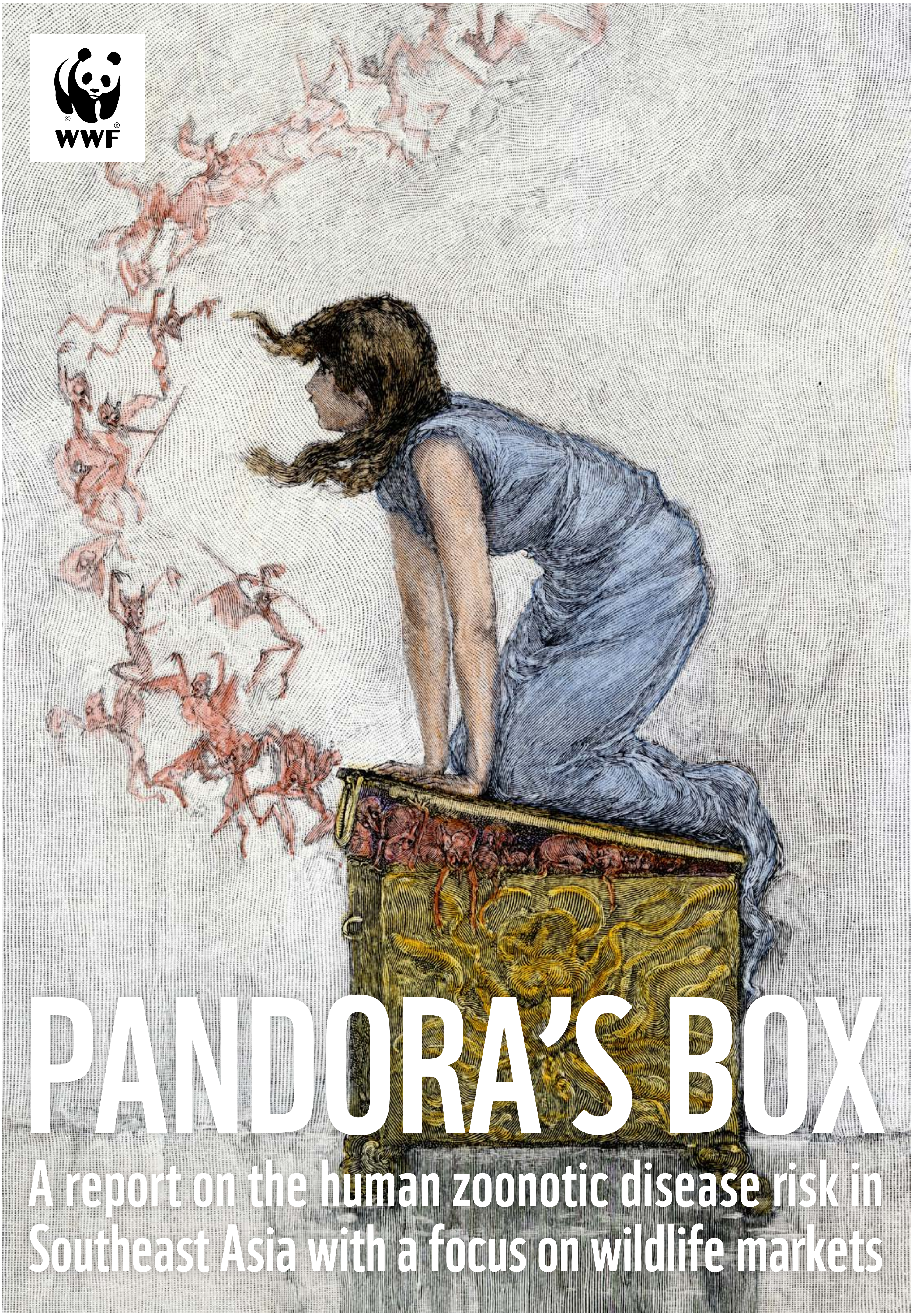

PANDORA'S BOX

A report on the human zoonotic disease risk in Southeast Asia with a focus on wildlife markets

List of Acronyms

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
COVID-19	Corona virus disease 2019
eDNA	environmental DNA
EID	Emerging infectious disease
eRNA	environmental RNA
GMS	Greater Mekong Subregion
SARS	Severe Acute Respiratory Syndrome
SBCC	Social and Behaviour Change Communications
WWF	World Wide Fund for Nature

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Summary

In the last decade, China and Southeast Asia have been at the center of global attention regarding Emerging Infectious Diseases (EIDs). More than 60% of global EIDs are zoonoses. In general, any situation which leads to increased contact between wildlife and humans, between wildlife and livestock, or between previously separated wildlife species, is a potential zoonotic risk situation. In the last decades, large-scale changes in human ecology, including human encroachment on wildlife habitat and an increase in wildlife trade, have spurred the increased emergence of such situations. Several factors that significantly contribute to the potential emergence of zoonotic diseases come together in Southeast Asia to make this region a zoonotic hotspot.

Population growth: Southeast Asia's population has more than tripled in less than 40 years; population d Analyse Zoonosen in Asien ensity was found to be a significant predictor of emerging infectious disease events.

Biodiversity: Southeast Asia is also a globally significant biodiversity hotspot. The Greater Mekong Region alone hosts over 350 terrestrial mammal species as well as some 1,200 bird species, potentially acting as reservoirs or amplifiers from which new infectious diseases of humans might emerge.

Deforestation: Southeast Asia is a major deforestation hotspot. Between 1990 and 2010, Southeast Asia's forest cover was reduced from 268 million ha to 236 million ha. This increases the number of contact zones between humans and the wild animal reservoirs of pathogenic germs.

Growing demand for animal protein: The population trend is accompanied by a doubling of per capita meat consumption owing to rising incomes. The rising affluence of the middle classes has also spurred the demand for wild meat, attracting more poachers to the forests.

Wildlife consumption and trade: Wildlife in the region is indiscriminately hunted, consumed, and traded to the extent that larger vertebrate defaunation is common in heavily hunted sites. Tens of millions of wild animals are transported in the region each year regionally and from around the world for food or use in traditional medicine. The trade in wildlife involves close contact between humans, animals and animal products, while extracting wildlife from its natural habitat, during storage and transport, and finally, at the market. This intensified human-animal contact increases the risk of pathogen spillover.

Most common taxa or species hunted or found in markets in Southeast Asia are rodents (squirrels, gerbils, bamboo rats), carnivores (civets, ferret badgers, dhole, golden jackal, racoon dog, and occasionally cats), wild boars, birds, deer and bats. Small rodents, bats, and other species, like palm civets, not subject to wildlife trade restrictions, are openly sold in physical markets as can be found throughout the region.

