How loss of biodiversity compromises human and animal health

Hur förlust av biologisk mångfald riskerar att påverka människors och djurs hälsa negativt

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Introduction

The media and public opinion often portray wildlife as the cause of infectious diseases and the resulting impact on human health and domestic animals. There are various reasons for this: the lack of knowledge about wildlife, the lack of individual and societal capacity to control threats, the novelty that wildlife can represent for urban, suburban and extra urban populations. As a result, there is a tendency to overestimate wildlife-related disease risks (Buttke et al., 2015). However, there is less information about the role that human-induced habitat destruction and biodiversity play in disease transmission. On the one hand, as described in the review of Myers et al., actions carried out by humans with the intention of benefiting public health have facilitated the entry of disease vectors, altered the interactions between humans and wildlife, and contributed to the potential risk of zoonoses through hunting and the consumption of wild meat (Myers et al., 2013). On the other hand, biodiversity can play a dual role in the exposure and transmission of infectious diseases. In fact, in areas of high biodiversity can be a reservoir of origin for new pathogens and at the same time, the loss of biodiversity, understood as a reduction in both the density and diversity of hosts, tends to increase pathogen transmission and disease incidence (Keeling et al., 2010).
Thus, there is no single culprit involved in the transmission of infectious diseases. Indeed, human health, animal health and ecosystem health are interdependent, which is why it is necessary to study health with a cross-sectoral and transdisciplinary approach, for example through the One Health approach (Redford et al., 2022). The themes chosen are very topical, as after the COVID-19 pandemic the relationship between health, well-being and biodiversity has acquired great importance and the need to preserve natural habitats and ecosystems has grown, in order to reduce the risk of spreading pathogen agents and spillovers (Convention on Biological diversity, 2022). Furthermore, biodiversity and health, as well as the well-being of all living beings, are issues included in the "2030 Agenda for Sustainable Development" adopted by the United Nations in 2015. It represents an action plan to improve and make economic, social and environmental development more sustainable by 2030. Among the 17 goals set (Sustainable Development Goals, SDGs), goals number 3, 14 and 15 in particular are those which concern health (3) and biodiversity (14,15) (United Nations, 2015).

Aim

This review aims to investigate, through a One Health approach, the subtle relationship between biodiversity and health, focusing on the consequences that biodiversity loss has on human and animal health. Among the consequences, more attention has been paid to emerging and re-emerging infectious diseases affecting humans, domestic animals and wild animals. The final part of the review deals with possible solutions to preserve biodiversity and to avoid spillover episodes and zoonoses. In addition, the review aims to raise the reader's awareness of wildlife, emphasising its important role in collective health. In fact, each species contributes to maintaining the balance of the ecosystem. For example, bats and bees are essential pollinators, coral reefs produce oxygen and capture CO2, fruit-eating species disperse seeds in the environment, and predators help keep other species constant (WOAH-m). In addition, wild species represent, especially for indigenous peoples and local communities, a source of food, traditional medicines of energy and income, and they are used for religious and cultural purposes (IPBES, 2022).

One Health approach

The definition of One Health has changed over time. As Lerner et al. describe in their theoretical analysis about One Health approach, the One Health concept has moved from a narrower to a broader conception. The narrow conception is inspired by the One Medicine approach, it is focused on human health (human medicine) and animal health (veterinary medicine). Instead, the broader conception encompasses other sciences, including social sciences, and adds environmental health, ecology, biodiversity to human and animal health (Lerner et al., 2017). In fact, One Health acts at the individual, community, regional, national and global level in areas such as human medicine, veterinary medicine, public health, biosafety, food safety, epidemiology, ecology, disease ecology, ecosystem restoration, climate change, globalisation, anthropology, social sciences and economics (Redford et al., 2022). It is applicable to the study of transmissible diseases, for example it is used to coordinate multisectoral efforts of prevention, preparedness and response to zoonotic diseases such as rabies, Avian influenza or viral haemorrhagic fever (WOAH-g), non-transmissible diseases, such as diseases caused by pollutants or diseases respiratory problems, and is also applicable to many cross-cutting issues such as antimicrobial resistance. Furthermore, its application is relevant for both natural and altered ecosystems and for urbanized and rural areas because there is considerable interest in the disease risk associated with habitat conversion (Redford et al., 2022). The networks “One Health Sweden” and “One Health Initiative” have developed the “One Health Umbrella” to illustrate better the scope of the “One Health concept” [Fig.1]. In this symbolic “umbrella” all relevant aspects of One Health are encompassed (Lerner & Berg, 2015).
A definition developed in 2021 by the One Health High Level Expert Panel is the following:

"One Health is 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).

This definition describes the One Health approach as a multisectoral and multidisciplinary approach and underlines the interdependence between human health, animal health and the environment.
One Health High Level Expert Panel adds that this approach mobilizes various sectors and disciplines at different levels of society to promote collective well-being by addressing threats to health and ecosystems, the collective need for clean water, energy and air, acting on climate change and contribution to sustainable development (One Health Commission).

The broader One Health concept seems to approach the concept of Eco Health, which promotes the health of humans, animals and ecosystems, also including environmental sustainability and socio-economic stability. Like One Health approach, even Eco Health operates in the fields of human medicine, veterinary medicine, public health, anthropology and social sciences and humanities, but compared to the One Health approach it places great emphasis on biodiversity and the well-being of all living species in a single ecosystem (Lerner et al., 2017). In this regard, the Convention on Biological Diversity has provided guidance for integrating biodiversity into the One Health approach. Firstly, the guidance emphasises the value of the One Health approach for addressing the crosscutting issue of biodiversity and human health, as it is "an integrated approach consistent with the ecosystem approach [...] that integrates the complex relationships between humans, microorganisms, animals, plants, agriculture, wildlife and the environment." (Convention on Biological Diversity, 2017). Secondly, it compares the One

Health and Eco Health approaches and suggests that lessons learned from the application of the Eco Health approach should be taken into account in One Health policies, plans and research projects because biodiversity conservation and the dynamics ecosystems have received less attention in One Health research than human-animal interconnections in assessing disease risk. In fact, integrating the range of biodiversity-health interconnections in the One Health approach would give greater attention to preventive measures based on the strengthening of socio-ecological systems and broaden the concept of health. Furthermore, integration would contribute to the application of the One Health approach in the study and prevention of infectious (vector- and non-vector-borne), non-infectious diseases, food security, nutrition and other factors that contribute to biodiversity loss, such as climate changes (Convention on Biological Diversity, 2017).

To complete the One Health framework, reference should be made to the One Welfare approach: One Welfare serves to highlight the interconnections between animal welfare, human well-being and the environment (Pinillos et al., 2016). The concepts of Health and Well-being are also included among the goals of the 2030 Agenda for Sustainable Development. In particular, goal 3 "ensures healthy lives and promotes wellbeing for all at all ages" (United Nations, 2015). Although the 2030 Agenda neither recognizes nor explicitly states the contribution that good animal health and welfare can make to achieve the SDGs, there are interconnections between human health and well-being and animal health and welfare (Keeling et al., 2019). Indeed, some examples showing the possible interconnection between the two approaches are: improved animal welfare - improved food safety; improved animal and farmer welfare - improved farming productivity; improved animal welfare - improved food security and sustainability; improved biodiversity conservation, environmental aspects and human wellbeing (One Welfare). The first three examples cover all aspects links between animal welfare and food safety and security: situations of stress or poor animal welfare lead to an increase in the release and virulence of a series of infectious diseases (e.g. Salmonella) which risk leading to zoonoses. Furthermore, better animal welfare in farms implies better productivity, with positive effects on the breeding, on the welfare and health of the farmer and on the local economy (Pinillos et al., 2016). The last example comprises the links between environmental and conservation issues in relation to animal welfare/human wellbeing (One Welfare). Therefore, in addition to there being a need to integrate animal health and welfare into the SDGs (Keeling et al., 2019), it is evident as the One Welfare approach complements and extends the One Health approach, combining the concept of well-being with that of health and promoting choices that aim for a sustainable future (Pinillos et al., 2016)

Thus, in this review, a One Health approach have been chosen to investigate the consequences that biodiversity loss has on the health of humans, domestic animals and wild animals, focusing on emerging and re-emerging infectious diseases affecting these three groups. Indeed, as the Convention on Biological Diversity states, the One Health approach, through its holistic view, can contribute to understanding (and reducing) the risk of zoonotic diseases, vector-borne and non-vector-borne diseases, and the health and well-being of all (Convention on Biological diversity, 2022).

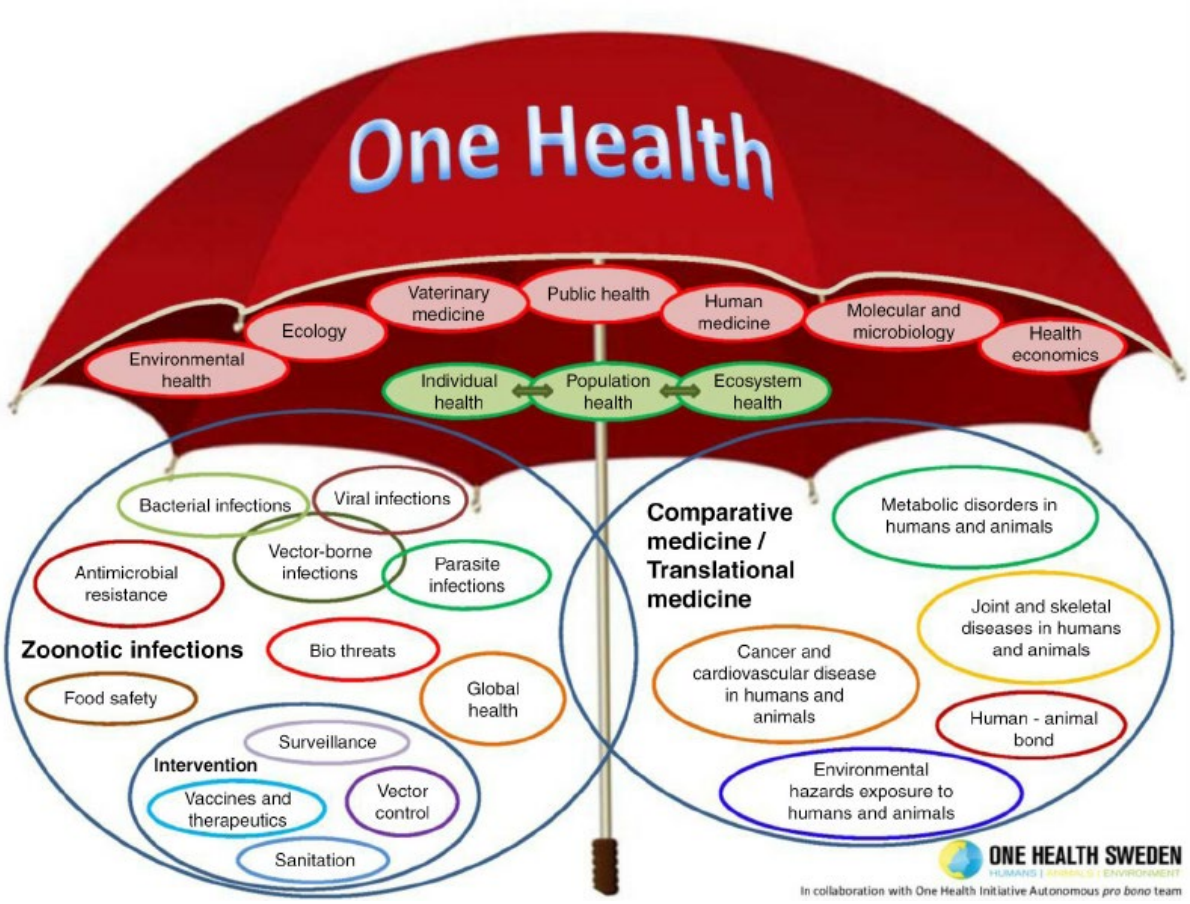

Fig.1 the One Health Umbrella
November 29, 2019 Available on www.onehealthinitiative.com

Biodiversity

The Convention on Biological Diversity defined Biological Diversity ("Biodiversity"), as the "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems." (Convention on Biological Diversity, 1992). This definition reflects different levels of biodiversity, including genetic diversity, species, ecosystems and the complexities of biotic and abiotic interactions (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015).

Biodiversity plays a fundamental role in the functioning of ecosystems and in the provision of goods and services essential to human and animal health and well-being. In fact, the conservation and sustainable use of biodiversity ensures services such as food, pollination, clean air, freshwater quantity and quality, climate regulation and environmental disasters, pest and disease regulation, medicines and even spiritual and cultural values (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). However, as biodiversity is declining globally, the loss of genetic and species diversity and the degradation of ecosystems compromise collective health, making it more vulnerable in many ways and

creating potential new opportunities for disease outbreaks (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020). Due to its decline and the environmental, social and economic consequences, Biodiversity was included in Sustainable Development Goals 14,15 of the 2030 Agenda for Sustainable Development. These goals are dedicated to "conserve and sustainably use the oceans, seas and marine resources for sustainable development"(Goal 14) and to "protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss" (Goal 15) (United Nation).

