognizing the values of natural capital and the dependence of economic sectors on natural capital and in internalizing those values into decision- and policymaking processes.

People and planet are inextricably linked, and environmental discussions entail consideration of social and economic dimensions—dimensions that are also gendered. Dominant economics has been recognized, by some for decades, for its gender deficit (Waring 1998).

To date, however, such reform attempts remain marginal. Policymakers and the populations they serve need to understand that many forms of planetary limit exist. The dominant class cannot perpetually steal resources from vulnerable people, including women and girls, 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, was the foundation of the One Medicine movement, the predecessor of One Health. Rudolf Virchow, one of the founders of this concept (as well as of social medicine) is credited with coining the term "zoonosis" in 1855 (Brown 2003). 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 (Essack 2018; Zinsstag *et al*. 2020).

One Health approaches have been called on by many to reduce pandemic risks. Supporters of One Health, for instance, 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" (Lebov *et al*. 2017).

However, as with changing the measurement of economic systems, such aspirations are far easier to propose than to achieve, partly owing to institutional structures and practices. One Health requires a whole of society approach—on that includes the public and private sectors, the research community and civil society, as well as governments. Ministries of environment, health and agriculture around the world are all relevant to One Health and may have more influence if they cooperate synergistically. However, substantial cultural change is a crucial enabling factor to One Health, as it is very often resisted if the change is viewed to originate from the outside. 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 (whether in schools or via the media) that highlight the elevated pandemic risk owing to proliferating wildlife trade (whether legal or illegal) may gradually alter behaviour, especially that of younger people, and build support for risk reduction.

Lastly, policies and public health efforts have repeatedly failed to adequately address the gender-differentiated effects of disease outbreaks. Understanding these gender-differentiated impacts of disease is fundamental to creating effective, equitable policies and interventions. Key contributors to this knowledge come from a variety of disciplines. The COVID-19 pandemic demonstrates that the need to work together on this concern has never been greater.

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

While many indigenous peoples today recognize the deep dependence of humans on nature[63] (Wilder *et al*. 2016; Eisenstadt and West 2017; Berkes, Colding and Folke 2000) a dominant societal view is that nature can be managed indefinitely (Butler and Higgs 2018), even beyond planetary boundaries (Steffen *et al*. 2015). In this view, for as much as humans are an animal species, they do not recognize that they are part of nature. 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, experimental evidence and any reasonable burden of proof[64] (Sekar and Shiller 2020).

Humans are likely to continue to harm other species. However, the scale and cruelty of this behaviour may be altered if more humans understand that our "war on nature" ultimately damages human well-being, including that for future generations (Atwoli *et al*. 2021). Greater respect for nature would manifest in behaviour to (i) reduce deforestation, other forms of ecosystem degradation and the abuse of non-human animals and (ii) adopt "full-cost" accounting, to include that of social and environmental harm (Managi 2020). 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 governmental and private sector decision-making and planning processes.

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

Though the consumption of exotic wildlife meat is considered prestigious and healthy in some cultures, it is unnecessary for optimal human nutrition. Moreover, 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. Because excessive protein[65] may be oncogenic (cancer-promoting), diets low in meat can be associated with lower mortality, provided the plant-based foods are of sufficient quantity, quality and variety[66] (Willett *et al*. 2019). Diets low in red meat (especially from digastric sources, such as cattle, sheep and goats) are associated with not

63 Not all, however. Many examples exist of "ecological overshoot" as a result of unsustainable indigenous practices (Krech III 1999; Wehi *et al*. 2018).

64 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 the ability to recognize hundreds of human words (Sekar and Shiller 2020).

65 High-quality protein is important for the growth of infants and young children and possibly for muscle mass retention of older adults. 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 (Willett *et al*. 2019).

66 A 2015 review by the United States Dietary Guidelines Advisory Committee concluded that for people older than 2 years, a balanced vegetarian diet can be healthful. They also found, in the largest prospective study of its kind, that people following vegan, vegetarian, pescatarian or semi-vegetarian diets had 12 per cent lower overall mortality risk than did omnivores; the lowest risk was among pescatarian diets (Willett *et al*. 2019).

only reduced rates of cancer and heart disease but also significantly lower carbon emissions (Potter 2017; Willett *et al*. 2019). 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 (Gupta *et al*. 2020). 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, in the Asia Pacific, some people may have limited or no access to such animal products, including eggs. For them, meat consumption via the hunting or trapping of locally available wildlife may be their best route to adequate nutrition. Though this practice may drive zoonosis risk it is unlikely to generate a pandemic.

