AiPol

Australasian Institute of Policing

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COVID-19 & ILLEGAL WILDLIFE TRADE

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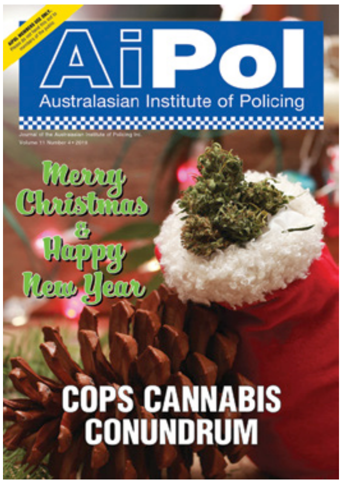

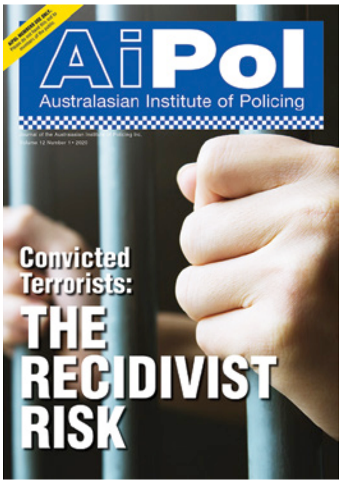

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Editorial

DR AMANDA DAVIES

Editor, Assistant Professor Policing and Security at the Rabdan Academy, Abu Dhabi

As we grapple with the daily toll on humanity, the economy and managing our personal and work life, as a community we seek answers as to how this occurred in our 21st century, medically advanced society.

Welcome to the June edition of AiPol. This edition is the first in a series planned to bring you key articles and information related to the COVID-19 global pandemic, particularly the impact on current and future policing activities and initiatives.

Whilst there is value in debating whether the pandemic is a black swan event or as suggested by Bill Gates in 2015, predictable, the reality is here and globally communities have each to varying degrees been caught unprepared. As we grapple with the daily toll on humanity, the economy and managing our personal and work life, as a community we seek answers as to how this occurred in our 21st century, medically advanced society.

The media is awash with articles, interviews, news flashes, documentaries and special editions in efforts to keep the public informed and AiPol plans to navigate a path with issues devoted to the major areas of impact brought to the world by the pandemic and their connectivity to law enforcement and security. Commencing this informative journey with exploring the potential source of the virus places the spotlight on the illegal trafficking and marketing of animals. Interestingly, as indicated in the articles authored by scientists and subject matter experts in this issue, it suggests a lack of surprise with the notion that the virus began with wild animals traded in wet markets. Further, the rational arguments offered, lay the foundation for understanding the potential dangers to humanity in terms of disease and from a policing perspective, the dangers in tracking and disrupting the illegal trade of unique and highly priced ‘trophies’. As discussed in this issue, the challenges faced by law enforcement officers across the globe in combating illegal animal trafficking requires vigilance, resilience and interagency cooperation, nationally and internationally to maintain the momentum and continue to build on the good work and successes that have been achieved.

As the world is experiencing, the pandemic with its lockdowns, restrictions on people movement, gatherings, work and social lives, the criminal fraternity is similarly experiencing a seismic shift in their modus operandi and policing resources are through necessity being directed towards the immediacy of the needs of the pandemic situation and its associated emerging crimes at the expense of such activities as policing illegal animal trafficking. The question for consideration is to look towards the post pandemic world. Will those areas of crime which have received less attention have escalated whilst our attention is elsewhere, and grown to an extent which makes the previous gains in disrupting and reduction of less impact?

Across the globe, communities and nations are beginning small steps to establish a return to a post pandemic normal, in its many and varied forms. As this is progressed the reality of the impact of policing the pandemic, the redeployment of policing resources and efforts will be realised. In the light of the key focus of this edition of AiPol, there is the potential that there has been an increase in wins against illegal animal trafficking due to the spotlight cast on such activities as wet markets and the worlds’ reaction to their existence and their threat (memories of previous viral outbreaks allegedly emanating from animals are a constant reminder). It will be some time before an accurate measurement will be available.

In the meantime, tracking and analysing the impact of the pandemic on the wider crime landscape is being reported on a near to daily basis across the globe. Presenting the progress in this COVID-19 related area of impact in the next issue will offer opportunity for a holistic perspective of the relationship between the pandemic and maintaining safety and security in our communities.

To those of the policing community who may have suffered loss through this pandemic we extend our sincere condolences and thank all of you for the job you do every day in keeping your community safe.

Foreword

JON HUNT-SHARMAN

President, Committee of Management, Australasian Institute of Policing

As this edition of the Aipol journal goes to print the illnesses, death toll and economic damage across the world is still growing as a result of the novel coronavirus outbreak, known as COVID-19.

Greater focus on the illegal wildlife trade may have prevented COVID-19

Although it remains unclear how the virus crossed into human population, bats are widely believed to be the source of COVID-19. A number of scientific findings suggest it did not jump from bats to humans directly. Instead, pangolins, the group of scaly anteaters that constitute the most illegally trafficked mammals in the world, are suspected to be the intermediary.

China's Xinhua News Agency has reported that researchers found the closest genetic match yet to the novel coronavirus infecting humans in a virus detected in pangolins. However, as this edition goes to print scientists have cautioned against jumping to conclusions before the research is published and reviewed.

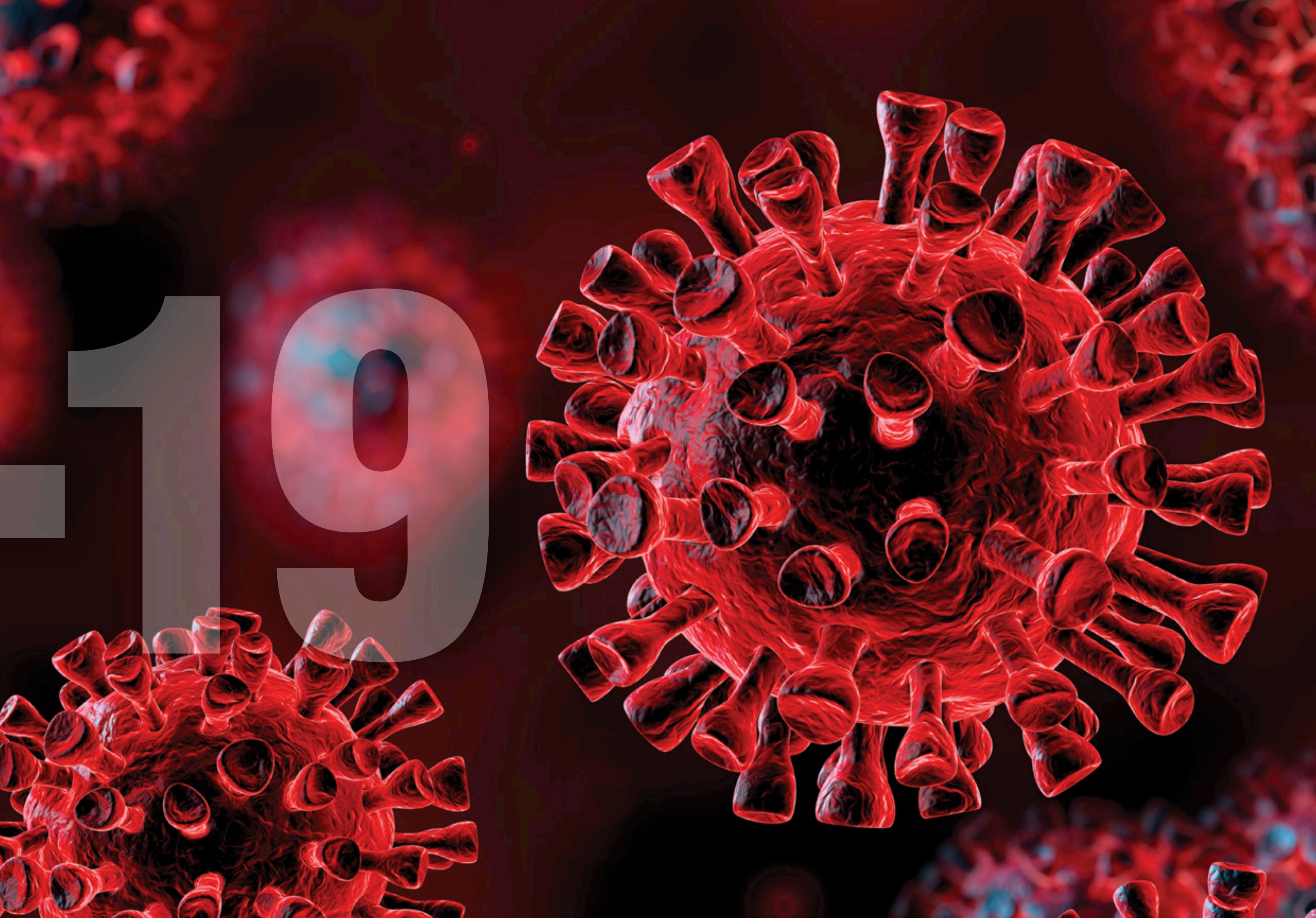
If pangolins did act as an intermediary host, the massive illegal trade in pangolins could have led to the current pandemic.

All existing pangolin species, belonging to the family Manidae, are threatened with extinction; three of the four Asian species Chinese (*Manis pentadactyla*), Sunda (*M. javanica*) and Philippine (*M. culionensis*) are listed as critically endangered by the International Union for Conservation of Nature (IUCN).

The international trade in all eight pangolin species has been banned since 2016 under the Conservation on International Trade in Endangered Species (CITES), the treaty that regulates global trade in wildlife. It's estimated that more than 2.7 million pangolins enter the illegal market each year.

China is a major destination for pangolins and pangolin products. Despite the ban, between 2016 and 2019, about 206 tons of pangolin scales were seized in 52 raids, according to the Wildlife Justice Commission. It said these were conservative estimates.

From a law enforcement perspective, what is obvious is that international



law enforcement efforts are failing in the prevention, detection and investigation of organised criminal enterprises involved in the significant illegal wildlife trade.

If the source of the COVID-19 outbreak was one of the eight species of pangolins, as scientific research indicates, that definitely is a result of the illegal animal trade as under CITES it is illegal to have, sell or buy pangolins without a special exemption, for places like zoos and animal sanctuaries.

The fact that the illegal wildlife trade likely played a role, will make it harder to pinpoint the actual transmission route because traders and buyers will be less likely to share information openly with researchers or officials.

The contraband nature and the potentially very harsh repercussions for getting caught will make it difficult to directly find the source of the infection.

This all points to the fact that prevention, detection and investigation of criminal networks in order to disrupt and dismantle the illegal trade in wildlife is a more effective strategy than carrying out an investigation after a novel coronavirus, such as the COVID-19, has negatively impacted on the health of the human population in the form of a global pandemic.

In an analogy, counter terrorism investigations are not deemed successful if the terrorist attack actually takes place and investigators then carry out an investigation into the source of the attack.

In the SARS (severe acute respitory syndrome) epidemic that gripped south-east Asia in 2003, Asian palm civets (*Paradoxurus hermaphroditus*) were identified as the intermediate host. In the case of MERS (Middle East Respiratory Syndrome), it was camels. Bats are considered a reservoir for many viruses that could trigger disease outbreaks in humans.

Aipol believes that COVID-19 is a wakeup call to all governments that the illegal trade of wildlife, in particular protected species, is an international security threat if it is proven to be an enabler to novel coronavirus pandemics. This requires strengthening of laws and the appropriate policing resourcing to enforce those laws.

At a 3 February 2020 meeting about the control of the outbreak, Chinese President Xi Jinping said it was "necessary to strengthen market supervision, resolutely ban and severely crackdown on illegal wildlife markets and trade, and control major public health risks from the source," according to the Chinese news agency Xinhua.

On 10 February 2020, China's legislature, the National People's Congress, said it would update wildlife protection laws and regulations to "toughen the crackdown on wildlife trafficking," according to local media reports. Xinhua quoted an official saying that "the supervision, inspection and law enforcement should be strengthened to ensure that wildlife trade markets are banned and closed."

In a statement, the IUCN Pangolin Specialist Group said that despite the uncertainty of the link between the species and the deadly virus, "ending the illegal trade in pangolins could contribute to mitigating potential health risks associated with consuming wildlife."

Aipol congratulates the Australian Government's strong stance in recommending a full investigation into the COVID-19 outbreak, including the genesis of the virus, and trust that the illegal wildlife trade and its connection to wet markets will be investigated as part of that independent review.

COVID-19 may have been prevented

March 28, 2020

BY LIAM MANNIX

This article appeared in the *Sydney Morning Herald* as: We should have had vaccine already: Australian Expert who cracked virus code

The pandemic may have been prevented if governments had not become complacent about bat coronaviruses after SARS was defeated, Professor Edward Holmes says.

The Australian professor who cracked the genetic code of the virus that causes COVID-19 said the world should have been working on a coronavirus vaccine for years but governments had become "complacent" about bat coronaviruses after SARS was defeated.

Edward Holmes, a researcher based at the University of Sydney who is considered among the world's leading experts on the virus's genetics, evolution and origin, said a pandemic had been inevitable but governments refused to take the threat seriously.

"It is no surprise another coronavirus emerged in humans. We have been monitoring these viruses. They've been jumping species boundaries," Professor Holmes said. "We knew this was going to happen.

"Bats have been carrying these viruses for millennia. It's not them that's changed, it's us – the way we interact with them."

After narrowly avoiding disaster with SARS in the early 2000s and MERS in the past decade, governments should have cracked down on wet markets and illegal wildlife trading, and started making broad-based coronavirus vaccines and drugs in readiness for the next coronavirus to emerge, he said.

Professor Holmes, the first to publish a genetic sequence of SARS-CoV-2, the virus that causes COVID-19, said coronaviruses seem to be uniquely able to jump species for reasons scientists do not understand.

We have to cut our exposure. Those markets have to go. The illegal trade in wildlife has to end.

SARS-CoV-2 is the third coronavirus from bats to jump into humans in the past 20 years, after SARS and MERS, which killed hundreds.

Ebola, while not a coronavirus, is also believed to have come from bats.

SARS-CoV-2 is far more infectious than MERS and SARS and has already claimed the lives of more than 27,000 patients.

"It is blindingly obvious that we, as humans, have to change the way we interact with the animal world. We have to cut our exposure. Those markets have to go. The illegal trade in wildlife has to end.

"The whole world is now set up for a pandemic; we live in mega cities, there is transport. It's an accident waiting to happen, and it happened."

Michelle Baker, a world-leading bat immunity researcher based at the CSIRO, agreed that scientists had been waiting for the next coronavirus outbreak and she expected they would become more frequent.

"I wasn't expecting it to be this bad. But I'm not surprised it's a coronavirus at all," she said.

When Dr Baker started in the field a decade ago, she "could review everything we knew about bat immunology in an afternoon. There were no resources, no reagents.

"We have been completely complacent. Not nearly enough research has been done.

"It gets really difficult to get funding when there is not an outbreak. People feel a sense of security. They don't feel it's relevant any more."

"We were just waiting for the next outbreak. I'm not surprised at all. And I hope we can learn from this one. Because they are probably going to become more frequent."

Why wild animals are a key ingredient in China's coronavirus outbreak

January 22, 2020

BY ECHO XIE, JANE CAI IN BEIJING AND GUO RUI IN GUANGZHOU

This article appeared in the *South China Morning Post* as: The exotic animals that were sold in Wuhan

Civets and wolf cubs were just some of the exotic items advertised for sale at the Wuhan market at the epicentre of the infections. Novel dishes are part of identity for some people in China but diners just need to say no to eating such food, researcher says.

Before its closure, exotic animals – from snakes to civet cats – were available at a wet market in the central Chinese city of Wuhan that is ground zero of a new virus killing people with pneumonia-like symptoms and infecting growing numbers of others around the world.

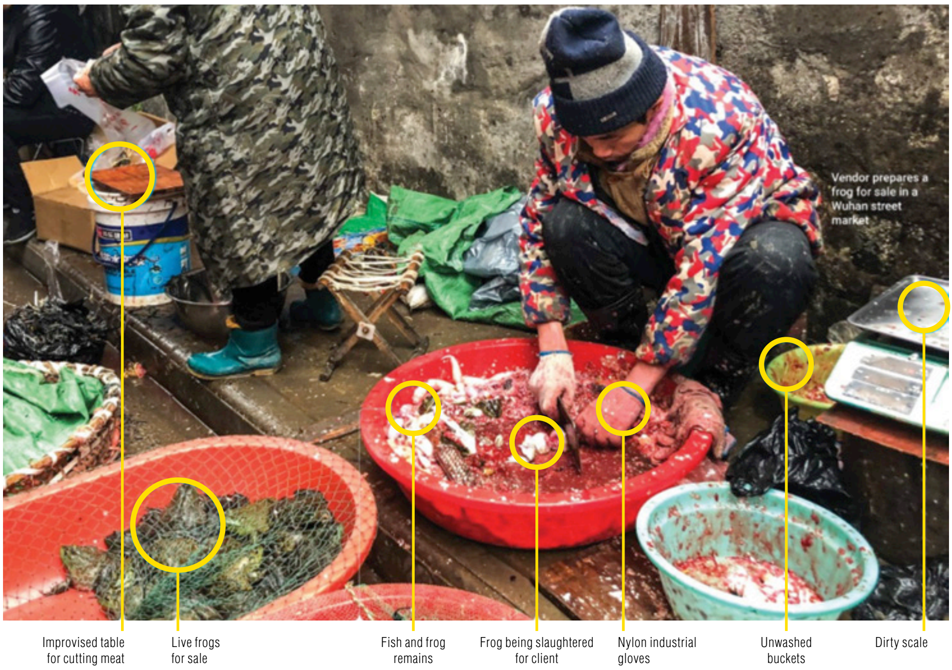
According to official reports, as of 11pm Wednesday, the previously unknown coronavirus had killed 17 people and infected 541 others.

Most of the infections and all of the deaths were in Hubei province where Wuhan is located, including 375 in the city itself. Many worked or lived near Huanan Wholesale Seafood Market, which experts believe is the source of the outbreak, with the virus jumping from wild animals on sale there.

The market was shut down in late December at the start of the outbreak and is now under surveillance by security staff.

One stall that was on the east side of the market caught people's attention online. According to a menu posted by the stallholder on Dazhong Dianping – the most popular review and rating app in China, around 100 varieties of live animals and poultry were available, from foxes to wolf cubs and masked palm civets.

The civets are thought by the World Health Organisation to have been an intermediate host carrying a virus from bats that jumped to humans in a wet market in Guangdong province near Hong



Graphic: SCMP

Kong that led to the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2002-03. Sars killed 774 people worldwide and infected 8,098 in total.

Residents confirmed that crab, shrimp and striped bass were the main items sold in the 50,000 square metre (12.35 acre) market, but in other corners, exotic animals were also on offer.

A woman living nearby surnamed Ai, 59, said she saw some stallholders selling live animals in the market.

"There were turtles, snakes, rats, hedgehogs and pheasants," she said. She added that more stalls in the west part of the market sold live animals.

Another stallholder who sells vegetables near the seafood market said he knew the market sold live animals.

"Some stalls have more kinds (of live animals) and some have less, but they have sold these for a long time," he said, declining to give his name because of the sensitivity of the issue.

A wide range of exotic animals was available at the wet market, according to a price list posted online. Photo: Weibo

A notice from the Wuhan Administration for Industry and Commerce in September also showed that live animals were on sale in the market. In the notice, it said government officials inspected eight stalls that sold live animals, including tiger frogs, snakes, and hedgehogs, and checked their wildlife business licences and approval documents. “Unapproved wildlife business is strictly forbidden,” it said.

Captive breeding of wildlife for commercial purposes is allowed in China but companies must get a licence from provincial authorities, according to the national wildlife protection law.

Health authorities in Wuhan said on Sunday they would increase controls on agriculture and seafood markets, and ban the sale of live poultry and wildlife.

That ban was spelt out in banners hanging from the gate and along the streets to Wuhan’s Bashazhou agricultural market just outside the third ring road on Tuesday. The market is the biggest wholesale outlet of its kind in central China and sells vegetables, fruit, seafood and agricultural by-products. But one of the vendors, Duan, who mainly sells salmon, said he had never heard about wild animals being traded in the market.

There was also no obvious sign of live poultry or wildlife for sale 1,000km away at a wet market in Yuexiu district in Guangzhou, a city known for adventurous diners.

Many mainland cities including Guangzhou, Shenzhen, and Beijing have banned sales of live poultry and animals in their downtown area in the wake of epidemic disease outbreaks in recent years.

However, one Yuexiu vendor said he had live chickens for sale. “Wait a moment. I’ll get it from the back door,” he said.

Trading was hectic in a market in Conghua district, also in Guangzhou, where the sale of live poultry was legal. Live chickens were sold at 17 yuan (US$2.46) for half a kilogram at some stands, where dozens of potential customers were in lively bargaining with stall holders, undeterred by developments in Wuhan.