Methods

The aforementioned literature review writing process consists of five steps:

- Reading and understanding articles in the literature related to topics such as One Health, Eco Health, One welfare

- Choice of title and topic to be addressed based on the following keywords: **One Welfare**, **One biology**, **Conservation Medicine**, **One Health**, **Eco Health**, **wildlife**, **conservation**, **wildlife management**, **animal health** and **animal welfare**

- Writing of the initial part introducing the concepts of One Health and Biodiversity

- Writing of the middle part in which a One Health approach is used to highlight the correlation between biodiversity loss and human and animal health

- Writing the final part in which solutions are suggested to mitigate damage to human and animal health

This literature review is based on past and recent studies, scientific research and articles from the international literature, on topics such as One Health and Biodiversity. Most of the information comes from literature reviews and systematic reviews, but also from reports of international organisations (e.g. WWF, WHO, WOAH, IPBES etc.). The literature search strategy consisted of consulting databases such as "SLU University Library", "PubMed" and "Google Scholar"; the searches of official institutes were carried out on Google Chrome. The choice of articles was based on criteria such as language (English only), number of keywords searched (at least three keywords present), relevance of the title to the topic searched and date. Regarding the latter criterion, the preferred range was between 2015 and 2023, but other dates were not excluded when the otherwise dated article could be useful for writing purposes. Thus, the dates of references are from 1992 (document containing the definition of Biodiversity) to 2023. This review has not a limited geographical area on which it focuses, on the contrary, due to the theme addressed. On the contrary, there are many comparisons between the various Nations. The searches have started on April 2023 and have ended on June 2023.

Loss of biodiversity: what it is caused by and what it entails

In accordance with the reports “Global Biodiversity Outlook 4” (GBO-4) by Secretariat of the Convention on Biological Diversity and "The Global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES” by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the main causes of biodiversity loss are dependent on human action. (Convention on Biological Diversity, 2014; IPBES, 2019). They are five and are interconnected with each other: degradation and fragmentation of natural habitats, overexploitation of biological resources, climate changes, pollution and invasive alien species. There are also indirect causes, which contribute in a limited way to the decline of biodiversity. They are the lack of awareness of biodiversity and its values; the frequent absence of biodiversity in accounting systems and in decisions on economic development and planning; the absence of financial incentives and patterns of consumption and production that determine how resources are used (Convention on Biological Diversity, 2014). Each of these causes has consequences on human, animals and ecosystem health and well-being.
Since, the consequences on collective health and well-being are many and often depend on several causes and not just one, this chapter contains a summary of the main consequences triggered by the main causes of biodiversity loss, in order to give a general idea of how biodiversity and health are closely related.

1. Degradation and fragmentation of natural habitats

The degradation of natural habitats is due to land use change. It represents the greatest threat to terrestrial, freshwater biodiversity and the second-most important threat to marine biodiversity for about 50 years. Some forms of land use change are urbanization, agricultural expansion and infrastructure expansion related to population growth. While, some forms of sea use are water abstraction (affecting freshwater ecosystems), coastal development and aquaculture (concerning marine ecosystems) (IPBES, 2019).
In general, human action has altered three-quarters of the earth's environment and about two-thirds of the marine environment, at the same time more than one-third of the world's land surface and almost 75% of freshwater resources are used for crop or livestock production (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020).
In particular, losses of intact ecosystems have occurred primarily in the tropics, where there are the highest levels of biodiversity on the planet. In fact, 100 million hectares of tropical forest were destroyed between 1980 and 2000 due to cattle ranches in Latin America (about 42 million hectares) and palm plantations in South East Asia (about 7.5 million hectares) (IPBES, 2019).

Consequences on health and wellbeing

The consequences of the destruction of natural habitats due to land use change affect both well-being and health.

On the one hand, growing urbanization has limited the interactions between humans and nature, depriving them of the physiological and psychological benefits that nature provides. In fact, interaction with nature, including pets and wild animals, helps relieve depression, anxiety and behavioural problems (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). It also helps reduce recovery times and improve recovery

outcomes for hospital patients (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). It increases physical activity levels and improve life expectancy by reducing the risk of several non-communicable diseases and improving the immune system (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). On the other hand, urban centres represent areas of rapid amplification of diseases due to the high population density and other factors. It may be vulnerable to disease and climate impacts, as heat gain from rural areas to the city centre (urban heat islands) provides high-risk habitats for disease vector arthropods (e.g. mosquitoes, vectors of dengue in Southeast Asia, Africa and Latin America)
(Daszak et al., 2020) In addition, city parks and gardens host animals such as squirrels, hedgehogs and rats, which live in high densities in close contact with humans and represent reservoirs of zoonotic agents (e.g. zoonotic pathogens transmitted by the rats: hantavirus, bacterium *Borrelia burgdorferi*) (Daszak et al., 2020; Environmental Health Safety). Another example is represented by the urban areas in Latin American: they are home to large numbers of feral dogs that favour the presence of sand flies and protozoa such as *Leishmania*, putting human and animal health at risk (Daszak et al., 2020).

With regard to land use change for agricultural production, it affects human and animal health through intensification of livestock farming. As the study conducted by Morand (2020) shows, the continuous increase in livestock herds seems to contribute to the number of recorded infectious outbreaks and to the increase in the number of threatened wildlife species, in the period from 2000 to 2016 (Morand, 2020). The expansion of livestock contributes to the spread of infectious agents responsible for numerous outbreaks (e.g. bovine tuberculosis, brucellosis, salmonellosis and other diseases) (Myers et al., 2013). They contribute trough cultural and agricultural practices, also increased potential host populations and contact rates between animals (Myers et al., 2013). In addition, where there is a major proximity between domestic and wild species there is a spillover risk. For example, in the early 2000s, there was in Asia the H5N1 avian influenza, caused by high rates of mixing between flocks and the contamination of bird breeding environments, which resulted in the deaths of millions of chickens and hundreds of people (Myers et al., 2013). Other problems arising from the expansion of livestock farms are the excessive use of antibiotics, both to prevent disease and to promote animal growth, and the reduced gene diversity within the farm, which affect animal and human health. Gene selection pressures, due to the use of antibiotics, can lead to the development of resistant strains that would pose risks to food safety and risks of zoonotic diseases (for the farmers and for their animals). These resistant pathogens can be transmitted through direct contact with treated animals, consumption of food and use of manure as fertilizer (Myers et al., 2013).
However, these last problems appear in a more or less limited way, depending on the geographical area and on the use of antibiotics and genetic selection' regulations.

In general, land use change is an important factor in disease transmission and occurrence (causing more than 30% of emerging infectious diseases), it has a large impact on the emergence of new zoonoses such as Ebola, dengue fever, yellow fever, malaria (Daszak et al., 2020). This is because phenomena dependent on land use change such as the degradation of natural habitats, the loss, replacement and homogenization of biodiversity, the influx of human populations into places once occupied by indigenous peoples, create new opportunities for contact among humans, livestock and wildlife (Daszak et al., 2020).

2. Overexploitation of biological resources

The overexploitation of biological resources refers to the direct exploitation of animals, plants and other living organisms through overhunting, overfishing, overgathering and logging, activities carried out in order to produce food and feed, materials (e.g. wood, leather, paper etc.), medicine, energy, ornamentals and to use the resources in ceremonies or rituals (IPBES, 2019; IPBES, 2022).

It represents the greatest threat to wild species in marine ecosystems and the second greatest threat in terrestrial and freshwater ecosystems (IPBES, 2022). Unsustainable fishing has increased the risk of extinction of sharks and rays (449 species of sharks and rays were considered threatened, out of 1199 assessed) (IPBES, 2022). Unsustainable hunting has threatened both wild mammals (669 species were considered threatened, out of 1341 assessed) and birds; deforestation threatens 12% of tree species while unsustainable harvesting is a major threat to plant groups such as cacti cycads and orchids (IPBES, 2022).

The overexploitation of biological resources is also associated with the smuggling of dead and alive wild animals. Often these species are rare or protected and illegal trade threatens them starting from the ways in which they are captured and the conditions of transport (WWF, 2018).

Consequences on health and wellbeing

The consequences of overexploitation due to over- hunting/ fishing and harvesting, deforestation and wildlife market affect both well-being and health.

The over-harvesting practices may threaten even non-target species and may alter ecological dynamics if carried out in an unsustainable manner (e.g. decreased seed dispersal potential and implications in the food chain concerning both humans and animals) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). The over-hunting/fishing and the over-harvesting cause local protein sources decrease (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). This decrease has a negative impact on the production of vaccines, medicines, traditional medicines, since they often derive from natural sources (penicillin, artemisinin, and digitalis) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2020; World Health Organization and the Secretariat of the Convention on Biological Diversity, 2015). As a result, health is at risk because many diseases that were once curable may no longer be curable due to a lack of medicines. Moreover, the lack of traditional medicines may also compromise the well-being of millions of people who rely on it not only for treatment, but also for daily routines, rituals and customs (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2015).

The decline of wild species due to exploitative practices also results in decrease of nutrients and inadequate nutrition. Wild species contribute to food production and food security in many agro-systems. Some species are much richer in vitamins, micronutrients and proteins than conventional domestic species, thus their decline poses a threat to the health and well-being of urban and especially rural communities, which are heavily dependent on them (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2015). One example is the rural communities of the Amazon rainforest and floodplains, which have been affected by the decline of large vertebrates such as the black caiman (*Melanosuchus niger*), the giant otter (*Pteronura brasiliensis*) and the white-lipped peccary (*Tayassu pecari*) (Campos-Silva et al., 2017). Speaking of large vertebrates, large mammals are the most targeted species for subsistence hunting (IPBES, 2022). This type of hunting, called 'selective hunting', which targets a particular species, can affect ecosystem structure and processes, even causing changes in the genetic structure of the species concerned (IPBES, 2022).

Furthermore, hunting in areas that have not previously been targeted for food supply (newly

established mining camps, in previously pristine habitat) and the subsequent consumption of wild meat may bring new risks of disease transmission associated with food (food-borne disease) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015).

The exploitation due to the wildlife market or the sale of wild and domestic species in the markets can cause the mixing and diffusion of their agents resulting in global epidemics (e.g. the outbreak of Severe Acute Respiratory Syndrome in 2003) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Indeed, frequent trade and the duration of transport represent sources of stress for animals that negatively affect their fitness, weakening their immune systems and increasing the likelihood of infection. During transport and during live animal markets, the mixing of species and the close contact with large groups of people circling to buy wild animals can generate spillover events and, like the case of SARS in 2002 or the recent SARS CoV19, zoonoses diseases (Daszak et al., 2020). Obviously, these risks increase where there is a lack of proper hygienic practices and the implementation of policies to control the protection of animals during transport and sale.

3. Climate changes

Climate change plays an increasingly important role in the loss of biodiversity. It is closely linked to the other causes both because it depends on some of them, such as the transformation of freshwater, marine and terrestrial landscapes, the overexploitation of biological resources and the pollution, and because it amplifies the impact of these, such as the invasion of alien species (European Commission, 2023; IPCC, 2018). In fact, the land use change and the deforestation have contributed to the release of greenhouse gases (GHG) (IPBES, 2019; Mikhaylov et al., 2020). The release of GHG causes temperatures to rise by about 1° C compared to pre-industrial times (0.2°C per decade) (IPCC, 2018), altered precipitation regimes, frequent extreme weather events (heat waves, cold waves, floods, droughts, hurricanes, tropical cyclones, heavy rain, and snowfalls) (Hashim & Hashim, 2015), oxygen depletion and acidification of aquatic environments. All of these phenomena adversely affect biodiversity (IPCC, 2018; European Commission, 2023). According to the report of the Intergovernmental Panel on Climate Change (IPCC) regarding global warming, the temperature increase between 1,5°C and 2°C, reachable between 2030 and 2052, would threaten the geographical area of several species. In fact, if the global temperature increases by 2°C, 18% of insects, 16% of plants and 8% of vertebrates, out of 105,000 studied, are at risk. Furthermore, the 2°C increase would amplify the impact that forest fires and the invasion of alien species have on biodiversity (IPCC, 2018).

Consequences on health and wellbeing

The consequences of extreme weather events due to climate change could have direct and indirect impact on wellbeing and health (Balbus et al., 2016).

They are influenced by local environmental conditions, level of economic development, income level and distribution, population density, food availability, pre-existing health status and the quality and availability of public health care (MedEC, 2020; WWF, 2022). Indeed, extreme events have a greater impact in areas that are more vulnerable geographically, such as Mediterranean region, considered hotspot climate change due to enhanced warming trend and precipitation decline (Cos et al., 2022; Chandler, 2020) or socio-economically, such some developing countries in the Asia Pacific region with high population growth rates (Hashim & Hashim, 2015). In addition, climate change and extreme events have a huge negatively effects

on the least industrialised, poorest populations due to lack of health infrastructure and access to care (WWF, 2022).

Extreme weather events, like heat waves, can exacerbate pre-existing pathological conditions in patients with diabetes or cardiovascular disease, particularly susceptible to heat stress (Balbus et al., 2016). High temperature also negatively affects obese people and people with mental illness (Balbus et al., 2016). With regard to the latter condition, mortality attributed to mental and behavioural disorders may increase during heatwaves in the elderly and in people taking psychotropic drugs, such as hypnotics, anxiolytics and antipsychotics, possibly due to the combined effect of high temperatures and disruptions in thermoregulation triggered by certain psychotropic drugs (Charlson et al., 2021). In addition, increased frequency and intensity of heat waves may negatively affect livestock health by causing metabolic alterations (e.g. rumen acidosis, alkalosis and ketosis), oxidative stress, immune suppression, compromising reproductive efficiency, production efficiency, animal welfare, facilitating the onset of infections and/or leading to an increased use of antibiotics (Lacetera, 2018). Heatwaves and other weather events also affect wild animals, such as fruit bats, considered among the most important mammalian reservoirs of potentially pandemic diseases (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015; Daszak et al., 2020). They are very sensitive to heat and a strong heat wave during the summer of 2014 in Australia killed 100,000 specimens, affecting the health of the volunteers who removed the carcasses (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). In general, the increase in global temperature has meant that vectors of diseases such as the *Aedes aegypti* mosquito, responsible for the transmission of yellow fever, dengue and chikungunya, and the tick, vector of diseases such as Crimean Congo haemorrhagic fever and Lyme disease, can find hospitable habitats even at higher latitudes and altitudes than in the past (Nel, 2022). In fact, for *Ixodes persulcatus* ticks, the increase in temperature has allowed them to expand into areas such as northern Russia, where there was an increase in tick-borne encephalitis from 1980 to 2009 (Nel, 2022).