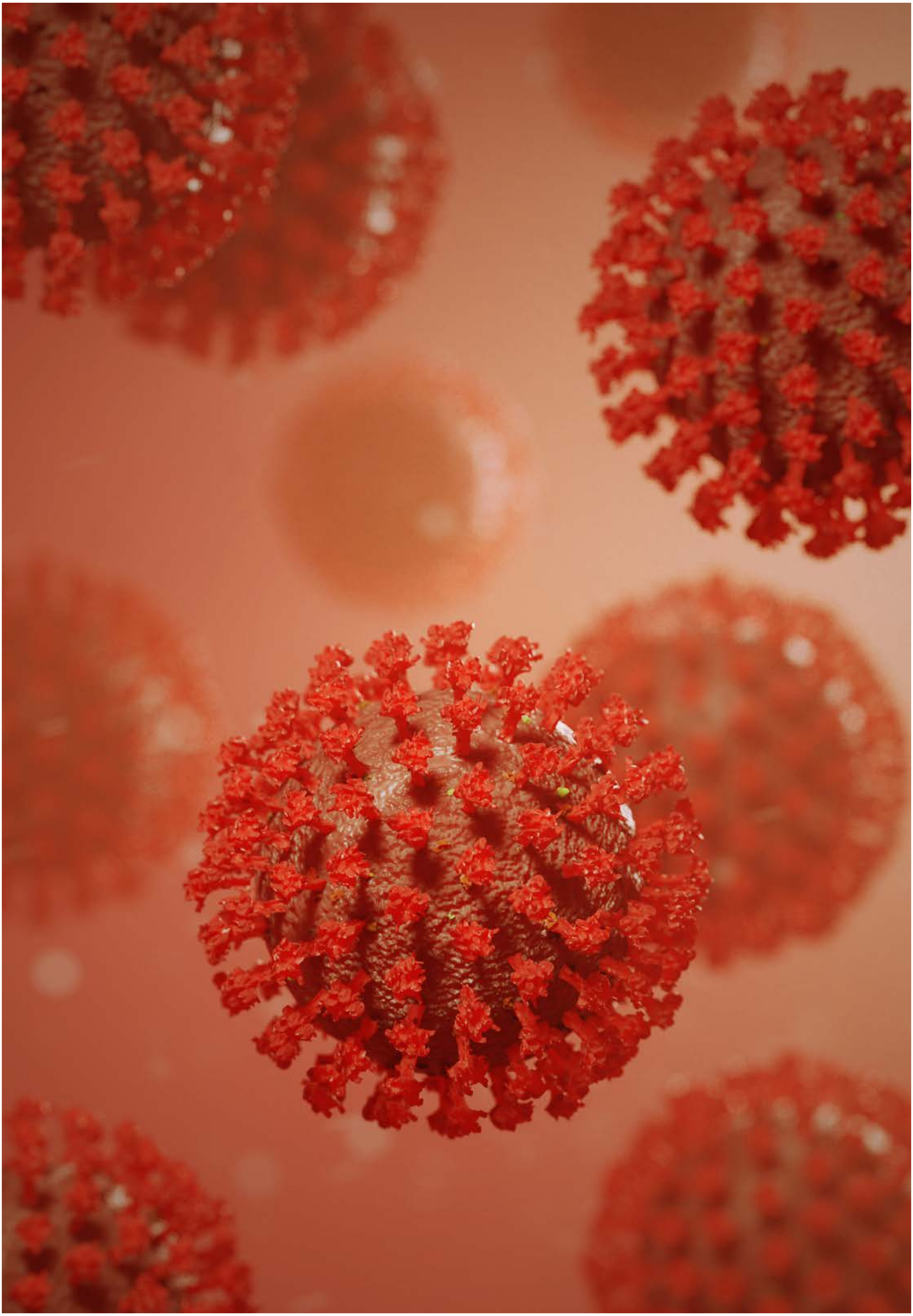
The majority of wildlife traded in Southeast Asia is for human consumption, be it as food or for health purposes. In rural settings, many communities still rely on hunting for subsistence and food security, particularly in remote areas with high levels of malnutrition amongst children. Increasingly though, wildlife is hunted for sale to urban markets. Huge, crowded markets selling wild meat are particularly relevant for zoonosis risks. So-called wet markets as exist throughout much of the region sometimes have stalls where live wild and domestic animals are sold and slaughtered alongside each other, restaurants serving wildlife, wildlife farms, as well as online and roadside sales are potential pathogen/host melting pots.

Over the past couple of decades, wildlife farms have been promoted as an approach to relieving hunting pressure on wild populations and at the same time as a poverty alleviation and food security strategy for rural communities. However, this practice is now under scrutiny since it has brought more people into contact with wildlife pathogens to which no previous protective immunity exists. Thus, the risk of transmission from infected animals to susceptible wildlife farm workers and consumers increases, particularly if health and safety standards are low.

National laws governing protected areas, hunting, firearm possession, farming, trade and consumption of wild animals vary between countries; what is common to all of them is that they are often not effective at controlling wild animal poaching, trade and consumption. However, the outbreak of COVID-19 might change this situation sustainably. China has started to curb the supply of wild meat, be it farmed or from the wild. In February 2020, just weeks after the disease outbreak and in stark contradiction with previous state policy encouraging the production of wild meat, China enacted a permanent ban on wildlife farming for meat. In January 2020, Vietnam issued a temporary ban on all wild animal imports. However, the official guidance issued in February by the Ministry of Agriculture and Rural Development exempted parts of wild animals processed into medicines, perfumes and other products from this ban.

Wildlife markets and the legal and illegal wildlife trade bring live and dead wild animals into contact with hunters, traders, transporters, consumers, and all those involved in this commerce. An effective way to reduce future pandemic risk in Southeast Asia is to follow Chinas lead, ban the sale of wildlife especially of high risk taxa completely and avoid high risk trade situations. Stopping illegal, unregulated and high-risk wildlife trade and consumption is equally important as enforcing hygienic and safe practices across wildlife markets and restaurants. However, regional networks and national agencies monitoring wildlife trade and enforcing regulations are severely underfunded and capacity to ensure hygienic and safe practices is limited. Thus, forecasting and identifying places of underlying high zoonotic potential are essential. Only through increased law enforcement, the application of hygienic rules and the testing of highly pathogenic viral pathogens in humans and animals can pandemic risks be mitigated. WWF and partners are calling on decision-makers to:

- End high-risk wildlife trade, particularly in high-density urban areas.
- Scale up efforts to combat illegal wildlife trafficking.
- Control the legal trade in wild animals more closely and introduce improved hygiene standards widely.
- Strengthen efforts to reduce consumer demand for high-risk wildlife trade products.
- Prevent the high-risk purchase, sale, transport and consumption of wildlife in markets or restaurants as well as on virtual marketplaces.
- Ensure that fines, criminal penalties and license revocation measures are strict enough to be effective.
- Revise laws to close loopholes.
- Introduce effective market and restaurant monitoring mechanism to reduce risks in wildlife trade, i.e. through strict observation of hygiene standards, close control of traded taxa, etc.



1. Zoonoses: an introduction

As the world is in the grip of COVID-19, there has been a renewed focus on emerging infectious diseases, particularly regarding those emanating from animals, and the pathogenic risks encountered at the wildlife-human interface.

A zoonosis is any disease or infection that is naturally transmissible from vertebrate animals to humans and vice versa. Infectious pathogens usually naturally live and reproduce in a population of host organisms called the reservoir. Pathogens and their natural reservoir have co-evolved in a way that the pathogen often causes no or only mild disease symptoms in the reservoir itself, so as not to compromise its survival in the host (for example, Herpes viruses in humans).

When a pathogen is transmitted to a new host population, this is called spillover. In an event of spillover, humans represent dead-end hosts to the majority of animal pathogens. Occasionally though, after a virus has crossed the animal-human species barrier, it adapts to human-to-human transmission, thereby diversifying away from its source species with the potential of becoming an epidemic (Weiss & McMichael 2004). Some pathogens even become exclusive to humans and have evolved into specialized human pathogens, such as measles, mumps, syphilis and HIV/AIDS (Wolfe et al 2007).

Almost two thirds (60.3 %) of global emerging infectious diseases (EID) are zoonoses. The majority of EIDs (71.8%) originate in wildlife, and the emergence of zoonoses has been increasing significantly over time (Jones et al. 2008). Zoonoses can emerge at any human-animal interface. Viruses are particularly critical in the context of zoonoses; 80% of viruses pathogenic to humans were found to be of animal origin, followed by bacteria (50% zoonotic origins) (Taylor et al. 2001). Also, a disproportionate number of diseases that reach epidemic or pandemic proportions are viruses (Morse et al. 2012). Researchers have estimated that there are between 650,000 and 840,000 viruses with zoonotic potential; meaning they could possibly cross the species barrier but have not yet done so (Carroll et al. 2018).

Indeed, a pandemic such as is happening at the moment caused by the SARS-CoV-2 virus has been predicted by scientists for over a decade, as a consequence of human population growth, resource use, urbanization, land use change (i.e. deforestation for agricultural expansion), and global trade and travel (e.g. Weiss & McMichael 2004, Jones et al. 2008, Horby et al. 2013, Han et al. 2016, UNEP & ILRI 2020). All of these are aspects of anthropogenic ecological and large-scale human behavioral changes that are driving the accelerated rate of zoonotic infectious disease emergence.

Spotlight on Southeast Asia

Several scientific studies have attempted to identify potential future emerging zoonotic disease hotspots by integrating predictive factors that reflect the drivers and risk species (e.g. Jones et al. 2008, Morand et al. 2014, Han et al. 2016, Olival et al. 2017).

Potential emerging zoonotic hotspots were found to be expected in regions where the following general factors overlap[1]:

(1) High mammal and bird diversity,

(2) Increased human-wildlife contact expressed as:

- (I) high human population growth and density within a species range (i.e. high ratio of urban to rural populations),
- (II) high deforestation rates,
- (III) high proportion of endangered/threatened bird and mammal species,

(3) high diversity and/or range overlap of specific zoonosis-carrying species or taxonomic groups

In the last decade, Southeast Asia - which is defined as the ten member countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam) of the Association of Southeast Asian Nations (ASEAN) - has been at the center of global attention regarding emerging infectious diseases, after the emergence of SARS, bird flu, local appearances of potentially deadly viruses such as Nipah virus, and recurring emergence of new recombinants of influenza A H1N1 viruses (the pathogen causing the Spanish and Swine flu, among others) (Coker et al. 2011, Wen et al. 2016). This report particularly focuses on the Greater Mekong region which spans Cambodia, Laos, Myanmar, Thailand, Vietnam and the southern province of Yunnan in China.

1 Other factors also play a role, such as mean temperature, host phylogenetic proximity to humans, viral traits or specific host traits.