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. Understanding the multiple threats and complexities that different community groups face is essential towards gender-responsive, risk-informed policy and intervention formulation. Prevention and preparedness initiatives should consider the specific challenges faced by women and other vulnerable groups adversely impacting their adaptive capacities.

Recommendation 5: Reduce practices that drive unsustainable and potentially unhealthy wildlife farming

The farming of "non-traditional" species (here called "wildlife farming") helps to meet a demand from consumers to eat an additional range of species, and creates employment. However, if the supply of animals in such farms is supplemented by creatures from the wild then there is a theoretical risk of new pathogens being introduced, which could, for example, via "viral mixing", lead to the evolution of new form of viruses, generating new risks to human health. Restricting or eliminating the introduction of wild animals to such farms will reduce this risk.

Of note, such farms are unlikely to fully quench the demand to eat species directly from the wild, due to beliefs such as "ye wei", i.e. that the "wild taste" is also healthier.

Several factors, other than the supply of meat for human consumption, also influence wildlife farming. These include to meet the demand of the global pet trade (Pavlin, Schloegel and Daszak 2009); fur farming, including of mink (Xia, Lam and Sonne 2020), red foxes and raccoon dogs (Lytras *et al*. 2021); and the use of traditional medicines, derived from species such as bats (Wassenaar and Zou 2020).

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

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.[67] For instance, corruption, clientelism and

67 For example, many governments and heads of state have institutionalized corruption. Courts and legal processes, in many settings, lack transparency and sufficient accountability.

"money politics" influence the loss and conversion of natural resources (Cisneros, Kis-Katos and Nuryartono 2021). Examples include the conversion of habitats (e.g. for plantations or prawn farming), the burning of fossil fuel and the illegal trade of wildlife.

Penalties for violating environmental laws are comparatively light in many countries, including those for smuggling wildlife (Yang *et al*. 2020). If governments seriously wish to reduce the risk of pandemic emergence, then laws for illegal wildlife trade must be enforced and associated penalties increased.

In this context, structures have been proposed to include those addressing the criminal justice system, the political environment and the economic environment (Wyatt *et al*. 2018). These larger social structures thus also need to be reformed. For one idea, critics have suggested that funding for National Biodiversity Strategies and Action Plans under the Convention on Biological Diversity be substantially raised (Dobson *et al*. 2020).

Finally, 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 means of monitoring and surveillance systems associated with zoonotic disease are needed at the local, national and regional levels. Elements include enhancing human-based surveillance, the use of big data and artificial intelligence, and improved sanitation and food system safety. However, transparency is vital for effective surveillance.

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

Global Biodiversity Outlook 5 (Secretariat of the Convention on Biological Diversity 2020) acknowledges a relationship between human population growth and declining biodiversity. In fact, investing in human capital, including the education of women and girls, is likely to postpone marriage, lower fertility and increase child spacing (Lutz *et al*. 2019). This investment will benefit biodiversity (Crist, Mora and Engelman 2017) and, in some settings, accelerate human development.[68] Many determinants of lower fertility will be promoted if the Sustainable Development Goals can be realized, especially those relating to gender, health and education (Abel *et al*. 2016). However, such strategies also require greater trust between stakeholder groups with rival views (Leuprecht 2010).

Although sustainable wildlife management is central to eradicating zoonoses, gender issues are often not considered when addressing approaches to sustainable wildlife management and conservation. Yet key factors influencing sustainable wildlife management all have significant gender dimensions, such as unsustainable and illegal trade, tenure rights, poverty and food and livelihood security. When these issues are not addressed, they undermine the effectiveness of management measures and may exacerbate gender inequalities. In sum, gender equality and a rights-based approach remain key ingredients for sustainability as well as for accelerating progress towards the achievement of the SDGs.

