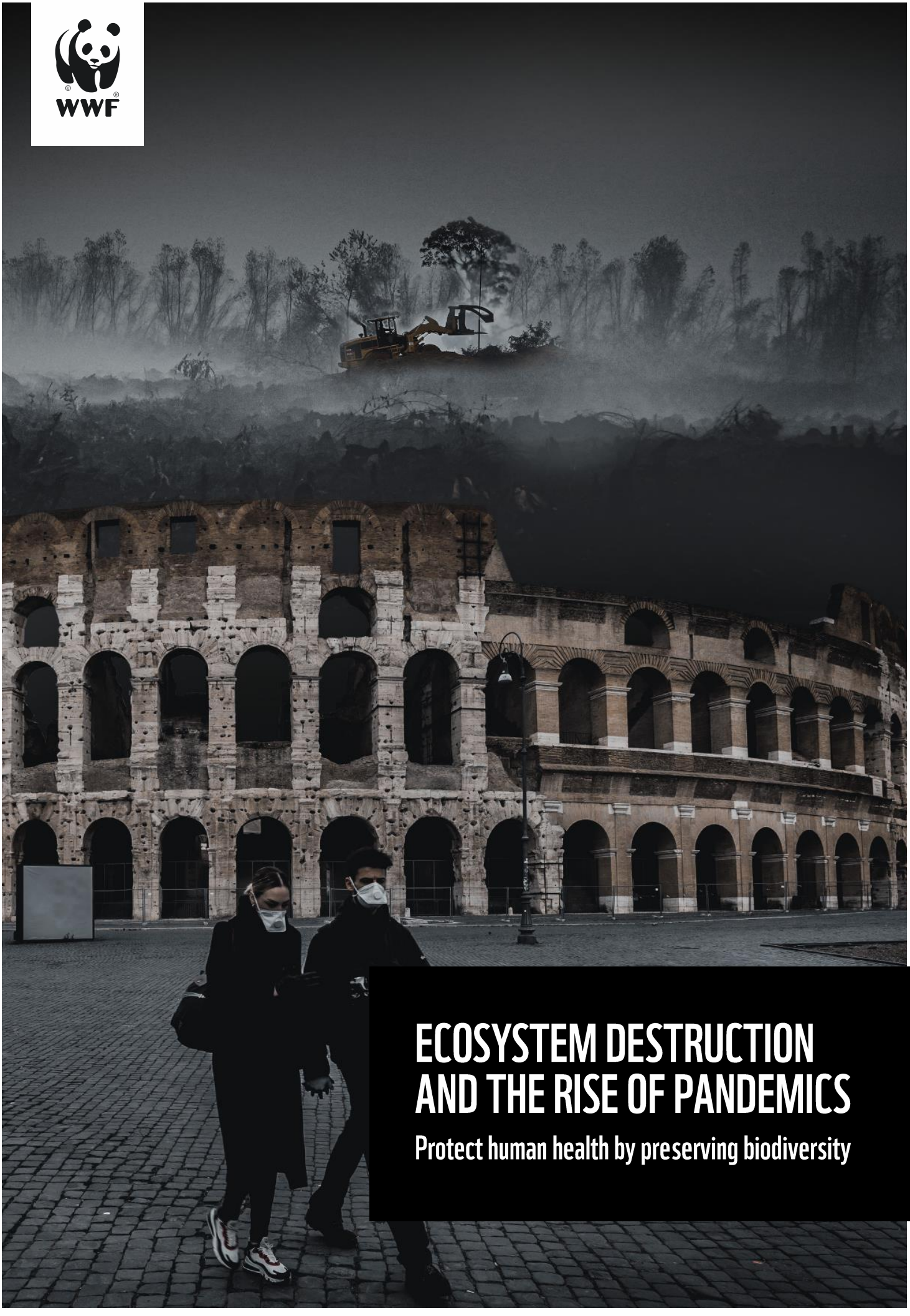

ECOSYSTEM DESTRUCTION AND THE RISE OF PANDEMICS

Protect human health by preserving biodiversity

"When the trees fall, and the native animals are slaughtered, the native germs fly like dust from a demolished warehouse".

David Quammen (2012)

ECOSYSTEM DESTRUCTION AND THE RISE OF PANDEMICS

Protect human health by preserving biodiversity

By Isabella Pratesi

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SUMMARY

INTRODUCTION

Many of the so-called emerging diseases - such as Ebola, AIDS, SARS, avian influenza, swine flu and today the new coronavirus (SARS-CoV-2, name of the virus responsible for COVID-2019) are not random catastrophic events, but the consequence of our impact on natural ecosystems.

Human beings with their activities have significantly altered three quarters of the land and two thirds of the oceans, changing the planet to such an extent as to determine the birth of a new era called the “Anthropocene”.

Many pandemics of the last decades have originated in the markets of Asian or African metropolises where the illegal or uncontrolled trade of live wild animals, such as monkeys, bats, snakes, pangolins, and many other reptiles, mammals and birds. The use of 'through' makes it sound as though we know all those species have caused pandemics. These activities create dangerous opportunities for contact between humans and the diseases of these organisms, creating the conditions for the development of old and new zoonoses, infectious diseases that can be transmitted from animals to humans.

In this report we will try to illustrate the links, still mostly unknown, between our actions on ecosystems and biodiversity and the consequences they have on the spread of certain diseases and therefore on public health, and on the socio-economic conditions of our societies.

From this perspective, the SARS-CoV-2 coronavirus pandemic seriously affecting the world today offers the opportunity for an in-depth reflection on the increasingly globalized relationship between human beings and nature.

KEY MESSAGES

- Viruses, bacteria, archaea and other microorganisms such as protozoa and fungi play an essential role in the biogeochemical cycles of the biosphere. They constitute the precondition for the persistence of life on Earth since 3.8 billion years. In the vast majority of cases they are absolutely harmless, in fact they are often essential for ecosystems and human health (just think of the human microbiome or innumerable symbioses between organisms and microbes).

- Some of these, however, such as pathogenic bacteria and viruses or parasitic protozoa, can have significant negative effects on human health. This is the case of the SARS-CoV-2 coronavirus responsible for the ongoing pandemic.

- In many cases, their origin derives from the transformation of these pathogens, which allows them to pass from wild animals to humans.

- The passage of pathogens (like viruses) from wild animals to humans is facilitated by the progressive destruction and modification of ecosystems due to the penetration of human beings in the last uncontaminated areas of the planet and often due to the illegal or uncontrolled trade of wild species which determines intimate contact between animals and their pathogens. These emerging diseases can have a dramatic cost in terms of human lives and strong socio-economic impacts.

- The growing human impact on ecosystems and wild species, combined with the impact of global climate change, leads to the weakening of natural ecosystems and facilitates the spread of pathogens by increasing human exposure to these risks.

- Nature conservation and the restoration of damaged habitats is an essential tool for preserving our health and well-being.

PUBLIC ENEMY NUMBER ONE: THE CORONAVIRUS SARS-CoV-2

Coronaviruses are a large family of viruses widespread in many animal species, including birds and mammals such as humans, with which often live without ill-effect.

They can cause pathologies of different nature and severity, ranging from the common cold to more serious diseases such as the Middle East Respiratory Syndrome (MERS, which first appeared in Saudi Arabia in 2012) and the Severe Acute Respiratory Syndrome (SARS, which first appeared in the Guangdong province of southern China in 2002).

The virus responsible for the outbreak that is currently affecting hundreds of countries in the world, and which has therefore been defined by the World Health Organization (WHO) as a pandemic, is a new strain of coronavirus, which had never before affected the human population. WHO has given the disease the official name CoVID-19, short for COronaVIrus Disease-2019, while the International Committee on Taxonomy of Viruses (ICTV) has assigned to the virus that causes the disease the official name SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2). This name was chosen because the virus is genetically related to the coronavirus responsible for the SARS outbreak of 2003. While related, the two viruses differ for two fundamental characteristics, SARS-CoV-2 is more contagious but has a lower mortality rate.