The most famous Zoonosis

One of the most widely spread diseases occurring every year all over the world is influenza A, commonly known as “the flu”. The archetype of influenza A viruses is widely accepted to have originated in waterfowl somewhere in China where the first influenza pandemic possibly occurred around 6,000 BC (Mordini & Green 2013). Most antigenically novel and evolutionarily successful strains of seasonal influenza A (currently subtype H3N2) originate in East, South, and Southeast Asia (Wen et al. 2016). Pandemic human influenza viruses have a complex evolution of mixing of viruses in domestic animals, such as pigs and poultry, with human influenza viruses (UNEP & ILRI 2020). Live poultry markets have been known to be a source of influenza viruses since the 1970s (Webster 2004).

Beds with patients in an emergency hospital in Camp Funston, Kansas in the midst of the “Spanish flu” pandemic in 1918.

Southeast Asia in general, and the Greater Mekong region in particular, are considered zoonotic disease hotspots because the region is characterized by several factors that significantly contribute to the potential emergence of zoonotic diseases:

Population growth:

Covering about 3% of the Earth's land area, Southeast Asia's population makes up more than 9% of the global human population, having grown from 214 million in 1980 to just below 670 million in 2020[2]. Jones et al. (2008) found human population density to be a significant predictor of emerging infectious disease events. Urbanization is rapidly progressing and is associated with changes in social structures, including increased personal mobility (Coker et al. 2011).

Growing demand for animal protein:

The population trend is accompanied by a doubling of per capita meat consumption over the last four decades, owing to rising incomes (UNEP & ILRI 2020). Although fish and seafood continue to be Southeast Asians' preferred choice for animal protein, poultry and pig farming have been showing the most dramatic increases (Lee & Hansen 2019). The rising affluence of the growing middle classes has also spurred a taste for wildlife and increases the frequency of transmissible contacts at the human-wildlife interface.

Biodiversity:

The dominant trend is an increase in risk of disease emergence with higher mammalian species richness (Allen et al. 2017). As one of the globally significant biodiversity hotspots, the Greater Mekong region covers a land area of over two million km^2 and harbors enormous habitat and species diversity with high levels of endemism. This hotspot includes over 350 terrestrial mammal species of which approximately one quarter are only found in this region (Myers et al. 2000, Bell et al. 2004), as well as some 1,200 bird species[3], potentially acting as reservoirs or amplifiers from which new infectious diseases of humans might emerge (Horby et al. 2013).

Deforestation:

While being home to nearly 15% of the world's forests, Southeast Asia is a major deforestation hotspot. Estimates suggest that biodiversity loss in Southeast Asia is the most severe in global terms. Between 1990 and 2010, Southeast Asia's forest cover was reduced from 268 million ha to 236 million ha (Estoque et al. 2019).

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2 https://www.worldometers.info/world-population/south-eastern-asia-population/ (accessed 08.07.2020)
3 https://greatermekong.panda.org/discovering_the_greater_mekong/

Wildlife consumption and trade:
Any situation that increases the close and sustained proximity between wildlife, livestock and humans promotes disease spillover (Kruse et al. 2004). Against this background, Southeast Asia is of special concern, as wildlife is indiscriminately hunted, consumed, and traded throughout the region to the extent that larger vertebrate defaunation (mammals, birds, reptiles) is common in heavily hunted sites, such as in the Central Annamites in Vietnam (Tilker et al. 2019).

According to Karesh et al. (2005), tens of millions of wild animals are transported in East and Southeast Asia each year regionally and from around the world for food or use in traditional medicine. The trade in wildlife involves close contact between humans, animals and animal products; while extracting wildlife from its natural habitat; during storage and transport; and finally, at the market (see fig. 2). This intensified human-animal contact increases the risk of pathogen spillover. There is also evidence that the virus load of traded rodents and bats kept in crowded cages increases along the transport to wildlife markets and restaurants, as this increases contact between different species and the chances of pathogen spillover between them (Huong et al. 2020). In addition, once a pathogen has crossed an animal- human species barrier, domestic and international trade networks heighten the risk of spreading the infection among the human population (Borsky et al. 2020).

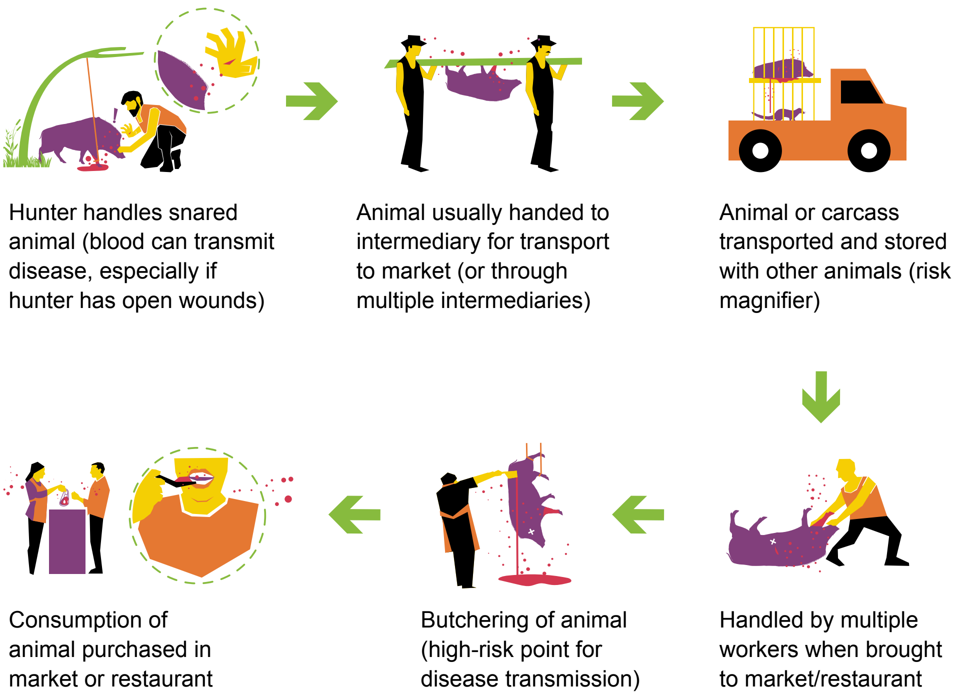


Figure 1: Potential zoonotic pathogen exposure along the wildlife supply chain. Source: Belecky & Gray 2020.

How do anthropogenic ecological changes drive zoonosis emergence?

The implication of these factors in the emergence, transmission and spread of novel zoonoses can be illustrated by the “three stages” model of zoonotic disease emergence (see fig. 2):