Other extreme events caused the deaths of an estimated 600,000 people and billions of dollars in damage in the last decade of the 20th century (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Sea level rise can cause increased flooding and erosion of coastal ecosystems endangering coastal communities, increased salinization of coastal aquifers, disruption of storm water and sewage drainage endangering both water and food security (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). This type of event can affect people's health and well-being both during exposure and afterwards. For example, the immediate consequences of floods include physical injury and a high risk of mortality, due to drowning, electrocution, water-borne diseases and severe stress caused by the event (Marcelle et al., 2019). While, health impacts in the aftermath of the event may depend on the lack of electricity, water supply and limited access to health services (Marcelle et al., 2019). Animal health is also vulnerable to these events. Indeed, there is a high mortality rate during the initial event and livestock animals can become very stressed and aggressive with people who approach them (ECDC, 2021; LEGS, 2014). In addition, there can be considerable losses in terms of animal production and welfare (WOAH-e).

4. Pollution

Pollution is induced by various human activities, such as domestic, agricultural and industrial activities. All these actions threaten the environment, endangering collective health and biodiversity. In fact, pesticides and fertilizers for agriculture and heavy metals for industrial activities are released into the air and water, if they are in high concentration they become toxic

(Prakash & Verma, 2022). Gases released by the combustion of fossil fuels can remain in the air in the form of polluting particles, or fall to the ground in the form of acid rain, causing acidification of streams, lakes and forest soils (Prakash & Verma, 2022). Other big threats for the environment are plastic, microplastic and nanoplastic, oil spills and toxic dumping which have a strong negative effect on freshwater, marine water and soil quality (IPBES, 2019).
Pollutants affect biodiversity in different ways: changing the genetic heritage of populations through the chronic exposure of heavy metals' low doses (Saleh & Aglan, 2018); biomagnifying, with consequences on physiology, behaviour, reproductive success and survival rates in a wide variety of species (e.g. songbirds), and on their habitat (Sauer & Evers, 2015); contaminating soil, air and water (e.g. marine plastic pollution has affected at least 267 marine species) (IPBES, 2019).

Consequences on health and wellbeing

The consequences of environmental pollution pose many threats to well-being and health.

The release of gaseous and particulate matter into the atmosphere, such as sulphur dioxide (SO2), nitrogen oxide (NO2), carbon monoxide (CO), particulate matter (PM) and volatile organic compounds, caused by anthropogenic activities, has a great direct impact on human health (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). In fact these compounds cause and exacerbate pathological conditions such as asthma, pulmonary (e.g. chronic obstructive pulmonary disease) and cardiovascular diseases, various forms of cancer, and also affects the nervous system (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015; Balbus et al., 2016).They also affects health through damage to the environment. Some examples are acid rain, accumulation of particles in the leaves and damage plants and trees (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). These phenomena don't allow plants and trees to perform function as lowering air temperatures, reducing emissions of certain heat-dependent pollutants (evaporation of VOCs) and absorbing CO2, SO2 or NO2 (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015; UNECE). The ocean acidification dependent by the emissions of CO2, but also by the increase of water temperature, causes many aquatic organisms to invest additional energy to maintain their acid-base balance, metabolic processes or other biological functions, with consequences on growth, reproduction and survival (Falkenberg, 2020). It also facilitates the entry of invasive species resistant to high concentrations of CO2 such as Japanese algae (*Undaria pinnatifida*), "killer" algae (*Caulerpa taxifolia*), very toxic to native herbivores, and stinging jellyfish (*Pelagia noctiluca*, *Merrington, 2015*) . These changes can change the balance between species and affect collective health and well-being, through the consumption of seafood damaged by acidification of waters, breathing the air in the most affected coastal areas and also through physical and mental experiences in marine ecosystems (Falkenberg, 2020).

The excessive and prolonged exposure to pesticides, used to eliminate agricultural pests and vector insects, also have a negative impact on human and animal health (Rohr et al., 2019). In fact, they are often endocrine disrupters and have potential negative effects on the immune system of individuals who are exposed to them, for example, they reduce the ability to defend themselves against additional stressors (Rohr et al., 2019). Furthermore, in humans, they can contribute to cancers, child development disorders, birth defects, and miscarriages (Rohr et al., 2019). The use of pesticides also has an impact on collective well-being, as it poses a threat to both bird populations (which have declined by 20%-25% since pre-farming times) and insect populations, which both play the role of pollinators (Secretariats of the Basel, Rotterdam, Stockholm Conventions and the Minamata Convention on Mercury, 2021). Thus, their decline

grieves food crop yields and food supply, but above all the genetic diversity of wild plants, affecting ecosystem services such as medicines, fibre and construction materials, and also the recreational activities that ecosystems can offer (Secretariats of the Basel, Rotterdam, Stockholm Conventions and the Minamata Convention on Mercury, 2021). In addition, pesticides also influence the development of infectious diseases and do so both by altering the density of parasites, hosts or their natural enemies, and by increasing the resistance of vectors of pathogens to pesticides (Rohr et al., 2019).

The presence of mercury in the air, soil and water represents a serious threat to humans and animals, as it is a highly toxic heavy metal, which persists for a long time in the environment (Secretariats of the Basel, Rotterdam, Stockholm Conventions and the Minamata Convention on Mercury, 2021). It is easy to come into contact through the ingestion of contaminated food (fish and other marine species contaminated by methyl-mercury) and through the inhalation of mercury vapours. (Secretariats of the Basel, Rotterdam, Stockholm Conventions and the Minamata Convention on Mercury, 2021). Its neurotoxic action affects human brain development (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015) and the physiology, behaviour and reproductive success of many species of fish and fish-eating animals in both tropical and arctic ecosystems (Secretariats of the Basel, Rotterdam, Stockholm Conventions and the Minamata Convention on Mercury, 2021).

The phenomenon of eutrophication, caused by an excessive input of nutrients (e.g. phosphorus nitrogen) in freshwater and marine ecosystems generates and accelerates proliferation of harmful alga, increases the presences of cyanobacteria, contributes to the decline and loss of coral reefs in marine ecosystems, impacting health and well-being (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). With regard to algae, some species pose a threat to both animals and humans, who may come into direct contact with through exposure to contaminated water or through ingestion of poisoned shellfish and fish. (Trtanj et al., 2015). Examples of dangerous alga are the benthic algae *Gambierdiscus*, which produces toxins responsible for ciguatrea poisoning of fish and shellfish, the algae *Alexandrium*, which induces paralysis in shellfish, and the algae *Karenia brevis*, which can aerosolise in water droplets and cause acute respiratory illnesses or exacerbate pathological conditions in patients with respiratory diseases (e.g. asthma) (Trtanj et al., 2015). Regarding cyanobacteria, also known as blue-green algae (Trtanj et al., 2015), can produce cyanotoxins that affect the neuromuscular system (anatoxin a, saxitoxin) and the liver (microcystins, nodularin) and can be carcinogenic to vertebrates, including humans. (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Some of these toxins (myrcocystins) bioaccumulate in fish, mussels and zooplankton and reach humans or animals that feed on fish species through ingestion, while others are present in unpurified drinking water and represent a threat not only for the individual, but for the community (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). In fact, they can spread through medical facilities, as happened in 1996 in a dialysis center in Brazil, jeopardizing public health and collective well-being (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). About coral reef, its loss or decline, which also depends on the temperature, would cause very serious damage to the aquatic species that depend on it, to collective health and to services, such as food, coastal protection, medicines, safe harbours and recreational activities, which it offers to the communities, above all to the populations that inhabit the coast (UNFCCC, 2023). Furthermore, the coral reef contributes a limited amount of CO2 absorption; their loss would undermine the main carbon sinks (for example, seagrass beds) and cause the release of stored carbon (UNFCCC, 2023).

The release of antibiotics into the environment from hospitals, farms and aquaculture can contaminate water resources through manure, urban waste water and biosolids (Serwecińska, 2020; World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Their presence at subinhibitory concentrations causes antibiotics to function as signalling molecules, induce changes in bacterial gene expression and lead to biofilm formation (Serwecińska, 2020). In addition, subinhibitory concentrations of antibiotics for prolonged exposure can accelerate the development of antibiotic resistance genes (ARGs) in bacteria (e.g. *Pseudomonas*, *Staphylococcus*, *Salmonella*) through horizontal transfer of drug resistance genes, that pose risks to human and animal health (Serwecińska, 2020; World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). In fact, antibiotic resistance is a rapidly emerging threat to human health, but also to animal health, where the use of antibiotics is not prudent, since they cause deaths because of failure to treat common infections (Elmberg et al., 2017).
In addition, antibiotics released into the environment can also be absorbed by plants and interfere with the processes of photosynthesis, germination and development (Serwecińska, 2020).

5. Invasive alien species

Alien species are animals, plants or other organisms that invade spaces outside their natural ranges and endanger local biodiversity (IUCN, 2021a). Among the causes of this phenomenon are globalisation (the movement of people and goods around the world), climate change and the resulting extreme weather events (hurricanes, floods and droughts), which can encourage alien species to enter more favourable areas and at the same time decrease the resilience of habitats to invasions (IUCN, 2021a), also the illegal and unsustainable wildlife trade (WWF, 2006). Out of 21 countries, the number of invasive species has increased by 70% since 1970 (IPBES, 2019). The arrival of already widespread species to ecological communities and the lack of their natural enemies, or other limiting factors, have favoured their establishment and rapid spread, causing the decline of endemic species, the widespread erosion of differences between ecological communities in different places and the so-called biotic homogenisation phenomenon (IPBES, 2019; Polce et al., 2023). The International Union for Conservation of Nature (IUCN), with the Invasive Species Specialist Group (ISSG) has created a list of "100 of the world's worst invasive alien species" (Lowe et al., 2000). In this list, there are one hundred species from more taxonomic groups, which have serious impact on biodiversity, human activities, such as agriculture, forestry or aquaculture, and collective health and wellbeing (Luque et al., 2013; Lowe et al., 2000). Some examples of invasive species on this list are the European red fox introduced in Australia and North America, the Argentine ant that has invaded sub-tropical and temperate regions, feral pigs and rats present on much of the world's territory, and other species are disease carriers (Lowe et al., 2000; ISSG, 2019).

Consequences on health and wellbeing

The consequences of introducing invasive species into the environment affect both health and well-being.

Although in specific cases invasive species can be a source of socio-economic gain, as in the case of the Red Sea rabbitfish and goatfish, which make Lebanon's blue economy more resilient, in general they represents a threat for native species, ecosystems and ecosystem

services, causing risk for collective health and wellbeing (FAO, 2022; Pyšek & Richardson, 2010). Indeed, the decline of native species implies the loss of ecosystem services (food and fibre supply, traditional medicines, cultural and recreational activities) causing a large negative effect on the well-being of humans, especially on indigenous or rural populations, closely interconnected with nature, and on the well-being of local species which must compete with non-local species for space, food and other resources (Pyšek & Richardson, 2010; World Health Organization and Secretariat of the Convention on Biological Diversity, 2015; FAO, 2022). Recording this, species like the European red foxes (*Vulpes vulpes*) and the Argentine ant (*Linepithema humile*) cause the decline of species native to the places where they have been introduced (WWF, 2020). In fact, the European red foxes, introduced in Australia and in temperate regions of North America, are dangerous to many native species such as smaller canids, ground-nesting birds in North America, and many small rodent and marsupial species in Australia (WWF, 2020). The Argentine ant poses a serious threat to the survival of various arthropods endemic to Hawaii, both insects and crustaceans, and replaces native ants, important seed dispersers or plant pollinators, due to its different genetic and social composition, which gives it a higher level of invasiveness, resulting in a decrease in arthropods, especially native ants, and disruption of native ecosystems (IUCN, 2021a; ISSG, 2019). Other species, such as feral pigs, alter soil quality through grazing large areas of native vegetation and the spread of weeds, causing direct and indirect damage to crops, property and livestock (Lowe et al., 2000; World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). In the case of wild pigs, even their eradication would have negative effects on human well-being, as there are communities that appreciate them for hunting and food and therefore do not want to deprive themselves of them (Lowe et al., 2000).

Furthermore, the introduction of the alien species can pose risks to human and animal health, for example the Asian gypsy moth (*Lymantria dispar*), which has invaded the northern hemisphere, as well as having a negative impact on shrubs of different types (shade, fruit and ornamental trees), causes allergies in some people through stinging hairs on larvae and egg masses (Pyšek & Richardson, 2010, ISSG, 2019). Instead, some species, such as the aforementioned feral pig and rats, are carriers of infectious diseases and jeopardize both human and animal health (Lowe et al., 2000; IUNC, 2021a). In fact, feral pigs can transmit zoonotic diseases such as Leptospirosis and Trichinellosis or diseases such as foot and mouth disease (FMD), a severe contagious viral disease in cows, sheep, goats, deer, pigs and other animal with divided hooves (Lowe et al., 2000.; WOAH-l; USDA, 2013). Regarding the rat, the ship rat (*Rattus rattus*), native to the Indian subcontinent, is now widespread throughout the world and its presence is associated with the catastrophic decline of island birds. It poses a threat to the health of humans and pets as it carries diseases such as the plague (IUCN, 2021a; ISSG, 2019; CDC, 2019d).