68 Claims that low population growth in high-income settings is harmful (Vollset *et al*. 2020) need to be challenged.

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.[69] Although such studies are generally undertaken in laboratories with high security (Biosafety Level-4), 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 potential consequences include the extensive or even global spread of a potential pandemic pathogen (Evans, Lipsitch and Levinson 2015; Lipsitch 2018).

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

Increased interdisciplinary approaches are required, not only with One Health perspectives but also by the strengthened integration of environmental and related considerations within the United Nations system.

One example is the Tripartite Collaboration, involving WHO, FAO and OIE.[70] In 2020, a formal collaboration between UNEP and this Tripartite was announced, with the heads of WHO, OIE, FAO and UNEP agreeing to create a One Health High-Level Expert Council. Moreover, in December 2021, this group announced an agreed-upon definition of One Health.[71]

Scientific enquiry into the complex gender-differentiated, 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 "Potential pandemic pathogens" (also referred to as "PPPs") are potentially highly contagious and deadly but not currently present in the human population (Klotz and Sylvester 2014). A 2012 report found 42 facilities engaged in researching the live pathogens (Klotz and Sylvester 2012).

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

71 For a Joint Tripartite (FAO, OIE, WHO) and UNEP Statement, see "Tripartite and UNEP support OHHLEP's definition of 'One Health'", issued on 1 December 2021.

6 CONCLUSION

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. 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 outbreaks with previously unknown organisms. Poverty is also a factor because it provides incentives for poor persons to break laws and to engage in practices that erode natural capital—for instance, 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, appropriated or purchased from other users, into goods, services, money and power for some must be reformed; this must be achieved not only for the benefit of the poor but even to improve the security of the wealthy.

Irrespective of the origin of this current pandemic, its emergence should be recognized as signifying a profound warning to civilization, which faces other interacting crises, including rising hunger and undernutrition (especially affecting women and children), a record number of displaced persons, biodiversity loss, widespread pollution and climate change (Butler 2020d; Atwoli *et al*. 2021).

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 cooperation, a new economic system, greater respect for nature and reduced corruption. To this end, greater transparency is required, particularly concerning the ethics of gain of function research. Also required is a globally equitable distribution of effective vaccinations, with persisting immunity.

GLOSSARY

Aerosol transmission Tang *et al.* (2021) argue that communicable disease terminology introduced in the past century has led to confusion, by creating a poorly defined division between the concepts of "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 regardless of the range, the particles are all aerosols because they can be inhaled directly from the air. Moreover, traditionalists maintain that the tiniest suspended particles can remain airborne for hours, constituting an important route of transmission; they point 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 (whether 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. Because increased production is critical for expanding food supply, intensification makes efficient use of inputs and 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 via 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. Examples include insects, arachnids (such as ticks and spiders), myriapods and crustaceans. Biologydictionary.net

Asymptomatic carriers Also known as "passive" or "healthy" disease carriers. While infected with a pathogen, these individuals neither report nor appear to have any symptoms or signs of illness. WHO

Avian influenza A severe, often fatal, type of influenza that although adapted to birds, especially poultry, can also also stably adapt and sustain person-to-person transmission. Known informally as "avian flu" or "bird flu", the type with the greatest risk is the highly pathogenic avian influenza (commonly referred to as "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, and for the most part, it is associated with this type of influenza. (See also "highly pathogenic avian influenza".) WHO

Behavioural immunity 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. It includes diversity within species, between species and of ecosystems. CBD

Bovine spongiform encephalopathy Commonly known as "mad cow disease" or "BSE", this progressive, fatal disease of the nervous system of cattle is 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

CITES The Convention on International Trade in Endangered Species of Wild Fauna and Flora, concluded in 1973, aims to promote international cooperation to protect more than 36,000 listed species against over exploitation through international trade. The scope of CITES is limited to species affected by international trade and does not consider zoonoses. CITES

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

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 that can cause serious human illness and death. 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

Crimean-Congo haemorrhagic fever Also referred to as "CCHF", this viral haemorrhagic fever is usually transmitted by ticks. The fever 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. https://www.medicinenet.com/cysticercosis/article.htm WHO