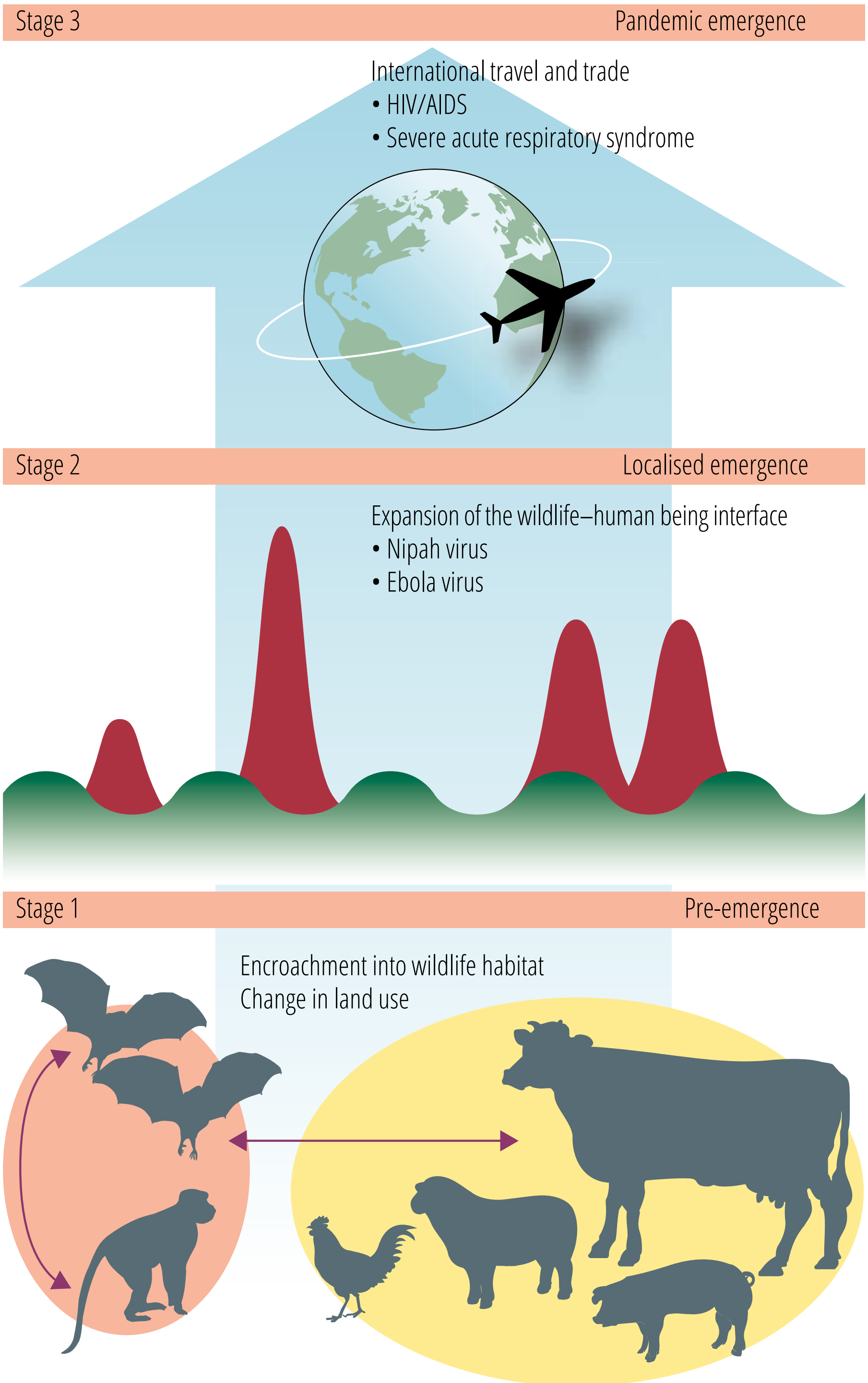


Figure 2: The three-stage model of zoonotic disease emergence. Source: Morse et al. 2012.

Stage 1: In the pre-emergence stage, the putative pathogen is still in its natural animal reservoir. Human population growth and/or increased consumption lead to expanded agricultural production. Humans encroach into wildlife habitat (forests), creating new interfaces between wildlife and domestic animals and/or humans. This can be the case when livestock is brought to a region for the first time, or when wildlife is taken from a region and transported away (e.g. for food or as pets).

Nipah virus: human encroachment and livestock expansion into wildlife habitat

The Nipah virus first appeared in peninsular Malaysia in 1998 killed 105 persons and led to the slaughter of approximately 1.1 million pigs. At first thought to be Japanese encephalitis, it turned out to be a virus hitherto unknown in humans, which had crossed over from fruit bats to humans via pigs. Humans had planted fruit orchards in previously forested areas on a large scale, in a region inhabited by fruit bats, the natural reservoir of Nipah virus. Human settlers also established intensively managed pig farms at the edge of fruit bat habitat. The bats started feeding off the fruit trees around pigsties, bringing the two previously spatially separated species together and, thereby, facilitating viral transmission, which then passed on to humans (Yob et al. 2001, Coker et al. 2011, Morse et al. 2012).

Fruit bats of the Pteropodidae family are the natural host of Nipah virus.

Stage 2 (localized emergence): Wildlife viruses spill over to humans directly or via livestock. This can happen when live or dead wildlife or infected livestock is handled at markets or in restaurants, or when wild and domesticated animals are sold next to each other in markets. At this stage, human to human transmission may or may not become possible.

Bird flu: spillover from birds to humans

Bird flu, caused by the influenza A H5N1 virus, is a widespread disease among birds (both wild and domesticated), which has in the past caused substantial economic impacts. This virus is thought to originate from wild waterfowl (most likely from the duck and geese family Anseriformes), who are natural hosts to a wide range of Orthomyxoviridae, the virus family of H5N1. H5N1 viruses are now thought to have become endemic to domestic poultry in some populations in East Asia (Kaplan & Webby 2013). Avian influenza is highly pathogenic and has caused significant economic damage to poultry farmers throughout the world (e.g. Karesh et al. 2007, Edmunds et al. 2011). Cases of lethal infections of humans with H5N1 have been recorded by the World Health Organization (WHO) since 2003 from 17 countries4. There is a probability that H5N1 may acquire the possibility for human-to-human transmission. Its high mortality rate (455 out of 861 laboratory-confirmed infected since 20035) is a cause for concern, especially if the virus does not undergo major mutations or genetic reassortment to lower its pathogenicity (Monto 2005). This virus is on virologists' priority watchlist for preventing a new pandemic.

4 https://www.who.int/influenza/human_animal_interface/2020_MAY_tableH5N1.pdf www.who.int/influenza/human_animal_interface/2020_MAY_tableH5N1.pdf (accessed 03.07.2020)
5 Ibid.

Live bird markets often bring together a mixture of bird species that make them potential sources of avian influenza viruses.

Stage 3 (pandemic emergence): At this stage, sustained person-to-person transmission has been established. Increased short and long-distance movement of people and goods due to urbanization, globalization of trade and increased international air travel, increases the chances of the pandemic emergence of a new virus, such as we are experiencing with SARS-CoV2 (the virus causing COVID-19).

SARS: the averted pandemic

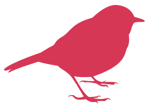
In 2002/2003, a new viral disease originating from China reached epidemic proportions, with more than 8,000 confirmed cases, leading to 774 mortalities in 29 countries6. The disease was named Severe Acute Respiratory Syndrome (SARS), and coronavirus SARS-CoV was confirmed to be its cause. It is thought to have originated from palm civets sold for their meat at live animal markets in Guangdong province, China. The animal reservoir is very likely bats. Through international air travel, the disease quickly spread to various countries around the globe. Luckily, the outbreak could be limited due to relatively low rates of human to human transmission of the virus (Luk et al. 2019).

6 https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5249a2.htm (accessed 07. 07.2020)

Palm civets are capable of spreading the SARS virus to humans.

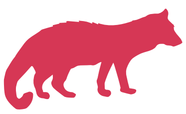
Are there high risk species?

Wild animals seem to be the source of most pathogenic zoonoses, and undoubtedly of the majority of pandemics in the past 100 years (Kruse et al. 2004, Morse et al. 2012.



The majority of natural animal reservoirs of infectious diseases are mammals (80%) and, to a lesser extent, birds. Ungulates are the mammalian taxa with which humans share the most pathogens - in all likelihood owing to the fact that these animals have been major food sources and many species were domesticated and living in close proximity to people for millennia (Morse et al. 2012).

Rodents, carnivores, bats and primates are the wild animal reservoirs with the highest proportion of zoonotic viruses compared to other mammals (Daszak et al. 2000, Olival et al. 2017, Johnson et al. 2020, see fig. 1). Generally, research indicates that potential human pathogen abundance in a taxonomic group is proportional to the species richness of the taxon (Mollentze & Streicker 2020, Johnson et al. 2020, see fig. 3). Non-human primates host a relatively higher proportion of human-compatible pathogens, as the species barrier is weak due to our close relatedness (Wolfe et al. 2007). There are 97 primate species recognized in Southeast Asia.



Many of the forests in the Greater Mekong Region are have had their top predators (tiger, leopard, clouded leopard) extirpated. Thus, relieved of direct and indirect competition, smaller carnivores (e.g., palm civets, spotted linsang, leopard cat) thrive and their populations increase (Tilker et al. 2019). Approximately one third of the 35 confirmed carnivore species in the Greater Mekong Region are known to harbor zoonoses (Han et al. 2016). Thus, defaunation may directly result in an amplification effect since lower host diversity often leads to higher infection prevalence in hosts (Khalil et al. 2016).

Bats may be the most notorious wildlife reservoir hosts of viruses implicated with emerging zoonoses. Viruses from bats can spill over to humans either directly or, more commonly, via wild or domesticated intermediary hosts. Southeast Asia hosts many more zoonotic host bat species even though it is a much smaller land mass than other bat hotspots, like South America or equatorial Africa (Han et al. 2016). Bats are implicated in several recently emerged zoonoses, including Nipah, Hendra and Marburg viruses, Ebola and SARS-related coronaviruses (SARS-CoV-1 / CoV-2) (Plowright et al. 2015, Boni et al. 2020). Han et al. (2016) identified several Southeast Asian bat species to be filovirus-positive (the virus class Ebola belongs to), and Boni et al. (2020) found the virus lineage giving rise to SARS-CoV-2 to have been circulating unnoticed in bats for decades. More than 200 viruses have been associated with bats. Almost all of those viruses are RNA viruses that pose serious threats to global public health since they have arisen repeatedly by jumping into humans from other vertebrate hosts (Allocati et al. 2016). Bats travel considerable distances from roost sites to feeding locations, and their physiology and roosting behavior have been hypothesized as influencing exposure to viruses and susceptibility to infection (Woolhouse et al. 2012).