Zhong Nanshan, director of the China State Key Laboratory of Respiratory Disease and a world expert on the Sars virus, said after a visit to Wuhan that the source of the new type coronavirus was probably from wildlife, such as bamboo rats or badgers.

“The outbreak concentrated in two districts in Wuhan, where there are big seafood markets,” Zhong said in an interview with state broadcaster CCTV on Monday.

“While they are called seafood markets, many vendors are selling game. According to preliminary epidemiological analysis, the virus is probably transmitted from wildlife (at the markets) to humans.”

Shi Zhengli, a researcher with the Wuhan Institute of Virology at the Chinese Academy of Sciences, said the real problem was in people’s behaviour, rather than with the animals.

“The simplest way to prevent such infectious diseases is to stay away from wildlife, say no to game, avoid their habitats and livestock and farms mixing with wildlife,” Shi said.

Hu Xingdou, an independent political economist, said Chinese people’s love for eating wildlife had deep cultural, economic and political roots.

“While the West values freedom and other human rights, Chinese people view food as their primary need because starving is a big threat and an unforgettable part of the national memory,” Hu said.

“While feeding themselves is not a problem to many Chinese nowadays, eating novel food or meat, organs or parts from rare animals or plants has become a measure of identity to some people.”

The 2003 SARS outbreak saw a decline in consumption of exotic animals by normally adventurous Chinese diners in the following years. According to a survey released in 2006 by San Francisco-based WildAid and the official China Wildlife Conservation Association, about 70 per cent of 24,000 people surveyed in 16 mainland cities had not eaten wild animals in the previous year, up from 51 per cent in a similar survey in 1999. While number fell, it showed 30 per cent of those surveyed were still eating wildlife.

The spread of pathogens through trade in wildlife

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Summary

Discussions on diseases of wildlife have generally focused on two basic models: the effect of disease on wildlife, and the role that wildlife plays in diseases affecting people or domestic animal health, welfare, economics and trade. Traditionally, wildlife professionals and conservationists have focused on the former, while most human/animal health specialists have been concerned largely with the latter. Lately, the (re-)emergence of many high-profile infectious diseases in a world with ever-increasing globalisation has led to a more holistic approach in the assessment and mitigation of health risks involving wildlife (with a concurrent expansion of literature). In this paper, the authors review the role of wildlife in the ecology of infectious disease, the staggering magnitude of the movement of wild animals and products across international borders in trade, the pathways by which they move, and the growing body of risk assessments from a multitude of disciplines. Finally, they highlight existing recommendations and offer solutions for a collaborative way forward.

Keywords

Globalisation – Infectious disease – Risk assessment – Trade – Wildlife – Wildlife disease – Wildlife trafficking – Zoonoses.

Wildlife, globalisation and disease

The disruption of intact biodiverse ecosystems severely affects the ability of those environments to provide clean water, energy, food, recreation and other services that contribute to human health and well-being (64, 91, 114, 148, 189). Biodiversity is currently threatened across the globe as wildlife extinctions are estimated to be 100 to 1,000 times greater than the historical norm, and up to 50% of the higher taxonomic groups are endangered (184). While rarely the cause of extinction, diseases play a role in shaping biodiversity, causing unpredictable but often drastic declines or local extirpation of keystone species (115, 136, 184). Over harvesting and unsustainable trade are often among the top factors contributing to species decline (178, 199). When diseases co-mingle with anthropogenic factors, such as habitat destruction and international trade, the impact can increase substantially, affecting biodiversity and ecosystem services crucial to people, especially in underdeveloped countries (69, 84, 184).

Not surprisingly, changes in biodiversity can also affect the risk of transmitting diseases to humans (157). As biodiversity within an ecosystem increases, so do the number of potential pathogens available in the ecosystem, but this does not necessarily translate to the risk of transmission and spread within the same environment (141). For instance, the 'dilution effect' model predicts that high species diversity often results in the protection of humans against transmission of zoonotic diseases (158, 188, 189). However, there is still uncertainty surrounding this effect in different complex ecological contexts and thus zoonotic transmission in nature remains difficult to predict (43, 49, 165).

Wildlife plays a complex and important role in the maintenance of endemic diseases, as well as the emergence of new diseases (43, 49, 92, 141, 158, 165, 188, 189). In the last 20 years, the term 'emerging disease' has gained prominence in the popular press, due to well-publicised outbreaks of pathogens such as Ebola haemorrhagic fever virus, severe acute respiratory syndrome (SARS), monkeypox, Nipah and Hendra viruses, and West Nile virus (44, 79). These events have increased global attention on the relationship between wildlife and diseases of regulatory importance (i.e. rabies, tuberculosis, brucellosis, tularemia, avian influenza and plague). The unique role that wildlife plays in the ecology of these diseases highlights the fact that valid methods need to be available to properly assess and mitigate risks to human and animal health, as well as the potential impacts on the global economy.

The recent emergence and re-emergence of many infectious diseases appear to be driven largely by globalisation and ecological disruption, while the loss of habitat and biodiversity has also resulted in a homogenisation of biota, which, in turn, has allowed the increased distribution of diseases (158). Large shifts in human behaviour and cultural practices contribute to the emergence and spread of infectious diseases by influencing the rate and quality of contact between domestic animals, people, wildlife and their products (92, 126, 220). For instance, the historic shift in human lifestyle from pastoralism to agro-pastoralism, with accompanying animal domestication, resulted in a change in contacts between humans and animals, which led to a wave of zoonotic disease emergence (126,

[220]. Recently, as agro- pastoralists have settled into more permanent and high-density communities, there has been a shift from infectious to chronic diseases, partly due to decreased everyday contact with animals [59]. However, in less developed places, where relatively little industrialisation has occurred, infectious diseases remain of primary importance [41]. In temperate latitudes, such as Europe and North America, disease emergence has mostly been associated with intensification of agricultural practices (i.e. antibiotic resistance leading to the re-emergence of diseases such as tuberculosis), while in tropical areas with greater biodiversity wildlife has played a larger role [92].

Emerging diseases are important because they represent an unknown risk in a risk-averse world. Thus, the need to assess and mitigate the risks posed by these diseases is often of paramount importance. In 2001, it was shown that approximately 61% of human pathogens, 77% of livestock pathogens, 90% of carnivore pathogens and 75% of emerging pathogens are zoonotic or have multiple hosts [32, 194]. In 2008, it was established that the majority (71.8%) of emerging zoonotic infectious diseases originate in wildlife, and that the role that wildlife plays in disease emergence is increasing significantly over time [92]. Lately, globalisation has resulted in an unprecedented volume of trade in meat and animal products [31, 41, 195, 229]. In turn, this has supported the creation of new pathways, both legal and illegal, to supply wildlife and wildlife products, in the form of exotic companion animals, trophies, crafts, bushmeat (food) and both modern and traditional medicines. It has been shown that the trade in wildlife and wildlife products represents a significant pathway of risk for the release of pathogens of importance to humans, domestic animals and other wildlife [30, 96, 128, 185, 191, 213, 219].

For example, amphibian populations, crucial in wetland ecosystems and sentinels of environmental and human health, are currently in decline around the world, due to the global spread of chytridiomycosis, a recently emerged disease [45, 103, 153]. Some estimates state that one-third or more of the 6,300 species of amphibians worldwide are threatened with extinction, as a result [209]. One of the major pathways of disease spread is thought to be the farming and transport of infected amphibians [130, 173, 180]. Understanding the volume of these movements and the risks associated with them is fundamental in elucidating the epidemiology, and thus the risks [63].

Examining the source: scope and scale of the global trade in wild animals and wildlife commodities

Trade

There are many definitions of ‘wildlife’ and ‘commodity’. For this discussion, the authors use the United States Fish and Wildlife Service definition of wildlife:

‘... any wild animal, whether alive or dead, including any wild mammal, bird, reptile, amphibian, fish, mollusk (i.e., clam, snail, squid, octopus), crustacean (i.e., crab, lobster, crayfish), insect, sponges, corals, or other invertebrate, whether or not bred, hatched, or born in captivity, and including any part, product (including manufactured products and processed food products), egg, or offspring’ [202].

For ‘commodity’, the World Organisation for Animal Health (OIE) definition is used:

‘... live animals, products of animal origin, animal genetic material, biological products and pathological material (means samples obtained from live or dead animals, containing or suspected of containing infectious or parasitic agents, to be sent to a laboratory).’

The global trade in wildlife, encompassing the sourcing, selling and consumption of live specimens, as well as wildlife commodities, occurs across a wide range of trade routes, at various geographic and economic scales. The wildlife trade occurs across all regions inhabited by humans and is supported by complicated networks that are increasing as human populations expand. Wildlife harvest and trade range in magnitude from local communities hunting or gathering species for subsistence living to large commercial enterprises, involving millions of specimens travelling long distances across international borders.

Global wildlife trade is challenging to quantify. Many trade sectors need to be considered, including the multitude of different species involved, large-scale legal trade (which often has inconsistent regulatory requirements internationally), illicit trade and internet commerce (both legal and illegal). Estimates from TRAFFIC, the Wildlife Trade Monitoring Network, in 2005 estimated the legal international wildlife trade to be worth over US$21 billion (€16 billion), calculated from declared international import statistics [55]. (This number excludes the fisheries industries, the inclusion of which would increase that figure exponentially.) Breaking down the US$21 billion includes such figures as US$338 million (€257 million) in reptile skins and US$319 million (€242 million) in ornamental fish [55, 168].

There is a massive illegal trade in wild animals and wildlife products at local, regional and global levels. Quantitative estimates for smuggling and the illegal wildlife trade are usually extrapolated and inferred from international seizure data, with numbers that are sometimes enormous. The worldwide illicit trade in wildlife is considered to be a multi-billion-dollar industry, with profits on a par with those of illicit drugs. The fact that penalties for wildlife trafficking are much less severe than those handed out for drug trafficking helps to maintain lucrative profits for wildlife trafficking, with relatively low risk from law enforcement. Occasionally, some drugs and arms traffickers also smuggle wildlife. The worldwide illegal trade in wildlife is a complex web, which capitalises on the variability of laws, cultures and wildlife markets among countries and regions. For instance, illegal trade is often intertwined with legal trade; species banned in international trade may literally be hidden beneath legal species, such as illegal bushmeat being claimed on importation documents to be fish [81]. Another example is illegally wild-harvested specimens being fraudulently identified as captive bred. Once in the marketplace, the sources are usually not distinguishable or not tested to verify their status.

A more complicated situation arises when animals are illegally harvested from the wild, but are imported into countries with less stringent or non-existent restrictions, as has been observed for abalone from South Africa and shark fins from South America, which end up in Asian markets [198]. Another variation on this theme includes the circumventing of import bans from particular regions by re-exporting from another country. An example of this occurred with African grey parrots (*Psittacus erithacus*).

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In the 1990s, the European Union (EU) imposed trade restrictions on the importation of these birds because of concerns about declining populations. The parrots were still harvested and exported from Côte d'Ivoire to Europe, but were simply re-exported through South Africa [55].

Drawing a global picture of the wildlife trade process is a daunting task. A basic evaluation of risk factors along the supply chain, such as collection, preservation, packing and shipment methods, travel routes, and the impact of highly variable regulation of these commodities, results in countless opportunities for the generation and transfer of pathogens. Although there are some major trends and trade flows which can be identified, these 'industries' are fraught with complex circumstances, specific to both species and geographic areas, whether the trade is legal or illegal. However, in general, wildlife trade flows from developing to developed countries [169]. The largest consumers of wildlife are the People's Republic of China (China) and the United States, though for very different markets, products and uses. For instance, in China, exotic foods and traditional medicine products derived from wildlife (such as shark fin soup) are considered status symbols, while in the United States wildlife commerce is dominated by imports for the trade in exotic companion animals.

Wildlife commodities

Broadly speaking, there are four categories of wildlife commodities:

- food
- medicine
- clothing/fashion
- ornamental.

Many species have multiple uses, which affects trade routes and market networks, as well as the potential for regulation. For instance, Asian pangolins (*Manis* spp.) are traded for their meat, skin and scales (used in traditional medicines in Southeast Asia for their purported properties to treat inflammation and toxicosis). Despite the fact that all international trade in Asian pangolins is illegal, they are being smuggled in staggering volumes with multiple international seizures in recent years. For example, in June 2010, a vessel travelling from Southeast Asia to China was inspected and found to have 7.8 tonnes of frozen pangolins (for meat) and 1,800 kg of pangolin scales (destined for traditional medicine markets) [199].

Food

A vast proportion of the wildlife trade is for food. Food can be subdivided into several categories, such as food for subsistence, luxury foods (providing status, for instance), foods as part of a cultural tradition and medicinal food. Three well-documented examples are turtles, bushmeat and live reef fish.

Turtles are predominantly harvested or raised for food, but they are also sold as medicine and companion animals, while decorative products are made from their shells. In 2000, 25 tonnes of turtles were exported every week from Sumatra to China while 24,000 turtles were observed for sale in the major wildlife markets in southern China [216]. As turtle populations declined in China and neighbouring regions, such as Bangladesh and Vietnam, the market supply shifted to large-scale harvesting in other areas like Brazil and the United States, where new populations are still available and regulations are not yet in place [88, 205]. This shifting of supply after depletion to meet a focused demand from Asia makes the trade in turtles a good example of the heavy effects of globalisation on wildlife trade. Currently, in the southern United States, hundreds of thousands of freshwater softshell and snapping turtles, considered almost a nuisance species by farmers, are being shipped every year to Asia; China in particular [144].

Although largely synonymous with Africa, 'bushmeat' refers to the unsustainable harvesting and consumption of wildlife 'meat', consumed as a protein source for humans, anywhere in the world. For centuries, communities have harvested wildlife for local consumption, but traditional hunting practices and trade mechanisms have changed with development. For instance, guns and wire snares are now used to kill and trap species, and forest access has dramatically increased, due to new roads opened by logging concessions. Thus, the consumers of wildlife are no longer simply indigenous communities locally harvesting and trading wildlife for subsistence use, and bushmeat is available throughout the world's cities, where it is sold in restaurants and markets for higher prices. Internationally, there is a demand for bushmeat from the African diaspora, notably in the United States and Europe, where it is smuggled to be sold in covert markets and restaurants [75]. A variety of fauna are hunted, including endangered and threatened species. In 2001, Fa and Peres [60] calculated a conservative annual estimate of 28 million forest antelopes (*Tragelaphus eurycerus*), 7.5 million red colobus monkeys (*Procolobus kirkii*), 1.8 million river hogs (*Potamochoerus porcus*) and 15,000 chimpanzees (*Pan troglodytes troglodytes*) being harvested out of the forests of Central Africa. These are the conditions under which diseases such as Ebola virus, simian immunodeficiency virus/human immunodeficiency virus (SIV/HIV), and SARS have emerged.

The live reef fish trade involves the capture and sale of a variety of coral reef species, principally sold as luxury food, with some specimens being sold into the ornamental aquarium industry. Some fish are 'grown out' in an aquaculture setting before being sold. The most prominent species in the food fish trade are groupers, and some of the most popular fish are now threatened or endangered, such as the giant grouper (*Epinephelus lanceolatus*) and the humphead wrasse (*Cheilinus undulatus*). The live reef fish trade, centred around Southeast Asia, has mushroomed in recent decades, with the expansion of the Asian economy and effects of globalisation. Nearly all of the food fish and 85% of the ornamental aquarium fish are supplied from this region. Over 60% of the trade serves the demand in Hong Kong and China for live reef food fish. Fish supplies have dwindled around Hong Kong and, at present, the fish are sourced broadly in the Indo-Pacific region. Major exporting countries involved are Indonesia, the Philippines, Australia, Malaysia, Thailand and Vietnam. The total value of the trade exceeds US$1 billion (€0.76 billion) per year [24]. As evidenced by the substantial economic and widespread nature of this commerce, there are many communities dependent on the live reef fish trade for their livelihoods. This trade is complex, from source (fisher) to market (retailer) and is not, at present, well regulated [174].

Clothing/fashion

There is a wide range of species, products and markets catering to the clothing and fashion industry, in the form of skins, wool, fur, feathers and jewellery (e.g. pearls, coral, teeth). A report from TRAFFIC, using figures generated from 2005, lists global market values for animal products for clothing and ornamental use at €4 billion (US$5.3 billion) for animal furs and fur products, €255 million (US$296 million) in reptile skins,

€85 million (US$112 million) in ornamental corals and shells, and €57 million (US$75 million) for natural pearls [55]. Reticulated pythons are the most desired reptile skin for the fashion industry, along with skins from the water monitor (*Varanus* spp.), American alligator (*Alligator mississippiensis*), brown spectacled caiman (*Caiman crocodilus fuscus*), and black and white tegu (*Tupinambis merianae*). Most of these are harvested from the wild, with the top five exporters for the 2000 to 2004 period being Columbia, Argentina, Malaysia, the United States and, most of all, Indonesia [208]. Import statistics for exotic leather skins of species listed by the United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) into Europe for the five-year period between 2000 and 2005 tabulated 3.4 million lizard skins, 2.9 million crocodile skins and 3.4 million snake skins [55]. Trade data for the EU in 2005 for reptile skins alone totalled €100 million (US$132 million), ranking the EU first in this category, with skins going principally to Italy, France and Germany [55]. Some of the trade in skins is secondary to the trade in meat, for example, peccaries in Latin America and sharks, and thus these markets are linked but follow different trade pathways from source to consumer.

Ornamentals

Ornamental wildlife includes aquarium species, the companion animal trade, decorative products and hunting trophies. The examples are seemingly endless, and include a multi-billion-dollar global market for a variety of live animals and their parts and products, such as tropical fish and reptiles. The United States and Europe support an enormous trade in exotic companion animals. These species come from all over the world. Official importation records for the United States provided these numbers for 2006:

- 136,216 mammals
- 243,000 birds
- 1.3 million reptiles
- 4.6 million amphibians
- 222 million fish [228].

With such variation in specimens and source countries, regulation is a challenge.

Release pathways and hazard identification for wildlife diseases

Most microbe–wildlife interactions are harmless and present relatively few risks to humans or domestic animals. However, wildlife presents a risk to humans and domestic animals when it acts as a disease reservoir, intermediate host or biological amplifier [12, 16, 22, 25, 26, 41, 43, 49, 56, 78, 92, 96, 116, 160, 167, 177, 183, 190, 214, 220, 226]. From an ecological standpoint, the release of diseases from wildlife often involves a number of co-factors, including ecosystem alteration (anthropogenic or natural) [44, 64, 105, 148] and climate change [17, 57], changes in the microbes themselves [22, 31, 41, 43, 44, 227] and movement of hosts, pathogens or disease vectors (anthropogenic or natural) [12, 63, 95, 98, 109]. In addition, there has been a recent increase in the recognition of new pathogens from wildlife due to improved surveillance in some areas, and/or advances in diagnostic capabilities [22, 215].

Wildlife–human–domestic animal interactions broadly follow three major pathways:

- the increased direct exposure of people to wildlife, caused by the movement of one population into an area formerly dominated by the other (human encroachment into natural habitat or the expansion of wildlife or biological vectors into human habitation)
- persistent or increased contact between wildlife and domestic animals, highlighting transboundary disease issues of concern to regulatory medicine
- the risks inherent in the trade of wildlife and wildlife- associated products.

It is conceivable that the wildlife trade is the biggest risk factor in the global spread of zoonotic and emerging infectious diseases, and it is unarguably among the top- ranking modes of transmission [96]. The United States alone imports hundreds of millions of live animals every year, mostly for the companion animal and aquarium trade, but also for specialty markets and research laboratories [89, 179]. Invasive alien species pose a disease threat from multiple angles. Many species imported for food or the exotic companion animal trade are intentionally or inadvertently released and may harbour pathogens. In addition, these species may disrupt ecosystems, allowing for increased vulnerability to pathogens or creating favourable conditions for the emergence of a new pathogen [53, 228].

When the authors conducted a search for pathogens that were documented as having spread among animals (wild and domestic) or by zoonotic transmission as a result of the movement of wildlife, a variety of avenues for transmission were revealed. The intentional or accidental introduction of invasive species and housing animals from disparate parts of the world together (such as in zoological institutions, laboratory animal facilities or live animal markets) are two of the most common ways in which diseases move from one part of the world to another. Moreover, human encroachment or habitat alteration was associated with most of the emerging infectious diseases in Table I.

Types of movement were divided into seven pathways:

- the live animal trade
- trade in wild animal parts
- the research animal trade
- the accidental or intentional introduction of invasive species
- migration and expansion of habitat
- the bushmeat trade (both local and international)
- human encroachment into previously undisturbed habitats.

To refine this search, a preliminary list of 'pathogens of concern' was drawn up, including OIE-listed diseases, pathogens generally listed as 'emerging', or 'select pathogens', as defined by the Centers for Disease Control and Prevention (www.cdc.gov) or the World Health Organization (WHO) (www.who.int). Searches included the Google Scholar Engine (scholar.google.com/), as well as PubMed (www.ncbi.nlm.nih.gov/pubmed), BIOSIS Previews and CAB databases. Grey literature covering the wildlife 'pet' trade and emerging and zoonotic diseases of wildlife, people and domestic animals was also reviewed.