The new coronavirus infection can cause mild symptoms such as a cold, sore throat, cough and fever, or more severe symptoms such as pneumonia, severe acute respiratory syndrome, kidney failure. While we are still learning about how CoVID-19 affects people, the most susceptible to the severe symptoms appear to be the elderly and those with pre-existing diseases, such as diabetes, heart and respiratory diseases. Most people (about 80% of the infected) recover from the disease without the need for hospital treatment. However, some of those infected develop breathing difficulties, with complications that can be fatal[1].

[1]https://www.who.int/news-room/q-a-detail/q-a-coronaviruses

The SARS-CoV-2 contagion in human beings appears to have originated in the large animal market in Wuhan, in the Chinese province of Hubei, with an evident outbreak in December 2019.

In truth, the Wuhan market does not appear to have been the only source of the outbreak which, as suggested by a study by the Zhejiang University of Hangzhou[2], could have also occurred in other places. Analysis of the RNA sequences of the virus indicates that there are two 'sibling' strains of the SARS-CoV2 virus, called Type I and Type II. The latter seems to have originated in the Wuhan market, while Type I does not yet have a clear origin.

But where do these new viruses originate from?

The outbreak among humans of viruses previously circulating only in the animal world, is a phenomenon widely known as **spillover** (as described by the scientific journalist David Quammen in his book "Spillover", in ecology and epidemiology the term indicates the moment in which a pathogen passes from one species to another) and is thought to be at the origin of the new coronavirus.

Recent studies[3] highlight the similarities between SARS-CoV-2 and other similar coronaviruses found in some species of bats, belonging to the genus Rhinolophus, which could have constituted the natural reservoir for the virus[4]. These bats are abundant and widely present in southern China and throughout Asia, the Middle East, Africa and Europe. Mammals of the order Chiroptera are among those with the greatest "familiarity" with viruses, probably due to some biological factors, such as the marked sociality that leads them when resting or in hibernation, to aggregate in very high concentrations (up to one million individuals in one site), but also their long evolutionary history, which has led them to co-evolve with many viruses, as well as the ability to fly and therefore spread and contract viruses over very large areas. Scientific research carried out recently has revealed a high correspondence between the human SARS-CoV-2 genome and the coronavirus genome found in a bat in the Chinese province of Yunnan, even though immediate differences were registered between the Receptor Binding Domain (RBD) sequences, the genetic sequence that encodes the receptors that are used by viruses to bind to and penetrate cells. That leads us to think

[2] Zhang, Yang, Zhang, Lin, 2020. Genomic variations of SARS-CoV-2 suggest multiple outbreak sources of transmission. doi: https://doi.org/10.1101/2020.02.25.20027953
[3] Lu *et al*., 2020, Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. Lancet, 395:565-74. https://doi.org/10.1016/ S0140-6736(20), 30251-8.
[4] https://www.nature.com/articles/s41591-020-0820-9

that the bat virus could have passed through an intermediate host before reaching human beings.

This mechanism has already been observed in the past, when a virus, possibly originating in bats, adapted to dromedaries and subsequently to people causing the MERS epidemic in the Arabian Peninsula in 2012. But also in 2002, when the severe acute respiratory syndrome (SARS) appeared in a Chinese market that sold Asian palm civets (*Paradoxurus hermaphroditus*, that despite its name is a viverrid mammal also known as *luwak* or *musang*).

It is still uncertain which animal species may have acted as intermediate hosts in the case of the SARS-CoV-2, also because the city market of Wuhan, where the Type II strain evolved from, sells and slaughters on site live wild animals of many different species of birds and mammals.

To understand the evolution of the virus and its passage through different hosts, it is necessary to know that every time the virus infects a host, it can mix its genetic heritage with that of other viruses present in the host (such as influenza viruses) or rapidly mutate (such as RNA viruses). Then it reproduces at the expense of the cell that it infects and abandons the host, but with a different genetic makeup, sometimes allowing it to infect new species. This way, by analysing the DNA or RNA of the virus, it is possible to "trace" its passage through different species.

According to Chinese researchers from the South China Agricultural University, pangolins[5] might have helped spread the new coronavirus; but the SARS-CoV-2 genome has a correspondence between 85.5% and 92.4% with that of the coronavirus found in the pangolins analysed, too little to be sure that they were actually the intermediate host (the 99% similarity initially reported at the press conference held by the researchers only referred to the RBD).

The hypothesis remains however still open, given that pangolins are extremely sought after and therefore suffer from intensive illegal trading for a number of reasons; the main one being the keratin scales that cover their body. The keratin of which they are composed, according to ancient beliefs, and contrary to all scientific evidence, is considered curative and is unfortunately still used in traditional oriental medicine. Pangolin meat is also considered by some Asian and African communities to be a real delicacy. For these reasons, the pangolin has now become the most smuggled animal in the world, with over 120 tons of pangolins, or parts of, having been seized from 2010 to 2015, across over 150 different smuggling routes in over 60

[5] Insectivorous mammals, currently made up of eight existing species, family Manidae, all at risk of extinction (Red List of IUCN - International Union for the Conservation of Nature)

countries that cover every continent. The illegal trading is such that the Chinese subspecies has declined by 90% since 1960.

The international trade of pangolins has been illegal since 2016, when a CITES resolution[6] (the Convention on International Trade of Endangered Species) banned the trade of any parts or derivatives of the pangolin species. Unfortunately, illegal trade is by no means a thing of the past, but measures such as those adopted by China to restrict the consumption of wild animal meat could, in part, limit demand.

In the meantime, further research[7], undertaken by team of the Campus Bio-Medico University of Rome, suggests that the epidemic might well have originated from the bats sold alive and slaughtered in the Chinese markets, and then transmitted from animal to human and subsequently among humans via the respiratory system, through fluids, coughs and sneezing.

Ultimately, to date we do not yet have a clear answer on the origin of the SARS-CoV-2. Several researches show that the widespread diffusion of this new pathology might be linked to the often illegal or uncontrolled trade of live wild animals and their body parts. This practice is a vehicle for old, and new zoonoses, and increases the risk of pandemics that can have enormous health, social as well as economic impacts on all the communities involved.

[6] https://cites.org/sites/default/files/eng/com/sc/69/E-SC69-57-A.pdf

[7] Benvenuto *et al*., 2020. The 2019-new coronavirus epidemic: evidence for virus evolution. *BioRxiv*. doi: https://doi.org/10.1101/2020.01.24.915157

VIRUSES

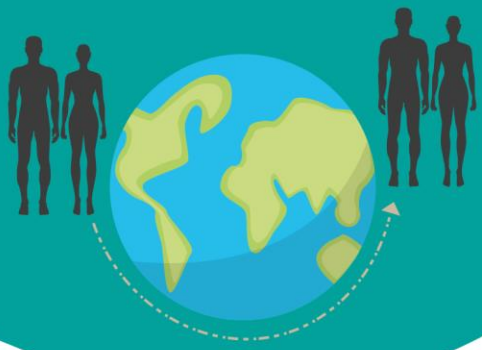
Viruses are incredibly simple organisms: essentially genetic material coated with a protein capsule. Their origin is however unclear: since they possess genetic material, reproduce and evolve through natural selection, they are considered by some biologists as real lifeforms. However, viruses are not able to reproduce autonomously, they always require a host cell, which can be an animal, plant, fungi, bacteria, or archaebacteria. Because they possess some, but not all, of the characteristics of other living beings, viruses have often been described as "organisms on the edge of life". However, at an ecological level, viruses perform an essential task, regulating the populations of host species and ensuring their balance within their ecosystems.