In degrading ecosystems, dietary and habitat specialists are the first to disappear, and opportunistic generalists, such as many small mammals, thrive. These species (e.g. rodents), that adapt well to human-altered ecosystems, tend to be more prolific than their larger counterparts, and harbor more potentially zoonotic pathogens (Mills et al. 2010, McFarlane at el. 2012, Johnson et al. 2020). Rodents are commonly trapped in rice fields in Vietnam and up to 3,600 tons are sold alive for consumption. Driving this trade are consumers in Vietnam and Cambodia, who report eating rats at least once per week (Nguyen et al. 2015). The circulation of Hantavirus has also been reported in rats in Vietnam (ibid.).

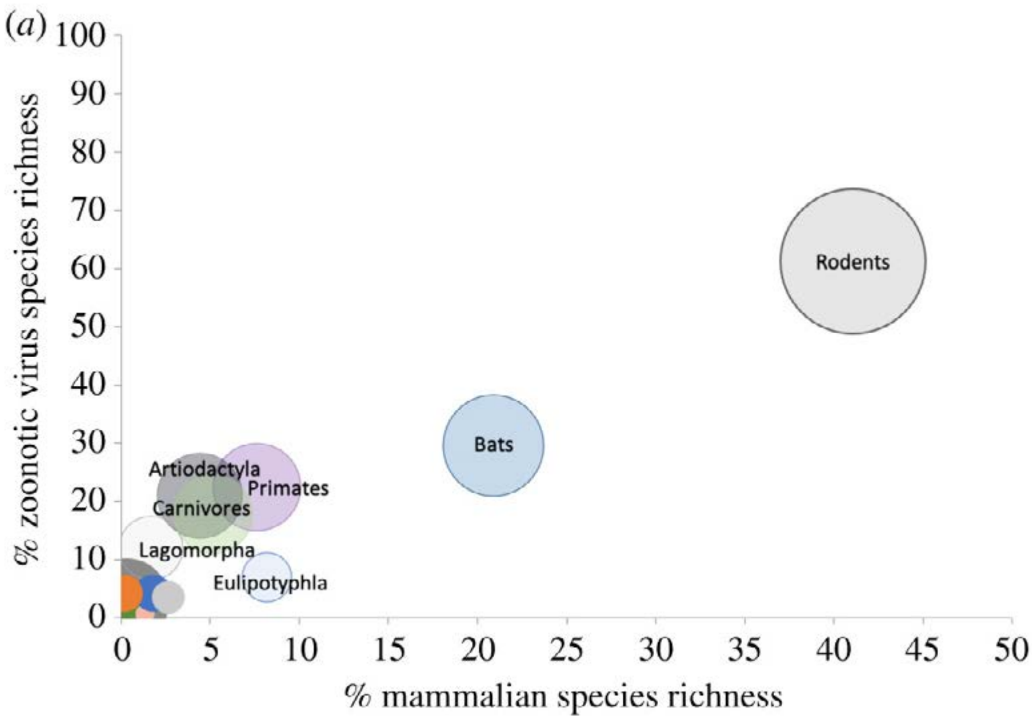


Figure 3: Zoonotic virus richness corresponding to species richness among wild mammalian orders. Area of the circles represents the proportion of zoonotic viruses found in species in each order out of the total number of zoonotic viruses among all mammalian species (from Johnson et al. 2020).

In Southeast Asia nearly all vertebrate taxa are hunted, traded and / or consumed as food or medicine across the entire region. Hunting in Southeast Asia is often opportunistic and indiscriminate. Depending on what people can hunt or snare, the harvest will be consumed by the family or sold (often via intermediaries) at the market. These species include small carnivores such as viverrids (mainly civets and genets), mustelids (ferret badgers, martens, weasels etc.) and canids (dog- like carnivores), as well as frugivores, which are caught by hunters waiting under fruiting trees, and animals that roost in flocks, such as flying foxes (Pteropus spp.), as these are relatively easy to prey on (Bell et al. 2004, Harrison et al. 2016). The number of animals consumed close to the source, in villages, rural towns, and nearby cities, is far greater than the number traded internationally (Harrison et al. 2016).

A brief literature review on species hunted, traded and/or consumed locally and regionally in different countries in Southeast Asia revealed that rodents, bats, carnivores and primates are all hunted and consumed all over the region. Most common taxa or species hunted or found in markets are rodents (squirrels, gerbils, bamboo rats), carnivores (civets, ferret badgers, dhole, red fox, golden jackal, racoon dog, and occasionally cats), wild boars, birds, deer and bats[7]. As an example for species consumed as a delicacy by affluent urban consumers, Song (2008) lists 13 species served in wildlife-specialized restaurants in Hanoi, Vietnam: snakes, palm civets, monitor lizards, porcupines, leopards, pangolins, monkeys, forest pigs, hard-shell turtles, soft-shell turtles, civets, boas, and birds. Of these, the most common are snakes, civets, forest pigs and birds.

7 Cook & Karesh 2008, Singh 2010., Rao et al. 2011, Johnson et al. 2012, McFarlane et al. 2012, Zhan & Yin 2013, Greatorex et al. 2016, Schweikhard et al. 2018, Coad et al. 2019, Pruvot et al. 2019.

2. Wildlife Trade and Consumption in Southeast Asia

The outbreak of COVID-19 and other zoonoses has been linked to wildlife trade, a cardinal issue in addressing the emergence of infectious diseases. So-called wet markets as exist throughout much of China and southeast Asia sometimes have stalls where live wild and domestic animals are sold and slaughtered alongside each other, restaurants serving wildlife, wildlife farms, as well as online and roadside sales are potential pathogen/host melting pots. SARS, which emerged in China in 2003, is thought to have originated from SARS-like coronaviruses in bats, which were then passed on to civet cats (and other small carnivores), which are known to be sold in wet markets in China and Southeast Asia for human consumption[8] (Bell et al. 2004, Li et al. 2005). Similarly, SARS-CoV-2 is widely accepted to have emanated from bats (Zhou et al. 2020, Boni et al. 2020) perhaps through a yet unknown intermediate host.

8 https://www.who.int/ith/diseases/sars/en/

The first documented site of infection for COVID-19 has been traced back to a market in Wuhan, China. The consumption of and trade in wildlife is prevalent in China. However, a focus on Chinese markets fails to see the bigger picture: while China represents the largest consumer market for wildlife and its derivates, many markets in China source their wildlife from other Southeast Asian countries (Bell et al. 2004, Zhang et al. 2008). Products are mainly sourced from Vietnam (which is also growing in significance as a consumer country), Cambodia, Thailand and, most notably, Myanmar and Lao PDR. Most of these countries at the same time act as transit countries for wildlife from other parts of the world destined for China (World Bank 2005, Lee et al. 2014).

Food and medicine

The majority of wildlife traded in China and Southeast Asia is for human consumption, be it as food or for health purposes. There is a notable dichotomy in the underlying factors that drive the consumption of wildlife as food between rural and urban communities. In rural settings, many communities still rely on hunting for subsistence and food security, particularly in remote areas with high levels of malnutrition amongst children (Pruvot et al. 2019). Increasingly though, wildlife is hunted for sale to urban markets. This is being reinforced by improved rural infrastructures and better market access through the liberalization of economies. In urban populations, consuming wildlife is viewed as an expression of status and prestige and is thus regarded as a luxury good or it is perceived to be more "natural" and thus healthier than meat from farmed animals. Rising incomes and a growing middle class are spurring the demand for wildlife and driving the trade, mainly in China and Vietnam, but also in other Southeast Asian countries (Lee et al. 2014, Greatorex et al. 2016, Sandalj et al. 2016, Haffner 2020).

The long-distance trade for luxury consumption involves mostly large mammals (>1 kg) and reptiles, such as turtles and tortoises, crocodiles, large snakes, monitor lizards, Tokay gecko, and salamanders (Zhang et al. 2008, Duckworth et al. 2012). A large proportion of wild animals traded for their meat, however, are not emblematic or charismatic species.

The medicinal use of wild animal parts is deeply ingrained in East and Southeast Asian cultures; pangolin scales are used to treat a wide range of ailments from promoting blood circulation to increasing lactation in pregnant women (Hua et al. 2015); rhino horn supposedly alleviates fever, and tiger ground tiger bones are used in the treatment of a variety of diseases, including hemiplegia and joint sprains (Still 2003). This market is also expanding owing to rising incomes. The extinction of the

Javan Rhino (*Rhinoceros sondaicus*) in Vietnam, declared in 2010, was linked to poaching for the illegal trade in rhino horn (Brook et al. 2014). The preparation of the remedies may also bear the risk of transmission of zoonoses.