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Table I

Documented transmission of wildlife diseases through the movement of wildlife

Disease (disease agent)	Political importance	Type of animal	Movement route	Reference
African tick bite fever (Rickettsia africae)	Zoonotic, EID	Ticks	HE	(90)
Aleutian disease (Aleutian mink disease virus)	Invasive	American mink	IS, LAT	(119, 120)
Alveolar echinococcosis (Echinococcus multilocularis)	OIE-listed, zoonotic	Foxes, other small carnivores	IS	(106)
Argentine haemorrhagic fever (Junin virus)	EID, zoonotic	Rodents	HE	(46, 74, 156)
Australian bat lyssavirus (Australian bat lyssavirus)	EID, zoonotic	Bats	HE	(44, 124, 125)
Avian malaria (Plasmodium relictum)	Invasive	Birds	IS	(206)
Avian poxvirus (Poxvirus avium)	OIE-listed	Birds	IS	(206)
Bohle iridovirus (Bohle iridovirus)	Invasive	Anurans, fish	LAT	(39)
Bolivian haemorrhagic fever (Machupo virus)	EID, zoonotic	Rodents	HE	(29, 138)
Bovine tuberculosis (Mycobacterium bovis)	OIE-listed OIE-listed OIE-listed	Ungulates Brushtailed possums Rhinoceroses, monkeys	HE IS LAT	(151) (207) (186)
Brucellosis (Brucella abortus)	OIE-listed	Elk, bison	HE	(50)
Brucellosis (Brucella suis)	OIE-listed	Wild boar	LAT, HE, WAP	(70)
Cholera (Vibrio cholerae)	Zoonotic, invasive	Marine invertebrates, oyster-eating fish	IS	(47, 118)
Chytridiomycosis (Batrachochytrium dendrobatidis)	Invasive	Amphibians	LAT, RT, IS	(45)
Crayfish plague (Aphanomyces astaci)	Invasive	North American crayfish	IS	(4)
Ebola virus	Zoonotic, EID	Primates	BM	(111)
Ehrlichiosis (Ehrlichia canis)	EID, zoonotic	Wild canids, domestic dogs	HE	(2)
Ehrlichiosis (Ehrlichia chaffeensis)	EID, zoonotic	Deer, rodents, ticks	HE	(27)
Giant liver fluke (Fascioloides magna)	Invasive	North American wapiti	IS	(140)
Foot and mouth disease (Aphtae epizooticae)	OIE-listed	African buffalo	HE, LAT	(176)
Korean haemorrhagic fever (Hantaan virus)	Zoonotic, EID	Norway rat	IS	(107)
Hantavirus (Sin Nombre hantavirus)	Zoonotic, EID	Rodents	HE	(58)
Hendra virus	Zoonotic, EID	Fruit bats	HE	(44)
Hepatitis E virus	Zoonotic, invasive	Deer, wild boar	LAT, BM	(193)
Herpes B virus	Zoonotic	Macaques	RT, HE	(54, 86)
Elephant endotheliotropic herpesvirus	Invasive	African elephant	LAT	(166)
Human immunodeficiency virus	EID	Primates	BM	(67)
Infectious keratoconjunctivitis (Mycoplasma conjunctivae)	Invasive	Alpine chamois	IS	(68)
Influenza H5N1	OIE-listed, zoonotic OIE-listed, zoonotic	Crested hawk eagle Birds	LAT LAT	(203) (211)
Lagos bat lyssavirus	Zoonotic, EID	Bat	LAT	(30)
Leishmaniosis (Leishmania sp.)	OIE-listed, zoonotic	Wild canids	HE, LAT	(172)
Leprosy (Mycobacterium leprae)	Zoonotic, invasive	Monkeys, rodents, armadillo	HE, LAT	(170)
Leptospirosis (Leptospira sp.)	OIE-listed, zoonotic	Wild/domestic mammals, rodents	HE, LAT	(192)
Malignant catarrhal fever (Alcelaphine herpesvirus 1, ovine herpesvirus 2)	OIE-listed	Wild ruminants	LAT, HE	(2)
Marburg virus	Zoonotic, EID	African green monkeys	RT, HE	(83)
Menangle virus	Zoonotic, EID	Grey-headed and little red fruit bats	HE	(152)
Monkeypox virus	Zoonotic	Rodents	LAT	(77)

Disease (disease agent)	Political importance	Type of animal	Movement route	Reference
Mycobacterial tuberculosis (Mycobacterium sp.)	Zoonotic, EID	Elephants	LAT	(133)
Mycoplasma conjunctivitis (Mycoplasma gallisepticum)	OIE-listed, invasive	Birds	ME	(112)
Neospora caninum	Zoonotic, invasive	Wild canids, ruminants, felines	ME, HE	(72, 73)
Nipah virus	Zoonotic, EID	Fruit bats	HE, ME	(56)
Paramyxovirus	Invasive	Parrots, lovebirds, finches	LAT	(96)
(Avian paramyxovirus types)				
Paratuberculosis (Mycobacterium avium paratuberculosis)	OIE-listed	Wild rabbits, red deer		(42, 65)
Phocine distemper virus	Zoonotic, invasive	Harp seals	ME, HE	(43)
Pilchard herpesvirus	Invasive	American pilchard	LAT, WAP	(212)
Pseudamphistomum truncatum	Invasive	Sunbleak and topmouth gudgeon fishes	IS	(154)
Psittacosis (Chlamydophila psittaci)	OIE-listed, zoonotic	Parakeets, parrots, cockatiels	LAT	(137)
Rabbit haemorrhagic disease virus	OIE-listed, invasive	Wild European rabbits, domestic rabbits	IS	(110)
Rabbit myxomatosis virus	OIE-listed, invasive	Wild rabbits, domestic rabbits	IS, ME	(171)
Rabies virus	OIE-listed, Zoonotic	Kudu Raccoons Raccoon dog Marmosets	HE IS, ME, HE LAT, WAP LAT	(85) (225) (30) (61)
Ranavirus	Invasive	Amphibians	IS, LAT, WAP	(40, 187)
Rinderpest virus	OIE-listed	Ungulates	LAT, HE, ME	(48)
Salmonella (Salmonella sp.)	Zoonotic	Terrapins	LAT	(117)
Severe acute respiratory syndrome (SARS coronavirus)	EID, zoonotic	Bats, civets	LAT	(12)
Simian foamy virus	Zoonotic	Primates	LAT, BM	(222)
Squirrel parapoxvirus	Invasive	Grey squirrel	IS	(122, 197)
Steinhausiosis (Steinhausis sp.)	Invasive	Partula snails	IS, LAT	(43)
T-cell lymphotrophic virus-1	Zoonotic	Primates	BM	(221)
Toxoplasmosis (Toxoplasma gondii)	Zoonotic, EID	Marine mammals, rodents, felids, ruminants	LAT, HE, ME	(51, 108)
Trichinella (Trichinella native)	OIE-listed, zoonotic	Bears	BM	(5)
Tularemia (Francisella tularensis)	OIE-listed, zoonotic	Hares, rabbits, rodents Prairie dog	IS HE	(218) (3, 9)
Varroa jacobsoni	OIE-listed	European honey bee	IS	(143)
West Nile virus	Zoonotic, EID	Birds, mosquitoes, mammals	ME, HE,	(100, 161)
Yersinia pestis	Zoonotic	Rodents, fleas, domestic cats	HE, IS	(230)

BM: bushmeat trade
EID: emerging infectious disease
HE: human encroachment or habitat alteration
IS: invasive species/introduced species
OIE: World Organisation for Animal Health LAT: live animal trade
RT: research animal trade
ME: migration or expansion of habitat
WAP: wild animal parts

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Wildlife disease risk assessment

In 1998, Samet *et al.* [175] introduced readers of the *American Journal of Epidemiology* to the 'new' methods of disease risk assessment. They stated that: 'while epidemiologists and epidemiological data may have prominent roles in [health risk assessments], the epidemiologic literature contains surprisingly few discussions of risk assessment'. Today, there has been progress in some areas. A search of keywords that combine the terms 'infectious disease' and 'risk assessment' on the PubMed database (October, 2010), returned 911 citations; while the terms 'risk assessment' and 'OIE' returned 36. 'Risk assessment' and 'OIE' and 'wildlife' returned only four citations. These four citations highlighted the risks associated with foot and mouth disease surrounding Kruger National Park in South Africa [93], suggested methods for wildlife hazard identification/prioritisation methodology in New Zealand [123] and the United Kingdom [80], and examined the role of bats in rabies ecology [33]. On the other hand, wildlife is often included in risk assessments of zoonotic or regulatory diseases of domestic animals, particularly those of ungulates, suids and avian species. In these cases, wildlife experts are called on to assist and summaries often appear in the peer-reviewed literature [37, 76, 84, 98, 102].

Although formal disease risk assessments of the trade in wildlife, based on the methodology of the OIE (including release, exposure and consequence assessments), appear infrequently in the peer- reviewed literature, expanded search methods provide a great deal more information. Entering the search terms 'wildlife disease risk assessment and OIE and trade' into PubMed resulted in 'no items found', while the same terms entered into the Google internet search engine returned 18,800 results, many of which are downloadable reports and assessments completed by national governmental and non-governmental organisations. In fact, there are many well-constructed reports of this kind by various groups, such as agricultural and wildlife regulatory authorities, conservation organisations and even bioterrorism defence bodies, although locating and interpreting such reports often requires time and background knowledge of risk assessment methodology and terminology. These reports are of varying degrees of quality and transparency, requiring a great deal of time to assess their value.

Regulatory issues

Although the important role of wildlife in emerging disease ecology is well established, regulatory responsibility for wildlife is often unclear. As a result, wildlife issues often fall 'between the regulatory cracks', which often translates into a lack of organisation and funding for wildlife health policy in many countries. In addition, when policies are enacted, they are often reactionary rather than precautionary, leading to increased risk and costs of mitigation and control. A common exception is that of island nations, which often have particularly well-developed quarantine and pest protection procedures in place against invasive species. Even then, the existence of protocols does not ensure compliance. In general, wildlife is regulated by agencies dedicated to the management of natural resources, and is not under the purview of human or agricultural health officials. This means that health officials are commonly disengaged from those managing wildlife and exotic animals, making it difficult to organise proper wildlife health surveillance and risk assessment protocols. Exceptions occur in response to individual cases, such as regulation of the importation of rodents in the United States by the Centers for Disease Control in response to an outbreak of monkeypox, traced to the shipment of exotic animals destined for the companion animal trade. Regardless, despite a great deal of evidence that wildlife- associated diseases present significant potential risk to humans, domestic animals and other wildlife, they are still assigned a relatively low priority by many regulatory departments and officials.

Challenges and uncertainty

The high degree of uncertainty inherent in conducting wildlife risk assessments may limit their practical application. First, an overall lack of wildlife disease surveillance infrastructure (funding, people, expertise and equipment) limits the amount of data available for hazard identification. Insufficient wildlife population data (and even insufficient population estimation methodology, in many cases) often create uncertainty in the 'denominators' needed to calculate the important epidemiological rates used to assess baseline risk. Secondly, there are great logistical challenges involved in the collection of wildlife health data. Important wildlife reservoir species (e.g. rodents, bats, non-human primates) often live in remote places with little infrastructure, making sample collection, preservation and shipment a challenge. A lack of adequate diagnostic methodology for many wildlife species and emerging diseases can make it difficult to establish baselines and case definitions for outbreak investigations. Finally, incomplete wildlife trade pathway data limit the ability to conduct release and exposure assessments, even when important disease hazards have been identified (e.g. SARS). Although pathways of legally traded wildlife may be relatively easy to follow, there is usually limited information on the point of origin and health history. Individuals are rarely uniquely identified, making trace-back almost impossible, and are often shipped in groups, with little thought to stress reduction or disease exposure during transit. Thus, risk at export does not always equal risk at import.

There may be health protocols (e.g. quarantine and testing) in existence, but compliance is uncertain since wildlife units are often underfunded and understaffed. In addition, even when risk mitigation programmes exist for legal trade, the unknowable magnitude of illegal trade makes it hard to ascertain what percentage of the real risk is accounted for. Since pathway assessments often help to prioritise potential mitigation strategies, uncertainty in this area limits the effectiveness of both risk assessment and risk mitigation techniques in these cases.

Collaborative opportunities

Although few wildlife disease risk assessments have been conducted in accordance with OIE risk analysis standards, information on wildlife disease risk may be found in the substantial literature available from other disciplines. These include epidemiological risk factor studies, wildlife disease investigations conducted by field biologists, and disease ecology modelling conducted by conservation biologists and ecologists. Much of the literature focuses on the risk of disease emergence and the interaction of wildlife within a specific pathway of concern. Other publications focus on the biology, ecology or epidemiology of specific diseases, all of which could be considered assessments of risk, although not specifically ‘risk assessments’, *per se*. A few examples include public health studies examining the risk of cross-species transmission as a result of contact with wildlife during international travel [121, 139], through bushmeat hunting and exotic animal consumption [1, 95, 127, 134, 219, 221, 222] or via exotic companion animal ownership [3, 9, 28, 30, 38, 52, 162] or xenotransplantation [145]. Some of these mechanisms are now also being examined at the molecular level [147, 182]. There is a vast body of literature on the risk of domestic animal–wildlife interactions, resulting in the spread of animal regulatory diseases [15, 19, 21, 34, 36, 93, 98], and growing concern about risks associated with commonly found wildlife products [13, 14, 23, 132]. Aquatic animal health risk assessment is a growing field, with assessments published on wildlife interaction in fisheries [7], aquaculture facilities [20], fish translocation and international trade [82], as well as shrimp farming [113] and basic aquatic animal health management and hygiene [150].

Ecologists are increasingly applying models of climate change [66, 155], vector distribution and abundance [10, 11, 165], invasive species [6, 87, 163] and avian migration [94, 99], as well as land use and ecosystem services [18, 142, 164, 181], to find solutions to the risk of disease emergence and spread. Conservation biologists, zoologists and veterinarians are now more concerned about disease when discussing the preservation, recovery, translocation or reintroduction of endangered species [50, 109, 223, 224], and often specifically aim to integrate their methods with those of epidemiologists [104]. Finally, there is a growing body of literature discussing the issue of wildlife trade and disease emergence and spread; much of this being a reaction to concerns surrounding Ebola virus and avian influenza [63, 71, 96, 97, 149, 185, 191, 206].

The way forward

It is now well established in the global community that wildlife disease matters and that severe consequences have occurred, and are still occurring, as a result of human and domestic animal exposure to wildlife. It has also been established that these diseases are very difficult to control, even in developed countries [8, 217]. Of the three basic pathways of exposure to wildlife (direct exposure of humans to wildlife due to human encroachment into previously wild areas; increased co-mingling of domestic animals and wildlife due to changes in land use; and through the increasing volume of international movement of wildlife), trade is probably the pathway with the highest potential for exposure and with the least inherent control. Thus, collaborations must be strengthened to harness the great resources needed to improve the science of wildlife disease risk analysis. This, in turn, will help facilitate the development of effective policy in the face of rapidly changing risk. This can be accomplished by focusing on four areas:

- network development
- methodology development
- data acquisition
- policy formulation.

There have been many calls for such collaboration in recent years. Success on this front will require reconciling the ethics and values of multiple disparate disciplines (economists, regulatory officials, conservationists, public health practitioners, ecologists, veterinarians and wildlife biologists, to name a few). Solutions will only come through a transdisciplinary approach to this problem [146], and thus it should be the mandate of the OIE Working Group on Wildlife Diseases to foster these discussions and connections. Once proper partnerships and working relationships are established, wildlife disease risk assessment methodology must be enhanced and standardised, to some degree, as this will allow for greater transparency and repeatability, enhancing the reliability of the process and its potential for publication [135, 196, 200, 210].

Elegant models are only partially useful without quality data. Fortunately, a great deal of funding is currently being dedicated to increasing the amount of wildlife disease data and diagnostics available on a global scale [201]. There are also efforts to improve wildlife disease hazard identification and surveillance methods [123, 129, 131, 224]. However, there are still questions about the usefulness of regarding wildlife as sentinels for human disease [159]. For this reason, depending on human health needs to drive the funding for wildlife disease surveillance (as in the cases of Nipah virus, Ebola virus, SARS and West Nile virus, for instance) is not sustainable.

Wildlife questions are big and complex. Thus, unique approaches, requiring significant investment and sustained political support, are required immediately to address the issues presented in this paper. Novel relationships, such as public-private partnerships and international coalitions, must continue to be explored to aid in aligning objectives among differing interests while continuing to foster the ‘One Health’ philosophy currently in vogue. New partnerships among those with previously disparate or competing interests, such as international-trade-regulating bodies (e.g. CITES, the World Bank and the World Trade Organization), and continuation of fledgeling partnerships between international health agencies (WHO, the Food and Agriculture Organization of the United Nations and the OIE), created under the strain of recently emerging zoonotic diseases, must take a proactive lead and be supported, both politically and financially. Finally, models aimed at addressing complex wildlife questions must include input from numerous disciplines not usually included in the OIE-based risk assessment process, including expertise in land use planning [148], wildlife use and natural resource management [101], international conservation ethics, international regulation of wildlife trade and macro- and micro-economics, amongst many others [35]. Regionally and locally, this means that wildlife must have a clear place in the regulatory framework of nation states. Ideally, this would allow for the fostering of respect for the preservation of natural resources while simultaneously addressing real-world disease risks and concerns at a global level.

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References on following page.

References

1. Aghokeng A.F., Ayouba A., Mpoudi-Ngole E., Loul S., Liegeois F., Delaporte E. & Peeters M. (2010). – Extensive survey on the prevalence and genetic diversity of SIVs in primate bushmeat provides insights into risks for potential new cross-species transmissions. *Infect. Genet. Evol.*, **10** (3), 386-396.

2. Aguirre A.A. (2009). – Wild canids as sentinels of ecological health: a conservation medicine perspective. *Parasit. Vectors*, **2** (Suppl. 1), S7.

3. Alcalá Minagorre P.J., Fernández Bernal A., Sánchez Bautista A. & Loeda Ozores C. (2004). – *Francisella tularensis* infection transmitted by prairie dog [in Spanish]. *An. Pediatr. (Barc.)*, **60** (6), 583-584.

4. Alderman D.J. (1996). – Geographical spread of bacterial and fungal diseases of crustaceans. *In* Preventing the spread of aquatic animal diseases (B.J. Hill & T. Håstein, eds). *Rev. sci. tech. Off. int. Epiz.*, **15** (2), 603-632.

5. Ancelle T., De Bruyne A., Poisson D. & Dupouy-Camet J. (2005). – Outbreak of trichinellosis due to consumption of bear meat from Canada, France, September 2005. *Eurosurveillance*, **10** (10), E051013.3.

6. Anderson P.K., Cunningham A.A., Patel N.G., Morales F.J., Epstein P.R. & Daszak P. (2004). – Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends Ecol. Evol.*, **19** (10), 535-544.

7. Arsan E.L. & Bartholomew J.L. (2008). – Potential for dissemination of the nonnative salmonid parasite *Myxobolus cerebralis* in Alaska. *J. aquat. Anim. Hlth*, **20** (3), 136-149.

8. Artois M., Delahay R., Guberti V. & Cheeseman C. (2001). – Control of infectious diseases of wildlife in Europe. *Vet. J.*, **162** (2), 141-152.

9. Avashia S.B., Petersen J.M., Lindley C.M., Schriefer M.E., Gage K.L., Cetron M., DeMarcus T.A., Kim D.K., Buck J., Montenieri J.A., Lowell J.L., Antolin M.F., Kosoy M.Y., Carter L.G., Chu M.C., Hendricks K.A., Dennis D.T. & Kool J.L. (2004). – First reported prairie dog-to-human tularemia transmission, Texas, 2002. *Emerg. infect. Dis.*, **10** (3), 483-486.

10. Bataille A., Cunningham A.A., Cedeño V., Cruz M., Eastwood G., Fonseca D.M., Causton C.E., Azuero R., Loayza J., Martinez J.D. & Goodman S.J. (2009). – Evidence for regular ongoing introductions of mosquito disease vectors into the Galapagos Islands. *Proc. Biol. Sci.*, **276** (1674), 3769-3775. E-pub.: 12 August 2009.

11. Bataille A., Cunningham A.A., Cedeño V., Patiño L., Constantinou A., Kramer L.D. & Goodman S.J. (2009). – Natural colonization and adaptation of a mosquito species in Galapagos and its implications for disease threats to endemic wildlife. *Proc. natl Acad. Sci. USA*, **106** (25), 10230-10235. E-pub.: 5 June 2009.

12. Bell D., Roberton S. & Hunter P.R. (2004). – Animal origins of SARS coronavirus: possible links with the international trade in small carnivores. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **359** (1447), 1107-1114.

13. Bengis R.G. (1997). – Animal health risks associated with the transportation and utilisation of wildlife products. *In* Contamination of animal products: prevention and risks for animal health (P. Sutmoller, ed.). *Rev. sci. tech. Off. int. Epiz.*, **16** (1), 104-110.