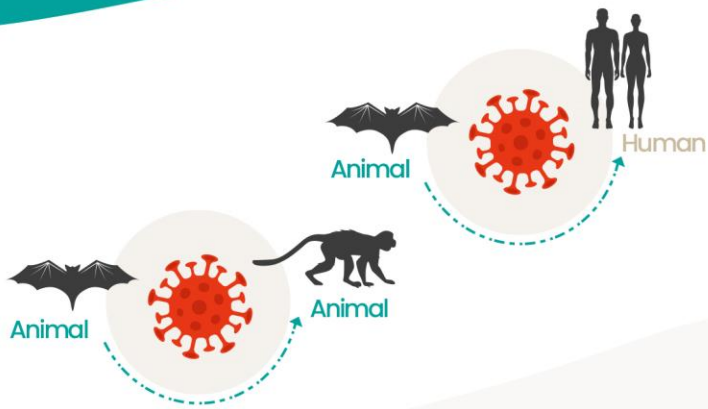
Viruses can be distinguished as DNA or RNA viruses, depending on the type of genetic material they contain, respectively composed by double or single strand nucleic acids.

RNA viruses, just like SARS-CoV-2, are a diverse and important group of viruses with over 158 known species that can infect humans. These viruses, mainly shared among mammals - including humans - and sometimes birds, are considered to be the most important viruses for the transmission of zoonoses because of their ability to mutate faster, evolve, adapt to new hosts and develop a resistance to drugs. This is especially the case when a cell is infected with different viruses, this leads to the exchange of part of the genetic materials giving rise to a new virus (antigenic shift). The mixing of species, typical of so many markets in Southeast Asia, can favor such situations, thus increasing the probability of the appearance of new viruses capable of infecting new species, such as humans, and create the conditions for current and new pandemics. Examples of particularly dangerous RNA viruses include HIV, SARS, Hendra, Nipah and MERS, to name just a few.

Like all organisms on Earth, viruses also try to maximize their survival and ability to reproduce. This point is crucial to understand how a virus in equilibrium with the species through which it has evolved does not cause excessive fatalities amongst that species, as the death of the host would most often mean the death of the virus itself. When there is a substantial change in the virus, which thus becomes able to infect a new species, this balance is lost. In the new host species, the initial rates of fatality are likely to be much higher, but will eventually settle as an equilibrium between the pathogen and the host species is reached.

The pathway of pandemics



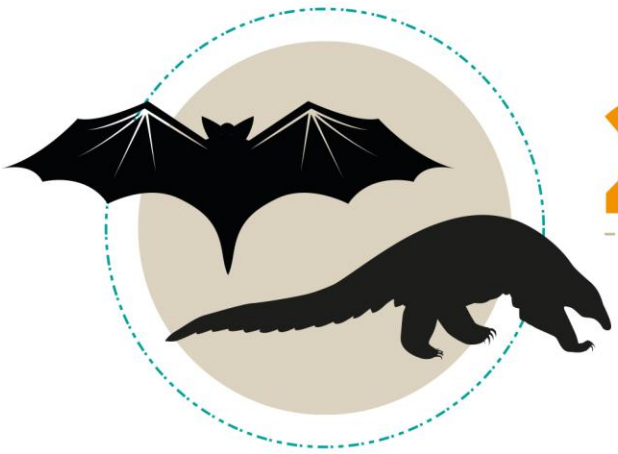


4. Spillover

Transmission from animal to animal, from animal to human and from human to human

3. Animal markets

crowding and closeness between species



2. Species collection and trafficking

1. Deforestation

WWF

FROM ANIMALS TO HUMANS: ZOONOSIS AND THEIR IMPACT

Human diseases can be generated by a great diversity of microorganisms, but those that currently arouse the greatest interest are those with a viral origin and especially zoonoses, also called zoonotic diseases.

A zoonosis is any disease or infection that is naturally transmissible from vertebrate animals to humans. These diseases include a diverse group of infections, which can be caused by viruses, bacteria, fungi, other organisms or abnormal protein agents (prions). The known zoonoses are very numerous - over 200 according to the WHO - and their study constitutes one of the areas of greatest interest in human and veterinary medicine. Rabies, leptospirosis, anthrax, SARS, MERS, yellow fever, dengue, HIV, Ebola, Chikungunya and Coronaviruses are all zoonotic, but also the most widespread flu, just to name a few.

As with viruses, the moment when a pathogen passes from one host species to another is called "spillover".

The transmission can take place, according to the case, by direct contact, as in the case of rabies, through other vector organisms, among which different insects (e.g. mosquitoes) or other arthropods (e.g. ticks), or other environmental and food vehicles. For our species the most dangerous zoonoses are those transmitted not only by other animals, but those which subsequently adapt to our species, allowing, as in the case of the Ebola virus, for the disease to spread between human beings. Zoonoses that manage to transmit from human to human are the most dangerous because with billions of human beings that gather, socialize and travel they can generate epidemics if not pandemics, favoured by the growing globalization.

Of all emerging diseases, **zoonoses of wildlife origin in the future could represent the most significant threat to the health of the world population**[8]. 75% of human diseases known to date derive from animals and 60% of emerging diseases have been transmitted by wild animals. Zoonoses each year cause around one billion cases of disease and millions of deaths[9].

But as well as the health implications and the consequent mortality due to these zoonoses, the value of which is clearly incalculable, it is also important to evaluate their socio-economic impact. For example, despite approximately 9,000 infected people, the economic loss due to the explosion of SARS in 2003

[8] Jones *et al*., 2008. Global trends in emerging infectious diseases. *Nature*, 451, doi:10.1038/nature06536

[9] Morse *et al*., 2012. Prediction and prevention of the next pandemic zoonosis. *Lancet*, 380, 1956-65.

cost the global economy in the range of 30 to 50 billion dollars. Other zoonoses, taken less in consideration by the media, such as the echinococcus, transmitted to humans by dogs and which has a number of ungulates as intermediate hosts, costs 4 billion dollars every year - in analyses and drugs. We also know that some diseases caused by zoonoses contribute dramatically to the poverty of some regions of the world.

Table 1: Main viral zoonoses registered worldwide in the last 50 years. Indicating for each one, when known or hypothesized, the timeframe, country and the species in which they originated, any intermediate hosts and the related impacts estimated in terms of human lives and economic costs[10].

YEAR	ZOONOSIS	COUNTRY OF ORIGIN	SPECIES OF ORIGIN	INTERMIDIATE HOST	DEATHS	ECONOMIC IMPACT (Billions of USD)
1976	Ebola	DRC	Bats		14.693	> 10
1983-1986	HIV-1, HIV-2	Central Africa	Primates		23-42 million (to date)	
1999	West Nile	Uganda	Birds	Mosquitoes	2199 (USA)	
2002	SARS	China	Bats	Asian palm civet	774	40
2003	Avian influenza H5N1	China	Wild birds	Farmed birds	861	40
2009	Swine flu H1N1	United States of America, Mexico	Pigs		429	45-55
2012	MERS	Saudi Arabia	Dromedaries		858	10
2013	Avian influenza H7N9	China	Birds		616	6.5
2014	Ebola	West Africa	Bats		11.310	53
2014	Zika	Chile, Brazil	Mosquitoes			7-18

This without taking into consideration food-borne outbreaks of viral, bacterial, fungal or animal origin transmitted to humans through food, such as those caused by *Salmonella* and *Campylobacter*, which affect millions of people every year, of which hundreds of thousands just in the EU[11].

[10] Sources: http://apps.who.int/gpmb/assets/annual_report/GPMB_annualreport_2019.pdf; https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646195/EPRS_BRI(2020)646195_EN.pdf; https://www.unaids.org/en/resources/fact-sheet

[11] https://www.ecdc.europa.eu/sites/default/files/documents/zoonoses-EU-one-health-2018-report.pdf

EMERGING DISEASES: WAITING FOR THE BIG ONE?