Pets

In the wake of the COVID-19 outbreak, media reports have been focusing on the consumption of wildlife as a possible point of spillover for zoonoses. However, the pet trade is another significant segment of the wildlife trade (Campbell 2020, Chng & Eaton 2016). In the context of zoonoses, open markets such as the Chatuchak market in Bangkok present high-risk situations. Here, live mongoose from Africa, primates from Southeast Asia and South America, and wild rodents crammed together in cages are on display in close proximity to each other. Live birds are sold by the thousands (Chng & Eaton 2016).

Birds are of importance for two reasons. Firstly, the trade in ornamental and songbirds is extensive and popular all over Southeast Asia (Siriwat & Nijman 2020). A survey found nearly 1130 birds of 117 species on sale at Chatuchak market (Chng & Eaton 2016). For example, birds represented the largest proportion of live or dead animals for sale at local wet markets in Lao PDR observed for a scientific study in 2016, by number of individuals (Greatorex et al. 2016). In Vietnamese markets, birds are among the most popular live wildlife, with wild birds being the most common wild animals traded in Hanoi (Edmunds et al. 2011, Cao Ngoc & Wyatt 2013). Live birds were also featured as the most commonly purchased wild animal in an opinion poll conducted by WWF in March 2020 in Vietnam, Myanmar, Thailand, Hong Kong and Japan (WWF 2020). Secondly, birds are known to carry diseases that can infect humans, most notably the H5N1 avian influenza virus, commonly also known as "bird flu".

Wildlife farms

Over the past couple of decades, wildlife farms have been promoted as an approach to relieving hunting pressure on wild populations and at the same time as a poverty alleviation and food security strategy for rural communities (WCS 2008, Standaert 2020). This practice has brought more people into contact with wildlife pathogens to which no previous protective immunity exists. Thus, the risk of transmission from infected animals to susceptible wildlife farm workers and consumers increases (Swift et al. 2007). Wildlife for meat is farmed all over China and Southeast Asia. Species commonly found in farms include civets, softshell turtles, deer, and porcupine. Species farmed for medicinal and other purposes are, for example, crocodiles, peafowl, Asiatic black bears (*Ursus thibetanus*), cobras (*Naja sp.*), and tigers (*Panthera tigris*) (Bell et al. 2004, Zhang et al. 2008, Drury 2011, Harrison et al. 2016).

Wildlife farms are controversial in many aspects. Their conservation value is disputed as farms often engage in illegal activities, including sourcing animals from the wild to restock their captive population or providing a guise for laundering wild animals. Moreover, a decline in several species in the wild has been linked directly to an increased demand for wildlife spurred by wildlife farming (e.g. Zhang et al. 2008, Drury 2001, Harrison 2016). Animal welfare concerns arise in farms where civets are bred in wire cages and the gall bladders of live bears are tapped for bile on a regular basis.

High-density wire caging also increases the risk of zoonosis transmission and spread between stressed animals. Various species are often farmed in the same facilities with little veterinary care, and often the species farmed are from taxa where little is known about the pathogens they host. In Vietnam, wildlife farms are among the high concern settings in terms of zoonosis risk (Yoganand, pers. comm.). A survey in Vietnam revealed that approximately one million animals were kept on the farms' premises and 70% of the farms also raised domestic animals (Nhu et al. 2014). Feeding practices may also pose a risk; in the early 2000s, a number of crocodile and python farms in Vietnam reported feeding H5N1-infected poultry to their animals in order to save money (WCS 2008). Commercial wildlife farming in Southeast Asia is hypothesized to contribute to the cause of pandemics, such as SARS and more recently COVID-19 (Swift et al. 2007).

Places of sale

Small rodents, bats, and other species, like palm civets, not subject to wildlife trade restrictions are openly sold in physical markets as can be found throughout China and Southeast Asia. Markets are particularly relevant for zoonosis risks where there are huge, crowded markets selling wild meat after referred to as wet markets. In Laos, wildlife meat is on sale in hundreds of small-scale markets in villages (Greatorex et al. 2016).

When it comes to species that are traded illegally, sale is more covert and under the counter in some established physical markets (e.g. in Mong La, Myanmar, see Nijman et al. 2016) and through online sales. As wildlife trade is becoming increasingly international, the trade in some species has shifted to a large extent to online platforms and social media like Facebook, Instagram or WhatsApp, particularly through the use of group chats (Krishnasamy & Zavagli 2020, Siriwat & Nijman 2020).

Upscale specialty restaurants catering to urban consumers' taste for eating exotic wildlife as a prestige-building social event offer a wide spectrum of species ranging from more accessible palm civets and wild pigs to illegal leopards or pangolin (Song 2008). In Vietnam and, increasingly, Cambodia, wild meat restaurants are one of the biggest concerns for zoonotic epidemic risk (Yoganand, pers. comm.)

The legal situation regarding hunting, wildlife trade and wildlife farming

Among various international and regional associations and agreements to monitor and regulate the international trade in specimens of wild animals and plants, CITES[9] (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is the most important. CITES entered into force in 1975 and currently has 183 signatories (parties). States and regional economic integration organizations adhere voluntarily to this agreement. CITES is legally binding on the parties, however it does not take the place of national laws. Each party is required to adopt its own domestic legislation to ensure that CITES is implemented at the national level.

While all Southeast Asian countries have legislated the implementation of CITES, many of the laws are inadequate and outdated to tackle wildlife trade effectively. In all GMS countries, illegal and unsustainable trade is persisting due to weak legislation, lack of regulatory systems, poor enforcement, corruption, and a general lack of political will to address long-standing problems (Krishnasamy & Zavagli 2020).

9 https://cites.org/eng (accessed 30.06.2020)

Challenges regarding the implementation of CITES in the GMS countries (Krishnasamy & Zavagli 2020):
In Lao PDR, Thailand and Cambodia, the trade in non-native CITES species is not clearly regulated by the respective CITES-implementing legislation; either by not including them in the list of regulated species (Lao PDR) or by lacking clear processes to manage, regulate and control the trade in non-native CITES species (Thailand and Cambodia).

In Cambodia, despite updates to the Natural Resource Environmental Code, proposed penalties are considered too low to be a deterrent. The Ministry of Environment is currently (July 2020) revising the Natural Resource and Environmental Code to improve regulations and implement CITES by regulating and prohibiting trade in non-native CITES-listed species.

In Lao PDR, wildlife farms involving protected species were outlawed by a Prime Minister's Order in 2018; this order calls for existing farms to be turned into zoos, but without strict controls to prevent illicit activities that could contribute to illegal trade. Additionally, a new agreement on Zoos and Breeding of Wildlife is ambiguous regarding licensing, permitting and management of captive facilities, including for commercial breeding and trade.

In Myanmar, the Conservation of Biodiversity and Protected Areas Law (CBPA) was passed in May 2018, which includes provisions for increased penalties for violations concerning illegal hunting and trade, but generally levels of apprehension of wildlife criminals or their prosecution and/or conviction are low.

In Thailand, the newly revised WARPA (Wild Animal Reservation and Protection Act B.E 2562), which was passed in 2019, includes a new category for "Controlled Wild Animal" which covers CITES listed species that will be regulated under the law, including 50 non-native species. The WARPA also considers internet trading a violation.

In Vietnam, even with numerous laws and regulations in place, the majority of bird species observed in trade do not fall under any protection as there is no framework to regulate the trade in wild caught birds. Under the revised Penal Code No. 100/2015/QH13 that came into force in 2018, species in CITES Appendices I and II receive extended protection under criminal law.

National laws governing protected areas, hunting, firearm possession, farming, trade and consumption of wild animals vary between countries; what is common to all of them is that they are often not effective at controlling wild animal poaching, trade and consumption. Hunting in Southeast Asia has intensified to such a degree since the 1980s that many forests, and even protected areas, are now practically devoid of wildlife (Harrison et al. 2016). Pervasive and high-level corruption and a lack of political will are the strongest limiting factors, according to many conservation professionals in the region.

Responses to COVID-19 regarding wildlife trade

The outbreak of COVID-19 in China and its subsequent spread across the globe has prompted China to clamp down on the wild meat industry, be it farmed or from the wild. On February 24, 2020, just weeks after the disease outbreak and in stark contradiction with previous state policy encouraging the production of wild meat, China enacted a permanent ban on wildlife farming for meat. This ban is still waiting to be adopted into national law. In the meantime, wildlife markets have been closed on provincial and city levels (Myers 2020).

On January 28th, 2020, Vietnamese Prime Minister Nguyen Xuan Phuc issued a temporary ban on all wild animal imports (Directive No. 5 on Prevention and Combating COVID-19). However, the official guidance issued in February by the Ministry of Agriculture and Rural Development exempted parts of wild animals processed into medicines, perfumes, watches and bags from this ban.