14. Bengis R.G. & Veary C.M. (1997). – Public health risks associated with the utilisation of wildlife products in certain regions of Africa. *In* Contamination of animal products: prevention and risks for public health (P. Sutmoller, ed.). *Rev. sci. tech. Off. int. Epiz.*, **16** (2), 586-593.

15. Bengis R.G., Kock R.A. & Fischer J. (2002). – Infectious animal diseases: the wildlife/livestock interface. *In* Infectious diseases of wildlife: detection, diagnosis and management (Part One) (R.G. Bengis, ed.). *Rev. sci. tech. Off. int. Epiz.*, **21** (1), 53-65.

16. Bengis R.G., Leighton F.A., Fischer J.R., Artois M., Morner T. & Tate C.M. (2004). – The role of wildlife in emerging and re-emerging zoonoses. *In* Emerging zoonoses and pathogens of public health concern (L.J. King, ed.). *Rev. sci. tech. Off. int. Epiz.*, **23** (2), 497-511.

17. Black P.F., Murray J.G. & Nunn M.J. (2008). – Managing animal disease risk in Australia: the impact of climate change. *In* Climate change: impact on the epidemiology and control of animal diseases (S. de La Rocque, S. Morand & G. Hendrickx, eds). *Rev. sci. tech. Off. int. Epiz.*, **27** (2), 563-580.

18. Blackburn J.K., McNyset K.M., Curtis A. & Hugh-Jones M.E. (2007). – Modeling the geographic distribution of *Bacillus anthracis*, the causative agent of anthrax disease, for the contiguous United States using predictive ecological [corrected] niche modeling. *Am. J. trop. Med. Hyg.*, **77** (6), 1103-1110. Erratum: *Am. J. trop. Med. Hyg.*, **78** (2), 358.

19. Boklund A., Goldbach S.G., Uttenthal A. & Alban L. (2008). Simulating the spread of classical swine fever virus between a hypothetical wild-boar population and domestic pig herds in Denmark. *Prev. vet. Med.*, **85** (3-4), 187-206. E-pub.: 12 March 2008.

20. Bondad-Reantaso M.G., Subasinghe R.P., Arthur J.R., Ogawa K., Chinabut S., Adlard R., Tan Z. & Shariff M. (2005). – Disease and health management in Asian aquaculture. *Vet. Parasitol.*, **132** (3-4), 249-272.

21. Brook R.K. & McLachlan S.M. (2009). – Transdisciplinary habitat models for elk and cattle as a proxy for bovine tuberculosis transmission risk. *Prev. vet. Med.*, **91** (2-4), 197-208. E-pub.: 9 July 2009.

22. Brown C. (2004). – Emerging zoonoses and pathogens of public health significance – an overview. *In* Emerging zoonoses and pathogens of public health concern (L.J. King, ed.). *Rev. sci. tech. Off. int. Epiz.*, **23** (2), 435-442.

23. Brugère-Picoux J. & Chomel B. (2009). – Importation of infectious diseases to Europe via animals and animal products: risks and pathways [in French]. *Bull. Acad. nat. Méd.*, **193** (8), 1805-1818; discussion, 1819.

24. Burke L., Selig E. & Spalding M. (2002). – Reefs at risk in Southeast Asia. World Resources Institute, Washington, DC. Available at: www.wri.org/publication/content/8228 (accessed on 19 October 2010).

25. Calisher C.H., Childs J.E., Field H.E., Holmes K.V. & Schountz T. (2006). – Bats: important reservoir hosts of emerging viruses. *Clin. Microbiol. Rev.*, **19** (3), 531-545.

26. Cattoli G., Monne I., Fusaro A., Joannis T.M., Lombin L.H., Aly M.M., Arafa A.S., Sturm-Ramirez K.M., Couacy-Hymann E., Awuni J.A., Batawui K.B., Awoume K.A., Aplogan G.L., Sow A., Ngangnou A.C., El Nasri Hamza I.M., Gamatié D., Dauphin G., Domenech J.M. & Capua I. (2009). – Highly pathogenic avian influenza virus subtype H5N1 in Africa: a comprehensive phylogenetic analysis and molecular characterization of isolates. *PLoS ONE*, **4** (3), e4842. E-pub.: 17 March 2009.

27. Charron D.F. (2002). – Potential impacts of global warming and climate change on the epidemiology of zoonotic diseases in Canada. *Can. J. public Hlth*, **93** (5), 334-335.

28. Chastel C. (2009). – Human monkeypox [in French]. *Pathol. Biol.*, **57** (2), 175-183. E-pub.: 3 April 2008.

29. Childs J.E., Mills J.N. & Glass G.E. (1995). – Rodent-borne hemorrhagic fever viruses: a special risk for mammalogists? *J. Mammalogy*, **76** (3), 664-680.

30. Chomel B.B., Belotto A. & Meslin F.X. (2007). – Wildlife, exotic pets, and emerging zoonoses. *Emerg. infect. Dis.*, **13** (1), 6-11.

31. Cleaveland S., Haydon D.T. & Taylor L. (2007). – Overviews of pathogen emergence: which pathogens emerge, when and why? *Curr. Top. Microbiol. Immunol.*, , 85-111.

32. Cleaveland S., Laurenson M.K. & Taylor L.H. (2001). – Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **356** (1411), 991-999.

33. Cliquet F. & Picard-Meyer E. (2004). – Rabies and rabies- related viruses: a modern perspective on an ancient disease. *In* Emerging zoonoses and pathogens of public health concern (L.J. King, ed.). *Rev. sci. tech. Off. int. Epiz.*, **23** (2), 625-642.

34. Coleman J.D. & Cooke M.M. (2001). – *Mycobacterium bovis* infection in wildlife in New Zealand. *Tuberculosis (Edinb.)*, **81** (3), 191-202.

35. Cooper M.E. & Rosser A.M. (2002). – International regulation of wildlife trade: relevant legislation and organisations. *In* Infectious diseases of wildlife: detection, diagnosis and management (Part One) (R.G. Bengis, ed.). *Rev. sci. tech. Off. int. Epiz.*, **21** (1), 103-123.

36. Corner L.A. (2006). – The role of wild animal populations in the epidemiology of tuberculosis in domestic animals: how to assess the risk. *Vet. Microbiol.*, **112** (2-4), 303-312. E-pub.: 2 December 2005.

37. Costard S., Wieland B., de Glanville W., Jori F., Rowlands R., Vosloo W., Roger F., Pfeiffer D.U. & Dixon L.K. (2009). – African swine fever: how can global spread be prevented? *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **364** (1530), 2683-2696.

38. Cross G.M. (1991). – Newcastle disease. V*et. Clin. N. Am. (small Anim. Pract.)*, **21** (6), 1231-1239.

39. Cullen B.R. & Owens L. (2002). – Experimental challenge and clinical cases of Bohle iridovirus (BIV) in native Australian anurans. *Dis. aquat. Organisms*, **49** (2), 83-92.

40. Cunningham A.A., Hyatt A.D., Russell P. & Bennett P.M. (2007). – Emerging epidemic diseases of frogs in Britain are dependent on the source of ranavirus agent and the route of exposure. *Epidemiol. Infect.*, **135** (7), 1200-1212. E-pub.: 21 December 2006.

41. Cutler S.J., Fooks A.R. & van der Poel W.H. (2010). – Public health threat of new, reemerging, and neglected zoonoses in the industrialized world. *Emerg. infect. Dis.*, **16** (1), 1-7.

42. Daniels M.J., Hutchings M.R., Beard P.M., Henderson D., Greig A., Stevenson K. & Sharp J.M. (2003). – Do non-ruminant wildlife pose a risk of paratuberculosis to domestic livestock and *vice versa* in Scotland? *J. Wildl. Dis.*, **39** (1), 10-15.

43. Daszak P., Cunningham A.A. & Hyatt A.D. (2000). – Emerging infectious diseases of wildlife – threats to biodiversity and human health. *Science*, **287** (5452), 443-449. Erratum: *Science*, **287** (5459), 1756.

44. Daszak P., Cunningham A.A. & Hyatt A.D. (2001). – Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta trop.*, **78** (2), 103-116.

45. Daszak P., Cunningham A.A. & Hyatt A.D. (2003). – Infectious disease and amphibian population declines. *Divers. Distrib.*, **9** (2), 141-150.

46. Davis S.A., Calvet E.A. & Leirs H.A. (2005). – Fluctuating rodent populations and risk to humans from rodent-borne zoonoses. *Vector borne zoonotic Dis.*, **5** (4), 305-314.

47. DePaola A., Capers G.M., Motes M.L., Olsvik O., Fields P.I., Wells J., Wachsmuth I.K., Cebula T.A., Koch W.H. & Khambaty F. (1992). – Isolation of Latin American epidemic strain of *Vibrio cholerae* O1 from US Gulf Coast. *Lancet*, **339** (8793), 624.

48. Dobson A. (1995). – The ecology and epidemiology of rinderpest virus in Serengeti and Ngorongoro Conservation Area. *In* Serengeti II: dynamics, management, and conservation of an ecosystem (P. Arcese, ed.). University of Chicago Press, Chicago, 485-505.

49. Dobson A. & Foufopoulos J. (2001). – Emerging infectious pathogens of wildlife. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **356** (1411), 1001-1012.

50. Dobson A. & Meagher M. (1996). – The population dynamics of brucellosis in the Yellowstone National Park. *Ecology*, 77 (4), 1026-1036.

51. Dubey J.P., Zarnke R., Thomas N.J., Wong S.K., Van Bonn W., Briggs M., Davis J.W., Ewing R., Mense M., Kwok O.C., Romand S. & Thulliez P. (2003). – *Toxoplasma gondii, Neospora caninum, Sarcocystis neurona*, and *Sarcocystis canis*-like infections in marine mammals. *Vet. Parasitol.*, **116** (4), 275-296. Erratum: *Vet. Parasitol.*, **135** (3-4), 385.

52. Editorial team, Bertrand S., Rimhanen-Finne R., Weill F.X., Rabsch W., Thornton L., Perevoscikovs J., van Pelt W. & Heck M. (2008). – *Salmonella* infections associated with reptiles: the current situation in Europe. *Eurosurveillance*, **13** (24), 18902.

53. Ehrenfeld D. (2005). – The environmental limits to globalization. *Conserv. Biol.*, **19** (2), 318-326.

54. Engel G.A., Jones-Engel L., Schillaci M.A., Suaryana K.G., Putra A., Fuentes A. & Henkel R. (2002). – Human exposure to herpesvirus B-seropositive macaques, Bali, Indonesia. *Emerg. infect. Dis.*, **8** (8), 789-795.

55. Engler M. & Parry-Jones R. (2007). – Opportunity or threat? The role of the European Union in global wildlife trade. TRAFFIC-Europe, Brussels, Belgium, 52 pp.

56. Epstein J.H., Field H.E., Luby S., Pulliam J.R.C. & Daszak P. (2006). – Nipah virus: impact, origins, and causes of emergence. *Curr. infect. Dis. Rep.*, **8** (1), 59-65.

57. Epstein P.R. (2001). – Climate change and emerging infectious diseases. *Microbes Infect.*, **3** (9), 747-754.

58. Escutenaire S. & Pastoret P.-P. (2000). – Hantavirus infections. *In* An update on zoonoses (P.-P. Pastoret, ed.). *Rev. sci. tech. Off. Int. Epiz.*, **19** (1), 64-78.

59. Ewald P.W. (1993). – Evolution of infectious disease. Oxford University Press, Oxford, New York.

60. Fa J.E. & Peres C.A. (2001). – Game vertebrate extraction in African and neotropical forests: an intercontinental comparison. *In* Conservation of exploited species (J.D. Reynolds, G.M. Mace, J.G. Robinson & K.H. Redford, eds). Cambridge University Press, Cambridge, 203-241.

61. Favoretto S.R., de Mattos C.C., Morais N.B., Alves Araújo F.A. & de Mattos C.A. (2001). – Rabies in marmosets (*Callithrix jacchus*), Ceará, Brazil. *Emerg. infect. Dis.*, 7 (6), 1062-1065.

62. Fenichel E.P., Tsao J.I., Jones M. & Hickling G.J. (2008). – Fish pathogen screening and its influence on the likelihood of accidental pathogen introduction during fish translocations. *J. aquat. Anim. Hlth*, **20** (1), 19-28.

63. Fèvre E.M., Bronsvoort B.M., Hamilton K.A. & Cleaveland S. (2006). – Animal movements and the spread of infectious diseases. *Trends Microbiol.*, **14** (3), 125-131. Epub.: 7 February 2006.

64. Foley J.A., Defries R., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N. & Snyder P.K. (2005). – Global consequences of land use. *Science*, **309** (5734), 570-574.

65. Fraquelli C., Carpi G., Bregoli M., Ostanello F., Pasolli C., Pozzato N. & Rosati S. (2005). – Epidemiology of paratuberculosis in two red deer (*Cervus elaphus*) populations of Trentino (Northern Italy). *In* Proc. 8th International Colloquium on Paratuberculosis (S.S. Nielsen, ed.), 14-17 August, Copenhagen, 605-612.

66. Gale P., Brouwer A., Ramnial V., Kelly L., Kosmider R., Fooks A.R. & Snary E.L. (2010). – Assessing the impact of climate change on vector-borne viruses in the EU through the elicitation of expert opinion. *Epidemiol. Infect.*, **138** (2), 214-225. E-pub.: 7 July 2009.

67. Gao F., Bailes E., Robertson D.L., Chen Y., Rodenburg C.M., Michael S.F., Cummins L.B., Arthur L.O., Peeters M., Shaw G.M., Sharp P.M. & Hahn B.H. (1999). – Origin of HIV-1 in the chimpanzee *Pan troglodytes troglodytes. Nature*, **397** (6718), 436-441.

68. Giacometti M., Janovsky M., Jenny H., Nicolet J., Belloy L., Goldschmidt-Clermont E. & Frey J. (2002). – *Mycoplasma conjunctivae* infection is not maintained in alpine chamois in eastern Switzerland. *J. Wildl. Dis.*, **38** (2), 297-304.

69. Gillespie T.R., Nunn C.L. & Leendertz F.H. (2008). – Integrative approaches to the study of primate infectious disease: implications for biodiversity conservation and global health. *Am. J. phys. Anthropol.*, **137**, 53-69.

70. Godfroid J., Cloeckaert A., Liautard J.P., Kohler S., Fretin D., Walravens K., Garin-Bastuji B. & Letesson J.J. (2005). – From the discovery of the Malta fever's agent to the discovery of a marine mammal reservoir, brucellosis has continuously been a re-emerging zoonosis. *Vet. Res.*, **36** (3), 313-326.

71. Gómez A. & Aguirre A.A. (2008). – Infectious diseases and the illegal wildlife trade. *Ann. N.Y. Acad. Sci.*, **1149**, 16-19.

72. Gondim L.F.P. (2006). – *Neospora caninum* in wildlife. *Trends Parasitol.*, **22** (6), 247-252. E-pub.: 17 April 2006.

73. Gondim L.F.P., McAllister M.M., Pitt W.C. & Zemlicka D.E. (2004). – Coyotes (*Canis latrans*) are definitive hosts of *Neospora caninum. Int. J. Parasitol.*, **34** (2), 159-161.

74. Gonzalez Ittig R.E. & Gardenal C.N. (2004). – Recent range expansion and low levels of contemporary gene flow in *Calomys musculinus*: its relationship with the emergence and spread of Argentine haemorrhagic fever. *Heredity*, **93** (6), 535-541.

75. Goudarzi S. (2006). – Ape meat sold in US, European black markets. *Natl Geographic News*, 18 July. Available at: news.nationalgeographic.com/news/pf/70296375.html (accessed on 10 July 2010).

76. Goutard F., Roger F., Guitian F.J., Balança G., Argaw K., Demissie A., Soti V., Martin V. & Pfeiffer D. (2007). – Conceptual framework for avian influenza risk assessment in Africa: the case of Ethiopia. *Avian Dis.*, **51** (1 Suppl.), 504-506.

77. Guarner J., Johnson B.J., Paddock C.D., Shieh W.J., Goldsmith C.S., Reynolds M.G., Damon I.K., Regnery R.L., Zaki S.R. & Veterinary Monkeypox Virus Working Group (2004). – Monkeypox transmission and pathogenesis in prairie dogs. *Emerg. infect. Dis.*, **10** (3), 426-431.

78. Halpin K., Hyatt A.D., Plowright R.K., Epstein J.H., Daszak P., Field H.E., Wang L., Daniels P.W. & Henipavirus Ecology Research Group (2007). – Emerging viruses: coming in on a wrinkled wing and a prayer. *Clin. infect. Dis.*, **44** (5), 711-717. E-pub.: 23 January 2007.

79. Hansen G.R., Woodall J., Brown C., Jaax N., McNamara T. & Ruiz A. (2001). – Emerging zoonotic diseases. *Emerg. infect. Dis.*, 7 (3 Suppl.), 537.

80. Hartley M. & Gill E. (2010). – Assessment and mitigation processes for disease risks associated with wildlife management and conservation interventions. *Vet. Rec.*, **166** (16), 487-490.

81. Hays T. (2007). – Monkey meat at center of NYC court case. *Washington Post*, 24 November. Available at: www.washington post.com/wp-dyn/content/article/2007/11/24/ AR2007112400782.html (accessed on 1 November 2010).

82. Hedrick R.P. (1996). – Movement of pathogens with the international trade of live fish: problems and solutions. *In* Preventing the spread of aquatic animal diseases (B.J. Hill & T. Håstein, eds). *Rev. sci. tech. Off. int. Epiz.*, **15** (2), 523-531.

83. Hensley L.E., Jones S.M., Feldmann H., Jahrling P.B. & Geisbert T.W. (2005). – Ebola and Marburg viruses: pathogenesis and development of countermeasures. *Curr. mol. Med.*, **5** (8), 761-772.

84. Hoberg E.P., Polley L., Jenkins E.J. & Kutz S.J. (2008). – Pathogens of domestic and free-ranging ungulates: global climate change in temperate to boreal latitudes across North America. *In* Climate change: impact on the epidemiology and control of animal diseases (S. de La Rocque, S. Morand & G. Hendrickx, eds). *Rev. sci. tech. Off. int. Epiz.*, **27** (2), 511-528.

85. Hübschle O.J.B. (1988). – Rabies in the kudu antelope (*Tragelaphus strepsiceros*). *Rev. infect. Dis.*, **10** (Suppl. 4), S629- S633.

86. Huff J.L. & Barry P.A. (2003). – B-virus (Cercopithecine herpesvirus 1) infection in humans and macaques: potential for zoonotic disease. *Emerg. infect. Dis.*, **9** (2), 246-250.

87. Hulme P.E. (2009). – Trade, transport and trouble: managing invasive species pathways in an era of globalization. *J. appl. Ecol.*, **46** (1), 10-18.

88. Hylton H. (2007). – Keeping US turtles out of China. *Time*, 8 May. Available at: www.time.com/time/health/article/ 0,8599,1618565,00.html (accessed on 15 September 2010).

89. Jenkins P.T., Genovese K. & Ruffler H. (2007). – Broken screens: the regulation of live animal imports in the United States. Defenders of Wildlife, Washington, DC.

90. Jensenius M., Parola P. & Raoult D. (2006). – Threats to international travellers posed by tick-borne diseases. *Travel Med. infect. Dis.*, **4** (1), 4-13. E-pub.: 20 December 2004.

91. Johnson P.T. & Thieltges D.W. (2010). – Diversity, decoys and the dilution effect: how ecological communities affect disease risk. *J. experim. Biol.*, **213** (6), 961-970.

92. Jones K.E., Patel N.G., Levy M.A., Storeygard A., Balk D., Gittleman J.L. & Daszak P. (2008). – Global trends in emerging infectious diseases. *Nature*, **451** (7181), 990-993.

93. Jori E., Vosloo W., Du Plessis B., Bengis R., Brahmbhatt D., Gummow B. & Thomson G.R. (2009). – A qualitative risk assessment of factors contributing to foot and mouth disease outbreaks in cattle along the western boundary of the Kruger National Park. *Rev. sci. tech. Off. Int. Epiz.*, **28** (3), 917-931.

94. Jourdain E., Gauthier-Clerc M., Bicout D.J. & Sabatier P. (2007). – Bird migration routes and risk for pathogen dispersion into western Mediterranean wetlands. *Emerg. infect. Dis.*, **13** (3), 365-372.

95. Karesh W.B. & Noble E. (2009). – The bushmeat trade: increased opportunities for transmission of zoonotic disease. *Mt Sinai J. Med.*, **76** (5), 429-434.

96. Karesh W.B., Cook R.A., Bennett E.L. & Newcomb J. (2005). – Wildlife trade and global disease emergence. *Emerg. infect. Dis.*, **11** (7), 1000-1002.

97. Karesh W.B., Cook R.A., Gilbert M. & Newcomb J. (2007). – Implications of wildlife trade on the movement of avian influenza and other infectious diseases. *J. Wildl. Dis.*, **43** (3 Suppl.), 55-59.