Cysticercosis A parasitic tissue infection caused by ingesting eggs of the pork tapeworm, ***Taenia solium,*** found in the faeces of a person with intestinal pork tapeworm (in contrast to taeniasis, which occurs after ingesting raw or undercooked pork). Infecting brain, muscle or other tissue, the eggs eventually develop into cysts, which are a major cause of adult-onset seizures in most low-income countries. These are spread through contaminated food and water or surfaces contaminated with faeces, often by pigs who are raised in those areas or infected food preparation workers. Both 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. CDC (Aung and Spelman 2016)

Disease X This is a putative, currently unknown disease (lacking adequate treatment or vaccine) caused by "pathogen X, an infectious agent that is not currently known to cause human disease." Such a disease could be an agent of a future outbreak with epidemic or pandemic potential. WHO and (Simpson *et al.* 2020; Van Kerkhove, Ryan and Ghebreyesus 2021)

DNA virus A virus containing deoxyribonucleic acid 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 A rare, deadly disease in human and non-human primates, also referred to as "EVD". Though the viruses that cause Ebola are found mainly in Sub-Saharan Africa, Ebola Reston is found in the Philippines. Humans can contract Ebola through direct contact with an infected animal (bat or non-human primate) or, otherwise, a sick or dead person infected with the 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 microorganism, vegetable and animal 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 humans. IPBES

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

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. 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 Processes by which continuous habitats are divided into smaller patches, separated from each other. These processes may occur naturally (e.g. flooding, forest and grassland fires) or via human activities (forestry, agriculture and 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. Although some habitats are naturally discontinuous 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 A highly contagious disease (also referred to as "HPAI") caused by viruses that occur mainly in birds and that can be deadly, especially in domestic poultry. Since 2003, the 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. CDC

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

Host An organism, whether plant or animal, infected with or fed upon by a parasitic or pathogenic organism (e.g. a virus, nematode, fungus). In such case, although an animal or plant nourishes and supports a parasite; the host does not benefit from 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 A type of retrovirus that infects a type of white blood cell called a T-lymphocyte and 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 referred to as "primate T-cell leukaemia viruses". The close relationship between HTLV Type 1 and STLV Type 1 suggests a simian origin for HTLV Type 1, owing to multiple interspecies transmissions between primates and humans and between different primate species. Courgnaud *et al*. (2004)

Japanese encephalitis virus A flavivirus related to dengue, yellow fever and West Nile viruses that is spread by mosquitoes. Found principally in Asia and the Western Pacific, it 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 that 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 poverty or poor health (poor housing, undernutrition or a weak immune system) and environmental changes (urbanization, deforestation, building of dams or irrigation schemes) especially those resulting in population displacement. An estimated 700,000 to 1 million new cases occur annually. WHO

Leptospirosis A disease caused by bacteria of the genus ***Leptospira*** and carried by wild and domestic animal species. These bacteria are spread through the urine of infected animals, which can survive for weeks to months in soil or water. In humans, it can cause a wide range of symptoms such as fever, headache, diarrhoea and 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. 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), first identified in Saudi Arabia in 2012. Typical symptoms include fever, cough and shortness of breath. Although 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, about 35 per cent of reported MERS cases have been fatal. The largest outbreaks have occurred in Saudi Arabia, the Republic of Korea and the United

Arab Emirates. 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, or what is commonly referred to as "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 diseases are found in communities in low-resource settings across the world, where they impose a dual burden on people's health and on the livestock they depend upon for their livelihoods. Their management requires collaborative, cross-sectoral efforts of human and animal health systems; it also requires a multidisciplinary approach that considers the complexities of the ecosystems where humans and animals coexist. Where feasible, preventing and mitigating the occurrence of these diseases 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 FAO-OIE-WHO Tripartite Alliance and financially supported by 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 An integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent. 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) (Porta *et al.* 2014)

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 or damage in a host—an infectious agent is either pathogenic or not. ScienceDirect

Peri-domestic Pertaining to species 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 that are modifiable by human actions and 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 Model. 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 zoonotic, viral disease that is vaccine-preventable,. Once clinical symptoms appear, rabies is virtually 100 per cent fatal. It can spread to humans and animals 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 be derived from both domestic and wild animals. The virus can cause disease in the brain, ultimately resulting in death.