The Prime Minister's Directive No. 29 on urgent solutions to manage wildlife, issued on July 23rd, contrary to many media reports, does not introduce new restrictions on the trade and consumption of wild animals as seen in China. Instead, it repeats the existing ban and adds additional exemptions. However, the Directive does request courts and prosecutors to impose strict penalties on those who abuse their position and authority to commit wildlife crimes. This is remarkable in being the first time such corruption has been acknowledged and prioritized (WCS 2020).

Meanwhile, a consumer opinion survey on wildlife consumption and trade in five Asian markets (Vietnam, Myanmar, Thailand, Hong Kong and Japan), conducted by WWF in March 2020 amid the COVID-19 pandemic, revealed that overall, 93% of interviewees supported measures by governments to close down illegal and unregulated markets selling wildlife.


DAMORBEAR

3. Potential zoonosis hotspots in the Greater Mekong - markets to keep an eye on

Predicting outbreaks of zoonotic diseases either by novel or known pathogens remains one of the biggest challenges of our time (Han et al. 2016). Since markets selling wildlife appear to have a central role in catalysing the outbreak of zoonoses of epidemic and pandemic potential (Dobson et al. 2020), assessing the potential risks of those places is important. Unfortunately, there is no comprehensive register available that provides information where, how many (wild) animals and what species assemblages are traded. However, food markets that sometimes sell live and freshly dead wildlife are known to exist throughout much of China and Southeast Asia (Bell et al. 2004). Furthermore, there is evidence that the number of wild animals consumed close to the source, in villages, rural towns, and nearby cities, is far greater than the number traded internationally (Harrison et al. 2016). Thus, local parameters, such as population density and geographic distribution ranges of host species can be useful proxy predictors for risk assessments of disease outbreaks from markets selling wild animals (Jones et al. 2008, Han et al. 2016).

We assumed that markets which sell wildlife under conditions that increase the probability of outbreaks of zoonoses of pandemic potential operate in urban areas with at least 40,000 inhabitants. Almost 500 of such places were identified throughout the Greater Mekong Region. Half of those places are also characterized by a population density of >3,700 inhabitants per km^2 (see figure 5).

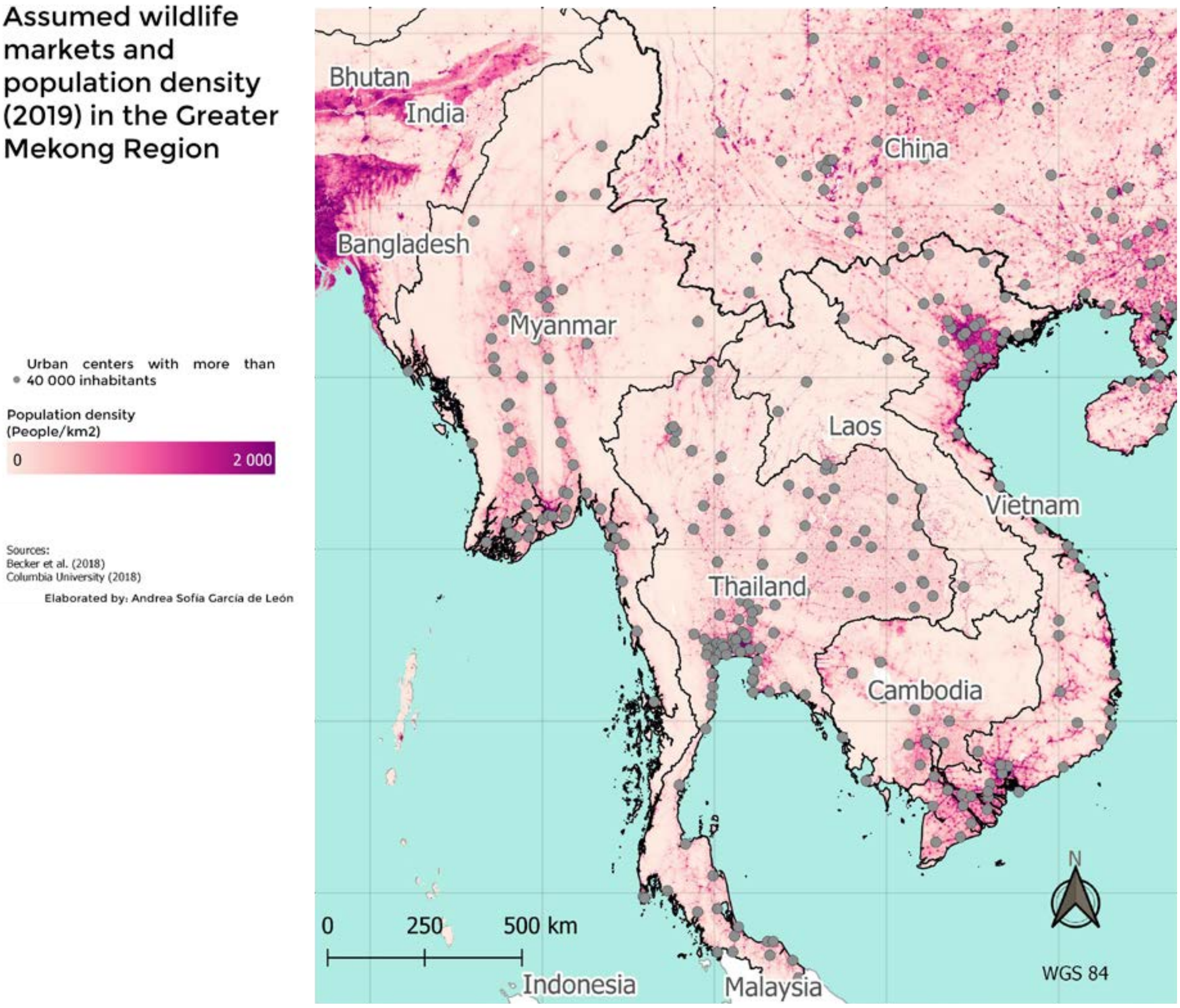


Figure 5: Assumed wildlife markets (i.e. urban centres with more than 40,000 inhabitants) and population density (2019) in the Greater Mekong region.

Furthermore, Southeast Asia is also characterized as a major zoonotic hotspot where zoonotic hosts overlap in geographic range, and thus their zoonotic pathogens also overlap (Han et al. 2016): 50% of all assumed wildlife markets in the Greater Mekong Region lie in areas which harbour at least 76 known zoonoses in the wild terrestrial mammal reservoirs (see figure 6).