Emerging infectious disease and re-emerging infectious disease: threats to humans, domestic and wild animals

Declining biodiversity can increase the risk of transmission of pathogens, such as viruses, bacteria or parasitic animals, between different species, including humans (Daszak et al., 2020; World Health Organization and the Secretariat of the Convention on Biological Diversity,

2020). Risk drivers comprise increased direct contact and indirect contact (e.g. trough vectors) between wildlife, livestock and people, and loss of species density and diversity (Daszak et al., 2020; Keesing et al., 2010). Recording the first driver, it is caused by human activities such as degradation and loss of natural habitats, exploitation and unsafe sale of animal species, climate change, air, water and soil pollution, and the introduction of alien species into new habitats (Daszak et al., 2020; World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Concerning the second driver, the loss of density of species that compete with the host species of the pathogen increases the quantity of the host species and, therefore, increases the transmission of the pathogen (Daszak et al., 2020; Myers et al., 2013; Keesing et al., 2010). While, the loss of suboptimal species, or incompetent species for the pathogen, understood as the loss of species diversity, increases the transmission of the pathogen through the host species, or competent species (Van Langevelde et al., 2020; Daszak et al., 2020; Myers et al., 2013; Keesing et al., 2010). In this way the dilution effect is eliminated, according to which a greater diversity of intermediate hosts can dilute the pool of competent hosts, which amplify the transmission of the pathogen (Myers et al., 2013).

Due to increased contact between species and loss of species density and diversity, the transmitted pathogen, evolved into new strains, can find new competent hosts and perform a species spillover (Daszak et al., 2020; Keesing et al., 2010). Once spillover of the pathogen into a new host has occurred, the high densities of that host species may facilitate the establishment and transmission of the pathogen within the new host population as a whole (Keesing et al., 2010). If the pathogen is transmitted from animals to humans, the infection is referred to as Zoonosis or Anthropozoonosis, whereas if it is transmitted from humans to animals, the infection is referred to as Zooanthroponosis (Daszak et al., 2020). There are pathogens that require a vector to pass from one host to another, such as mosquitoes, ticks, sandflies, triatomine bugs, tsetse flies, fleas, black flies, aquatic snails and lice (Marcelle et al., 2019). The infections they cause are called vector-borne diseases and can be transmitted from animals to humans and between humans (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020; World Health Organization, 2017).

Thus, the loss of biodiversity is closely correlated with emerging or re-emerging of infectious diseases (Daszak et al., 2020; Keesing et al., 2010). With regard to these infectious diseases, European Commission defines Emerging and Re-Emerging Diseases (EIDs) “infections that have newly appeared in a population or have existed previously but are rapidly increasing in incidence or geographic range” (European Commission). They cause major public health problems either locally or globally and pose threats to domestic and wild animals’ health and welfare. In fact, most EIDs have a zoonotic origin (up to 75%), for example Hendra virus diseases, Nipah virus disease, Leishmaniosis, Cholera and Leptospirosis [Table1] (Wang et al., 2021; World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020; Van Langevelde et al., 2020). Of the zoonoses, many originate from wildlife (about 70 %), such as SARS CoV-19, Ebola haemorrhagic fever, Malaria, Lyme disease and plague [Table2], while others can come from domestic animals and intensive animal husbandry, like avian influenza (H5N1 e H7N7), swine influenza, Cryptosporidiosis, Brucellosis and Q fever [Table 3] (Spernovasilis et al., 2022; Wang et al., 2021; World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020; Shinwari et al., 2012). There is also a large number of EIDs affecting domestic animals and wildlife, such as African Swine Fever (ASF), Canine distemper and East Coast Fever (ECF) [Table 4], and a proportion of emerging infectious diseases due to various multi-drug resistant microorganisms related to the overuse and misuse of antibiotics, for example MRSA (Methicillin-resistant Staphylococcus aureus), ESBLl-Enterobacteriaceae and Multidrug-resistant tuberculosis

infections [Table 5] (Kolakowski et al., 2022; Spernovasilis et al., 2022; Wang et al., 2021; Daszak et al., 2020; Van Langevelde et al., 2020; Sánchez-Cordón et al., 2018; Daszak, 2000). They can be transmitted through direct contact, aerosol droplets, water, food, vectors and/or fomites (Spernovasilis et al., 2022).

Although most zoonotic diseases originate from wildlife, wildlife as a source of human diseases is often indirect. Indeed, domestic animals can act as amplifiers of pathogens, whose reservoirs are wild animals, and potentially transmit diseases to humans, given the generally closer contact between them and humans (Convention on Biological Diversity, 2017). However, wild animals may contribute to the spread of antibiotic-resistant bacteria, as they often come into contact with antibiotics released into the environment by human activities (Laborda et al., 2022).

Table 1. Examples of zoonotic emerging and re-emerging infectious disease (EIDs)

DISEASES	PATHOGEN	HOSTS	MAIN GEOGRAPHICAL AREA	FACTORS ASSOCIATED	REFERENCE
Hendra virus diseases	**Hendra virus**	Reservoir host: **Bat fruit** Host: **Horses**, **Human**	**Australia** **Papua New Guinea**	**Land use change**	(Daszak et al., 2020) (Daszak, 2000)
Nipah virus disease	**Nipa virus**	Reservoir host: **Bat fruit** Host: **Domestic pigs**, **dogs**, **Human**	**Malaysia** **Singapore**	**Agricultural intensification**	(Daszak et al., 2020) (Daszak, 2000)
Leishmaniosis	***Leishmania* spp.**	Vector: **Female phlebotomine sandflies** Reservoir host: **Rodents** Host: **Dogs**, **Human**	**African Region** **Region of the Americas** **Eastern Mediterranean Region** **European Region** **South-East Asia Region**	**Increasing urbanization** **Environmental and climate changes** **Population mobility** **Socioeconomic conditions**	(World Health Organization, 2022a) (Daszak et al., 2020)
Cholera	***Vibrio cholerae***	Reservoir host: **Aquatic copepods**, **algae**, **crustacea** Host: **Birds**, **Terrestrial herbivores**, **Human**	**Tropical Southeast Asia** **Africa** **Americas**	**Rising Ocean temperature** **Extreme environmental events** **Ingestion of not security food and water**	(World Health Organization, 2022) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015) (Trtanj et al., 2015) (Wolfe et al., 2007)
Leptospirosis	***Leptospira* spp.**	Reservoir host: **Rodents**, **Cattle**, **Buffaloes**, **Horses**, **Sheep**, **Goat**, **Pigs**,**Dogs** Host: **Human**	**South-East Asia Region**	**Extreme environmental events** **Ingestion of not security food and water**	(Van Langevelde et al., 2020) (World Health Organization, 2009)

Table 2. Examples of zoonotic emerging and re-emerging infectious disease (EIDs) with wild animals

DISEASE	PATHOGEN	HOSTS	MAIN GEOGRAPHICAL AREA	FACTORS ASSOCIATED	REFERENCE
SARS CoV-19	**COVID-19**	Reservoir host: **Insectivorous Bat** Host: **Mink**, **Ferrets**, **Civets**, **Lions**, **Tigers**, **Pangolins**, **Cats**, **Dogs**, **Human**	**Panglobal**	**Trade and consumption of wildlife** **Population mobility**	(Daszak etal.,2020)
Ebola	**Ebola virus**	Reservoir host: **Insectivorous** or **Fruit Bat** Host: **Nonhuman Primates**, **Human**	**Sub-Saharan Africa** **Indonesia** **Philippines**	**Hunting, farming and butchering wildlife** **Contact with infected human or nonhuman carcasses or patients**	(Daszak etal.,2020) (Daszak, 2000)
Malaria	***Plasmodium* spp.**	Vector: **Mosquito (genus *Anopheles*)**, **Snail** Reservoir host: **Nonhuman primates (uncertain)** Host: **Nonhuman primate**, **Human**	**South America** **Sub-Saharan Africa**	**Agricultural intensification** **Rising global temperature** **Deforestation and habitat encroachment**	(Su & Wu, 2021) (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020) (Daszak et al.,2020) (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015)
Lyme disease	***Borrelia* spp.**	Vector: **Ticks** Reservoir host: **White-footed mice, Eastern chipmunks, Short-tailed shrews** Host: **Human**	**North America** **North Europe**	**Rising global temperature** **Habitat fragmentation**	(Van Langevelde et al., 2020) (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020) (Daszak et al.,2020)
Plague	***Yersinia pestis***	Vector: **Fleas** Reservoir host: **Rodents** Host: **Human**	**Panglobal** **India (notably)** **South Western America (notably)**	**Enzootic foci are remnant of last panzootic outbreak in early 1900s**	(Van Langevelde et al., 2020) (Daszak, 2000)

Table 3. Examples of zoonotic emerging and re-emerging infectious diseases (EIDs) with prevalent domestic animals origin

DISEASE	PATHOGEN	HOSTS	MAIN GEOGRAPHICAL AREA	FACTORS ASSOCIATED	REFERENCE
Avian influenza	**H5N1, H7N7 influenza virus**	Reservoir host: **Turkeys, Layers, Broilers, Poultry** Host: **Human**	**Asia** **South Africa**	**Deforestation and habitat encroachment** **Live animal market** **Intensified poultry production**	(Van Langevelde et al., 2020) (World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020) (Daszak, 2020)
Swine influenza	**H1N1 influenza virus**	Reservoir host: **Pigs** Host: **Turkeys**, **Human**	**North and South America** **Europe** **Parts of Asia** **Africa**	**Intensified livestock production**	(Van Langevelde et al., 2020) (WOAH-j)
Cryptosporidiosis	***Cryptosporidium parvum***	Reservoir host: **Cattle, Buffalos** Host: **Livestock**, **Poultry**, **Companion Animal**, **Human**	**Sub-Sarharan Africa** **South-East Asia**	**Ingestion of not security food and water**	(Van Langevelde et al., 2020) (WOAH-d)
Brucellosis	***Brucella* spp**	**Sheep**, **Goat**, **Cattle**, **Pigs**, **Horses**, **Human**	**South Europe** **South America** **Africa** **Asia**	**Intensified livestock production** **Ingestion of not security food (milk)**	(Van Langevelde et al., 2020) (WOAH-c)
Q fever	***Coxiella burnetii***	Vector: **Ticks** Host: **Cattle**, **Sheep**, **Goat**, **Human**	**Australia** **New Zealand**	**Intensified livestock production** **Ingestion of not security food (milk)**	(Van Langevelde et al., 2020) (WOAH-h)

Table 4. Examples of emerging and re-emerging infectious diseases (EIDs) affecting domestic animals and wild animals

DISEASE	PATHOGEN	HOSTS	MAIN GEOGRAPHICAL AREA	FACTORS ASSOCIATED	REFERENCE
East Coast Fever	***Theileria* spp**	Vector: **Ticks** Host: **Cattle**	**Sub-Sharhan Africa** **Europe** **Asia**	**Translocation of native animals in enzootic area** **Distribution of the tick vector**	(Kolakowski et al.,2022) (WOAH)
African Swine Fever	**African Swine Fever virus**	Reservoir host and Vector: **Soft Ticks** **Domestic pigs, wild pigs**	**Africa** **Europe** **Asia**	**Density of smallholder pig farming** **High wild boar density** **Human activity**	(WOAH) (Ruiz-Saenz et al., 2022) (Bergmann et al., 2021)
Canine distemper	**Canine distemper virus**	**Wide range of carnivores, including Domestic dog**	**USA** **Africa** **Asia** **Europe**	**Spillover from domesticated dogs**	(Martella et al.,2008) (Daszak, 2000)
Bluetongue	**Bluetongue virus**	Vector: **Culicoides midges** **Sheeps, Goats, Cattle, Buffaloes, Deer, Antilopes**	**Panglobal**	**Climate Change**	(WOAH, 2021b) (Daszak, 2020) (Maclachlan et al., 2019)
Amphibian Chytridiomycosis	***Batrachochytrium dendrobatidis***	**Amphibian species (e.g., anurans and salamanders)**	**Australia** **Central and North America**	**Climate change** **Introduction of invasive alien species**	(Miranda Paez et al., 2022) (Daszak, 2000)

Table 5. Examples of emerging multi-drug resistant microorganisms related to the overuse and misuse of antibiotics

DISEASE	PATHOGEN	HOSTS	MAIN GEOGRAPHICAL AREA	FACTORS ASSOCIATED	REFERENCE
MRSA	***Staphylococcus aureus***	**Pigs, Horses, Cattle, Ewe, Sheep, Dog, Cat, Bird Human**	**Americas Western Pacific Europe**	**Overuse of antibiotics Prolonged hospitalization Proximity between livestock and human Ingestion of not security food (meat, milk)**	(Hasanpour et al., 2023) (Siddiqui & Koirala, 2021) (Algammal et al., 2020) (Van Langevelde et al., 2020) (Mehndiratta & Bhalla, 2014)
ESBLl-Enterobacteriaceae	**Enterobacteriaceae**	**Poultry, Cows Pigs Human**	**Americas Europe Asia Africa**	**Overuse of antibiotics Hospitalization Proximity between livestock and human Ingestion of not security food (meat, milk)**	(Tseng et al., 2023) (Van Langevelde et al., 2020) (Widodo et al., 2020) (CDC, 2019b) (Klous et al., 2016)
Multidrug-resistant *Mycobacterium* spp.	***Mycobacterium tuberculosis*** ***Mycobacterium bovis***	**Cattle, Wildlife bovine Human**	**Asia Africa Russia Federation Europe (Ukraine)**	**Overuse of antibiotics Proximity between livestock and human Ingestion of not security food (meat, milk)**	(WOAH) (WHO, 2022) (World Health Organization, 2021) (Wang et al.,2021)

1. Zoonotic EIDs

Hendra virus diseases

Hendra virus infection is an important emerging zoonotic disease in Australia, characterised by high mortality rates (Yuen et al., 2021). HeV belongs to the family *Parmayxoviridae* and it pleomorphic, enveloped virus containing a single stranded, negative-sense, and unsegmented ribonucleic acid (RNA) genome. Its natural host is the fruit bat, such as the Australian flying-fox (*Pteropus conspicillatus* and *Pteropus alecto*) but spillover events have allowed the virus to infect horses and humans (Yuen et al., 2021; Degeling et al., 2018). It causes severe respiratory and neurological damage in horses and humans. In horses, there are symptoms such as tachypnoea or frothy nasal discharge (respiratory symptoms) and ataxia, head tilt, circling, depression or recumbence (neurological symptoms) (WOAH-f). In humans the mortality rate is high (57%) and the symptoms are respiratory illness with severe flu-like signs and illness may progress to encephalitis (CDC, 2019c). The risk factors associated with the emergence of this zoonosis are closely related to the loss of biodiversity. Indeed, the loss of natural habitats, such as forests in northern Australia, climate change affecting the flowering of trees on which bats feed, and the depletion of native natural sources contribute to the displacement of bats into agricultural and peri-urban areas, increasing the risk of Hendra virus transmission in equine and human populations. In addition, depletion of food sources (e.g. nectar from eucalyptus trees) can lead to nutritional stress that impacts on bat health, thus increasing viral shedding and seroconversion of the virus (Yuen et al., 2021; Degeling et al., 2018).