Fifty years ago, following the production and large-scale use of antibiotics and vaccines, the battle against infections appeared to have been won by humankind. Since then, however, as well as an increase in antibiotic resistance among bacterial pathogens, there has been an increase in the outbreak of old and new zoonoses, mostly viral, often transmitted by wildlife, sometimes causing real epidemics.

According to the WHO, **emerging diseases** are those that appear for the first time in a certain population or that were already present but see a rapid increase in number or geographical spread.

The term "emerging disease" specifically includes one of these three categories:

- a known infectious agent appearing in a new geographical area;
- a known infectious agent (or a close relative) appearing in a hitherto unsuspected species;
- an unknown infectious agent classified for the first time.

Emerging zoonoses are those that concern humanity most because they are appearing at an unprecedented rate and because they have an important impact on human health, as well as social and economic systems.

According to some scientists, we are facing a new "epidemiological" situation in which globalization, with the growing movement of people and goods, together with the growing human impact on ecosystems, is accompanied by new emerging diseases and the onset of old diseases that were believed to be under control. The obvious consequence is that globalization is allowing the widespread diffusion of a highly infectious pathogen such as the Coronavirus at a planetary level.

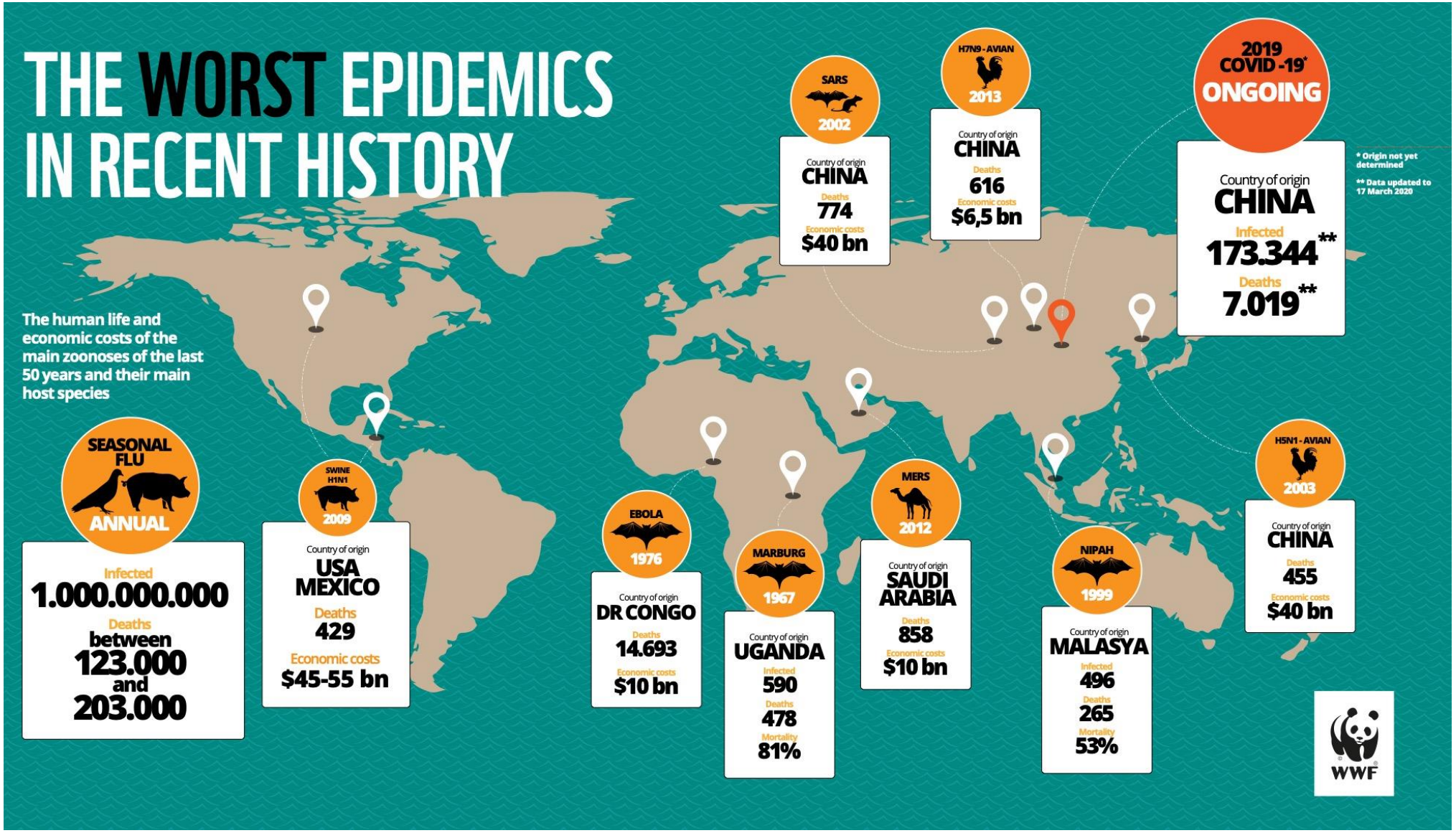
The new emerging zoonoses are at the centre of intense research. This attention is probably linked to the aversion of human society towards the unknown, but also due to the awareness that sooner or later an epidemic of catastrophic proportions could develop among humanity, a real "**Big One**". Awareness is in fact growing along the notion that the worst threat to humanity may not be a third world war, a nuclear explosion, or a global terrorism act, but rather an extraordinarily effective virus that, originating from some deforested area or wild animal sold in an wildlife market, might spread like wildfire among humans. On the other hand, humankind has already had to deal with zoonoses that have determined the course of history, such as the bubonic plague, transmitted to our species by the fleas of rodents

(including rats) and caused by the *Yersina pestis* bacterium, which in the Middle Ages killed up to a third of the European population.

All this can lead to perverse scenarios in which the fear of the disease can add on to the direct impact of the epidemic itself.

A striking example occurred in Central Africa, during a recent epidemic caused by the Ebola virus, during which it is estimated that more people died from malaria, as they avoided health facilities where they feared they could contract Ebola, than from the virus itself[12].

[12] Plucinski *et al*., 2015. Effect of the Ebola-virus-disease epidemic on malaria case management in Guinea, 2014: a cross-sectional survey of health facilities. *Lancet*, 15 (9), 1017-1023.


THE WORST EPIDEMICS IN RECENT HISTORY
The human life and economic costs of the main zoonoses of the last 50 years and their main host species
SEASONAL FLU
ANNUAL
Infected
1.000.000.000
Deaths
between
123.000
and
203.000
SWINE H1N1
2009
Country of origin
USA
MEXICO
Deaths
429
Economic costs
$45-55 bn
EBOLA
1976
Country of origin
DR CONGO
Deaths
14.693
Economic costs
$10 bn
MARBURG
1967
Country of origin
UGANDA
Infected
590
Deaths
478
Mortality
81%
SARS
2002
Country of origin
CHINA
Deaths
774
Economic costs
$40 bn
H7N9 - AVIAN
2013
Country of origin
CHINA
Deaths
616
Economic costs
$6,5 bn
MERS
2012
Country of origin
SAUDI ARABIA
Deaths
858
Economic costs
$10 bn
NIPAH
1999
Country of origin
MALASYA
Infected
496
Deaths
265
Mortality
53%
2019
COVID -19*
ONGOING
Country of origin
CHINA
Infected
173.344**
Deaths
7.019**
* Origin not yet determined
** Data updated to 17 March 2020
H5N1 - AVIAN
2003
Country of origin
CHINA
Deaths
455
Economic costs
$40 bn
WWF

FROM THE DAMAGE TO ECOSYSTEMS TO THE RISKS TO OUR HEALTH

It is now established that natural ecosystems, whether they are temperate or tropical forests, river basins or coastal wetlands, grasslands or peatlands, have a crucial role in supporting and nourishing life, including that of our species.