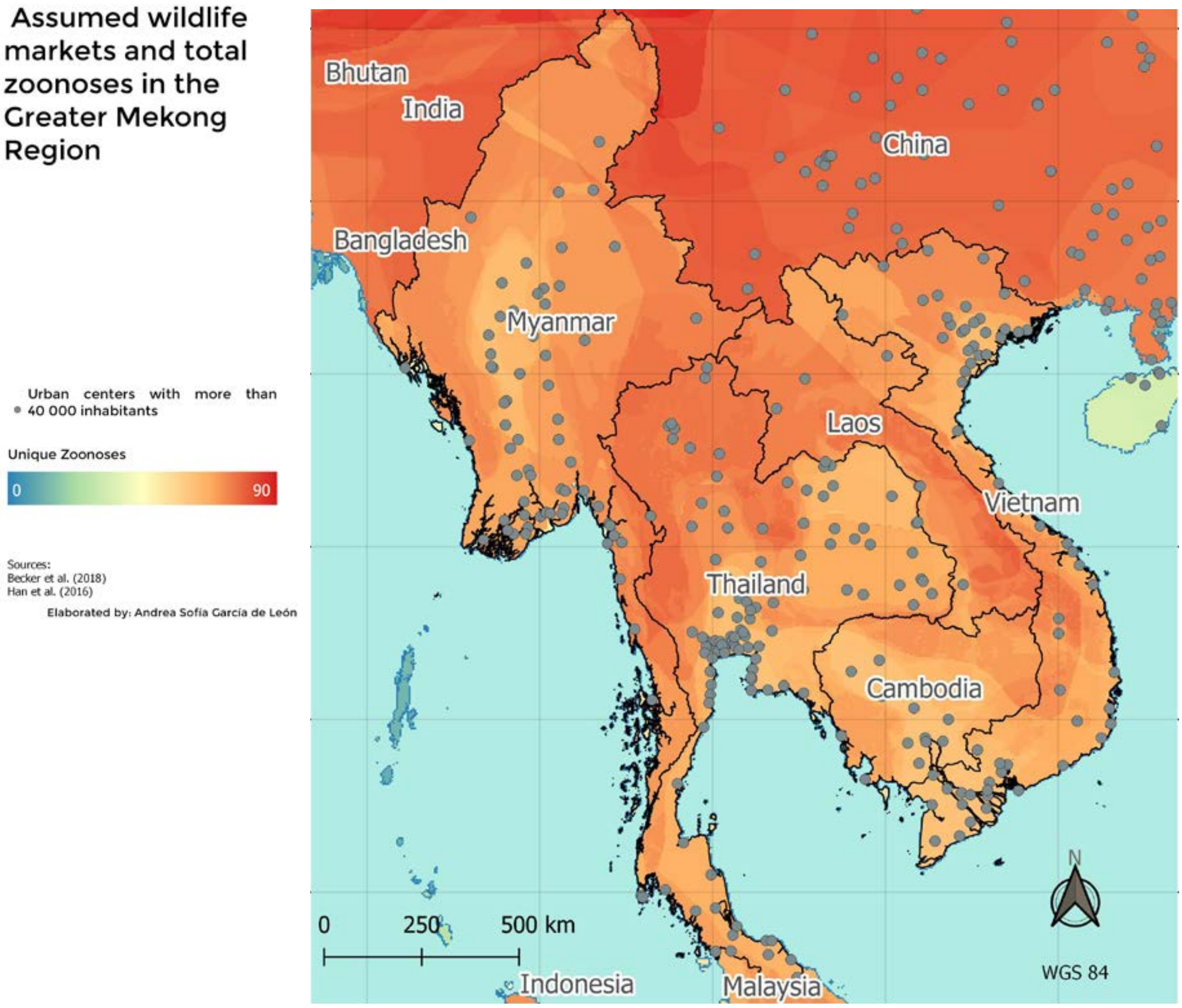


Figure 6: Assumed wildlife markets and overlapping geographic ranges of zoonotic diseases carried in natural reservoirs of mammal host species in the Greater Mekong Region.

Wildlife markets and the legal and illegal wildlife trade bring live and dead wild animals into contact with hunters, traders, transporters, consumers, and all those involved in this commerce (Dobson et al. 2020). An effective way to reduce future pandemic risk in Southeast Asia is to follow Chinas lead, ban the sale of wildlife especially of high risk taxa completely (Olson, pers. comm.). Stopping illegal, unregulated and high-risk wildlife trade and consumption is equally important as enforcing hygienic and safe practices across wildlife markets and restaurants. However, regional networks and national agencies monitoring wildlife trade and enforcing regulations are severely underfunded and capacity to ensure hygienic and safe practices is limited (Dobson et al. 2020). Thus, forecasting and identifying places of underlying high zoonotic potential is essential where increased law enforcement, application of hygienic rigor and viral testing of humans and livestock is needed and can be directed to.

Our assumption that only markets with at least 40,000 inhabitants sell wildlife may have introduced a bias. Furthermore, risks of zoonosis disease emergence might also occur in areas of the wildlife supply chain other than markets. Human zoonotic disease risk can be defined as the probability of successful transmission of a pathogen from an animal host to human hosts, and of manifestation of such infections as diseases in human hosts (Han et al. 2016). Several external factors (e.g., urbanization, agriculture, host and human population dynamics) shape the frequency of transmissible contacts at the human-wildlife and the wildlife-livestock interface. Intrinsic factors, such as host susceptibility and behavior as well as rapid evolutionary changes in pathogens contribute to diseases risk in humans (ibid).

4. Outlook and the Way Forward

Global collaboration for preventing zoonoses: One Health Concept

Given the current trends of anthropogenic ecological changes, population growth and emerging and re-emerging zoonoses, the necessity for implementation of the "One Health" concept is becoming more and more evident. The One Health approach recognizes that the health of people is closely linked to the health of (wild and domesticated) animals and that of our shared environment[10] (see fig. 7). Efforts in only one of the three areas cannot prevent or eliminate the transmission and spread of pathogens. The One Health approach can improve the understanding of causes and factors influencing infectious diseases and move from reactive to preventive measures. Thus, One Health is a concept for designing and implementing programs, policies, legislation and research in an interdisciplinary way to achieve better public health outcomes[11].

Figure. 7: The One Health Concept (source: WWF Germany).

10 https://www.cdc.gov/onehealth/basics/index.html
11 https://www.who.int/news-room/q-a-detail/one-health

WWF calls for implementing the One Health Paradigm

The health of humans, wildlife (and livestock) and the environment must be consistently considered together in the future: The links between habitat destruction and global biodiversity loss on the one hand and human health on the other must be given greater weight in global health care and research. We need to break up any silo thinking and tackle these challenges in a more interdisciplinary way. We must assume that in the future, there will be an increased threat of epidemics such as SARS, bird flu or COVID-19. The ecological processes that lead to the emergence of such outbreaks must be better understood and taken into account. This insight must be given greater emphasis in future research and funding programs.

Targeting Wildlife Trade and Consumption in Southeast Asia

Social and Behavior Change Communications (SBCC) techniques are widely and often successfully used in the health and development sectors. These methods have recently been recognized as critical by the conservation community in the fight against illegal wildlife trade (Burgess 2016). The vast majority (80%) of SBCC campaigns to date have focused on reducing the consumption of iconic species such as rhinoceros, elephant, tigers or pangolins, the trade in which is illegal (Veríssimo & Wan 2018, Belecky & Gray 2020). Wildlife meat consumption in general has not been an area of special focus. However, to tackle the issue of unsustainable wildlife consumption in Southeast Asia, there is a critical need for well-thought SBCC campaigns to influence consumer choices for reducing the demand for (not only illegal) wildlife meat. The current COVID-19 epidemic may be a pivotal point to increase leverage for this message. There is currently elevated susceptibility for measures improving public health concerns, particularly for reducing potentially epidemic zoonoses.

WWF and partners are leading a global call to action on COVID-19 and wildlife trade (preventpandemics.org). This campaign is calling on policymakers to:

- End high-risk wildlife trade, with a priority focus on those in high-density urban areas.

- Assess markets and other physical and virtual places where wildlife is traded by applying a uniformally agreed risk analysis.

- Scale up efforts to combat wildlife trafficking.

- Control the legal trade in wild animals more closely and introduce improved hygiene standards widely.

- Strengthen efforts to reduce consumer demand for high-risk wildlife trade products.

For the effective implementation of these recommendations within a Southeast Asian context, WWF calls on the governments of the region to:

- Prevent the purchase, sale, transport and consumption of all high-risk taxa (alive or dead) in
  markets or restaurants, directing the first efforts at high-density urban areas.

- Ensure that fines, criminal penalties and license revocation measures are strict enough to be
  effective.

- Revise laws to close loopholes.

- Introduce effective market and restaurant monitoring mechanisms to ensure high-risk wildlife products are not being sold and hygiene standards are strictly observed.

- Ensure involvement of ministries responsible for environment, health and public security in the development and implementation of regulations.

- Strengthen efforts to reduce consumer demand for high-risk wildlife products and incorporate Social and Behaviour Change Communications (SBCC) approaches.

Surveying High-Risk Trade: Scientific Research Input Needed

Initial methods such as those undertaken in this report to identify high-risk markets should be refined and attempted with a rigorous scientific approach. The markets identified as potential zoonotic hotspots in this way can serve as "predictive hotspots" for potential emerging zoonoses throughout Southeast Asia. Furthermore, research efforts are needed to identify high risk species because it is not expedient to put entire orders of mammals under general suspicion.

Whether prohibiting wildlife markets is the best strategy to follow is debated. There is concern over closing down wildlife markets, as this will not eliminate demand and drive wildlife markets more underground, making them more difficult, if not impossible, to monitor. Instead, focusing survey efforts on markets identified as potential hotspots may be a feasible way to implement early warning systems. This is already being done in poultry markets in the USA to predict new outbreaks of bird flu (H5N1 influenza) and could be realized for other zoonotic pathogens such as SARS-related coronaviruses (Webster 2004).

A non-invasive approach to monitoring potential zoonotic pathogens from food markets that sometimes sell live and freshly dead wildlife is the application of environmental DNA and RNA (eDNA and eRNA) sampling and sequencing methods. eDNA and eRNA are genetic material obtained directly from environmental samples (soil, sediment, water, etc.) without the presence of the source organisms (Thomsen & Willerslev 2015). Essentially, eDNA and eRNA are genetic traces of organisms that have been present in the environment in question. eDNA sampling is finding wide application in biodiversity monitoring (Thomsen & Willerslev 2015, Seymour 2019). eDNA testing for the presence of viruses has been conducted by Alfano et al. (2020), and recently, eRNA has also been receiving closer attention by the scientific community (e.g. Ammon et al. 2019, Cristescu 2019, Starr et al. 2019). Rapid developments in DNA and RNA sequencing technologies and research in this field could be paving the road for fast and cost-effective means for real-time sampling and identification of potential zoonotic pathogens (especially viruses) from food markets in potential zoonotic high-risk regions.

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