Rabies is one of the “neglected tropical diseases” that predominantly affects poor and vulnerable populations who live in remote rural locations. In fact, although rabies is present on all continents, except Antarctica, over 95 per cent of human deaths occur in the Asian and African regions. This may be owing to the fact that despite the existence of effective human vaccines and immunoglobulins 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, although it may or may not be the source from which an agent is transferred to a host. 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 Viruses that contain ribonucleic as its genetic material and may be either single- or double-stranded. Examples include reoviruses, picornaviruses, togaviruses, orthomyxoviruses and rhabdoviruses. Most RNA viruses replicate in the cytoplasm of the host cells. Some human diseases they cause are SARS, influenza and hepatitis C. Biology Online

Severe acute respiratory syndrome (SARS) A viral respiratory illness caused by SARS-CoV, the SARS-associated coronavirus. 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 2004, in association with laboratory accidents. CDC

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) A novel coronavirus causing the current coronavirus pandemic. On 11 February 2020, WHO named the new virus SARS-CoV-2 because the virus is genetically related to SARS-CoV, the coronavirus responsible for the 2003 SARS outbreak. WHO announced “COVID-19” as the name of this new disease on the same day, following guidelines previously developed with OIE and FAO. 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 an inactivated polio virus) and Sabin (administered orally, using an attenuated polio virus). (Butel 2000)

Social distancing A form of behavioural immunity, also referred to as "physical distancing", requiring keeping six feet (two metres) of space between people outside of their home, not gathering in groups, staying out of crowded places and avoiding mass gatherings. Adapted from 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)

Sustainable agricultural intensification A concept that challenges current global agricultural practices (regarding crops, livestock, forests, fisheries) to achieve a major increase (probably short of a doubling) in world food production while sustaining the environment. To feed a growing global population, food production efficiency needs to improve, 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, particularly Goal 2, so the efficiency with which resources are used will have to be enhanced to ensure ecosystems services are maintained. Sustainability also requires ensuring social equity in the productive process and environmental benefits from sustainable agricultural intensification; otherwise, the poorer segments of the farming population and women farmers risk being left behind or displaced by the promotion of intensification. NRI

Swine (porcine) epidemic diarrhoea A non-zoonotic viral disease of pigs caused by a coronavirus and characterized by watery diarrhoea and weight loss. The disease 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. First identified and reported in 1971, this contagious disease is transmissible mainly by the faecal-oral route. Prevention and management control are focused on strict biosecurity and early detection, but there is no specific treatment for the disease. OIE

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

Tripartite (FAO-OIE-WHO) Alliance on One Health A collaboration between FAO, OIE and 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 this formal alliance of these 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

Vector An organism or vehicle that transmits the causative agent or disease-causing organism from the reservoir to the host. Many living vectors are blood-sucking insects and ticks (or possibly animals or inanimate objects), which ingest disease-producing microorganisms during a blood meal from an infected host (human or animal). After the pathogen has replicated, vectors later transmit the pathogens into a new host. Often, once a vector becomes infectious, it can transmit the pathogen for the rest of its life during each subsequent bite or blood meal. Biology Online

Vector-borne diseases Human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors. These 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. Derived from the Latin term meaning "slimy liquid" or "poison". Encyclopaedia Britannica

Wild meat Wildlife is an important source of food security for many people, especially for indigenous people and those in low-income settings. 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 fat and pesticide profile 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 owing to over-hunting or other causes, whether direct (e.g. habitat degradation) or indirect (e.g. weak governance or climate change) could significantly affect food security and nutritional health for many. Furthermore, an increasing number of vertebrate species are being hunted to dangerously low levels owing to commercial demand for meat and medicines, with many now in danger of extinction. Though the term "wild meat" is used in this report, it is more commonly called "bushmeat". FAO

Vermin Wild animals, such as rodents, that are believed to carry disease or be harmful to crops, game or farm animals. 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 are asymptomatic, and others suffer only mild symptoms (general malaise, headache, fever, rash, conjunctivitis or muscle and joint pain) for 2–7 days. During pregnancy, however, infection can cause infants to be born with microcephaly and other congenital malformations, known as "congenital Zika syndrome", and it is associated with other complications of pregnancy, including preterm birth and miscarriage. Outbreaks of Zika virus disease have been reported in Africa, the 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 deaths occur from rabies and other zoonotic diseases such as avian influenza. These diseases affect not only human health but also animal health and welfare, resulting in lowered productivity (e.g. 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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