Malaria

Malaria is a re-emerging infection caused by Plasmodium spp. (*Plasmodium facliparum*, *P. vivax*, *P.ovale*, *P.malariae*, etc.) and transmitted to humans through the bites of female *Anopheles* mosquitoes (Chala & Hamde, 2021). Its prevalence is in Africa, where there is the highest mortality rate (80 % in 2017) (Chala & Hamde, 2021). Symptoms of the disease usually occur within 10-15 days of contact with the vector and the most common ones are fever, headache and chills, while other symptoms can be severe illness (e.g. extreme tiredness and fatigue, impaired consciousness, multiple convulsions, difficulty breathing, dark or bloody urine, jaundice and abnormal bleeding) and death, especially in those most at risk such as children, pregnant women or people with compromised immune systems (World Health Organization, 2023). The emergence of vector-borne diseases, such as malaria, appears to be associated with climatic factors and the loss of natural habitats (Chala & Hamde, 2021). In fact, the global rise in temperatures, deforestation and land use change, such as the construction of dams and irrigation systems can increase the spread of vector mosquitoes, which prefer warm and humid areas (Chala & Hamde, 2021; World Health Organization and the Secretariat of the Convention on Biological Diversity, 2020). Due to the increase in temperatures, rainfall and humidity, mosquitoes could proliferate even in higher latitudes, where they have never been reported before, or they could grow faster in lower latitudes, where they have always been, increasing the transmission of the pathogen (S.D. Fernando, 2015). Concerning deforestation, deforestation activities in Africa, Asia and Latin America are correlated to an increase of malaria in these countries, probably because the converted lands often include more areas of stagnant water, necessary for the reproduction of the mosquitoes (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015).

Brucellosis

Brucellosis is one of the most widespread zoonoses in the world and it caused by the Gram – negative bacterium belonging to the genus *Brucella* (*Brucella abortus*, *B. melitensis, B. suis*) (Ducrotoy et al., 2015). *Brucella* infects human, cattle, pigs, sheep and goats, but also wild boars and camels. In the domestic animals listed above, the bacterium mainly causes abortion, in pregnant female specimens, and infertility in both male and female specimens, which can be infected through abortion products and birthing materials, or through vertical and sexual transmission, or through lactation transmission (WOAH; Ducrotoy et al., 2015). Instead, it provokes in human flu-like illness with fever, weakness, malaise, myalgia and weight loss, and it can be transmitted by the livestock through contact with infected food-producing animals, consumption of contaminated food products or via inhalation of bacteria in aerosols (WOAH; Ducrotoy et al., 2015). The intensification of livestock farming can be a risk factor for the re-emergence of brucellosis, due to the density of animals and proximity to humans (Vets, Sheepherders, Lab technicians) (Van Langevelde et al., 2020; Ducrotoy et al., 2015). However, this risk factor is to be considered relative to conditions in which hygiene regulations are not respected.

Although, both wild animals (wild boars, camels) and domestic animals (cattle, pigs, sheep and goats) can transmitter the bacterium *Brucella* to humans, in this case paragraph domestic animals are represented as the main origin of Brucellosis zoonosis, on the basis of some articles in the literature (Van Langevelde et al., 2020; Klous et al., 2016).

2. EIDs affecting domestic animals and wild animals

East Coast Fever

Theileleriosis, also known as East Coast Fever (ECF), is a neglected infectious disease caused by a re-emerging protozoan *Theileria* spp., which is transmitted to cattle by the tick *Rhipicephalus* spp. (Kolakowski et al.,2022). *Theileria parva* represents one of the biggest threats to bovines in Africa (from southern Sudan to eastern South Africa and as far west as the Democratic Republic of Congo) (Olwoch et al., 2008). Indeed, from an estimated 170 million cattle in 12 sub-Saharan countries in 2020, at least 40 million were at risk (Kolakowski et al.,2022). Instead, *Theileria annulata* is most present in South Europe (e.g. Menorca island) (WOAH-k). *Theileria* spp. generally cause a subclinical infection, or unqualifiable effects such as poor weight gain, low fertility rates, reduced growth and milk production, or paralysis (effects that also depend on the specimen's previous state of health), with consequences that also impact on the local economy (WOAH-l; Kolakowski et al.,2022; Olwoch et al., 2008). The distribution of the pathogen and the occurrence of ECF in new areas (e.g. north into Southern Sudan and western Cameroon) is strongly correlated with the spread of the tick and the movement of livestock, in turn influenced by climate change and probably other factors (host population size and density, habitat modification, vector control programmes and social environments) (Kolakowski et al., 2022; Olwoch et al., 2008).

African swine Fever

African swine fever (ASF) is a re-emerging infectious disease (Ruiz-Saenz et al., 2022) caused by the ASF virus, a large, complex, enveloped DNA virus characterised by high environmental stability (Bergmann et al., 2021). It affects wild and domestic pigs in more than 50 countries on three continents (Africa, Asia and Europe) and it can be transmitted in a directly or indirectly way: the directly way consists in physical contact between sick animals, contact trough excretions and secretions and through solely air contact; the indirectly way means through soft ticks (both reservoir of the virus and transmission vector), during tick feeding, and

contaminated fomites, feed, and drinking water (WOAH-b; Mazur-Panasiuk et al., 2019). Depending on the virus strain, whether it is more or less virulent, it can cause symptoms such as high fever, loss of appetite, haemorrhages on the skin and in internal organs, and death in 4-10 days (more virulent strain) or mild fever, reduced appetite and depression (WOAH-a). In addition to posing a threat to animal health and welfare, AFS severely harms pig production, trade in pigs and derived products, affecting the local economy and possibly social welfare (Bergmann et al., 2021). It also concern for biodiversity and the balances of ecosystem due to the potentially high mortality rate in eleven native wild pigs species (e.g. *Sus Barbatus*, *Sus philippensis*) that are edge of extinction (IUNC, 2021b). The risk factors for the spread of African swine fever may depend on the density of the animals, for example a high density of wild boars in endemic areas and a high density of domestic pigs on small farms, or on human action, which contributes to the spread of African swine fever virus from an infected area to an uninfected area, through the transport of contaminated products and materials, or through the release of waste containing traces of infected meat (WOAH, 2022; WOAH, 2021a; Bergmann et al., 2021).

Bluetongue

Bluetongue (BT) is a globally re-emerging infectious disease caused by the Bluetongue virus, a double-stranded RNA virus (Maclachlan et al., 2019). It is transmitted to wild and domestic animals (e.g. sheeps, goats, cattle, buffaloes, deer, and antilopes) primarly through a *Culicoides* midges, which can spread the virus among susceptible ruminants, having become infected by feeding on viraemic vertebrate host. It can be also transmitted through direct vertical, oral and possibly venereal transmission or through reused needles, but these last route of transmission remain uncertain (WOAH, 2021b). The symptoms of the disease depend on the viral strain and the infected species. Indeed in cattle, the infection is generally subclinical, with the exception of BTV-8 infection (WOAH, 2021b). While in sheep, deer and wild ruminants it can cause fatal diseases (WOAH, 2021b). In general, the clinical signs of BT are attributable to increased vascular permeability, comprising fever, hyperemia and congestion, edema and facial haemorrhages, erosion of mucous membranes and organs (WOAH, 2021b). Among the probable risks associated with the emergence and re-emergence of this disease in different geographical areas such as European (Mediterranean basin), American (United States of America and Canada), and Asian (South Korea) is climate change, which contributes to the spread of the virus by affecting the dynamics of midges and the vector capacity of indigenous midge populations, including those not considered competent vectors (Maclachlan et al., 2019; Purse et al., 2008).

3. EIDs due to overuse of antibiotics

In this section, overuse of antibiotics indicates a disproportionate use of antibiotics in both human and veterinary medicine and their dispersion in the environment. Before delving into the emerging issues related to antibiotic resistance, it should be noted that the use of antibiotics in veterinary medicine is regulated differently in different states. For example, Europe has banned the use of antibiotics as growth promoters in animal husbandry, thanks to the Regulation 1831/2003/EC on additives for use in animal nutrition, replacing Directive 70/524/EEC on additives in feeding-stuffs (EUR-Lex, 2003).

MRSA

Methicillin-resistant *Staphylococcus aureu*s (MRSA) is an emerging pathogen (Joffe et al., 2011) that causes serious problems in both humans and animals. In humans can cause food poisoning due to ingestion of contaminated food, pyogenic endocarditis, suppurative

pneumonia, otitis media, osteomyelitis and pyogenic skin and soft tissue infections (Algammal et al., 2020). While in animals, the symptomatology depends on the species: horses may develop a purulent infection and botryomycosis; cattle and sheep may develop a pyogenic infection and severe mastitis; dogs and cats may manifest pustular dermatitis or may become intoxicated by ingesting contaminated food; pigs can have an exudative epidermatitis (Algammal et al., 2020). Studies conducted by Wardyn et al. and published in the web journal "Journal of Wildlife Disease", report the presence of MRSA strains also in wild animals: white-tailed rabbits (*Sylvilagus floridanus*), Lesser Yellowhammers seabirds (*Tringa flavipes*), hamsters, chinchillas, turtles, squirrels and bats (Wardyn et al., 2012). In addition they and suggest that these animals may act as vectors of the bacterium for both domestic animals and humans (Wardyn et al., 2012). MRSA is present in the Americas (USA), Europe (e.g. Italy, France, and Spain) and in the West Pacific, where it poses a public health concern (Hasanpour et al., 2023). Risk factors related to the emergence of MRSA infections are the overuse of antibiotics in human medicine and the irrational non-therapeutic use of antibiotics in veterinary medicine (Mehndiratta & Bhalla, 2014). In addition, MRSA intensification may be associated to prolonged hospitalization and lack of correct hygienic practices in the hospital (Siddiqui & Koirala, 2021), but also to direct or indirect contact (e.g. contaminated food) between livestock human, infected by MRSA (Algammal et al., 2020; Klous et al., 2016).

ESBL- Enterobacteriaceae

Enterobacteria, such as *Escherichia coli* (E.coli), which produce the enzyme Extended-spectrum β-lactamases (ESBL), are resistant to β-lactam antibiotics (e.g. penicillin) (Tseng et al., 2023), antibiotics used also to treat human infections (urinary tract infections, pneumonia, sepsis), and therefore ESBL- Enterobacteriaceae pose a threat to human health (Widodo et al., 2020). Livestock animals such as cows, pigs and poultry are the main reservoirs of this pathogen (Widodo et al., 2020). But, wild animals such as vampire bats, wild ungulates and wild birds can also act as host reservoirs, which is normally not exposed to clinically used antimicrobial agents and they can acquire antimicrobial resistant bacteria through contact with humans, domesticated animals and the environment (Tseng et al., 2023; Guenther et al., 2011). As a recent study of Tseng et al., shows, ESBL-producing enterobacteria are widespread throughout the world, and have been found in Africa (Egypt, Kenya, Tunisia), Asia (Pakistan, India, Qatar), Europe (Finland, Germany, Spain) and the Americas (USA, Brazil, Peru) (Tseng et al., 2023). The great spread of these pathogens resistant to beta-lactam antibiotics is due to the abuse of antibiotics, which has allowed bacteria to evolve and develop resistance to certain drugs (Tseng et al., 2023). Also hospital practices and direct and indirect contact between humans and both domestic and wild animals can contribute to the spread, for example through contaminated food and water (Widodo et al., 2020; Klous et al., 2016). In fact, as far as domestic animals are concerned, they contribute to the spread of the bacterium mainly through the food chain and the production of potentially infected faeces (Widodo et al., 2020). While, wild animals can act as amplifiers and, as in the case of migrating wild birds, spread rapidly and for long distance the pathogen (Guenther et al., 2011).

Multidrug-resistant tuberculosis

The emergence of mycobacteria that are resistant to multiple drugs used to treat tuberculosis (multidrug resistant tuberculosis, MDR- TB), such as isoniazid (INH) and rifampicin (RIF), poses a threat to human and animal health (Borham et al., 2022). Indeed the increased incidence of MDR-TB is correlated with a resurgence of tuberculosis in different geographical areas (World Health Organization, 2022b; Borham et al., 2022; Xi et al., 2022). *Mycobacterium tuberculosis* (MTB) is the aetiological agent of human tuberculosis, it can be transmitted from person to person or from person to animal, in fact it has been identified in diseased cattle in

Ethiopia, Nigeria, Egypt and India (Borham et al., 2022). On the other hand, *Mycobacterium bovis* (bTB) is the aetiological agent of bovine tuberculosis; it can affect domestic animals such as cows, wild animals, for example buffaloes or species under strict protection, such as European bison or African elephants, and humans, in fact it is a zoonotic agent (Borham et al., 2022) and it is naturally resistant to pyrazinamide (WOAH-i). These pathogens can affect the lugs, extrapulmonary sites, including lymph nodes and the other organs of the mammals and adversely affect milk and meat production in domestic animals, causing also an economic and social issue (WOAH-i; Borham et al., 2022). For this reason MDR-TB represent a treat for the public health and for the welfare. According with the World Health Organization it is widespread in different country, including (China, Ethiopia, Russia, and Ukraine) (World Health Organization, 2021). Drug-resistant TB may due to the drugs used to treat TB are misused or mismanaged (e.g. wrong dose or length time, not complete full course of TB treatment) (CDC 2019a). Transmission of resistant strains can be influenced by proximity between humans and animals, either through direct contact (human-to-animal in the case of Mtb, animal-to-human in the case of bTB), especially in rural areas where humans live in close contact with animals, or through contamination of food (in the case of humans) or feed (in the case of animals). In addition, some wild animals such as the buffalo can become infected by domestic animals, act as a reservoir for the pathogen and transmit the disease to other species (Borham et al., 2022).