98. Kasari T.R., Carr D.A., Lynn T.V. & Weaver J.T. (2008). – Evaluation of pathways for release of Rift Valley fever virus into domestic ruminant livestock, ruminant wildlife, and human populations in the continental United States. *JAVMA*, **232** (4), 514-529.

99. Kilpatrick A.M., Chmura A.A., Gibbons D.W., Fleischer R.C., Marra P.P. & Daszak P. (2006). – Predicting the global spread of H5N1 avian influenza. *Proc. natl Acad. Sci. USA*, **103** (51), 19368-19373. E-pub.: 7 December 2006.

100. Kilpatrick A.M., Daszak P., Goodman S.J., Rogg H., Kramer L.D., Cedeño V. & Cunningham A.A. (2006). – Predicting pathogen introduction: West Nile virus spread to Galáipagos. *Conserv. Biol.*, **20** (4), 1224-1231.

101. Kock R.A. (1995). – Wildlife utilization: use it or lose it – a Kenyan perspective. *Biodivers. Conserv.*, **4** (3), 241-256.

102. Kock R., Kebkiba B., Heinonen R. & Bedane B. (2002). – Wildlife and pastoral society – shifting paradigms in disease control. *Ann. N.Y. Acad. Sci.*, **969**, 24-33.

103. Kriger K.M. & Hero J.M. (2009). – Chytridiomycosis, amphibian extinctions, and lessons for the prevention of future panzootics. *EcoHealth*, **6** (1), 6-10. E-pub.: 7 May 2009.

104. Lafferty K.D. & Gerber L.R. (2002). – Good medicine for conservation biology: the intersection of epidemiology and conservation theory. *Conserv. Biol.*, **16** (3), 593-604.

105. Lebarbenchon C., Feare C.J., Renaud F., Thomas F. & Gauthier-Clerc M. (2010). – Persistence of highly pathogenic avian influenza viruses in natural ecosystems. *Emerg. infect. Dis.*, **16** (7), 1057-1062.

106. Lee G.W., Lee K.A. & Davidson W.R. (1993). – Evaluation of fox-chasing enclosures as sites of potential introduction and establishment of *Echinococcus multilocularis. J. Wildl. Dis.*, **29** (3), 498-501.

107. Lee H.W., Baek L.J. & Johnson K.M. (1982). – Isolation of Hantaan virus, the etiologic agent of Korean hemorrhagic fever, from wild urban rats. *J. infect. Dis.*, **146** (5), 638-644.

108. Lehmann T., Marcet P.L., Graham D.H., Dahl E.R. & Dubey J.P. (2006). – Globalization and the population structure of *Toxoplasma gondii. Proc. natl Acad. Sci. USA*, **103** (30), 11423-11428. E-pub.: 18 July 2006.

109. Leighton F.A. (2002). – Health risk assessment of the translocation of wild animals. *In* Infectious diseases of wildlife: detection, diagnosis and management (Part One) (R.G. Bengis, ed.). *Rev. sci. tech. Off. int. Epiz.*, **21** (1), 187-195.

110. Lenghaus C., Westbury H., Collins B., Ratnamohan N. & Morrissy C. (1994). – Overview of the RHD project in Australia. *In* Rabbit haemorrhagic disease: issues in assessment for biological control (R.K. Munro & R.T. Williams, eds). Bureau of Resource Sciences, Canberra, 104-129.

111. Leroy E.M., Rouquet P., Formenty P., Souquière S., Kilbourne A., Froment J.M., Bermejo M., Smit S., Karesh W., Swanepoel R., Zaki S.R. & Rollin P.E. (2004). – Multiple Ebola virus transmission events and rapid decline of central African wildlife. *Science*, **303** (5656), 387-390.

112. Ley D.H., Berkhoff J.E. & Levisohn S. (1997). – Molecular epidemiologic investigations of *Mycoplasma gallisepticum* conjunctivitis in songbirds by random amplified polymorphic DNA analyses. *Emerg. infect. Dis.*, **3** (3), 375-380.

113. Lightner D.V., Redman R.M., Poulos B.T., Nunan L.M., Mari J.L. & Hasson K.W. (1997). – Risk of spread of penaeid shrimp viruses in the Americas by the international movement of live and frozen shrimp. *In* Contamination of animal products: prevention and risks for animal health (P. Sutmoller, ed.). *Rev. sci. tech. Off. int. Epiz.*, **16** (1), 146- 160.

114. Lipper L., Sakuyama T., Stringer R. & Zilberman D. (eds) (2009). – Payment for environmental services in agricultural landscapes: economic policies and poverty reduction in developing countries. Springer/Food and Agriculture Organization of the United Nations, Rome.

115. Lips K.R., Brem F., Brenes R., Reeve J.D., Alford R.A., Voyles J., Carey C., Livo L., Pessier A.P. & Collins J.P. (2006). – Emerging infectious disease and the loss of biodiversity in a neotropical amphibian community. *Proc. natl Acad. Sci. USA*, **103** (9), 3165-3170. E-pub.: 15 February 2006.

116. Liu W., Li Y., Learn G.H., Rudicell R.S., Robertson J.D., Keele B.F., Ndjango J.B., Sanz C.M., Morgan D.B., Locatelli S., Gonder M.K., Kranzusch P.J., Walsh P.D., Delaporte E., Mpoudi-Ngole E., Georgiev A.V., Muller M.N., Shaw G.M., Peeters M., Sharp P.M., Rayner J.C. & Hahn B.H. (2010). – Origin of the human malaria parasite *Plasmodium falciparum* in gorillas. *Nature*, **467** (7314), 420-425.

117. Lynch M., Daly M., O'Brien B., Morrison F., Cryan B. & Fanning S. (1999). – *Salmonella tel-el-kebir* and terrapins. *J. Infection*, **38** (3), 182-184.

118. McCarthy S.A., McPhearson R.M., Guarino A.M. & Gaines J.L. (1992). – Toxigenic *Vibrio cholerae* O1 and cargo ships entering Gulf of Mexico. *Lancet*, **339** (8793), 624-625.

119. McDonald R. & Lariviere S. (2001). – Diseases and pathogens of *Mustela* spp., with special reference to the biological control of introduced stoat *Mustela erminea* populations in New Zealand. J. roy. Soc. N.Z., **31**, 721-744.

120. McDonald R.A. & Lariviere S. (2001). – Review of international literature relevant to stoat control. *Sci. Conserv.*, **170**, 78 pp.

121. McGuigan C. (2005). – Cryptosporidium outbreak after a visit to a wildlife centre in northeast Scotland: 62 confirmed cases. *Eurosurveillance*, **10** (4), E050428.2.

122. McInnes C.J., Gilray J., Wood A., Buxton D., Coulter L., Lurz P., Rushton S., Sainsbury T., Gurnell J., Bruemmer C. & Nettleton P. (2007) . – The impact of squirrelpox in the UK on the replacement of red squirrels by grey squirrels. *In* Proc. Scottish Squirrel Forum (M. Tonkin, ed.), 21-22 April, Dundee. Scottish Natural Heritage, Edinburgh, 33-37.

123. McKenzie J., Simpson H. & Langstaff I. (2007). – Development of methodology to prioritise wildlife pathogens for surveillance. *Prev. vet. Med.*, **81** (1-3), 194-210. E-pub.: 7 May 2007.

124. Mackenzie J.S., Chua K.B., Daniels P.W., Eaton B.T., Field H.E., Hall R.A., Halpin K., Johansen C.A., Kirkland P.D., Lam S.K., McMinn P., Nisbet D.J., Paru R., Pyke A.T., Ritchie S.A., Siba P., Smith D.W., Smith G.A., van den Hurk A.F., Wang L.F. & Williams D.T. (2001). – Emerging viral diseases of Southeast Asia and the Western Pacific. *Emerg. infect. Dis.*, **7** (3 Suppl.), 497-504.

125. Mackenzie J.S., Field H.E. & Guyatt K.J. (2003). – Managing emerging diseases borne by fruit bats (flying foxes), with particular reference to henipaviruses and Australian bat lyssavirus. *J. appl. Microbiol.*, **94** (Suppl. 1), 59S-69S.

126. McMichael A.J. (2004). – Environmental and social influences on emerging infectious diseases: past, present and future. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **359** (1447), 1049-1058.

127. Magnino S., Colin P., Dei-Cas E., Madsen M., McLauchlin J., Nöckler K., Maradona M.P., Tsigarida E., Vanopdenbosch E. & Van Peteghem C. (2009). – Biological risks associated with consumption of reptile products. *Int. J. Food Microbiol.*, **134** (3), 163-175. E-pub.: 12 August 2009.

128. Marano N., Arguin P.M. & Pappaioanou M. (2007). – Impact of globalization and animal trade on infectious disease ecology. *Emerg. infect. Dis.*, **13** (12), 1807-1809.

129. Mathews F. (2009). – Zoonoses in wildlife: integrating ecology into management. *Adv. Parasitol.*, **68**, 185-209.

130. Mazzoni R. (2003). – Emerging pathogen of wild amphibians in frogs (*Rana catesbeiana*) farmed for international trade. *Emerg. infect. Dis.*, **9** (8), 995-998.

131. Merianos A. (2007). – Surveillance and response to disease emergence. *Curr. Top. Microbiol. Immunol.*, **315**, 477-509.

132. Metcalf H.E. & McElvaine M.D. (1995). – Risk of introducing exotic disease through importation of animals and animal products. *In* Risk assessment for veterinary biologicals (E.G.S. Osborne & J.W. Glosser, eds). *Rev. sci. tech. Off. int. Epiz.*, **14** (4), 951-956.

133. Michalak K., Austin C., Diesel S., Bacon M.J., Zimmerman P. & Maslow J.N. (1998). – *Mycobacterium tuberculosis* infection as a zoonotic disease: transmission between humans and elephants. *Emerg. infect. Dis.*, **4** (2), 283-287.

134. Miko A., Pries K., Haby S., Steege K., Albrecht N., Krause G. & Beutin L. (2009). – Assessment of Shiga toxin- producing *Escherichia coli* isolates from wildlife meat as potential pathogens for humans. *Appl. environ. Microbiol.*, **75** (20), 6462-6470. E-pub.: 21 August 2009.

135. Miller P.S. (2007). – Tools and techniques for disease risk assessment in threatened wildlife conservation programmes. *Int. Zoo Yearbook*, **41** (1), 38-51.

136. Moleón M., Almaraz P. & Sanchez-Zapata J.A. (2008). – An emerging infectious disease triggering large-scale hyperpredation. *PLoS ONE*, **3** (6), e2307.

137. Moroney J.F., Guevara R., Iverson C., Chen F.M., Skelton S.K., Messmer T.O., Plikaytis B., Williams P.O., Blake P. & Butler J.C. (1998). – Detection of chlamydiosis in a shipment of pet birds, leading to recognition of an outbreak of clinically mild psittacosis in humans. *Clin. infect. Dis.*, **26** (6), 1425-1429.

138. Morse S.S. (1995). – Factors in the emergence of infectious diseases. *Emerg. infect. Dis.*, **1** (1), 7-15.

139. Muehlenbein M.P. & Ancrenaz M. (2009). – Minimizing pathogen transmission at primate ecotourism destinations: the need for input from travel medicine. *J. Travel Med.*, **16** (4), 229-232.

140. Novobilský A., Horácková E., Hirtová L., Modrý D. & Koudela B. (2007). – The giant liver fluke *Fascioloides magna* (Bassi 1875) in cervids in the Czech Republic and potential of its spreading to *Germany. Parasitol. Res.*, **100** (3), 549-553. E-pub.: 3 October 2006.

141. Nunn C.L., Altizer S.M., Sechrest W. & Cunningham A.A. (2005). – Latitudinal gradients of parasite species richness in primates. *Divers. Distrib.*, **11** (3), 249-256.

142. Nyhus P.J., Lacy R., Westley F.R., Miller P., Vredenburg H., Paquet P. & Pollak J. (2007). – Tackling biocomplexity with meta-models for species risk assessment. *Ecol. Soc.*, **12** (1), 31. Available at: www.ecologyandsociety.org/vol12/iss1/art31/ (accessed on April 3).

143. Oldroyd B.P. (1999). – Coevolution while you wait: *Varroa jacobsoni*, a new parasite of western honeybees. *Trends Ecol. Evol.*, **14** (8), 312-315.

144. O'Neill T. (2009). – Conservation: turtles in hot water. *Natl Geographic*, **215** (3).

145. Palmer S., Brown D. & Morgan D. (2005). – Early qualitative risk assessment of the emerging zoonotic potential of animal diseases. *BMJ*, **331** (7527), 1256-1260.

146. Parkes M.W., Bienen L., Breilh J., Hsu L.N., McDonald M., Patz J.A., Rosenthal J.P., Sahani M., Sleigh A. & Waltner-Toews D. (2005). – All hands on deck: transdisciplinary approaches to emerging infectious disease. *EcoHealth*, **2** (4), 258-272.

147. Parrish C.R., Holmes E.C., Morens D.M., Park E.C., Burke D.S., Calisher C.H., Laughlin C.A., Saif L.J. & Daszak P. (2008). – Cross-species virus transmission and the emergence of new epidemic diseases. *Microbiol. mol. Biol. Rev.*, **72** (3), 457-470.

148. Patz J.A., Daszak P., Tabor G.M., Aguirre A.A., Pearl M., Epstein J., Wolfe N.D., Kilpatrick A.M., Foufopoulos J., Molyneux D., Bradley D.J. & Working Group on Land Use Change and Disease Emergence (2004). – Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. *Environ. Hlth Perspect.*, **112** (10), 1092-1098.

149. Pavlin B.I., Schloegel L.M. & Daszak P. (2009). – Risk of importing zoonotic diseases through wildlife trade, United States. *Emerg. infect. Dis.*, **15** (11), 1721-1726.

150. Peeler E.J., Murray A.G., Thebault A., Brun E., Giovaninni A. & Thrush M.A. (2007). – The application of risk analysis in aquatic animal health management. *Prev. vet. Med.*, **81** (1-3), 3-20. E-pub.: 1 June 2007.

151. Pérez J., Calzada J., León-Vizcaíno L., Cubero M.J., Velarde J. & Mozos E. (2001). – Tuberculosis in an Iberian lynx (*Lynx pardina*). *Vet. Rec.*, **148** (13), 414-415.

152. Philbey A.W., Kirkland P.D., Ross A.D., Davis R.J., Gleeson A.B., Love R.J., Daniels P.W., Gould A.R. & Hyatt A.D. (1998). – An apparently new virus (family *Paramyxoviridae*) infectious for pigs, humans, and fruit bats. *Emerg. infect. Dis.*, **4** (2), 269-271.

153. Picco A.M. & Collins J.P. (2008). – Amphibian commerce as a likely source of pathogen pollution. *Conserv. Biol.*, **22** (6), 1582-1589. E-pub.: 19 August 2008.

154. Pinder A.C. & Gozlan R.E. (2003). – Sunbleak and topmouth gudgeon: two new additions to Britain's freshwater fishes. *Br. Wildlife*, **15** (2), 77-83.

155. Pinto J., Bonacic C., Hamilton-West C., Romero J. & Lubroth J. (2008). – Climate change and animal diseases in South America. *In* Climate change: impact on the epidemiology and control of animal diseases (S. de La Rocque, S. Morand & G. Hendrickx, eds). *Rev. sci. tech. Off. int. Epiz.*, **27** (2), 599-613.

156. Polop F., Provensal C., Scavuzzo M., Lamfri M., Calderon G. & Polop J. (2008). – On the relationship between the environmental history and the epidemiological situation of Argentine hemorrhagic fever. *Ecol. Res.*, **23** (1), 217-225.

157. Pongsiri M.J. & Roman J. (2007). – Examining the links between biodiversity and human health: an interdisciplinary research initiative at the US Environmental Protection Agency. *EcoHealth*, **4** (1), 82-85.

158. Pongsiri M.J., Roman J., Ezenwa V.O., Goldberg T.L., Koren H.S., Newbold S.C., Ostfeld R.S., Pattanayak S.K. & Salkeld D.J. (2009). – Biodiversity loss affects global disease ecology. *Bioscience*, **59** (11), 945-954.

159. Rabinowitz P., Gordon Z., Chudnov D., Wilcox M., Odofin L., Liu A. & Dein J. (2006). – Animals as sentinels of bioterrorism agents. *Emerg. infect. Dis.*, **12** (4), 647-652.

160. Rachowicz L.J., Hero J.M., Alford R.A., Taylor J.W., Morgan J.A.T., Vredenburg V.T., Collins J.P. & Briggs C.J. (2005). – The novel and endemic pathogen hypotheses: competing explanations for the origin of emerging infectious diseases of wildlife. *Conserv. Biol.*, **19** (5), 1441-1448.

161. Rappole J.H., Derrickson S.R. & Hubálek Z. (2000). – Migratory birds and spread of West Nile virus in the Western Hemisphere. *Emerg. infect. Dis.*, **6** (4), 319-328.

162. Reaser J.K., Clark Jr E.E. & Meyers N.M. (2008). – All creatures great and minute: a public policy primer for companion animal zoonoses. *Zoonoses public Hlth*, **55** (8-10), 385-401. E-pub.: 9 April 2008.

163. Reed R.N. (2005). – An ecological risk assessment of nonnative boas and pythons as potentially invasive species in the United States. *Risk Anal.*, **25** (3), 753-766.

164. Rees E.E., Pond B.A., Cullingham C.I., Tinline R., Ball D., Kyle C.J. & White B.N. (2008). – Assessing a landscape barrier using genetic simulation modelling: implications for raccoon rabies management. *Prev. vet. Med.*, **86** (1-2), 107-123. E-pub.: 28 April 2008.

165. Reperant L.A. (2010). – Applying the theory of island biogeography to emerging pathogens: toward predicting the sources of future emerging zoonotic and vector-borne diseases. *Vector borne Zoonotic Dis.*, **10** (2), 105-110.

166. Richman L.K., Montali R.J., Garber R.L., Kennedy M.A., Lehnhardt J., Hildebrandt T., Schmitt D., Hardy D., Alcendor D.J. & Hayward G.S. (1999). – Novel endotheliotropic herpesviruses fatal for Asian and African elephants. *Science*, **283** (5405), 1171-1176.

167. Roberton S.I., Bell D.J., Smith G.J.D., Nicholls J.M., Chan K.H., Nguyen D.T., Tran P.Q., Streicher U., Poon L.L.M., Chen H., Horby P., Guardo M., Guan Y. & Peiris J.S.M. (2006). – Avian influenza H5N1 in viverrids: implications for wildlife health and conservation. *Proc. roy. Soc. Lond., B, biol. Sci.*, **273** (1595), 1729-1732.

168. Roe D. (2008). – Trading nature: the contribution of wildlife trade management to sustainable livelihoods and the Millennium Development Goals. TRAFFIC International/ World Wildlife Fund, Cambridge, United Kingdom/Gland, Switzerland.

169. Roe D., Mulliken T., Milledge S., Mremi J., Mosha S. & Grieg-Gran M. (2002). – Making a killing or making a living. International Institute for Environment and Development/ TRAFFIC International/World Wildlife Fund, London.

170. Rojas-Espinosa O. & Lovik M. (2001). – *Mycobacterium leprae* and *Mycobacterium lepraemurium* infections in domestic and wild animals. *In* Mycobacterial infections in domestic and wild animals (E.J.B. Manning & M.T. Collins, eds). *Rev. sci. tech. Off. int. Epiz.*, **20** (1), 219-251.

171. Ross J., Tittensor A.M., Hamilton W.D., May R.M., Anderson R.M., Lawton J.H., Holme P., Brown R.A., Thompson H.V. & Gibbs A. (1986). – The establishment and spread of myxomatosis and its effect on rabbit populations [and discussion]. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **314** (1167), 599-606.

172. Rotureau B. (2006). – Ecology of the leishmania species in the Guianan ecoregion complex. *Am. J. trop. Med. Hyg.*, **74** (1), 81-96.

173. Rowley J.J., Chan S.K., Tang W.S., Speare R., Skerratt L.F., Alford R.A., Cheung K.S., Ho C.Y. & Campbell R. (2007). – Survey for the amphibian chytrid *Batrachochytrium dendrobatidis* in Hong Kong in native amphibians and in the international amphibian trade. *Dis. aquat. Organisms*, **78** (2), 87-95.

174. Sadovy Y.J., Donaldson T.J., Graham T.R., McGilvray F.A., Muldoon G.J., Phillips M.J., Rimmer M.A., Smith A. & Yeeting B. (2003). – While stocks last: the live reef food fish trade. Asian Development Bank, Manila, the Philippines.

175. Samet J.M., Schnatter R. & Gibb H. (1998). – Epidemiology and risk assessment. *Am. J. Epidemiol.*, **148** (10), 929-936.

176. Samuel A.R. & Knowles N.J. (2001). – Foot-and-mouth disease virus: cause of the recent crisis for the UK livestock industry. *Trends Genet.*, **17** (8), 421-424.

177. Schillaci M.A., Jones-Engel L., Engel G.A., Paramastri Y., Iskandar E., Wilson B., Allan J.S., Kyes R.C., Watanabe R. & Grant R. (2005). – Prevalence of enzootic simian viruses among urban performance monkeys in Indonesia. *Trop. Med. int. Hlth*, **10** (12), 1305-1314.