In-depth research has recently linked the important role of altering ecosystems to the development and spread of infectious diseases such as zoonoses.

Scientists around the world are aware that among the causes of the spread of **emerging infectious diseases**, such as Ebola, Marburg Haemorrhagic Fever, SARS, MERS, Rift Valley Fever, Zika and many others, are included important factors such as the loss of habitats, the creation of artificial environments, the manipulation and trade of wild animals and more generally the destruction of biodiversity[13].

Our destructive action on the complex dynamic balances of the biosphere as well as our intervention on ecosystems - on the functioning of which we still know very little - can lead to consequences that have a direct impact on our well-being and in particular on our health. This occurs through some simple mechanisms:

- increase in the breeding sites of disease vectors;
- amplified spread of main hosts;
- keeping wild species captive in close contact with each other;
- transfer of pathogens between different species;
- loss of predatory species;
- human-induced genetic changes of the vectors of diseases or pathogens (such as the resistance of mosquitoes to pesticides or the appearance of bacteria resistant to antibiotics);
- environmental contamination by the agents of infectious diseases.

If on the one hand the destruction of habitats and biodiversity creates favourable conditions for the spread of emerging zoonotic diseases, on the other hand the creation of artificial habitats or of even nature-poor environments and with a high human density can further facilitate it.

[13] Di Marco *et al.*, 2020. Sustainable development must account for pandemic risk. *PNAS*, 117 (8), 3888-3892, doi/10.1073/pnas.2001655117.

In these new conditions determined by human activities, the balance within ecosystems, populations and individuals capable of contrasting the microorganisms responsible for certain diseases is lost.

The degraded suburbs with no green spaces found in many cities are, for example, the perfect cradle for dangerous diseases and for the transmission of zoonoses; while the widespread use of irrigation systems, channels and dams allows the reproduction of dangerous vectors such as mosquitoes.

The complex but alarming relationship between the destruction of ecosystems (and the biological mechanisms that regulate them) and the spread of infectious diseases can be better understood if we look at a series of specific cases already illustrated in the first report on the state of the world's ecosystems, published in 2005, and sponsored by the United Nations, the **Millennium Ecosystem Assessment**[14].

- In some tropical countries, intensive agriculture practices with irrigation tools, such as dams and canals, has led to an increase in cases of schistosomiasis, this due to the new artificial habitats allowing the proliferation of snails that act as an intermediate host for the responsible parasite (a blood fluke, or small flat worm, of the genus Schistosoma, which infects around 207 million people worldwide).
- Deforestation has increased the risk of malaria in Africa and South America. This is largely due to the disruption of the ecological balance that reduces the spread of mosquitoes.
- Irrigated rice fields facilitate the reproduction of mosquitoes, which in turn spread serious diseases such as malaria, lymphatic filariasis, Japanese encephalitis and other pathologies.
- Habitat fragmentation in North America, and the consequent loss of biodiversity, have increased the presence of a group of bacteria (spirochetes belonging to the *Borrelia burgdorferi* bacterial species) that cause Lyme disease, transmitted to humans through the bite of an infected tick.
- The intensive use of drugs in intensive livestock breeding has led to the appearance of antibiotic-resistant strains of *Salmonella, Campylobacter* and *Escherichia coli*.
- Intensive zootechnical practices can facilitate the spillover of pathogens, leading to new and dangerous zoonoses, such as SARS and new flu strains.
- The uncontrolled urbanization of forest areas has been associated with viruses transmitted by mosquitoes in the Amazon and lymphatic filariasis in Africa.

[14] www.millenniumassessment.org/en/index.html

- Tropical urban areas with poor water supply systems and the lack of shelter have shown to favour the dangerous and widespread transmission of dengue fever.

Unfortunately, our understanding of the interactions between ecosystem change, disease regulation and human well-being is still limited. Not only do we know very little about the diversity of microorganisms present on our planet, but we have yet to discover and therefore fully understand much of the mechanisms that regulate the relationship between them and other species, including ours.

A better understanding of how our ecosystems function - and in particular their role in defending us from the spread of diseases - is fundamental to understand the importance of protecting and managing them better; so as to avoid having to run for cover at a later date, to rebuild and restore balances and ecological processes crucial to our health previously destroyed.

THE LEVEL OF THE DESTRUCTION OF ECOSYSTEMS IN THE WORLD

What is certain is that human activities are causing the degradation of the various natural ecosystems at a rate that has the characteristics of a cataclysm. The growing human population, that to date has almost reached 7.7 billion, and the rapid growth in per capita consumption of goods and services, which determine humanity's growing ecological footprint, are altering the planet's land cover, the rivers and oceans, the climate system, biogeochemical cycles and the way ecosystems function. With about half of the temperate and tropical forests having been cut down, almost half of the land surface free of ice converted into cultivated land or pastures and with more than 800,000 dams that prevent the flow of water through more than 60% of the world's rivers, changes in the use of our planet's soil and ground cover represent some of the most pervasive changes that humanity has made to Earth's natural systems.

"**Unprecedented**" is the adjective used in 2019 by the UN Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to define the destructive action of man on nature. The IPBES report is the most recent and influential report on the state of planetary biodiversity. According to the report[15], 75% of the terrestrial environment and about 66% of the marine environment have been modified in a significant way, with around 1

[15] IPBES, 2019. Global Assessment Report on Biodiversity and Ecosystem Services. https://ipbes.net/global-assessment.

million animal and plant species finding themselves in an unprecedented risk of extinction.

According to data from the **Living Planet Report** prepared by WWF in 2018[16], **in just over 40 years the abundance of vertebrate populations across the globe declined on average by 60%.**

Greenhouse gas emissions have doubled, causing global average temperatures to rise by 1°C compared to pre-industrial times, while the global average sea level has increased between 16 and 21 centimetres since 1900. In the past 50 years, the world population has doubled.

These changes have provoked widespread impacts on biodiversity, starting with species distribution, and giving rise to the definition of a new geological era: the Anthropocene. Global changes determine an uncertain future, not only for the biosphere, but for humanity itself. There is a broad debate on the ability of an altered global environment to meet the needs of a growing human population. Health is a dimension of human well-being that has received particular attention in this discussion.

DESTRUCTION OF FORESTS AND PANDEMIES

Forests cover **31% of the planet's lands**, they constitute the habitat for **80% of the Earth's biodiversity** and, in various forms and particularly due to the process of photosynthesis and the absorption of CO_2, contribute to mitigate climate change. They provide an infinite number of services that enable life on our planet, including not least the protection of our health.

According to most recent data, rainforests produce more than 40% of the earth's oxygen and deforestation is one of the main causes of global warming as it produces between 12 and 20% of greenhouse gas emissions.

To date we have lost almost half of the forest area that embraced and protected our planet. According to a study it is estimated that at the beginning of the agricultural revolution there were about 6,000 billion trees on Earth, while today there are about 3,000 billion[17].

Land use changes and destruction of natural habitats - such as tropical forests - are held responsible for at least half of emerging zoonoses[18].

[16] WWF, 2018. Living Planet Report - 2018: Aiming Higher. Grooten and Almond (Eds). WWF, Gland, Switzerland

[17] Crowther T.W. *et al.*, 2015, Mapping tree density at a global scale, *Nature* 525; 201-205

[18] Keesing *et al.*, 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, 468, 647-65.