Solutions to preserve biodiversity and contain spillover and zoonoses

Understanding how biodiversity loss affects human and animal health and well-being is not enough to avoid future threats. Instead, it would be necessary to implement solutions that envisage the conservation of biodiversity, understood as the conservation of habitats and wild species, and at the same time, it is necessary to increase health promotion activities.
It is necessary to implement strategies that aim to preserve biodiversity, conserving natural habitat and wild species. It is possible through planning, monitoring, reporting and review activities related to biodiversity (Chen, 2022), or through veterinary and biotechnological practices, such as assisted reproduction and the use of pluripotent stem cells, practices also adopted by the BioRescue consortium to save he northern white rhino from extinction (BioRescue, 2022). In addition, it is necessary to manage human-wildlife conflict and generate coexistence of human and wild animals, thus sharing landscape and natural resources with wildlife in sustainable ways. In this regard, the members of IUCN SSC Human-Wildlife Conflict & Coexistence Specialist Group (HWCCSG) have written a guidelines that aims support human and wildlife coexistence though five principles: “Do no harm, Understand issues and context, Work together, Integrate science and policy and Enable sustainable pathways” (IUCN, 2023).
In order to restore natural ecosystems, preserve species from extinction and mitigating human-wildlife conflict, the United Nations has agreed on the “Kunming-Montreal Global Framework for Biodiversity” (GBF), which includes 4 goals and 23 targets to be achieved by 2030. These measures can be summarized as follows (Chen, 2022):

- Protecting 30% of the Earth's lands, oceans, coastal areas and inland waters;
- Halving food waste and reduce waste production; ensuring management action to halt human Induced extinction of known threatened species and for recovery and conservation of the species, and manage human-wildlife interaction to minimize conflict;

- Allocating $200 billion annually in domestic and international biodiversity-related funding reduce harmful government subsidies by $500 billion annually;
- Increasing international financial flows from developed countries to developing countries (small island developing states and countries in economies in transition);
- Requiring large transnational corporations to transparently monitor, evaluate and disclose the impacts they have on biodiversity

It is important to include the biodiversity issue in the development of policies, plans, programs and research in line with One Health approaches. In this regard, the Convention on Biological Diversity has provided an exhaustive guidance, highlighting the need to integrate biodiversity with the One Health approach, as the conservation of biodiversity and the health of ecosystems, as well as supporting a healthy environment and society, contribute to the achievement of social and development objectives (Convention on Biological Diversity, 2017).
Furthermore, as World Health Organization and Secretariat of the Convention on Biological Diversity suggest in their report "Connecting Global Priorities: Biodiversity and Human Health", it would be ideal find solutions that combine employment of health and environmental ministries for the implementation of environmental health programs and national biodiversity strategies and action plans (World Health Organization and Secretariat of the Convention on Biological Diversity, 2015). Proposed strategies include:

- Promoting the health benefits provided by biodiversity (food security and nutrition, water supply, medicines and traditional medicines, mental health, physical and cultural well-being);
- Encouraging lifestyles that can contribute to positive health and biodiversity outcomes; addressing factors that affect biodiversity and have direct or indirect impacts on health (loss of natural habitats, deforestation, extreme weather events, pollution, introduction of invasive species);
- Managing ecosystems by preventing their degradation to reduce the risks of infectious diseases (vector-borne or non-vector-borne zoonotic diseases).

The correlation between the loss of biodiversity and the emergence of infectious diseases is another problem that needs to be considered in species protection and health promotion policies. However, this is not straightforward, since there is no single factor that contributes to the spread of pathogens, spillover and emergence of disease. For this reason, Van Langevelde et al. in their report entitled "The link between biodiversity loss and the increasing spread of zoonotic diseases" propose to introduce policies by dividing them into sections: policy for areas with limited human influence, policy for areas under anthropogenic influence and policy related to hunting and wildlife trade (Van Langevelde et al. 2020). Since species richness can dispel the emergence of diseases, the first policy promotes the conservation of biodiversity in potential "hot spots" (tropical forests, wetlands) of wildlife pathogen emergence and in peri-urban protected areas. The second policy aims to reduce the likelihood of pathogens becoming established in a new host population or species through several strategies: increased health checks of livestock, especially those livestock most exposed to wildlife; host management with mitigation measures such as animal vaccinations (e.g. baits with vaccines); monitoring of invasive alien species, potential vectors or new reservoirs, and better reporting of their impact on human and animal health; public awareness and transition to green finance. Finally, the third policy does not aim to eliminate wildlife trade altogether, as many indigenous peoples and local communities depend on them for their livelihoods. Rather, it believes that it is better to increase

border controls on known zoonotic pathogens, enforce regulatory mechanisms at the national and international level, and closely monitor people working in wet markets, as only a few countries carry out strict veterinary checks on imports and there are no global regulations on screening for pathogens associated with international trade. It also emphasises the importance of education and awareness raising on animal handling, the risks of wild animals as food, hygiene conditions and disease transmission.

Conclusion

Biodiversity affects the health and well-being of humans, animals and the environment. The holistic One Health approach allows to examine these correlations under various aspects: loss of biodiversity and human health, loss of biodiversity and animal health, loss of biodiversity and social and economic repercussions, with consequences on the well-being of humans and animals. Thanks to increased awareness of biodiversity and its integration into the One Health approach, the level of biodiversity could serve as a parameter to assess health risks, prevent environmental damage and protect indigenous peoples or local communities that strongly depend on it. Furthermore, greater awareness of biodiversity could improve the community's perception of wild animals, often represented as the main source of zoonotic diseases or labelled as dangerous, and reflect on the role of viruses, bacteria and parasites in the emergence and re-emergence of infectious diseases. In fact, the emergence of diseases does not exclusively concern the relationship between domestic animals or wild animals and humans, but as the Convention on Biological Diversity states, it concerns "the complexity of the system as a whole and the interactions between biotic and abiotic components". If gene and species diversity are compromised or even lost, and natural habitats are degraded, the complexity of the whole system is altered and new opportunities for disease emergence are created (Convention on Biological Diversity, 2017). In conclusion, it would be necessary to combine strategies that manage the human-wild animal conflict and those that aim to preserve biodiversity, in order to protect the ecosystem, not to lose the services it offers and to limit the spread of disease pathogens.

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References

Algammal, A., Hetta, H. F., Elkelish, A., Alkhalifah, D., Hozzein, W., Batiha, G., Nahhas, N. E., & Mabrok, M. (2020, September 22). *Methicillin-Resistant Staphylococcus aureus (MRSA): One Health Perspective Approach to the Bacterium Epidemiology, Virulence Factors, Antibiotic-Resistance, and Zoonotic Impact*. Infection and Drug Resistance. https://www.dovepress.com/methicillin-resistant-staphylococcus-aureus-mrsa-one-health-perspectiv-peer-reviewed-fulltext-article-IDR

Balbus, J., Crimmins, A., Gamble, J. L., Easterling, D. R., Kunkel, K. E., Saha, S., & M.C. Sarofim. (2016). Ch. 1: Introduction: Climate Change and Human Health. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, 25–42. https://health2016.globalchange.gov/climate-change-and-human-health

Bergmann, H., Schulz, K., Conraths, F. J., & Sauter-Louis, C. (2021). A Review of Environmental Risk Factors for African Swine Fever in European Wild Boar. *Animals*, *11*(9), 2692. https://doi.org/10.3390/ani11092692

BioRescue. (2022, April 4). *Pluripotent stem cells from the northern white rhinoceros: BioRescue moves one step closer to artificial egg cells | Biorescue*. Www.biorescue.org. https://www.biorescue.org/en/news/pluripotent-stem-cells-northern-white-rhinoceros-biorescue-moves-one-step-closer-artificial

Borham, M., Oreiby, A., El-Gedawy, A., Hegazy, Y., Khalifa, H. O., Al-Gaabary, M., & Matsumoto, T. (2022). Review on Bovine Tuberculosis: An Emerging Disease Associated with Multidrug-Resistant Mycobacterium Species. *Pathogens*, *11*(7), 715. https://doi.org/10.3390/pathogens11070715

Buttke, D. E., Decker, D. J., & Wild, M. A. (2015). THE ROLE OF ONE HEALTH IN WILDLIFE CONSERVATION: A CHALLENGE AND OPPORTUNITY. *Journal of Wildlife Diseases*, *51*(1), 1–8. https://doi.org/10.7589/2014-01-004

Campos-Silva, J. V., Peres, C. A., Antunes, A. P., Valsecchi, J., & Pezzuti, J. (2017). Community-based population recovery of overexploited Amazonian wildlife. *Perspectives in Ecology and Conservation*, *15*(4), 266–270. https://doi.org/10.1016/j.pecon.2017.08.004

CDC. (2019a). *Drug-Resistant TB*. CDC. https://www.cdc.gov/tb/topic/drtb/default.htm

CDC. (2019b). *ESBL-producing Enterobacteriaceae*. Centers for Disease Control and Prevention. https://www.cdc.gov/hai/organisms/ESBL.html

CDC. (2019c, February 27). *Signs and Symptoms | Hendra Virus Disease | CDC*. Www.cdc.gov. https://www.cdc.gov/vhf/hendra/symptoms/index.html

CDC. (2019d, July 31). *Ecology and transmission of plague | CDC*. Centers for Disease Control and Prevention. https://www.cdc.gov/plague/transmission/index.html#:~:text=Many%20types%20of%20animals%2C%20such

Chala, B., & Hamde, F. (2021). Emerging and Re-emerging Vector-Borne Infectious Diseases and the Challenges for Control: A Review. *Frontiers in Public Health*, *9*. https://doi.org/10.3389/fpubh.2021.715759

Chandler , D. L. (2020, June 17). *Why the Mediterranean is a climate change hotspot*. MIT News | Massachusetts Institute of Technology. https://news.mit.edu/2020/why-mediterranean-climate-change-hotspot-0617

Charlson, F., Ali, S., Benmarhnia, T., Pearl, M., Massazza, A., Augustinavicius, J., & Scott, J. G. (2021). Climate Change and Mental Health: A Scoping Review. *International Journal of Environmental Research and Public Health*, *18*(9), 4486. https://doi.org/10.3390/ijerph18094486

Chen, Y. (2022, December 19). *Press Release: Nations Adopt Four Goals, 23 Targets for 2030 In Landmark UN Biodiversity Agreement*. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/blog/2022/12/press-release-nations-adopt-four-goals-23-targets-for-2030-in-landmark-un-biodiversity-agreement/

Colonius, T. J., & Earley, R. W. (2013). One welfare: a call to develop a broader framework of thought and action. *Journal of the American Veterinary Medical Association*, *242*(3), 309–310. https://doi.org/10.2460/javma.242.3.309

Convention on Biological Diversity. (2014). *Global Biodiversity Outlook*. https://www.cbd.int/gbo/gbo4/publication/gbo4-en-hr.pdf

Convention on Biological Diversity. (2017). *Agenda item 5 GUIDANCE ON INTEGRATING BIODIVERSITY CONSIDERATIONS INTO ONE HEALTH APPROACHES 1*. https://www.cbd.int/doc/c/8e34/8c61/a535d23833e68906c8c7551a/sbstta-21-09-en.pdf

Convention on Biological diversity. (2022). *DRAFT DECISIONS FOR THE FIFTEENTH MEETING OF THE CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY*. https://www.cbd.int/doc/c/c9de/d8ef/7225d7bb822f39ad3426c52b/cop-15-02-en.pdf

Convention on Biological Diversity . (1992). *CONVENTION ON BIOLOGICAL DIVERSITY UNITED NATIONS 1992*. https://www.cbd.int/doc/legal/cbd-en.pdf

Cos, J., Doblas-Reyes, F., Jury, M., Marcos, R., Bretonnière, P.-A., & Samsó, M. (2022). The Mediterranean climate change hotspot in the CMIP5 and CMIP6 projections. *Earth System Dynamics*, *13*(1), 321–340. https://doi.org/10.5194/esd-13-321-2022

Daszak, P. (2000). Emerging Infectious Diseases of Wildlife-- Threats to Biodiversity and Human Health. *Science*, *287*(5452), 443–449. https://doi.org/10.1126/science.287.5452.443

Daszak, P., Neves, D., Hayman, C., Roche, T., Buss, C., Dundarova, P., Feferholtz, H., Földvári, Y., Liu, S., Suzan, Q., Wannous, M., Woolaston, C., & Reidl, M. (2020). *Suggested citation IPBES (2020) Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services Photo credits*. https://doi.org/10.5281/zenodo.4147317

Degeling, C., Gilbert, G. L., Annand, E., Taylor, M., Walsh, M. G., Ward, M. P., Wilson, A., & Johnson, J. (2018). Managing the risk of Hendra virus spillover in Australia using ecological approaches: A report on three community juries. *PLOS ONE*, *13*(12), e0209798. https://doi.org/10.1371/journal.pone.0209798

Ducrotoy, M. J., Ammary, K., Ait Lbacha, H., Zouagui, Z., Mick, V., Prevost, L., Bryssinckx, W., Welburn, S. C., & Benkirane, A. (2015). Narrative overview of

animal and human brucellosis in Morocco: intensification of livestock production as a driver for emergence? *Infectious Diseases of Poverty*, *4*(1). https://doi.org/10.1186/s40249-015-0086-5