178. Schipper J., Chanson J.S., Chiozza F., Cox N.A., Hoffmann M., Katariya V., Lamoreux J., Rodrigues A.S.L., Stuart S.N., Temple H.J. *et al.* (2008). – The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science*, **322** (5899), 225-230.

179. Schlaepfer M.A., Hoover C. & Dodd Jr C.K. (2005). – Challenges in evaluating the impact of the trade in amphibians and reptiles on wild populations. *Bioscience*, **55** (3), 256-264.

180. Schloegel L.M., Picco A.M., Kilpatrick A.M., Davies A.J., Hyatt A.D. & Daszak P. (2009). – Magnitude of the US trade in amphibians and presence of *Batrachochytrium dendrobatidis* and ranavirus infection in imported North American bullfrogs (*Rana catesbeiana*). *Biol. Conserv.*, **142** (7), 1420-1426.

181. Sehgal R.N. (2010). – Deforestation and avian infectious diseases. *J. experim. Biol.*, **213** (6), 955-960.

182. Shinya K., Makino A. & Kawaoka Y. (2010). – Emerging and reemerging influenza virus infections. *Vet. Pathol.*, **47** (1), 53-57.

183. Simmonds P. (2001). – Reconstructing the origins of human hepatitis viruses. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **356** (1411), 1013-1026.

184. Smith K.F., Acevedo-Whitehouse K. & Pedersen A.B. (2009). – The role of infectious diseases in biological conservation. *Anim. Conserv.*, **12** (1), 1-12.

185. Smith K.F., Behrens M., Schloegel L.M., Marano N., Burgiel S. & Daszak P. (2009). – Ecology. Reducing the risks of the wildlife trade. *Science*, **324** (5927), 594-595.

186. Stetter M.D., Mikota S.K., Gutter A.F., Monterroso E.R., Dalovisio J.R., Degraw C. & Farley T. (1995). – Epizootic of *Mycobacterium bovis* in a zoologic park. *JAVMA*, **207** (12), 1618-1621.

187. Storfer A., Alfaro M.E., Ridenhour B.J., Jancovich J.K., Mech S.G., Parris M.J. & Collins J.P. (2007). – Phylogenetic concordance analysis shows an emerging pathogen is novel and endemic. *Ecol. Letters*, **10** (11), 1075-1083. E-pub.: 10 September 2007.

188. Suzán G., Marcé E., Giermakowski J.T., Mills J.N., Ceballos G., Ostfeld R.S., Armién B., Pascale J.M. & Yates T.L. (2009). – Experimental evidence for reduced rodent diversity causing increased hantavirus prevalence. *PLoS ONE*, **4** (5), e5461.

189. Swaddle J.P. & Calos S.E. (2008). – Increased avian diversity is associated with lower incidence of human West Nile infection: observation of the dilution effect. *PLoS ONE*, **3** (6), e2488.

190. Swanepoel R., Smit S.B., Rollin P.E., Formenty P., Leman P.A., Kemp A., Burt F.J., Grobbelaar A.A., Croft J., Bausch D.G., Zeller H., Leirs H., Braack L.E., Libande M.L., Zaki S., Nichol S.T., Ksiazek T.G., Paweska J.T. & International Scientific and Technical Committee for Marburg Hemorrhagic Fever Control in the Democratic Republic of Congo (2007). – Studies of reservoir hosts for Marburg virus. *Emerg. infect. Dis.*, **13** (12), 1847-1851.

191. Swift L., Hunter P.R., Lees A.C. & Bell D.J. (2007). – Wildlife trade and the emergence of infectious diseases. *EcoHealth*, **4** (1), 25-30.

192. Szonyi B., Agudelo-Flórez P., Ramírez M., Moreno N. & Ko A.I. (2011). – An outbreak of severe leptospirosis in capuchin (*Cebus*) monkeys. *Vet. J.*, **188** (2), 237-239. E-pub.: 31 May 2010.

193. Takahashi K., Kitajima N., Abe N. & Mishiro S. (2004). – Complete or near-complete nucleotide sequences of hepatitis E virus genome recovered from a wild boar, a deer, and four patients who ate the deer. *Virology*, **330** (2), 501-505.

194. Taylor L.H., Latham S.M. & Woolhouse M.E. (2001). – Risk factors for human disease emergence. *Philos. Trans. roy. Soc. Lond., B, biol. Sci.*, **356** (1411), 983-989.

195. Thiermann A. (2004). – Emerging diseases and implications for global trade. *In* Emerging zoonoses and pathogens of public health concern (L.J. King, ed.). *Rev. sci. tech. Off. int. Epiz.*, **23** (2), 701-707.

196. Thomson G.R., Tambi E.N., Hargreaves S.K., Leyland T.J., Catley A.P., van't Klooster G.G. & Penrith M.L. (2004). – International trade in livestock and livestock products: the need for a commodity-based approach. *Vet. Rec.*, **155** (14), 429-433.

197. Tompkins D.M., White A.R. & Boots M. (2003). – Ecological replacement of native red squirrels by invasive greys driven by disease. *Ecol. Letters*, **6** (3), 189-196.

198. TRAFFIC International (2008). – What's driving the wildlife trade? A review of expert opinion on economic and social drivers of the wildlife trade and trade control efforts in Cambodia, Indonesia, Lao PDR and Vietnam. East Asia and Pacific Region World Bank, Washington, DC. Available at: web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/0,,contentMDK:21928118~menuPK: 208943~pagePK:146736~piPK:226340~theSitePK:226301, 00.html (accessed on 10 January 2011).

199. TRAFFIC International (2010). – Wildlife trade news. Huge pangolin seizure in China. Available at: www.traffic.org/ home/2010/7/13/huge-pangolin-seizure-in-china.html (accessed on 1 November 2010).

200. Travis D. & Miller M. (2003). – A short review of transmissible spongiform encephalopathies, and guidelines for managing risks associated with chronic wasting disease in captive cervids in zoos. *J. Zoo Wildl. Med.*, **34** (2), 125-133.

201. United States Agency for International Development (USAID) (2010). – USAID launches emerging pandemic threats program. USAID, Washington, DC. Available at: www.usaid.gov/press/releases/2009/pr091021_1.html (accessed on 19 September 2010).

202. United States Fish and Wildlife Service (USFWS) (2010). – Endangered species program. USFWS, Washington, DC. Available at: www.fws.gov/endangered/esa-library/index. html (accessed on 10 August 2010).

203. Van Borm S., Thomas I., Hanquet G., Lambrecht B., Boschmans M., Dupont G., Decaestecker M., Snacken R. & van den Berg T. (2005). – Highly pathogenic H5N1 influenza virus in smuggled Thai eagles, Belgium. *Emerg. infect. Dis.*, **11** (5), 702-705.

204. Van den Berg T. (2009). – The role of the legal and illegal trade of live birds and avian products in the spread of avian influenza. *In* Avian influenza (T. Mettenleiter, ed.). *Rev. sci. tech. Off. int. Epiz.*, **28** (1), 93-111.

205. Van Dijk P., Stuart B.L. & Rhodin A.G.J. (eds) (1999). – Asian turtle trade. *In* Proc. Workshop on conservation and trade of freshwater turtles and tortoises in Asia. Chelonian Research Monographs 2. Chelonian Research Foundation, Lunenburg, United States, 45-51.

206. Van Riper S.G., Goff M.L. & Laird M. (1986). – The epizootiology and ecological significance of malaria in Hawaiian land birds. *Ecol. Monogr.*, **56**, 327-344.

207. Viggers K.L., Lindenmayer D.B. & Spratt D.M. (1993). – The importance of disease in reintroduction programmes. *Wildl. Res.*, **20** (5), 687-698.

208. Wabnitz C., Taylor M., Green E. & Razak T. (2003). – From ocean to aquarium: the global trade in marine ornamental species. United Nations Environment Programme/ Earthprint, Cambridge, United Kingdom. Available at: www.unep-wcmc.org/resources/publications/ocean aquarium/index.htm (accessed on 10 October 2011).

209. Wake D.B. & Vredenburg V.T. (2008). – Colloquium paper: are we in the midst of the sixth mass extinction? A view from the world of amphibians. *Proc. natl Acad. Sci. USA*, **105** (Suppl. 1), 11466-11473. E-pub.: 11 August 2008.

210. Walshe T. & Burgman M. (2010). – A framework for assessing and managing risks posed by emerging diseases. *Risk Anal.*, **30** (2), 236-249. E-pub.: 29 October 2009.

211. Wang M., Di B., Zhou D.H., Zheng B.J., Jing H., Lin Y.P., Liu Y.F., Wu X.W., Qin P.Z., Wang Y.L., Jian L.Y., Li X.Z., Xu J.X., Lu E.J., Li T.G. & Xu J. (2006). – Food markets with live birds as source of avian influenza. *Emerg. infect. Dis.*, **12** (11), 1773-1775.

212. Whittington R.J., Jones J.B., Hine P.M. & Hyatt A.D. (1997). – Epizootic mortality in the pilchard *Sardinops sagax neopilchardus* in Australia and New Zealand in 1995. I. Pathology and epizootiology. *Dis. aquat. Organisms*, **28**, 1-15.

213. Wilkie D.S. & Carpenter J.F. (1999). – Bushmeat hunting in the Congo Basin: an assessment of impacts and options for mitigation. *Biodivers. Conserv.*, **8** (7), 927-955.

214. Williams E.S. (2002). – The transmissible spongiform encephalopathies: disease risks for North America. *Vet. Clin. N. Am.* (*Food Anim. Pract.*), **18** (3), 461-473.

215. Williams E.S., Yuill T., Artois M., Fischer J. & Haigh S.A. (2002). – Emerging infectious diseases in wildlife. *In* Infectious diseases of wildlife: detection, diagnosis and management (Part One) (R.G. Bengis, ed.). *Rev. sci. tech. Off. int. Epiz.*, **21** (1), 139-157.

216. Wingard J.R. & Zahler P. (2006). – Silent steppe: the illegal wildlife trade crisis in Mongolia: Mongolia discussion papers. East Asia and Pacific Environment and Social Development Department, World Bank, Washington, DC.

217. Wobeser G. (2002). – Disease management strategies for wildlife. *In* Infectious diseases of wildlife: detection, diagnosis and management (Part One) (R.G. Bengis, ed.). *Rev. sci. tech. Off. int. Epiz.*, **21** (1), 159-178.

218. Wobeser G., Campbell G.D., Dallaire A. & McBurney S. (2009). – Tularemia, plague, yersiniosis, and Tyzzer's disease in wild rodents and lagomorphs in Canada: a review. *Can. vet. J.*, **50** (12), 1251-1256.

219. Wolfe N.D., Daszak P., Kilpatrick A.M. & Burke D.S. (2005). – Bushmeat hunting, deforestation, and prediction of zoonoses emergence. *Emerg. infect. Dis.*, **11** (12), 1822-1827.

220. Wolfe N.D., Dunavan C.P. & Diamond J. (2007). – Origins of major human infectious diseases. *Nature*, **447** (7142), 279-283.

221. Wolfe N.D., Heneine W., Carr J.K., Garcia A.D., Shanmugam V., Tamoufe U., Torimiro J.N., Prosser A.T., Lebreton M., Mpoudi-Ngole E., McCutchan F.E., Birx D.L., Folks T.M., Burke D.S. & Switzer W.M. (2005). – Emergence of unique primate T-lymphotropic viruses among central African bushmeat hunters. *Proc. natl Acad. Sci. USA*, **102** (22), 7994-7999. E-pub.: 23 May 2005.

222. Wolfe N.D., Switzer W.M., Carr J.K., Bhullar V.B., Shanmugam V., Tamoufe U., Prosser A.T., Torimiro J.N., Wright A., Mpoudi-Ngole E., McCutchan F.E., Birx D.L., Folks T.M., Burke D.S. & Heneine W. (2004). – Naturally acquired simian retrovirus infections in central African hunters. *Lancet*, **363** (9413), 932-937.

223. Woodford M.H. (1993). – International disease implications for wildlife translocation. *J. Zoo Wildl. Med.*, **24** (3), 265- 270.

224. Woodford M.H. (2009). – Veterinary aspects of ecological monitoring: the natural history of emerging infectious diseases of humans, domestic animals and wildlife. *Trop. anim. Hlth Prod.*, **41** (7), 1023-1033. E-pub.: 20 November 2008.

225. Woodford M.H. & Rossiter P.B. (1993). – Disease risks associated with wildlife translocation projects. *In* Health and management of free-ranging mammals – part two (M. Artois, ed.). *Rev. sci. tech. Off. int. Epiz.*, **12** (1), 115-135.

226. Woolhouse M.E. (2002). – Population biology of emerging and re-emerging pathogens. *Trends Microbiol.*, **10** (10 Suppl.), S3-S7.

227. Woolhouse M.E. & Gowtage-Sequeria S. (2005). – Host range and emerging and reemerging pathogens. *Emerg. infect. Dis.*, **11** (12), 1842-1847.

228. Wyler L.S. & P. Sheikh A. (2008). – International illegal trade in wildlife: threats and US policy. Library of Congress, Washington, DC. Available at: opencrs.com/document/ RL34395/ (accessed on 1 October 2011).

229. Zessin K.H. (2006). – Emerging diseases: a global and biological perspective. *J. Vet. Med. B, infect. Dis. vet. public Hlth*, **53** (Suppl. 1), 7-10.

230. Zietz B.P. & Dunkelberg H. (2004). – The history of the plague and the research on the causative agent *Yersinia pestis*. *Int. J. Hyg. environ. Hlth*, **207** (2), 165-178.

Zoonotic viruses associated with illegally imported wildlife products

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Abstract

The global trade in wildlife has historically contributed to the emergence and spread of infectious diseases. The United States is the world's largest importer of wildlife and wildlife products, yet minimal pathogen surveillance has precluded assessment of the health risks posed by this practice. This report details the findings of a pilot project to establish surveillance methodology for zoonotic agents in confiscated wildlife products. Initial findings from samples collected at several international airports identified parts originating from nonhuman primate (NHP) and rodent species, including baboon, chimpanzee, mangabey, guenon, green monkey, cane rat and rat. Pathogen screening identified retroviruses (simian foamy virus) and/or herpesviruses (cytomegalovirus and lymphocryptovirus) in the NHP samples. These results are the first demonstration that illegal bushmeat importation into the United States could act as a conduit for pathogen spread, and suggest that implementation of disease surveillance of the wildlife trade will help facilitate prevention of disease emergence.

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Introduction

No adequate estimate of numbers of wildlife traded throughout the world exists given the large size and covert nature of the business. Beyond the threats to conservation, the intermingling of wildlife, domestic animals and humans during the process of wildlife extraction, consumption, and trade can serve as a vessel for pathogen exchange [1]. Nearly 75% of emerging infectious diseases in humans are of zoonotic origin, the majority of which originate in wildlife [2,3]. Therefore infectious diseases acquired from contact with wildlife, such as occurs via the wildlife trade, are increasingly of concern to global public health.

Trade in live animals and animal products has led to the emergence of several zoonotic pathogens, of which RNA viruses are the most common. SARS emerged as a respiratory and gastrointestinal disease in southwest China and within months had spread to 29 other countries, eventually leading to 8,098 cases and 774 deaths. Masked palm civets (*Paguma larvata*) traded in the markets of Guangdong were found to be infected and a large proportion of the early cases were restaurant workers who bought and butchered wildlife from these markets [4].

The United States is one of the world's largest consumers of imported wildlife and wildlife products [5]. Between 2000 and 2006, approximately 1.5 billion live wild animals (around 120,000,000 per year) were legally imported into the United States nearly 90% of which were destined for the pet industry [6], and an average of over 25 million kilograms of non-live wildlife enter the United States each year [5]. New York is the most frequently used port of entry into the United States, and in combination with Los Angeles and Miami accounts for more than half of all known wildlife imports. Imports most often refused entry (i.e., deemed to be illegal) into the United States included those from China, Philippines, Hong Kong, Thailand, and Nigeria [5] – countries with endemic pathogens such as highly pathogenic H5N1 influenza virus, Nipah virus, and simian retroviruses.

Health risks to the US public, agricultural industry, and native wildlife posed by the wildlife trade have generally not been quantified due to minimal surveillance of live animal imports and the absence of surveillance of wildlife product imports. Despite this, known examples of disease introductions to the United States via the wildlife trade have included pathogens of risk to wildlife, livestock and public health such as amphibian chytridiomycosis, exotic Newcastle's disease, and monkeypox, respectively. The monkeypox outbreak showed that a single shipment of infected animals can result in serious impact on public health, highlighting the challenges faced by agencies attempting to regulate both legal and illegal wildlife trade. The USDA regulates certain exotic ruminant species, some birds, some fish, a few species of tortoise, hedgehogs, tenrecs, and brushtail possums for specific foreign animal diseases to protect agricultural health. In general, there is no current remit for USDA to regulate species as potential threats to wildlife or public health. Species restricted by Centers for Disease Control and Prevention (CDC) include certain turtles, NHPs, bats, civets, and African rodents.

Hunting and butchering of bushmeat (for the purpose of this paper to be defined according to Oxford Dictionary as the meat of African wild animals) has been increasingly recognized as a source of disease emergence. Harvest of NHP bushmeat and exposure to NHPs in captivity have resulted in cross-species transmission of several retroviruses to humans including simian immunodeficiency virus (SIV), simian T-lymphotropic virus (STLV), and simian foamy virus (SFV) [7,8]. While SIV and STLV adapted to humans and spread to become the global pathogens human immunodeficiency virus (HIV) and human T-lymphotropic virus (HTLV), less is known about the distribution and public health consequences of SFV infection [7]. Much of the bushmeat smuggled into the United States from Africa by air passes through Europe en route, although amount and characteristics of bushmeat reaching US borders is not well described. One study estimated that 273 tons of bushmeat was imported every year into Paris Roissy-Charles de Gaulle Airport in France on Air France carriers alone [9].

Under the authority of the Public Health Service Act, the US Department of Health and Human Service (DHHS), CDC is responsible for preventing the introduction, transmission, and spread of communicable diseases, including those from animals or animal products to humans. CDC recognizes the potential public health risk posed by illegal trade in wildlife and regulations are in place that prohibit the importation of bushmeat products derived from CDC-regulated animals. To better understand and educate the public about risks to public health from smuggled bushmeat, beginning in 2008 CDC and inter-agency and non-governmental partners initiated a cooperative effort to assess those risks. This effort includes a pilot study to screen for evidence of zoonotic pathogens in CDC-regulated wild animal products. Here we report finding sequences of simian retroviruses and herpesviruses in bushmeat confiscated at five US airports.

Methods

Shipment confiscation and specimen collection

This pilot study was initiated at John F. Kennedy Airport (JFK) in Queens, NY, where CDC-regulated wildlife products were seized by US Customs and Border Protection (CBP) between October 2008 to September 2010. Beginning in April 2010, additional seizures from another four airports that receive international flights (Philadelphia, Washington Dulles, George Bush Intercontinental-Houston, and Atlanta Hartsfield-Jackson International) were included in the study. Illegally imported shipments were confiscated opportunistically and thus the pilot study established only the presence and not the prevalence of zoonotic agents in the specimens.

Site of origin and destination, flight data, mail shipment or carrying passenger identification, date of arrival, and date of sample collection were recorded for each confiscation. Items were photographed and identified to genus and species if possible. Biological samples were processed for aliquoting and storage at the CDC Quarantine Laboratory at JFK Airport, and any remaining tissues were incinerated according to standard protocols. All items were sampled while wearing full personal protective equipment and sterile instruments were used to avoid cross-contamination. The freshest

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part of each item was located (muscle appearing red or raw, joint fluid, bone marrow, etc.) and several samples were taken from each item, placed in cryotubes, and preserved immediately in liquid nitrogen.

An additional collection of bushmeat items was seized by US Fish and Wildlife Service (USFWS) at JFK airport in 2006, and provided for this study by USFWS and the United States Geological Survey National Wildlife Health Center (NWHC). Specimens included those central to a 2006 federal case against a person caught smuggling bushmeat into New York for resale [10]. These samples had been stored at USFWS forensic laboratories at -20°C from 2006 until 2010, when they were shipped to the NWHC for processing as part of this study. All specimens were then stored at -80°C, and thawed at -20°C before processing at the NWHC. Tissue dissection was performed as described above with some minor differences; 0.5 cm^2 samples were preserved in 1 mL Nuclisens lysis buffer (Biomerieux Inc, cat# 284135) prior to immediate storage at -80°C.

Sample analysis and preparation

Permission was obtained from the New York Department of Agriculture and Markets to transfer the frozen specimens from JFK Airport to CDC National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention (NCHHSTP), and/or Columbia University's Center for Infection and Immunity (CII) for testing. When an assured gross identification of species could not be made, samples were genetically identified by phylogenetic analysis of mtDNA genes, including cytochrome *c* oxidase subunits I and II (*COX1/2*), and/or cytochrome *b* (*CytB*) [11–15].