Tropical forests are not the only environment towards which the destructive force of our species has turned against, but they are certainly the richest in life and the most complex. Millions of species are believed to live in these ecosystems many of which are largely unknown to science. Among these millions of species are viruses, bacteria, fungi and many other organisms, many of which are parasites. Ebola, Marburg, Lassa, monkeypox, and the precursor of HIV are a minuscule sample of what could be a myriad of other undiscovered viruses. In most cases, they are benevolent parasites who cannot live outside their host. These days, however, the destruction of ecosystems seems to have, among its consequences, the increasingly frequent appearance of pathogens in larger areas than the original ones.

As David Quammen writes: "When the trees fall, and the native animals are slaughtered, the native germs fly like dust from a demolished warehouse"[19].

Viruses, especially those whose genome is made up of RNA, can be easily subject to mutations, and adapt well and quickly to new conditions and new hosts.

The destruction of forests can therefore expose humans to new forms of contact with microbes and with the wild species that host them.

For example, in the pristine forests of West Africa live bats carrying the **Ebola** virus. The change of land use such as the creation of access roads to the forest, the expansion of hunting territories and the collection of wild animal meat (**bushmeat**), the development of villages in previously wild territories, has brought the human population into closer contact with the virus at its onset.

Similarly, again in Africa, human communities entering into what were once intact forests, has increased the direct and indirect contact with disease reservoirs, leading to an increase in diseases such as **yellow fever** (transmitted through mosquitoes, from infected monkeys) and **leishmaniasis.**

Even **HIV** (*Human Immunodeficiency Virus*) has adapted to humans from the variant found in the apes of the forests of Central Africa. Having reached the human host, it was able to spread through human-human transmission, thus determining the current global spread of AIDS, which has counted more than 35 million deaths to date. Other more recent examples of pandemics triggered by deforestation and transmitted by non-human primates are

[19] Quammen D., 2012. Spillover. Animal Infections and the Next Human Pandemic. Norton & Co, ISBN 0393066800

monkey malaria, caused by several species of plasmodes in Asia and South America

Table 2: Emerging diseases and potential impact mechanisms of anthropic activities related to ecological changes (source: Millennium Ecosystem Assessment, Chapter 14[20])

DISEASE	GEOGRAPHICAL DISTRIBUTION	CASES PER YEAR	EMERGENCE MECHANISM	ANTHROPOGENIC DRIVERS
Malaria	tropical (America, Asia, and Africa)	350 million	niche invasion; vector expansion	deforestation; water projects
Schistosomiasis	America; Africa; Asia	120 million	intermediate host expansion	dam building; irrigation
Dengue fever	tropical	80 million	vector expansion	urbanization; poor housing conditions
Rabies	tropical	35,000 (deaths)	biodiversity loss, altered host selection	deforestation and mining
Lyme disease	North America and Europe	23,763 (U.S. 2002)	depletion of predators; biodiversity loss; reservoir expansion	habitat fragmentation
West Nile virus and other encephalitides	Americas; Eurasia	5,483 (US average 2002-2004)	niche invasion	international travel; climate variability
Ebola	Africa	-	forest encroachment; bushmeat hunting	forest encroachment

CASE STUDY: HOW TO LEARN FROM ERRORS OF THE PAST

THE CASE OF BELIZE: AGRICULTURE AND MALARIA

Some changes in land use directly affect disease exposure. In Belize, for example, the enrichment of nutrients with nitrogen and phosphorus from agricultural runoff hundreds of kilometres upstream - in deforested areas - causes a change in the vegetation pattern of lowland wetlands, which favours the most efficient vector for malaria, *Anopheles vestipennis*, compared to the less efficient carrier, *Anopheles albimanus*, leading coastal human populations to a greater exposure to malaria.

[20] https://www.millenniumassessment.org/documents/document.283.aspx.pdf

DISEASES TRANSMITTED BY TICKS AND HABITAT DESTRUCTION

Of all arthropods, ticks are those responsible for the transmission of the greatest number of diseases. The number of diseases due to ticks, both known and new, continue to increase as humans and their pets continue to occupy wildlife habitats. More than 40% of tick-borne pathogens have been discovered in the past two decades[21].

In particular, **Lyme disease** originated from a bacterium, *Borrelia burgdorferi*. The bacterium infects ticks, which can transmit it to humans and other animals. According to research, the risk for humans of contrasting this disease is significantly higher in areas with low vertebrate diversity, such as small forests (smaller than 2 hectares) and intensely fragmented habitats[22].

SWEDEN: ROE DEER AND ENCEPHALITES

Another interesting case, which can make us better understand how human intervention on ecosystems can lead to ecological imbalances that have an effect on our health, is what happened in Sweden. Here, the progressive reduction of roe deer (*Capreolus capreolus*) due to human intervention has led to an increase in recent decades of cases of **Tick-borne encephalitis (TBE).** This could be happening because roe deer is an important host for all stages of development of the carrier tick. The progressive scarcity of hosts has pushed the ticks to colonize voles, that are rodents and healthy carriers of TBE, more numerous than roe deer, with a growing population that therefore facilitated the transmission of the pathogen to humans[23].

MALARIA AND PLANT DIVERSITY

Deforestation, fragmentation and destruction of habitats inevitably reduce the diversity of plant species in any one area. This eventually has effects on the presence, abundance and distribution of mosquitoes, thereby increasing the risk of **malaria**[24] transmission. In the Peruvian Amazon, for example, deforested sites, compared to the still intact forests, have a higher density of *Anopheles darlingi*, the most efficient local mosquitoes for transmitting malaria[25].

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[21] Eisen *et al*., 2017. Tick-Borne zoonoses in the United States: Persistent and emerging threats to human health. *ILAR J.*: 1-17.
[22] Brownstein *et al*., 2005. Forest fragmentation predicts local scale heterogeneity of Lyme disease risk. *Oecologia*, 146, 469-475.
[23] McMahon, Morand, Gray, 2018. Ecosystem change and zoonoses in the Anthropocene. *Zoonoses and public health*, 65, 755-765.
[24] Yasuoka & Levins, 2007. Impact of deforestation and agricultural development on Anopheline ecology and malaria epidemiology. *The American Society of Tropical Medicine and Hygiene*, 76, 450-460
[25] Vittor *et al*., 2006. The effect of deforestation on the human-biting rate of *Anopheles darlingi*, the primary vector of falciparum malaria in the Peruvian amazon. *Am. J. Trop. Med. Hyg.,* 74, 3-11.

SCHISTOSOMIASIS AND THE DISAPPEARANCE OF PREDATORS

Schistosomiasis is a disease caused by blood flukes (trematode worms) of the genus *Schistosoma*. It is a parasitosis that has spread with the disappearance of predators. This parasite enters the human body through skin contact with larvae that live in the aquatic environment. These worms reproduce in some aquatic snails that act as an intermediate host. In Malawi, unsustainable fishing and the progressive disappearance of fish that feed on snails has led to the extensive spread of the parasitic worms[26]. Every year in the world 200 million people fall ill with schistosomiasis with over 10,000 deaths[27].

HANTAVIRUSES AND BIODIVERSITY

Hantaviruses are a family of viruses, spread mainly by rodents found in Europe, Asia and the Americas, which can cause haemorrhagic pulmonary and renal syndromes. Transmission between rodents occurs with bites and scratches, while humans can become infected through contact with the urine and faeces of the rodents. On the American continent hantaviruses cause major lung diseases with a mortality rate of 37%[28]. Research confirms that several factors, including the destruction of biodiversity, contribute to the onset of these diseases. In fact, researchers have found that a high diversity among rodent species keeps the population of those species that are carriers of viruses lower and, consequently, the number of human infections[29].

DISAPPEARANCE OF VULTURES AND THE INCREASE OF RABIES

A striking example of how the disappearance of biodiversity can contribute to the spread of certain zoonoses also comes from India. This country saw a rapid and major collapse of the populations of vultures during the last century, killed by Diclofenac, a powerful anti-inflammatory drug used on livestock, which remains in the carcasses that the birds of prey would feed on. The disappearance of vultures was followed by a rapid onset of cases of rabies in the human population; this is because the carcasses not being "disposed of" by the vultures had allowed a rapid increase in the population of wild dogs, which are the main vector of rabies for humans.