ECDC. (2021). *Extreme rainfall and catastrophic floods in western Europe*. https://www.ecdc.europa.eu/sites/default/files/documents/RRA-20210720-1799.pdf

Elmberg, J., Berg, C., Lerner, H., Waldenström, J., & Hessel, R. (2017). Potential disease transmission from wild geese and swans to livestock, poultry and humans: a review of the scientific literature from a One Health perspective. *Infection Ecology & Epidemiology*, *7*(1), 1300450. https://doi.org/10.1080/20008686.2017.1300450

Environmental Health Safety. (n.d.). *Zoonoses Associated with Wild*. Retrieved May 12, 2023, from https://ehs.princeton.edu/sites/g/files/toruqf5671/files/media_files/Zoonoses%20associated%20with%20Wild%20Rodents.pdf

EUR-Lex. (2003). *EUR-Lex - 32003R1831 - EN - EUR-Lex*. Eur-Lex.europa.eu. https://eur-lex.europa.eu/eli/reg/2003/1831/oj

European Commission. (n.d.). *Emerging and reemerging infectious diseases*. Research-And-Innovation.ec.europa.eu. https://research-and-innovation.ec.europa.eu/research-area/health/emerging-and-reemerging-infectious-diseases_en#:~:text=EU%20research%20in%20emerging%20and

European Commission . (2023, April 21). *Brief me on biodiversity, climate change and energy | Knowledge for policy*. Knowledge4policy.ec.europa.eu. https://knowledge4policy.ec.europa.eu/biodiversity/brief-me-biodiversity-climate-change-energy_en

Falkenberg, L. J. (2020). Ocean Acidification and Human Health. *International Journal of Environmental Research and Public Health*, *17*(12), 4563. https://doi.org/10.3390/ijerph17124563

FAO. (2022). *The State of Mediterranean and Black Sea Fisheries*. https://www.fao.org/3/cc3370en/cc3370en.pdf

Guenther, S., Ewers, C., & Wieler, L. H. (2011). Extended-Spectrum Beta-Lactamases Producing E. coli in Wildlife, yet Another Form of Environmental Pollution? *Frontiers in Microbiology*, *2*, 246. https://doi.org/10.3389/fmicb.2011.00246

Hasanpour, A. H., Sepidarkish, M., Mollalo, A., Ardekani, A., Almukhtar, M., Mechaal, A., Hosseini, S. R., Bayani, M., Javanian, M., & Rostami, A. (2023). The global prevalence of methicillin-resistant Staphylococcus aureus colonization in residents of elderly care centers: a systematic review and meta-analysis. *Antimicrobial Resistance & Infection Control*, *12*(1). https://doi.org/10.1186/s13756-023-01210-6

Hashim, J., & Hashim, Z. (2015). Climate Change, Extreme Weather Events, and Human Health Implications in the Asia Pacific Region. *Asia Pacific Journal of Public Health*, *28*(2), 8S14S. https://doi.org/10.1177/1010539515599030

IPBES. (2019). *The global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES SUMMARY FOR POLICYMAKERS SUMMARY FOR POLICYMAKERS OF THE IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES.*

https://www.ipbes.net/sites/default/files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf

IPBES. (2022, July 8). *Summary for policymakers of the thematic assessment of the sustainable use of wild species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)*. Zenodo. https://zenodo.org/record/7411847#.ZFpH4HbP1PY

IPCC. (2018). *Summary for Policymakers — Global Warming of 1.5 ºC*. IPCC; IPCC. https://www.ipcc.ch/sr15/chapter/spm/

ISSG. (2019). *GLOBAL INVASIVE SPECIES DATABASE*. Iucngisd.org. http://www.iucngisd.org/gisd/

IUCN. (2021a). *IUCN website IUCN issues briefs: Twitter: @IUCN iucn.org iucn.org/issues-briefs IUCN (International Union for Conservation of Nature) - INVASIVE ALIEN SPECIES AND CLIMATE CHANGE*. https://www.iucn.org/sites/default/files/2022-04/ias_and_climate_change_issues_brief_2021.pdf

IUCN. (2021b, August 23). *FAO, IUCN SSC and OIE warn of African swine fever impact on wildlife conservation | IUCN*. Www.iucn.org. https://www.iucn.org/news/species-survival-commission/202108/fao-iucn-ssc-and-oie-warn-african-swine-fever-impact-wildlife-conservation#:~:text=The%20impact%20of%20ASF%20on

IUCN. (2023). *IUCN SSC guidelines on human-wildlife conflict and coexistence : first edition*. Www.iucn.org. https://www.iucn.org/resources/publication/iucn-ssc-guidelines-human-wildlife-conflict-and-coexistence-first-edition

Joffe, H., Washer, P., & Solberg, C. (2011). Public engagement with emerging infectious disease: The case of MRSA in Britain. *Psychology & Health*, *26*(6), 667–683. https://doi.org/10.1080/08870441003763238

Keeling, L., Tunón, H., Olmos Antillón, G., Berg, C., Jones, M., Stuardo, L., Swanson, J., Wallenbeck, A., Winckler, C., & Blokhuis, H. (2019). Animal Welfare and the United Nations Sustainable Development Goals. *Frontiers in Veterinary Science*, *6*. https://doi.org/10.3389/fvets.2019.00336

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., Hudson, P., Jolles, A., Jones, K. E., Mitchell, C. E., Myers, S. S., Bogich, T., & Ostfeld, R. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, *468*(7324), 647–652. https://doi.org/10.1038/nature09575

Klous, G., Huss, A., Heederik, D. J. J., & Coutinho, R. A. (2016). Human–livestock contacts and their relationship to transmission of zoonotic pathogens, a systematic review of literature. *One Health*, *2*, 65–76. https://doi.org/10.1016/j.onehlt.2016.03.001

Kolakowski, J., Connelley, T., Lukacik, P., Pfuhl, M., & Werling, D. (2022). *East Coast fever, a neglected tropical disease with an outdated vaccine approach? 38*(11), 930–932. https://doi.org/10.1016/j.pt.2022.08.006

Laborda, P., Sanz-García, F., Ochoa-Sánchez, L. E., Gil-Gil, T., Hernando-Amado, S., & Martínez, J. L. (2022). Wildlife and Antibiotic Resistance. *Frontiers in Cellular and Infection Microbiology*, *12*. https://doi.org/10.3389/fcimb.2022.873989

Lacetera, N. (2018). Impact of climate change on animal health and welfare. *Animal Frontiers*, *9*(1), 26–31. https://doi.org/10.1093/af/vfy030

LEGS. (2014). *Livestock Emergency Guidelines and Standards (LEGS) Second edition*. https://www.livestock-emergency.net/wp-content/uploads/2021/09/LEGS-Handbook-2nd-edition-web-version-1.pdf

Lerner , H., Berg, C., Thys, S., & Levine, H. (2017). A Comparison of Three Holistic Approaches to Health: One Health, EcoHealth, and Planetary Health. *Vet. Sci*, *4*, 163. https://doi.org/10.3389/fvets.2017.00163

Lerner, H., & Berg, C. (2015). The concept of health in One Health and some practical implications for research and education: what is One Health? *Infection Ecology & Epidemiology*, *5*(1), 25300. https://doi.org/10.3402/iee.v5.25300

Lowe, Browne, Boudjelas, & De Poorter. (2000). *100 OF THE WORLD'S WORST INVASIVE ALIEN SPECIES A SELECTION FROM THE GLOBAL INVASIVE SPECIES DATABASE Published by In Association with Contribution to the Global Invasive Species Programme (GISP) SPECIES SURVIVAL COMMISSION*. https://portals.iucn.org/library/sites/library/files/documents/2000-126.pdf

Luque, G. M., Bellard, C., Bertelsmeier, C., Bonnaud, E., Genovesi, P., Simberloff, D., & Courchamp, F. (2013). The 100th of the world's worst invasive alien species. *Biological Invasions*, *16*(5), 981–985. https://doi.org/10.1007/s10530-013-0561-5

Machalaba, C. C., Loh, E. H., Daszak, P., & Karesh, W. B. (2015). Emerging Diseases from Animals. *State of the World 2015*, 105–116. https://doi.org/10.5822/978-1-61091-611-0_8

Maclachlan, N. J., Zientara, S., Wilson, W. C., Richt, J. A., & Savini, G. (2019). Bluetongue and epizootic hemorrhagic disease viruses: recent developments with these globally re-emerging arboviral infections of ruminants. *Current Opinion in Virology*, *34*, 56–62. https://doi.org/10.1016/j.coviro.2018.12.005

Marcelle, M., Stadler, J., Korn, H., Irvine, K. N., & Bonn, A. (Eds.). (2019). *Biodiversity and Health in the Face of Climate Change*. Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8

Martella, V., Elia, G., & Buonavoglia, C. (2008). Canine Distemper Virus. *Veterinary Clinics of North America: Small Animal Practice*, *38*(4), 787–797. https://doi.org/10.1016/j.cvsm.2008.02.007

Mazur-Panasiuk, N., Żmudzki, J., & Woźniakowski, G. (2019). African Swine Fever Virus – Persistence in Different Environmental Conditions and the Possibility of its Indirect Transmission. *Journal of Veterinary Research*, *63*(3), 303–310. https://doi.org/10.2478/jvetres-2019-0058

MedEC. (2020). *Climate and Environmental Change in the Mediterranean Basin - Current Situation and Risks for the Future*. MedECC. https://www.medecc.org/medecc-reports/climate-and-environmental-change-in-the-mediterranean-basin-current-situation-and-risks-for-the-future-1st-mediterranean-assessment-report/

Mehndiratta, P. L., & Bhalla, P. (2014). Use of antibiotics in animal agriculture & emergence of methicillin-resistant Staphylococcus aureus (MRSA) clones: need to assess the impact on public health. *The Indian Journal of Medical Research*, *140*(3), 339–344. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4248379/

Merrington, A. (2015, November). *Research suggests marine invasive species benefit from rising CO2 levels*. University of Plymouth.

https://www.plymouth.ac.uk/news/research-suggests-marine-invasive-species-benefit-from-rising-co2-levels

Mikhaylov, A., Moiseev, N., Aleshin, K., & Burkhardt, T. (2020, June). *Global climate change and greenhouse effect*. ResearchGate. https://www.researchgate.net/publication/342372335_Global_climate_change_and_greenhouse_effect

Morand, S. (2020). Emerging diseases, livestock expansion and biodiversity loss are positively related at global scale. *Biological Conservation*, *248*, 108707. https://doi.org/10.1016/j.biocon.2020.108707

Myers, S. S., Gaffikin, L., Golden, C. D., Ostfeld, R. S., H. Redford, K., H. Ricketts, T., Turner, W. R., & Osofsky, S. A. (2013). Human health impacts of ecosystem alteration. *Proceedings of the National Academy of Sciences*, *110*(47), 18753–18760. https://doi.org/10.1073/pnas.1218656110

Nel, J. (2022). Climate change and impact on infectious diseases. *Wits Journal of Clinical Medicine*, *4*(3), 129. https://doi.org/10.18772/26180197.2022.v4n3a1

Olwoch, J. M., Reyers, B., Engelbrecht, F. A., & Erasmus, B. F. N. (2008). Climate change and the tick-borne disease, Theileriosis (East Coast fever) in sub-Saharan Africa. *Journal of Arid Environments*, *72*(2), 108–120. https://doi.org/10.1016/j.jaridenv.2007.04.003

One Health Commission , O. H. C., & Global Reach Internet Productions, LLC - Ames, IA -. (n.d.). *What is One Health? - One Health Commission*. Www.onehealthcommission.org. https://www.onehealthcommission.org/en/why_one_health/what_is_one_health/#:~:text=Previous%20OHC%20definition%3A

One Health Initiative . (2019, November 29). *The One Health Umbrella*. One Health Initiative. https://onehealthinitiative.com/the-one-health-umbrella/

One Welfare. (n.d.). *One Welfare Conceptual Framework - Initial Proposal for Consultation*. One Welfare. Retrieved April 28, 2023, from https://www.onewelfareworld.org/book.html

Pinillos, R. G., Appleby, M. C., Manteca, X., Scott-Park, F., Smith, C., & Velarde, A. (2016). One Welfare – a platform for improving human and animal welfare. *Veterinary Record*, *179*(16), 412–413. https://doi.org/10.1136/vr.i5470

Polce, C., Cardoso, A. C., Deriu, I., Gervasini, E., Tsiamis, K., Vigiak, O., Zulian, G., & Maes, J. (2023). Invasive alien species of policy concerns show widespread patterns of invasion and potential pressure across European ecosystems. *Scientific Reports*, *13*(1), 8124. https://doi.org/10.1038/s41598-023-32993-8

Prakash, S., & Verma, A. K. (2022, March 3). *Anthropogenic Activities and Biodiversity Threats*. Papers.ssrn.com. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4048276

Purse, B., Brown, H., Harrup, L., Mertens, P., & Rogers, D. (2008). Invasion of bluetongue and other orbivirus infections into Europe: the role of biological and climatic processes. *Rev. Sci. Tech. Off. Int. Epiz*, *27*(2), 427–442. https://doc.woah.org/dyn/portal/digidoc.xhtml?statelessToken=9Jn0QH63n3hdrSeoW

QyGQkiob7UVwpyvCqI1mZ7QzR4=&actionMethod=dyn%2Fportal%2Fdigidoc.xhtml%3AdownloadAttachment.openStateless

Pyšek, P., & Richardson, D. M. (2010). Invasive Species, Environmental Change and Management, and Health. *Annual Review of Environment and Resources*, *35*(1), 25–55. https://doi.org/10.1146/annurev-environ-033009-095548