Nucleic acids were extracted from 10–30 mg of tissue using mechanical disruption (Qiagen tissue lyser II or Next Advance Inc Bullet Blender), followed by proteinase K treatment until complete digestion of the tissue was achieved. Purification of subsequent homogenates was performed using the Qiagen All-Prep DNA and RNA extraction kit or DNeasy Blood and Tissue kits according to the manufacturer's instructions. Nucleic acid quality was determined using the Agilent BioAnalyser (Agilent RNA nano 6000) or ß-actin PCR as previously described [16].

Figure 1. Nonhuman primate bushmeat specimens confiscated at US airports. Examples of smuggled simian bushmeat (a) skull, (b) hand, (c) skull and torso, and (d) arm. Ruler units are centimeters. doi:10.1371/journal.pone.0029505.g001

Microbial Screening

Samples were screened for multiple pathogens as described in detail elsewhere, including: leptospira and anthrax [17], herpesviruses [18], filoviruses [19], paramyxoviruses [20], coronaviruses [21], flaviviruses [22], orthopoxviruses [23] and simian retroviruses (SIV, STLV, SFV) [24–29]. All PCR-amplified bands approximately the expected size were confirmed by sequencing.

Sequence Analysis

Raw sequences were analyzed and edited in Geneious Pro v5.1.7 and MEGA 5.03. Multiple sequence alignments were constructed using ClustalW and phylogenetic comparisons made using Neighbor-Joining (NJ) and maximum likelihood (ML) algorithms. ModelTest was used to select the most appropriate nucleotide substitution model. Support for branching order was evaluated using 1,000 nonparametric bootstrap support. Sequence identity was calculated using uncorrected p-distances in PAUP* and BLAST.

Results

Specimen condition and species composition

From October 2008 to September 2010, 8 postal shipments confiscated at JFK Airport were included in this study. From June 2010 to September 2010, an additional 20 passenger-carried packages confiscated at the four other international airports were sampled for this study. Additional confiscations were made but were not included in this study due to poor condition of sample (e.g., severely degraded or chemically treated). In many cases multiple separate packages were included in a single shipment or carried by a single passenger. Specimens varied in condition,

Table 1. Species identification and viruses found in smuggled nonhuman primate bushmeat samples[1]

Species[2]	Common name	Sample number[1]	Tissue	LCV	CMV	SFV	Origin of package	Destination of package
Chlorocebus sabaeus	green monkey	CII-040	Bone marrow	+			Guinea	Staten Island, NY
Chlorocebus sabaeus	green monkey	CII-051	Bone marrow	+		+	Guinea	Staten Island, NY
Chlorocebus sabaeus	green monkey	CII-044	Trachea	+			Guinea	Staten Island, NY
Chlorocebus sabaeus	green monkey	CII-144	Trachea	+			Guinea	Staten Island, NY
Cercopithecus nictitans	greater white-nosed monkey	BM002	Muscle		+		Nigeria	Dallas, TX
Papio papio	baboon	CII-013	Bone marrow	+			Guinea	Staten Island, NY
Papio papio	baboon	CII-028	Spinal nerve			+	Guinea	Staten Island, NY
			Muscle		+			
Papio papio	baboon	CII-046	Right eye			+	Guinea	Staten Island, NY
Papio papio	baboon	CII-163	Optic nerve		+	+	Guinea	Staten Island, NY
			Right eye	+	+			
			Trachea	+		+		
Cercocebus atys	sooty mangabey	BM008	Muscle	+		+	Liberia	Philadelphia, PA
Cercocebus atys	sooty mangabey	BM010	Muscle			+	Liberia	Philadelphia, PA
Pan troglodytes ellioti	Nigeria-Cameroon chimpanzee	BM013	Muscle			+	Nigeria	Queens, NY

[1] Only samples testing positive are listed. All other rodent and simian samples were negative for all pathogens tested.
[2] Species identification inferred with phylogenetic analysis.
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including items that were fresh, raw transported in a cooler, lightly smoked, or well dried (Fig. 1A–D). Most items contained moist inner tissue. RNA quality was low with a predominance of degraded, low molecular weight fragments in the samples, while B-actin sequences were detected in the NHP specimens suggesting the presence of amplifiable DNA (data not shown). Samples from approximately 44 animals were included in this study, including 9 NHPs comprising 2 chimpanzees (*Pan troglodytes*), 2 mangabeys (*Cercocebus* spp.), and 5 guenons (*Cercopithecus* spp.; one of which was further analyzed and identified as *Cercopithecus nictitans*, white-nosed guenon) all confirmed by phylogenetic analysis; and 35 rodents comprised of 14 cane rats (*Thryonomys* sp.) confirmed by gross or phylogenetic analysis, 18 suspected cane rats (based on gross identification), and 3 rats (unknown species) confirmed by gross identification.

The USFWS specimens from 2006 included an additional 20 NHP tissues from 16 individual animals including 10 baboons (*Papio* sp.) and 6 African green monkeys (AGMs; *Chlorocebus* sp.) all confirmed by phylogenetic analysis.

Pathogen detection

Both SFV and herpesviruses were detected in the nonhuman primate bushmeat samples. All positive NHP samples are presented in Table 1. All NHP samples were negative for SIV and STLV sequences. All rodent samples were negative for leptospira, anthrax, herpesviruses, filoviruses, paramyxoviruses, coronaviruses, flaviviruses, and orthopoxviruses.

Simian Foamy Virus

SFV polymerase (*pol*, 465-bp) and long terminal repeat (LTR, ~357-bp) sequences were detected at CDC in tissues from one chimpanzee (BM013) and one mangabey (BM008). SFV LTR sequences were also identified in a second mangabey (BM010). BLAST analysis of the 425-bp *pol* sequences from BM013 and BM008 showed maximum nucleotide identity to SFVs from *P. t elliot*i and mangabey (*Cercocebus atys* and *Cercocebus agilis*), respectively. Phylogenetic analysis of the two *pol* sequences with those available on GenBank confirmed that the chimpanzee SFV was highly related to SFV from *P. t. ellioti* whereas the mangabey SFV clustered tightly with SFV from sooty mangabeys (*Cercocebus atys*) (Figure 2). *P. t. ellioti* are endemic to West-Central Africa in Nigeria and Cameroon while *Cercocebus atys* are found in West Africa from Senegal to Ghana. Phylogenetic analysis was not performed on LTR sequences since only limited SFV sequences in this region are available at GenBank. BLAST analysis was similarly limited and gave the highest nucleotide identity to chimpanzee and mandrill (*M. sphinx*) SFV LTR sequences, respectively. The two LTR sequences from mangabeys (BM008 and BM010) were 94% identical to each other due to an 8-bp deletion in the LTR of BM008 and 8 nucleotide substitutions.

In the USFWS samples SFV *pol* sequences were present in 3/10 baboons, and in 1/6 AGMs. The baboon SFVs shared >97% nucleotide identity, and had 88–90% nucleotide identity with the AGM SFV. Phylogenetic analysis of the short (156 bp) *pol* sequences shows that the three baboon SFVs clustered together, yet separately from the AGM SFV - suggesting some genetic relatedness that reflects host specificity as previously demonstrated [13] (Figure 3). However, while the short baboon SFV pol sequences detected in this study

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clustered together, they did not cluster with other published sequences from baboons (80.1–84.2% nucleotide identity). Similarly the AGM sequences did not cluster with published AGM sequences (85.8–86.5% nucleotide identity). These results may reflect poor phylogenetic signal from limited sequence data in this region.

All simian DNA samples from USFWS were also screened for larger SFV *pol* sequences (465-bp) as done at the CDC but were found in only one baboon sample (CII-163). Phylogenetic analysis of the larger *pol* sequence inferred a significant relationship to SFV from Guinea baboons (*P. papio*) (Figure 3), which correlated with the origin of the shipment (Guinea). Our inability to detect larger *pol* sequences in other SFV-positive baboon and AGM samples may be due to highly degraded nucleic acids in those specimens (confiscated in 2006) which limits detection of longer sequences.

Herpesviruses

Two genera of herpesvirus were detected in NHP specimens, including cytomegaloviruses (CMV; betaherpesvirus) and lymphocryptoviruses (LCV; gammaherpesvirus) (Table 1). CMV sequences from baboons CII-028 and CII-163 shared >99.5% nucleotide identity indicating they are likely to be the same virus. Comparison of this virus with the CMV sequence from white-nosed guenon BM002 showed these two CMVs are 91% identical. Overall, nucleotide sequence identity within the CMVs (for sequences included here) was shown to be 68.4–100% (μ = 85.0%).

LCVs were detected in four AGMs, two baboons, and one mangabey. LCV sequences in AGMs CII-044 and CII-144 were >99% identical and likely represent the same virus. A comparison of this virus with the other LCVs detected showed 88.2–95.5% sequence identity. Sequence identity for the entire LCV group was calculated to be 81.0–100% (μ = 87.5).

Phylogenetic analysis confirmed the presence and phylogenetic relatedness of CMV and LCV in these NHP specimens (Figure 4).

Mixed infections

Multiple viruses were detected within some samples. Both LCV and SFV were detected in the bone marrow of AGM CII-051 and muscle of mangabey BM008 (Table 1). CMV, LCV, and SFV were detected in baboon CII-163 (Table 1).

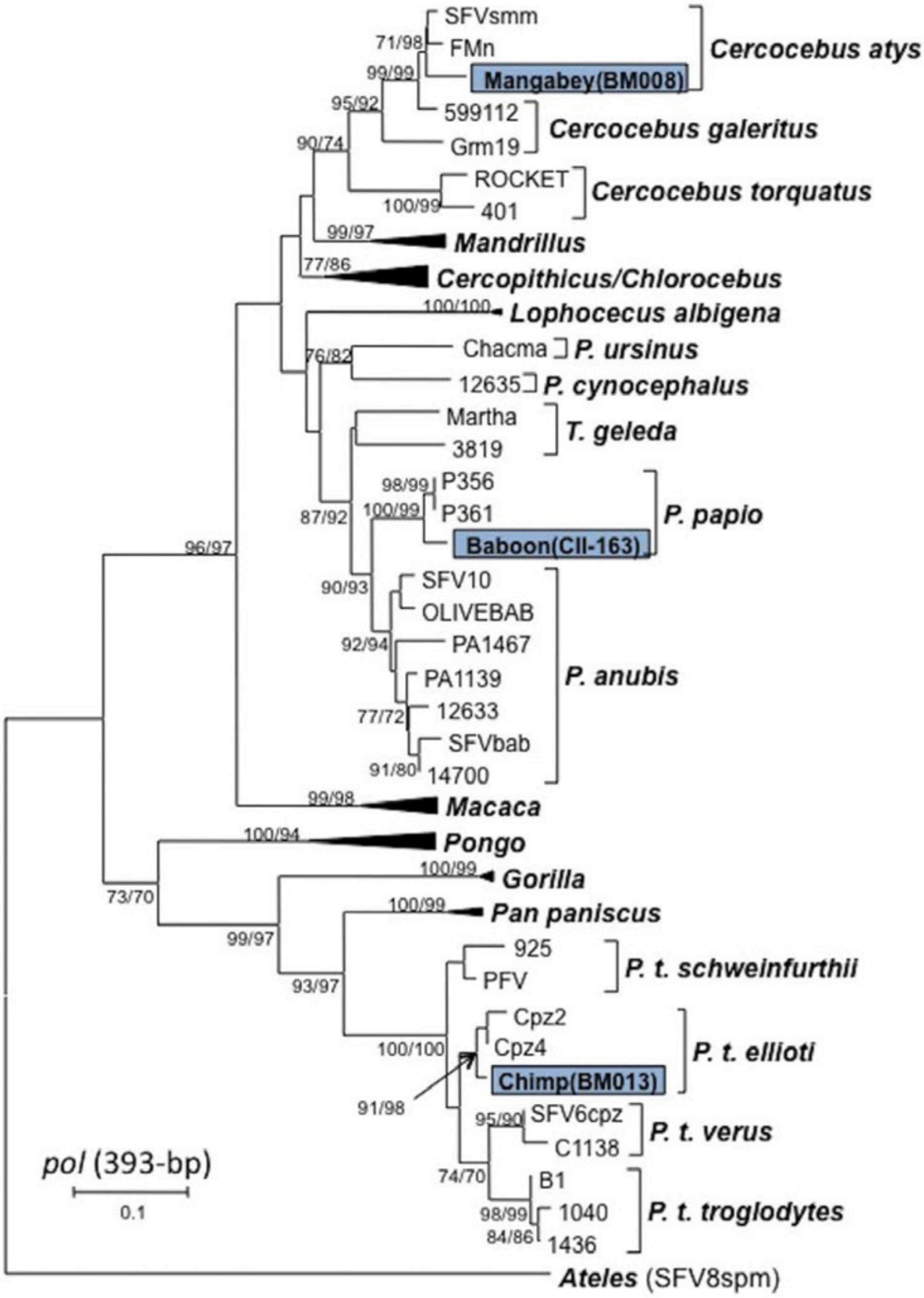

Figure 2. Inferred phylogenetic relationships of SFV pol sequences detected in bushmeat samples. Neighbor-joining (NJ) and maximum- likelihood (ML) analysis gave identical branching orders. New SFV sequences identified in this study are boxed. Clades of sequences from Mandrillus, Cercopithicus, Chlorocebus, Macaca, Pongo, Gorilla, and Pan paniscus are collapsed for presentation. Branch lengths are drawn to scale and only bootstrap values (NJ/ML) greater than 70% are shown. doi:10.1371/journal.pone.0029505.g002

GenBank Accession numbers

New SFV, herpesvirus, and mtDNA sequences identified in the current study have been deposited at GenBank with the following accession numbers: JF810903–JF810914 and JF828317–JF828329. Sequences less than 200 bp are available upon request.

Discussion

Our study is the first to establish surveillance for zoonotic viruses in wild animal products illegally imported into the United States in an effort to prevent the transmission of infectious agents from these shipments. The restricted number of samples included in this study were tested for a limited range of pathogens only and thus presence of additional pathogens not included in this study cannot be ruled out. We identified four SFV strains and two different herpesviruses (in some

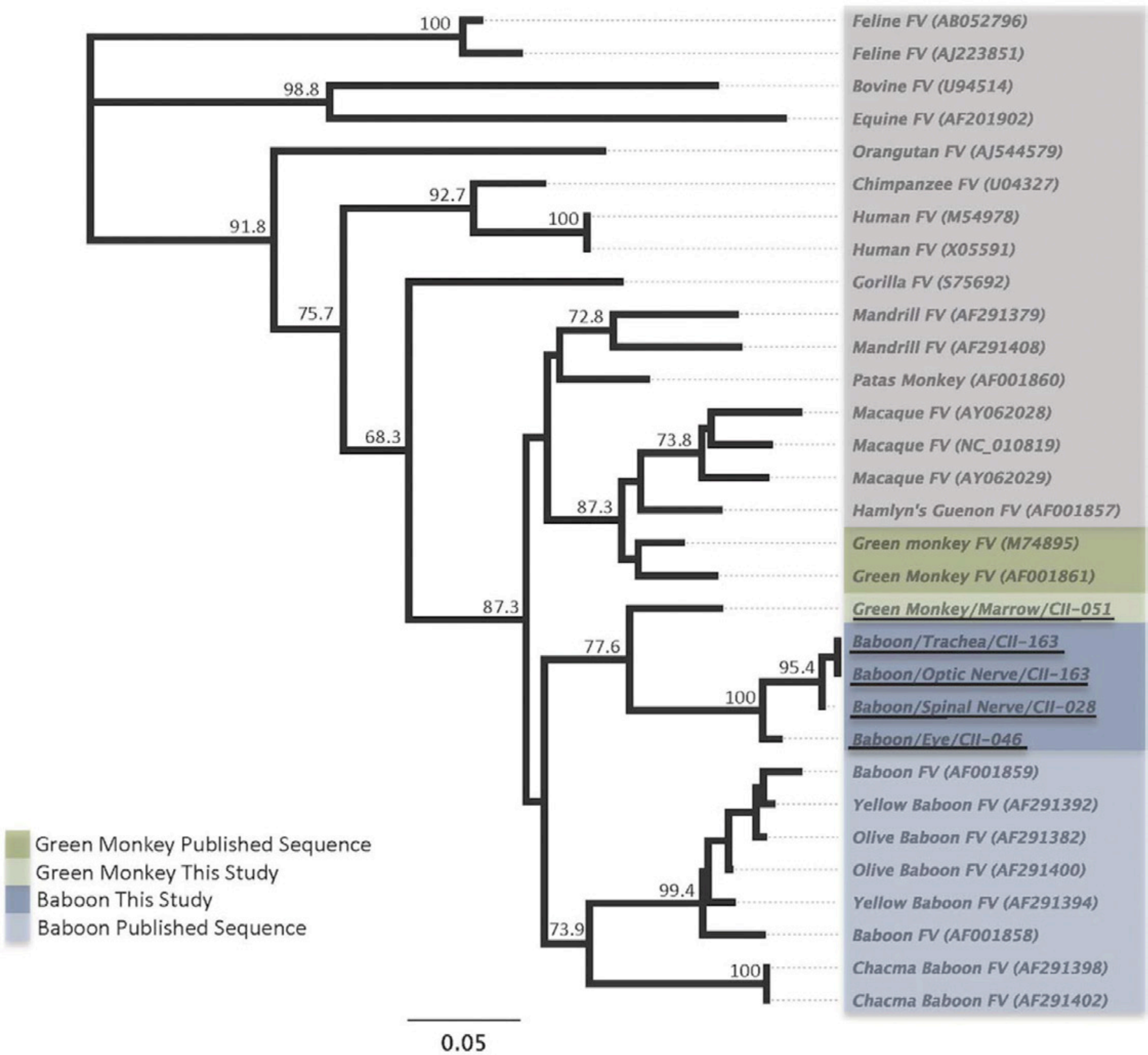

Figure 3. Inferred phylogenetic relationships of SFV pol (,153 bp) sequences detected in USFWS bushmeat samples. Neighbor- joining (NJ) and maximum-likelihood (ML) analysis gave identical branching orders. New SFV sequences identified in this study are underlined. doi:10.1371/journal.pone.0029505.g003

cases in the same tissues) in smuggled NHP bushmeat. Using phylogenetic analysis and gross examination, we were able to determine that bushmeat from nine NHP species and at least two rodent species were attempted to be smuggled into the United States. These results are consistent with the origin of the shipments from West Africa and included species of conservation importance (*P. papio, Cercocebus atys*, and *P. t. ellioti* are classified as ''near threatened'', ''vulnerable'', and ''endangered'', respectively by the International Union for Conservation of Nature), suggesting more education efforts or harsher penalties are needed regarding the handling, consumption, and illegal transportation of products from wildlife of conservation concern. In addition, the finding of mangabey, guenon, and cane rat bushmeat in our study is consistent with that reported by Chaber *et al* who found these and bushmeat from nine other species entering Paris-Charles de Gaulle Airport [9].