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[26] Stauffer *et al*., 2006. Schistosomiasis in Lake Malawi: Relationship of Fish and Intermediate Host Density to Prevalence of Human Infection. *EcoHealth*, 3, 22-27.
[27] Sayed *et al*., 2008. Identification of oxadiazoles as new drug leads for the control of schistosomiasis. *Nature Medicine*, 14, 407-412.
[28] Centers for Disease Control & Prevention. 2004. Case Information: Hantavirus Pulmonary Syndrome Case Count and Descriptive Statistics Atlanta, GA: Centers for Disease Control & Prevention.
[29] Suzan *et al*., 2009. Experimental evidence for reduced rodent diversity causing increased Hantavirus prevalence. *PLoS One*, 4(5): e5461. doi: 10.1371/journal.pone.0005461.

NIPAH VIRUS

In 1999, the Nipah virus spread to Malaysia, creating havoc and causing serious damage to the local economy. The virus is transmitted to humans through contact with pigs or bats, causing acute respiratory infections or encephalitis, with a lethality greater than 40%. Once isolated in laboratories, this virus turned out to be completely new to science. Subsequent research has shown that the same virus had lived undetected for years, if not centuries, in frugivorous bats without causing any harm. The factors that triggered its transmission are related to habitat destruction, climatic events and the expansion of industrialized agriculture[30].

WILDLIFE TRAFFICKING, BUSHMEAT AND PANDEMIES

The trade in wild species and direct contact with animal parts through the exchange of liquids, or other means, exposes humans to contact with viruses or other pathogens of which that animal can be a host.

The illegal killing of wild animals for food is increasingly considered by the international scientific and conservation community one of the main causes of decline in animal populations outside and inside forests, especially in those countries where political instability is reflected in an instability in the management and control of natural resources.

There is evidence that contact with wild species such as bats, Asian palm civets, monkeys and other animals (mainly birds and mammals) can lead to the onset and contribute to the spread of serious zoonoses. It is no coincidence that recurrent outbreaks of Ebola epidemics are often linked to the consumption of contaminated bushmeat (monkey meat).

In many areas of the world, the most varied animal species are hunted for food, from reptiles to pangolins, from antelopes to hippopotamuses, and dramatically also the great apes such as chimpanzees and gorillas.

Bushmeat is consumed directly in the forests, but also transported to the countryside and cities. In some cases, what is considered a delicacy, as is the unfortunate case of monkey meat, follow illegal trade routes that arrive in distant countries.

The constant population growth in countries where some food resources are scarce (such as proteins) and where the economic gap between the different social classes does not allow everyone to have access to the resources

[30] Brown, 2004. Emerging zoonoses and pathogens of public health significance - an overview. *Scientific and Technical Review of the Office International des Epizooties*, 23, 435-442.

available, wild animals are increasingly becoming a food and economic source of vital importance. Wildlife, however, as well as being a protein resource, can also be transformed into an easy source of income and commercial activity.

Bushmeat consumption worldwide is growing dramatically in many parts of the world.

In various researches carried out by TRAFFIC[31], the wildlife trade monitoring network, dramatic data on bushmeat consumption emerge: it has been calculated that in a single district of Kenya about 80% of families consume on average 14.1 kg of bushmeat per month, while in a rural area of Botswana 46% of families consume about 18.2 kg. In Central Africa alone, consumption goes from 1 to 3.4 million tons per year.

There also seems to be an inverse relationship between household income and bushmeat consumption: the lower the income, the higher the consumption. On the other hand, in urban areas wild meat is preferred for its flavour and its price is higher than domestic meat and therefore it is the higher income families that consume it the most. This also applies to some African communities that have moved abroad, whose eating habits support a rich illegal market even outside their homeland.

Bushmeat trade and consumption is far from being an exclusively African practice; it takes place in many other countries of the world. For an idea of its scale we should consider that every year in Peru alone 28,000 monkeys are hunted and consumed. In Indonesia, as well as monkeys and other wild mammals, 25 tons of turtles are captured and exported.

Just as hunting and the consumption of bushmeat poses very serious risks to human health, the same is true of the widespread trade in wildlife and animal parts: ***wildlife trafficking***. The cross-border trade in animals and plants is not only a primary cause of biodiversity loss, but it can also be an important mechanism for spreading zoonoses.

Wild animals of all kinds are trafficked along commercial roads that connect continents and distant countries, potentially amplifying the spread of pathogens.

In some cases, wild species are bred for trade. This still poses a danger, as the absence of adequate controls, as is the case in many clandestine or family-run farms, makes these animals dangerous for human health.

[31] TRAFFIC is a joint program of WWF and IUCN - the International Union for Conservation of Nature https://www.worldwildlife.org/initiatives/traffic-the-wildlife-trade-monitoring-network

In developing countries, but also in more developed ones, there are several markets offering live animals.

Farmed or wild animals have enormous potential to transmit viruses. They can scratch, defecate, urinate, cough, contaminating each other or, more worryingly, contaminating humans. Moreover, the close proximity of different species facilitates the genetic recombination between different viruses and with it spillover, that is the ability to infect new species.

The SARS virus - which in 2002-2003 caused more than 800 deaths and cost more than 80 billion US Dollars globally - emerged from bats, passed on to palm civets and, ultimately, infected people in southern China's live animal markets.

Similarly, as we have seen, the recent Coronavirus epidemic is suspected to have erupted in one of the many Chinese markets, where they wild animals including frugivorous bats and other wild species are sold.

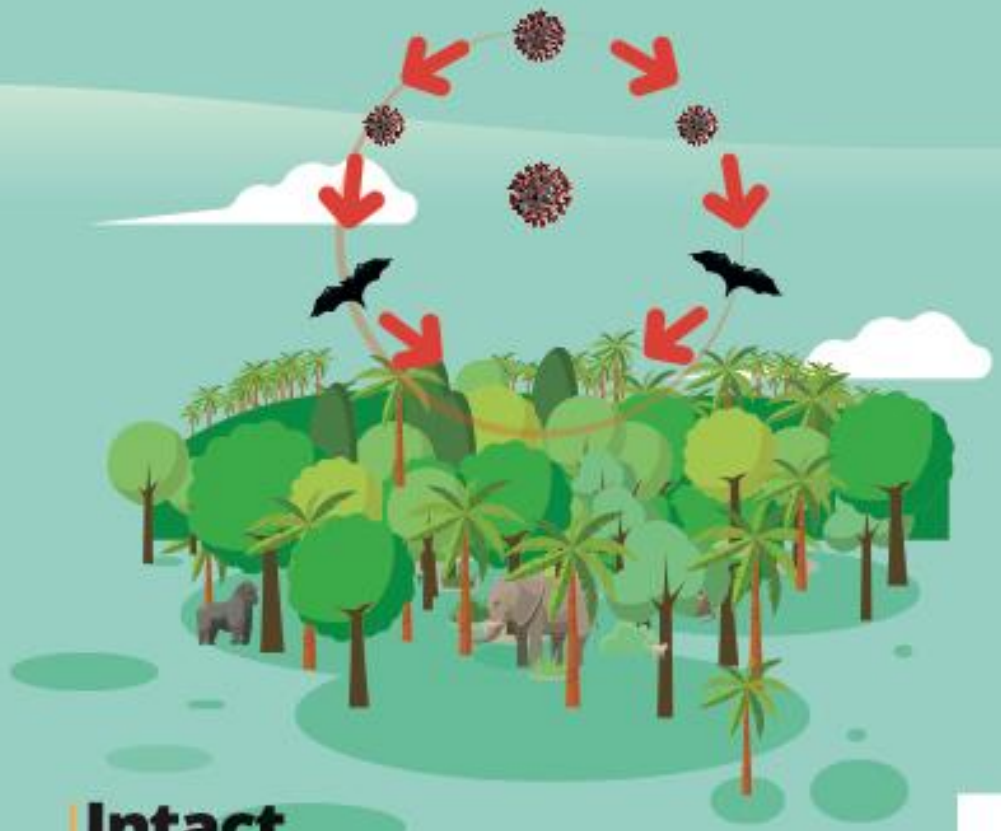
WWF has always fought the illegal wildlife trade, which is the fourth most important and widespread criminal market in the world. The United Nations has assessed that the business generated by this phenomenon, which involves the loss of biodiversity and increases the risk of pandemics, generates an income of between 7 and 23 billion US dollars a year[32].