Redford, K. H., da Fonseca, G. A. B., Gascon, C., Rodriguez, C. M., Adams, J., Andelman, S., Barron, D. H., Batmanian, G., Bierbaum, R., Daszak, P., Daugherty, C., Griffin, J., Kemper, K., Lee, A., Long, B., Lovejoy, T. E., McCauley, D., Romanelli, C., Paxton, M., & Sekhran, N. (2022). Healthy planet healthy people. *Conservation Letters*, *15*(3). https://doi.org/10.1111/conl.12864

Rohr, J. R., Barrett, C. B., Civitello, D. J., Craft, M. E., Delius, B., DeLeo, G. A., Hudson, P. J., Jouanard, N., Nguyen, K. H., Ostfeld, R. S., Remais, J. V., Riveau, G., Sokolow, S. H., & Tilman, D. (2019). Emerging human infectious diseases and the links to global food production. *Nature Sustainability*, *2*(6), 445–456. https://doi.org/10.1038/s41893-019-0293-3

Ruiz-Saenz, J., Diaz, A., Bonilla-Aldana, D. K., Rodríguez-Morales, A. J., Martinez-Gutierrez, M., & Aguilar, P. V. (2022). African swine fever virus: A re-emerging threat to the swine industry and food security in the Americas. *Frontiers in Microbiology*, *13*. https://doi.org/10.3389/fmicb.2022.1011891

S.D. Fernando. (2015). *Climate Change and Malaria - A Complex Relationship | United Nations*. Un.org; United Nations. https://www.un.org/en/chronicle/article/climate-change-and-malaria-complex-relationship

Saleh, H. E.-D. M., & Aglan, R. (2018). Heavy Metals. In *Google Books*. BoD – Books on Demand. https://books.google.se/books?hl=it&lr=&id=dnuQDwAAQBAJ&oi=fnd&pg=PA383&dq=pollution+biodiversity+threat&ots=UXukXpbToT&sig=rEydrRR2Jft0w8YAcNqjQSIG3ew&redir_esc=y#v=onepage&q=pollution%20biodiversity%20threat&f=false

Sánchez-Cordón, P. J., Montoya, M., Reis, A. L., & Dixon, L. K. (2018). African swine fever: A re-emerging viral disease threatening the global pig industry. *The Veterinary Journal*, *233*, 41–48. https://doi.org/10.1016/j.tvjl.2017.12.025

Sauer, A., & Evers, D. (2015). Biodiversity Research Institute. *Adirondack Journal of Environmental Studies*, *20*(1). https://digitalworks.union.edu/ajes/vol20/iss1/13/

Secretariats of the Basel, Rotterdam, Stockholm Conventions (BRS), and the Minamata Convention on Mercury . (2021). *INTERLINKAGES BETWEEN THE CHEMICALS AND WASTE MULTILATERAL ENVIRONMENTAL AGREEMENTS AND BIODIVERSITY: KEY INSIGHTS.* https://www.mercuryconvention.org/sites/default/files/documents/2021-07/Biodiversity_Interlinkages_Key_Insights.pdf

Serwecińska, L. (2020). Antimicrobials and Antibiotic-Resistant Bacteria: A Risk to the Environment and to Public Health. *Water*, *12*(12), 3313. https://doi.org/10.3390/w12123313

Shinwari, Z., Gilani, A., & Latif Khan, A. (2012). BIODIVERSITY LOSS, EMERGING INFECTIOUS DISEASES AND IMPACT ON HUMAN AND CROPS. *Pak. J. Bot*, *44*, 137–142. https://www.pakbs.org/pjbot/PDFs/44(SI2)/19.pdf

Siddiqui, A. H., & Koirala, J. (2021). *Methicillin Resistant Staphylococcus Aureus*. PubMed; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK482221/#:~:text=The%20commonly%20associated%20risk%20factors

Spernovasilis, N., Tsiodras, S., & Poulakou, G. (2022). Emerging and Re-Emerging Infectious Diseases: Humankind's Companions and Competitors. *Microorganisms*, *10*(1), 98. https://doi.org/10.3390/microorganisms10010098

Su, X., & Wu, J. (2021). Zoonotic Transmission and Host Switches of Malaria Parasites. *Zoonoses*, *1*(1). https://doi.org/10.15212/zoonoses-2021-0015

Trtanj, J., L. Jantarasami, J. Brunkard, T. Collier, J. Jacobs, E. Lipp, S. McLellan, S. Moore, H. Paerl, J. Ravenscroft, M. Sengco, & J. Thurston. (2015). Ch. 6: Climate Impacts on Water-Related Illness. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, 157–188. https://health2016.globalchange.gov/water-related-illness

Tseng, C.-H., Liu, C.-W., & Liu, P.-Y. (2023). Extended-Spectrum β-Lactamases (ESBL) Producing Bacteria in Animals. *Antibiotics*, *12*(4), 661. https://doi.org/10.3390/antibiotics12040661

UNECE. (n.d.). *Air pollution, ecosystems and biodiversity | UNECE*. Unece.org. https://unece.org/air-pollution-ecosystems-and-biodiversity

UNFCCC. (2023). *Coral reef*. Unfccc.int. https://unfccc.int/blog/coral-reefs?gclid=Cj0KCQjwyLGjBhDKARIsAFRNgW8wQI_pA2BEowAi68wUAcw7UezVM1FHapaRstNoj0WRO1wq9CiebnkaAucQEALw_wcB

United Nation. (n.d.). *Biodiversity and ecosystems | Department of Economic and Social Affairs*. Sdgs.un.org. https://sdgs.un.org/topics/biodiversity-and-ecosystems

United Nations. (2015). Transforming Our World: the 2030 Agenda for Sustainable Development. In *United Nations*. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

USDA. (2013). *USDA APHIS | Foot and Mouth Disease*. Usda.gov. https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/fmd/index#:~:text=Foot%2Dand%2Dmouth%20disease%20(

Van Langevelde, F., René, H., Mendoza, R., Matson, K., Esser, H., De Boer, W., & Schindler, S. (2020). *The link between biodiversity loss and the increasing spread of zoonotic diseases Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies*. https://www.europarl.europa.eu/RegData/etudes/IDAN/2020/658217/IPOL_IDA(2020)658217_EN.pdf

Wang, W.-H., Thitithanyanont, A., Urbina, A. N., & Wang, S.-F. (2021). Emerging and Re-Emerging Diseases. *Pathogens*, *10*(7), 827. https://doi.org/10.3390/pathogens10070827

Wardyn, S. E., Kauffman, L. K., & Smith, T. C. (2012). Methicillin-resistant Staphylococcus aureus in Central Iowa Wildlife. *Journal of Wildlife Diseases*, *48*(4), 1069–1073. https://doi.org/10.7589/2011-10-295

WHO. (2022). *2.3 Drug-resistant TB*. Www.who.int. https://www.who.int/teams/global-tuberculosis-programme/tb-reports/global-tuberculosis-report-2022/tb-disease-burden/2-3-drug-resistant-tb#:~:text=The%20proportion%20of%20TB%20cases

Widodo, A., Helmi Effendi, M., Khairullah, A., & Helmi, M. (2020). Extended-spectrum beta-lactamase (ESBL)-producing Eschericia coli from livestock. *Systematic Reviews in Pharmacy*, *11*(7), 382–392. https://www.sysrevpharm.org/articles/extendedspectrum-betalactamase-esblproducing-eschericia-coli-from-livestock.pdf

WOAH. (n.d.-a). *AFRICA SWINE FEVER (INFECTION WITH AFRICAN SWINE FEVER VIRUS)*. Https://Www.woah.org/Fileadmin/Home/Eng/Health_standards/Tahm/3.09.01_ASF.pdf.

WOAH. (n.d.-b). *African swine fever*. WOAH - World Organisation for Animal Health. Retrieved May 31, 2023, from https://www.woah.org/en/disease/african-swine-fever/#ui-id-6

WOAH. (n.d.-c). *BRUCELLOSIS (INFECTION WITH BRUCELLA ABORTUS, B . MELITENSIS AND B . SUIS)*. https://www.woah.org/fileadmin/Home/eng/Health_standards/tahm/3.01.04_BRUCELLOSIS.pdf

WOAH. (n.d.-d). *Cryptosporidiosis*. WOAH - World Organisation for Animal Health. Retrieved May 31, 2023, from https://www.woah.org/en/disease/cryptosporidiosis/

WOAH. (n.d.-e). *Emergency Preparedness*. WOAH - World Organisation for Animal Health. Retrieved June 15, 2023, from https://www.woah.org/en/what-we-offer/emergency-preparedness/

WOAH. (n.d.-f). *Nipah and Hendra virus diseases*. https://www.woah.org/fileadmin/Home/eng/Health_standards/tahm/3.01.15_NIPAH_HENDRA.pdf

WOAH. (n.d.-g). *One Health*. WOAH - World Organisation for Animal Health. https://www.woah.org/en/what-we-do/global-initiatives/one-health/

WOAH. (n.d.-h). *Q fever*. WOAH - World Organisation for Animal Health. https://www.woah.org/en/disease/q-fever/

WOAH. (n.d.-i). *ROADMAP TUBERCULOSIS*. https://www.woah.org/app/uploads/2021/03/roadmap-zoonotic-tb.pdf

WOAH. (n.d.-j). *SWINE INFLUENZA Aetiology Epidemiology Diagnosis Prevention and Control References*. Retrieved May 31, 2023, from https://www.woah.org/fileadmin/Home/eng/Animal_Health_in_the_World/docs/pdf/Disease_cards/SWINE_INFLUENZA.pdf

WOAH. (n.d.-k). *THEILERIOSIS IN CATTLE (INFECTION WITH THEILERIA ANNULATA, T . ORIENTALIS AND T . PARVA)*. Https://Www.woah.org/Fileadmin/Home/Eng/Health_standards/Tahm/3.04.15_THEILIERIOSIS.pdf.

WOAH. (n.d.-l). *Trichinellosis*. WOAH - World Organisation for Animal Health. https://www.woah.org/en/disease/trichinellosis/
WOAH. (n.d.-m). *Wildlife Health*. WOAH - World Organisation for Animal Health. Retrieved June 11, 2023, from https://www.woah.org/en/what-we-do/animal-health-and-welfare/wildlife-health/#ui-id-1
WOAH. (2021a). *African Swine Fever*. https://www.woah.org/app/uploads/2021/03/african-swine-fever.pdf
WOAH. (2021b). *BLUETONGUE (INFECTION WITH BLUETONGUE VIRUS)*. https://www.woah.org/fileadmin/Home/eng/Health_standards/tahm/3.01.03_BLUETONGUE.pdf
WOAH. (2022). *African swine fever in wild boar Ecology and biosecurity Second edition FAO ANIMAL PRODUCTION AND HEALTH / MANUAL 28*. https://www.woah.org/app/uploads/2022/07/asf-in-wild-boar-ecology-and-biosecurity-2nd-ed.pdf
Wolfe, N. D., Dunavan, C. P., & Diamond, J. (2007). Origins of major human infectious diseases. *Nature*, *447*(7142), 279–283. https://doi.org/10.1038/nature05775
World Health Organisation. (2022a, January 8). *Leishmaniasis*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/leishmaniasis
World Health Organisation. (2022b, October 27). *Global Tuberculosis Report 2022*. Www.who.int. https://www.who.int/teams/global-tuberculosis-programme/tb-reports/global-tuberculosis-report-2022
World Health Organization. (2009). *Leptospirosis 2*. https://apps.who.int/iris/bitstream/handle/10665/205437/B4221.pdf
World Health Organization. (2017, October 31). *Vector-borne diseases*. Who.int; World Health Organization: WHO. https://www.who.int/en/news-room/fact-sheets/detail/vector-borne-diseases
World Health Organization. (2021). WHO global lists of high burden countries for tuberculosis (TB), TB/HIV and multidrug/rifampicin-resistant TB (MDR/RR-TB), 2021–2025: background document. In *apps.who.int*. World Health Organization. https://apps.who.int/iris/handle/10665/341980
World Health Organization. (2022). *Cholera*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/cholera
World Health Organization. (2023, March 29). *Malaria*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/malaria
World Health Organization and Secretariat of the Convention on Biological Diversity. (2015). *Connecting Global Priorities: Biodiversity and Human Health A State of Knowledge Review*. https://www.cbd.int/health/SOK-biodiversity-en.pdf
World Health Organization and the Secretariat of the Convention on Biological Diversity. (2020, May 18). *Biodiversity and Infectious Diseases: Questions and Answers*. Convention on Biological Diversity. https://www.cbd.int/health/infectiousdiseases
WWF. (2006). *Species fact sheet: Illegal and unsustainable wildlife trade 1*. https://wwfint.awsassets.panda.org/downloads/wildlife_trade_factsheet2006.pdf
WWF. (2018). *Unsustainable and illegal wildlife trade*. Panda.org. https://wwf.panda.org/discover/our_focus/wildlife_practice/problems/illegal_trade/

WWF. (2020). *Impact of invasive alien species*. Panda.org. https://wwf.panda.org/discover/our_focus/wildlife_practice/problems/invasive_species/

WWF. (2022). *BUILDING A NATURE-POSITIVE SOCIETY LIVING PLANET REPORT 2022*. https://wwfint.awsassets.panda.org/downloads/embargo_13_10_2022_lpr_2022_full_report_single_page_1.pdf

Xi, Y., Zhang, W., Qiao, R.-J., & Tang, J. (2022). Risk factors for multidrug-resistant tuberculosis: A worldwide systematic review and meta-analysis. *PLOS ONE*, *17*(6), e0270003. https://doi.org/10.1371/journal.pone.0270003

Yuen, K. Y., Fraser, N. S., Henning , J., Halpin , K., Gibson, J. S., Betzien, L., & Stewart , A. J. (2021). Hendra virus: Epidemiology dynamics in relation to climate change, diagnostic tests and control measures. *One Health*, *12*, 100207. https://doi.org/10.1016/j.onehlt.2020.100207

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