China's recent decision to ban the trade of live animals for food on its national territory represents a choice of fundamental importance, but still not sufficient.

Once again, humans have to face with guilty delay a pandemic favoured by their own actions which will have enormous costs, socially, economically as well in terms of human lives.

[32] https://www.traffic.org/about-us/illegal-wildlife-trade/

Forests: our antivirus



Intact forest

VIRUSES ARE IN BALANCE WITH THE ENVIRONMENT AND THE DIFFERENT SPECIES

WWF

Degraded forest

VIRUSES MEET NEW SPECIES AND SPREAD GENERATING EPIDEMICS

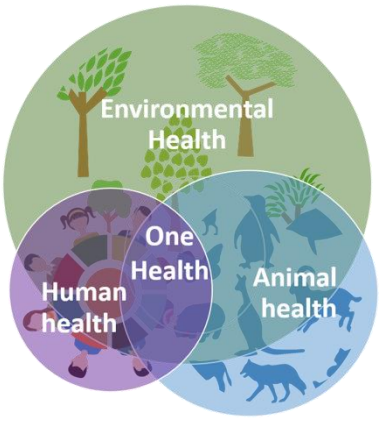
WHAT TO DO

To control or prevent zoonoses, humans have often used the approach of reducing populations of host or vector species (i.e. animals that, like mosquitoes, carry disease agents). In many parts of the world, drastic and high impact systems have been developed, such as the unbridled use of insecticides. A recent example has been the use of DDT against malaria.

These types of intervention have highlighted several limitations, including:

- the resistance acquired by insects and other vectors (such as ticks) to insecticides and other chemical substances;
- the unexpected change in the ecology of the host populations;
- the impact on non-target species (that is, wild species absolutely harmless to humans and of fundamental importance for the functioning of ecosystems);
- the negative, and often unexpected, consequences on ecosystems (just think of DDT which is still present in many environments);
- the socio-economic impact, when it comes to killing farm animals, see poultry in the case of the avian influenza.

For this reason, in the last decade, the "**One Health**" approach has become increasingly popular at a global level which recognizes how human health is closely linked to animal and environmental health. A strategic concept, formally recognized by many UN bodies, UNEP, UNDP, WHO, FAO, the World Organization for Animal Health (OIE), the European Commission, as well as research institutes all over the world, NGOs and other entities. One Health identifies a holistic concept of the health of people, animals, plants, living and working environments and ecosystems, promoting the application of a multidisciplinary and collaborative approach to address the potential or active risks that originate from the interface between living and working environment, animal populations and ecosystems.



To make the "One Health" approach truly effective, it is necessary to establish a better and systematic interaction between the most relevant professional groups, in particular between doctors and veterinarians, epidemiologists, ecologists and wildlife experts, but also sociologists, economists, jurists.

Only by recognizing that our health and well-being are closely linked to those of the nature that hosts us, can we protect our species from the most harmful effects of pandemics.

An effective and sustainable way forward should therefore ensure the natural functioning of ecosystems and their careful management to regulate diseases, hinder their spread and thus reduce their impact on human health.

NATURAL ANSWERS: THE DILUTION AND THE COEVOLUTION EFFECTS

The richness and abundance of species (two important components of biodiversity) can counteract the spread of diseases in different ways.

Among these, the **dilution effect** is the most studied and well known. The "dilution" effect describes how in an ecosystem with a rich community of potential hosts (species in which a virus or another organism can reproduce), a pathogenic organism is less likely to find a host in which it can easily multiply (a highly-competent host) and from which it can spread using another carrier. In a scenario rich in diverse species, it is easier for the pathogen to end up in an unsuitable species that will function as an "ecological trap" for the pathogenic organism or for its vector. Scientists call these species "dead-end hosts". Recent studies suggest that the dilution effect may explain the reduction of malaria transmission in various regions of the Brazilian Amazon.

In conditions of low biodiversity, few abundant species tend to prevail, and therefore become more exposed to contracting and spreading infections[33].

Another effect that is gaining ever stronger backing is the "**coevolution effect**". A number of researchers have been asking themselves the question as to where the many new pathogenic organisms that today put our health at risk may be coming from. The answer, the subject of recent research, is that when we destroy habitats, the remaining forest fragments act like islands, where the microbes and the animals that host them undergo a rapid diversification, thus increasing the probability that one or more of these microbes can manage to infect humans, spreading and creating epidemics[34].

[33] Lugassy *et al*., 2019. What is the evidence that ecosystem components or functions have an impact on infectious diseases? A systematic review protocol. *Environmental Evidence*, 8, 4.
[34] Zohdy, Schwartz, Oaks. 2019. The Coevolution Effect as a Driver of Spillover. *Trends in Parasitology*, 35, 399-408.

OUR ANSWER: PROTECT NATURE AND RESTORE DEGRADED ECOSYSTEMS

It is evident that preserving the ecosystems that are still intact, protecting the pristine areas of the planet, also by limiting accessibility, prohibiting the consumption and trafficking of wild species, favouring the natural balance of ecosystems and restoring damaged ones are among the most forward-looking choices that humanity can take.

The extraordinary web of life that supports the well-being of our species as well as all the others has been attacked and deteriorated by our species with such an intensity that in order to imagine a global future we need to intervene at a planetary level, through a new global agreement between humans and nature, we need a: ***New Deal for Nature & People***.

This new agreement must include the need to:

- **halve our footprint on Nature;**
- **stop the loss of natural habitats;**
- **stop the extinction of living species.**

Although the fundamental and priority objective is still maintaining the vitality of natural systems to preserve their evolutionary capacities and their dynamics, it is also necessary to proceed with actions to restore the functions, processes and dynamics of these extraordinary systems that nature has designed in billions of years of evolution of life. We must start a real work of "reconstruction" of the ecosystems that we have destroyed or degraded.

Aware of this difficult challenge, the United Nations has decided to dedicate this decade to ***Ecosystem Restoration***.

For the good of the planet and therefore for our own good, it has become an urgency and a priority not only to protect, but also to restore natural balances, restoring degraded habitats. The restoration of nature and its systems is fundamental for maintaining the function of all the mechanisms of the biosphere, including those of the climate.

"We all depend on healthy ecosystems for food and energy, water and biodiversity. Their continued degradation contributes to climate change and enhances the risk of severe ecological disasters. Widespread loss of function in both terrestrial and aquatic ecosystems will be catastrophic for our planet and a huge setback on progress made towards achieving the United Nations

Sustainable Development Goals. It's time to rebuild what has been lost" (https://www.decadeonrestoration.org/).

The solution for a future less tied to ever larger hospitals, increasingly powerful vaccines, increasingly toxic disinfectants, passes also through the reconstruction of what we have destroyed, putting together the pieces of the only systems that can protect us from epidemics and catastrophes: natural ecosystems.

It all depends on us and on the choices we make.

Working to sustain the natural world for the benefit of people and wildlife.

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