Our finding of SFV DNA in smuggled NHP specimens comprising of four species (baboon, chimp, mangabey, and AGM) is significant because SFV is a known zoonotic infection of humans exposed to NHPs. However, the mode of transmission to humans is poorly understood and while most infected people reported sustaining a NHP exposure (mostly bites) others did not, suggesting a less invasive mode of

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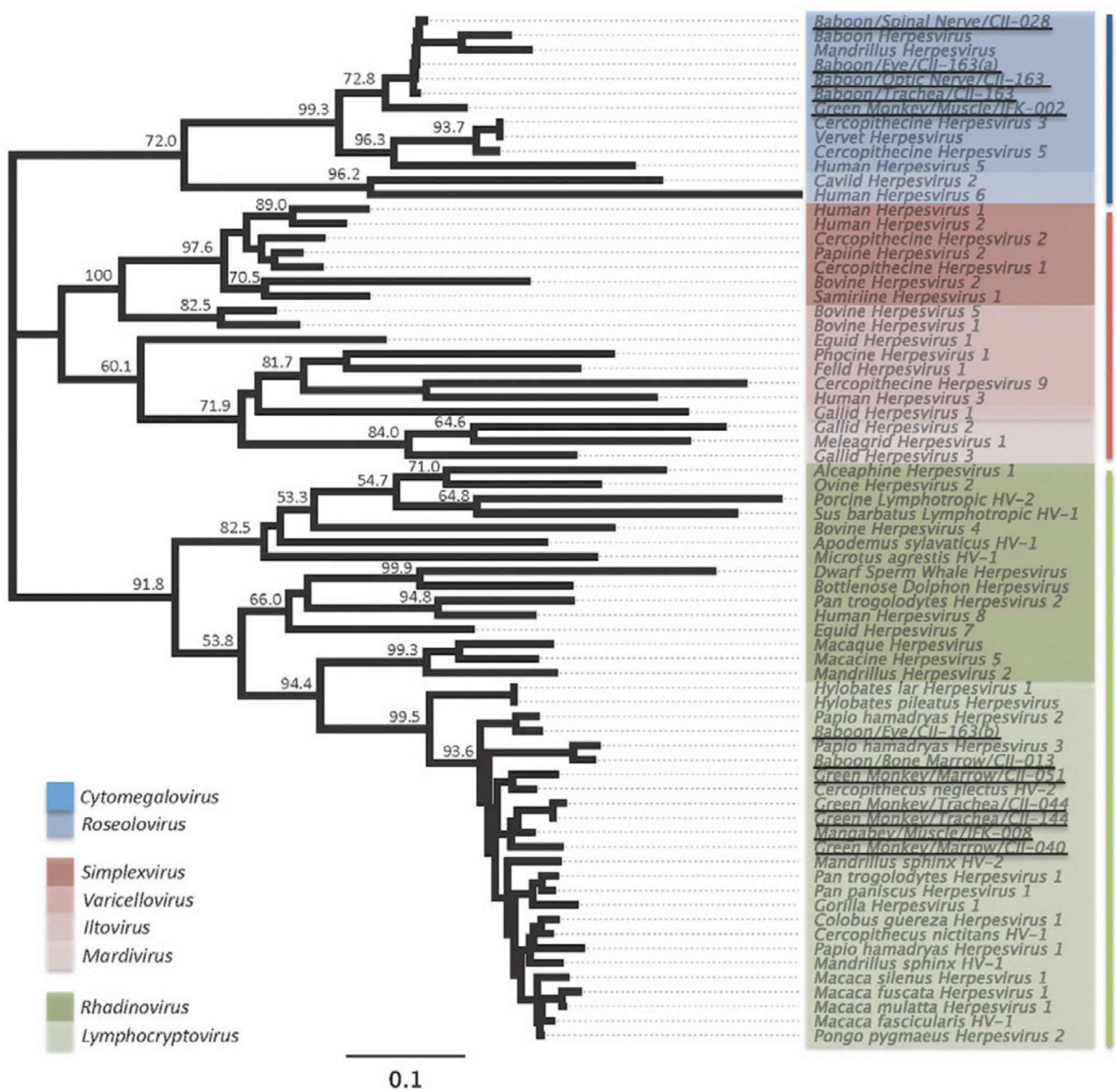

Figure 4. Inferred phylogenetic relationships of herpesviruses detected in siman bushmeat samples. Neighbor-joining (NJ) and maximum-likelihood (ML) analysis gave identical branching orders. Sequences identified in bushmeat products are underlined and cluster with sub- families betaherpesvirus (samples: CII-028, CII-163, BM-002), and gammaherpesvirus (samples: CII-163, CII-013, CII-051, CII-044, CII-144, CII-040, BM-008). doi:10.1371/journal.pone.0029505.g004

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infection is possible [7]. These viruses are probably not easily spread from human-to-human, although persistent infection has been documented [7]. Several SFV-positive people reported donating blood while infected and because blood banks do not screen for SFV, secondary transmission via contaminated blood donations may be possible [7]. Further research into the possibility of secondary transmission of SFV is required. The finding of SFV DNA in the bushmeat samples highlights a potential public health risk of exposure to these tissues along the hunting, transportation, and consumption continuum with multiple opportunities for primary transmissions. Unlike most retroviruses whose RNA genome is packaged in the viral particles, foamy viruses are unusual in that DNA and/or RNA can be present in the infectious virus particles. Thus, finding of only DNA does not exclude that SFV in these tissues is not infectious, especially in the more recently CDC confiscated items which contained fresher tissue compared to the USFWS items confiscated in 2006 that were partially degraded at the time of analysis in 2010. Human infection with SFV is of further concern because increases in the pathogenicity of simian retroviruses following cross-species transmission have been documented (e.g., HIV-1 and HIV-2) [30,31]. However, the limited number of cases, short follow-up duration, and selection biases in the enrolling of healthy workers or hunters to identify cases all limit the identification of potential disease associations [7].

Although we did not find SIV or STLV in the limited number of specimens in this study, these viruses have been found in high prevalences in NHP specimens at bushmeat markets and in hunted NHPs [8,32,33]. HIV-1 and HIV-2 emerged as a result of several spillover events of SIV from chimpanzees and mangabeys, respectively, that were likely hunted for bushmeat in central and western Africa [30]. Serosurveillance studies have shown thirty-five different species of African NHPs harbor lentivirus infections, with a prevalence of SIV in up to 35% of free-ranging chimpanzees, and 30–60% of free-ranging sooty mangabeys and green monkeys [30,31,33,34].

To date, four groups of HTLV viruses found in humans are believed to have originated from corresponding STLV strains in NHP species (including mangabeys, baboons, and chimpanzees) via multiple transmission events [35]. HTLV-1, closely related to STLV-1 group viruses, infects 15 to 20 million people worldwide and is spread from person to person via bodily fluids [35]. These viruses are capable of causing leukemia, lymphoma and neurologic disease in humans [35]. Discoveries of HTLV-3 and HTLV-4, and a novel STLV-1 strain were recently made in NHP hunters in Cameroon [7], and 89% of hunted bushmeat in Cameroon has been shown to be infected with STLV strains [8,32]. Although imported wildlife products are often not in a freshly-killed state, many are not smoked or processed in any manner, thus screening of larger sample collections of smuggled bushmeat may reveal evidence of these viruses.

Like retroviruses, herpesviruses can cause long-term latent infections in their host. Most herpesviruses are host-specific, yet particular strains are capable of causing severe disease in the non-host, examples of which include agents of malignant catarrhal fever and Herpes B virus [36,37]. CMVs are in the betaherpesvirus subfamily. Human CMV is typically asymptomatic in humans, with the exception of immunocompromised persons. Similarly, many NHPs are asymptomatic hosts of CMV that do not typically infect other species, including humans. However, baboon CMV (bCMV), like that identified in our study, has been shown to replicate in human tissues in vitro as well as infect and replicate in humans following a bCMV-positive liver xenotransplant [38].

Lymphocryptoviruses (LCV) are in the gammaherpesvirus subfamily, and include human LCV, and Epstein-Barr virus (EBV), the agent of infectious mononucleosis. Nearly 90% of adults in the United States have antibodies indicating exposure at some point to EBV. LCVs are typically asymptomatic in their host, with the exception of immunocompromised individuals who may develop B-cell tumors. Although much less efficient, baboon LCV can infect human B cells in immunocompromised persons or in persons co-infected with EBV and replicate in EBV-immortalized B cells with the theoretical potential for viral recombination [39]. However, it is unknown if the novel herpesviruses found in bushmeat specimens in our study can easily infect humans handling these tissues. Systematic studies examining herpesvirus transmission risks associated with handling or consumption of infected animal tissues have not been reported. In addition, virus isolation was not performed in our study to determine the infectiousness of the specimens at the time of confiscation.

In summary, our study establishes initial surveillance methodology to detect and identify zoonotic pathogens and species of origin of wildlife products entering the United States. While we were successful in demonstrating the presence of SFV and herpesviruses in bushmeat specimens, our pilot study was limited by the range, number, and variable condition of products available to us and was not intended to be a comprehensive review of presence or to measure prevalence of all pathogens imported in wildlife products. Because our study only included a small number of CDC-regulated species and excluded products of ungulate, carnivore, reptile, avian and other origin, as well as any live animal imports, all of which may carry zoonotic pathogens or diseases that threaten domestic livestock or native wildlife, in addition to the fact that virus isolation was not performed in our study to determine the infectiousness of the specimens at the time of confiscation, there is a large component of zoonotic disease risk assessment not included in this study. A further understanding of pathogen movements through the trade will only be recognized through broader surveillance efforts and pathogen identification and discovery techniques in wildlife and wildlife products arriving at US ports of entry so that appropriate measures can be taken to further mitigate potential risks.

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Author Contributions

Conceived and designed the experiments: KS SA WS NM GG SS JE TS PD DM WK WL GA S-OK JS. Performed the experiments: KS SA TS M.Sanchez M.Stuchin HJ WS SS TH DM S-OK. Analyzed the data: KS SA. Contributed reagents/materials/analysis tools: KS WL WS JS GA NM GG SS PD JE WK. Wrote the paper: KS SA WS. Provided access to confiscated specimens: NM GG.

References on following page.

References

1. Karesh WB, Cook RA, Bennett EL, Newcomb J (2005) Wildlife trade and global disease emergence. Emerg Infect Dis;Available: http://www.cdc.gov/ncidod/ eid/vol11no07/05-0194.htm Accessed 23 August 2011.

2. Woolhouse MEJ, Gowtage-Sequeria S (2005) Host range and emerging and reemerging pathogens. Emerg Infect Dis;Available: http://www.cdc.gov/ ncidod/EID/vol11no12/05-0997.htm Accessed 2011 August 23.

3. Cleaveland S, Haydon DT, Taylor L (2007) Overviews of Pathogen Emergence: Which Pathogens Emerge, When and Why. Curr Top Microbiol Immunol 315: 85–111.

4. Xu RH, He JF, Evans MR, Peng GW, Field HE, et al. (2004) Epidemiologic clues to SARS origin in China. Emerg Infect Dis. Available: http://www.cdc. gov/ncidod/EID/vol10no6/03-0852.htm Accessed 2011 August 23.

5. United States Fish and Wildlife Service Office of Law Enforcement Intelligence Unit. US Wildlife Trade: An Overview for 1997–2003. Available: http://www. fws.gov/le/pdffiles/Wildlife%20 Trade%20Overview%20Report.pdf. Accessed 2011 August 23.

6. Smith K, Behrens M, Schloegel LM, Marano N, Burgiel S, et al. (2009) Reducing the risks of the wildlife trade. Science 324: 594–5.

7. Switzer WM, Heneine W (2011) Foamy Virus Infection of Humans. In: Liu D, ed. Molecular Detection of Viral Pathogens. Boca Raton: CRC Press, Taylor and Francis Group. pp 131–143.

8. Courgnaud V, Van Dooren S, Liegeois F, Pourrut X, Abela B, et al. (2004) Simian T-cell leukemia virus (STLV) infection in wild primate populations in Cameroon evidence for dual STLV type 1 and type 3 infection in agile mangabeys (*Cercocebus agilis*). J Virol 78(9): 4700–9.

9. Chaber A, Allebone-Webb S, Lignereux Y, Cunningham AA, Rowcliffe JM (2010) The scale of illegal meat importation from Africa to Europe via Paris. Conserv Lett 00: 1–7.

10. Hays T (2007) Monkey Meat and Center of NYC Court Case. Associated Press. Available: http://www.msnbc.msn.com/id/21953654/ns/us_news-crime_and_ courts/t/nyc-case-highlights-african-monkey-meat-ritual/#.TIPKWs1vakl Accessed 2011 August 23.

11. Lorenz JG, Jackson WE, Beck JC, Hanner P (2005) The problems and promise of DNA barcodes for species diagnosis of primate biomaterials. Phil Trans R Soc B 360: 1869–77.

12. Townzen JS, Brower AVZ, Ju DD (2008) Identification of mosquito blood meals using mitochondrial cytochrome oxidase subunit I and cytochrome b gene sequences. Med Vet Ent 22: 386–93.

13. Switzer WM, Salemi M, Shanmugam V, Gao F, Cong M, et al. (2005) Ancient co-speciation of simian foamy viruses and primates. Nature 434: 376–380.

14. Ivanova NV, Zemlak TS, Hanner RH, Hebert PDN (2007) Universal primer cocktails for fish DNA barcoding. Mol Ecol Notes 7(4): 544–8.

15. Folmer O, Black M, Hoeh W, Lutz R, Vrijenhoek R (1994) DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. Mol Mar Biol Biotechnol 3(5): 294–9.

16. Wolfe ND, Switzer WM, Carr JK, Bhullar VB, Shanmugam V, et al. (2004) Naturally acquired simian retrovirus infections in Central African hunters. Lancet 363: 932–7.

17. Levi K, Higham JL, Coates D, Hamlyn PF (2003) Molecular detection of anthrax spores on animal fibres. Lett Appl Microbiol 36(6): 418–22.

18. VanDevanter DR, Warrener P, Bennett L, Schultz ER, Coulter S, et al. (1996) Detection and analysis of diverse herpesviral species by consensus primer PCR. J Clin Microbiol 34(7): 1666–71.

19. Zhai J, Palacios G, Towner JS, Jabado O, Kapoor V, et al. (2007) Rapid molecular strategy for filovirus detection and characterization. J Clin Microbiol 45(1): 224–6.

20. Tong S, Chern SW, Li Y, Pallansch MA, Anderson LJ (2008) Sensitive and broadly reactive reverse transcription-PCR assays to detect novel paramyx- oviruses. J Clin Microbiol 46(8): 2652–8.

21. Quan PL, Firth C, Street C, Henriquez JA, Petrosov A, et al. (2010) Identification of a severe acute respiratory syndrome coronavirus-like virus in a leaf-nosed bat in Nigeria. mBio 1(4): e00208–10.

22. Briese T (1999) Identification of a Kunjin/West Nile-like flavivirus in brains of patients with New York encephalitis. Lancet 354(9190): 1650.

23. Nitsche A, Ellerbrok H, Pauli G (2004) Detection of orthopoxvirus DNA by real- time PCR and identification of variola virus DNA by melting analysis. J Clin Microbiol 42(3): 1207–13.

24. Hunsmann G, Flu¨ gel RM, Walder R (1990) Retroviral antibodies in Indians. Nature 345(6271): 120.

25. Campbell M, Eng C, Luciw PA (1996) The simian foamy virus type 1 transcriptional transactivator (Tas) binds and activates an enhancer element in the gag gene. J Virol 70: 6847.

26. Switzer WM, Bhullar V, Shanmugam V, Cong M, Parekh B, et al. (2004) Frequent simian foamy virus infection in persons occupationally exposed to nonhuman primates. J Virol 78(6): 2780–9.

27. Goldberg TL, Sintasath DM, Chapman CA, Cameron KM, Karesh WB, et al. (2009) Coinfection of Ugandan Red Colobus (Procolobus [Piliocolobus] rufomitratus tephrosceles) with Novel, Divergent Delta-, Lenti-, and Spumar- etroviruses. J Virol 83(21): 11318–29.

28. Brown P, Nemo G, Gajdusek DC (1978) Human foamy virus: further characterization, seroepidemiology, and relationship to chimpanzee foamy viruses. J Infect Dis 137: 421–7.

29. Kuzmenok OI, Dvoryanchikov GA, Ponomereva EN, Goncharov AA, Fomin IK, et al. (2007) Myasthenia gravis accompanied by thymomas not related to foamy virus genome in Belarusian's patients. Int J Neurosci 117(11): 1603–10.

30. Hahn BH, Shaw GM, Sharp PM, De Cock KM (2000) AIDS as a Zoonosis: scientific and public health implications. Science 287: 607–14.

31. Heeney JL, Dalgleish AG, Weiss RA (2006) Origins of HIV and the Evolution of Resistance to AIDS. Science 313(5786): 462–466.

32. Sintasath DM, Wolfe ND, LeBreton M, Jia H, Garcia AD, et al. (2009) Simian T-lymphotropic virus diversity among nonhuman primates in Cameroon. Emerg Infect Dis;Available: http://www.cdc.gov/EID/content/15/2/175.htm. Accessed 2011 August 23.

33. Peeters M, Courgnaud V, Abela B, Auzel P, Pourrut X, et al. (2002) Risk to Human Health from a Plethora of Simian Immunodeficiency Viruses in Primate Bushmeat. Emerg Infect Dis;Available: http://www.cdc.gov/ncidod/EID/ vol8no5/01-0522. htm. Accessed 2011 August 23.

34. Keele BF, Heuverswyn FV, Li Y, Bailes E, Takehisa J, et al. (2006) Chimpanzee Reservoirs of Pandemic and Nonpandemic HIV-1. Science 313(5786): 523–526.

35. Wolfe ND, Switzer WM (2009) Primate Exposure and the Emergence of Novel Retroviruses. In: Huffman MA, Chapman CA, eds. Primate Parasite Ecology: The Dynamics and Study of Host-Parasite Relationships. Cambridge: Cam- bridge University Press. pp 353–70.

36. Schrenzel MD, Tucker TA, Donovan TA, Busch MDM, Wise AG, et al. (2008) New hosts for equine herpesvirus 9. Emerg Infect Dis;Available: http://www. cdc.gov/EID/content/14/10/1616.htm. Accessed 2011 Aug 23.

37. Huff JL, Barry PA (2003) B-virus (*Cercopithecine herpesvirus* 1) infection in humans and macaques: potential for zoonotic disease. Emerg Infect Dis. Available: http://www.cdc.gov/ncidod/EID/vol9no2/02-0272.htm. Accessed 2011 Aug 23.

38. Michaels MG, Jenkins FJ, St. George K, Nalesnik MA, Starzl TE, et al. (2001) Detection of Infectious Baboon Cytomegalovirus after Baboon-to-Human Liver Xenotransplantation. Journal of Virology 75(6): 2825–2828.

39. Moghaddam A, Koch J, Annis B, Wany F (1998) Infection of Human B Lymphocytes with Lymphocryptoviruses Related to Epstein-Barr Virus. Journal of Virology 72(4): 3205–3212.

Regulating wildlife conservation and food safety to prevent human exposure to novel virus

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Abstract:
Epidemiological investigation suggested that the current outbreak of COVID-19 virus was associated with a seafood market, and COVID-19 has been identified a probable bat origin. Similar with SARS event in 2003, such a zoonotic disease showed an animal-to-person and even more serious person-to-person spread, and posed a significant threat to the global health and socio-economic development. We analyzed the association of both outbreaks with wildlife diet in China, and proposed suggestions for regulating wildlife conservation and food safety to prevent human exposure to novel virus, including increasing social awareness of hazards in eating wild animals, strengthening legislation on eating and trading of wild animals, improving the standards for food safety, and establishing market supervision mechanism. Regulatory intervention is not only critical for China but also for other countries where wildlife hunting is prevalent to prevent from novel virus exposures.

Key words:
Wildlife conservation, food safety, zoonotic disease, human exposure, novel virus

The current outbreak of Novel coronavirus pneumonia (COVID-19), which was first reported from Wuhan of China on 31 December 2019 and can cause severe respiratory disease (1), has spread rapidly around the globe. As of 30 January 2020, 83 cases had been diagnosed in 18 countries except for China, at that time COVID-19 was declared by World Health Organization (WHO) a Public Health Emergency of International Concern (PHEIC). Epidemiological investigation suggested that this outbreak was associated with a seafood market in Wuhan, and COVID-19 has been identified a probable bat origin (2, 3). This can be reminiscent of another outbreak, Severe Acute Respiratory Syndrome (SARS), emerged in Guangdong, China at the end of 2002. Bat was identified as the natural reservoir host of SARS coronavirus 15 years later (4).

Both SARS in 2003 and COVID-19 this time showed the zoonotic sources of virus that can cross species to infect humans (5, 6). Such emerging infectious diseases which showed an animal-to-person and even more serious person-to-person spread, were caused by human exposures to viruses through a series of trading, marketing or consumption of the infected animals. Viral spill-over from intermediate hosts infected by bats had a close relationship to the special dietary habit of some Chinese people, especially in southern China. China has a long history of food culture and a prosperous catering industry. Prevalence of eating wild animals in ancient times was a supplement for protein due to insufficient intake. But nowadays, it becomes a weird dietary to meet the curiosity of some people, and even a symbolic of some Chinese Yuppies or tyrants because of the rarity and high price of the wild animals. Another infectious disease caused by Avian influenza A (H7N9) virus, which was found in March 2013 in China, showed human exposure to live poultry or potentially contaminated environments, especially markets where live birds were sold. Most of the zoonotic infection risk was associated with eating and trading of wild animals, which can pose a significant threat to the global health and socio-economic development. Regulating wildlife conservation and food safety to prevent human exposure to novel virus is of global significance.

Outbreaks of viral infections posed a significant threat to public health. In November 2002, clusters of pneumonia with unknown cause were reported in Guangdong province of China, now known as the SARS-CoV outbreak, and the number of cases of SARS increased substantially in the spring of 2003 in China and spread globally later (7). The mortality in China caused by SARS constituted 90.62% of the total death in the globe, with mortality rate of 10.18% (Fig. S1). The mortality rate caused by H7N9 reached 37.89% from 2016 to 2018 (Fig. S2). As of 27 February 2020, COVID-19 has caused infections in 46 countries outside China and a cruise ship currently in Japanese territorial waters, with 3664 confirmed cases and 57 deaths mainly in the Republic of Korea, Italy, Japan, Iran, France, Philippines, and the international conveyance “Diamond Princess” (Fig. S3). In the meantime, the situation in China was much more serious, as of 27 February 2020, the number of confirmed cases and deaths increased from 1 to 78630, and 1 to 2747,

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respectively. The number of suspected cases increased from 54 to 28942 from 20 January 2020 to 8 February 2020, and since then showed a decreasing trend (Fig. S4). The results indicated that COVID-19 is more serious than SARS and H7N9 in terms of spread speed and scope.

Extraordinary public health measures have been taken in and outside China to reduce further spread of the COVID-19 outbreak [8]. Currently, many foreign airline companies like United Airlines, Air Canada and British Airways have cut-off or reduced their flights to Wuhan and even to other major cities in China (Fig. S5). Although WHO has not recommended any international travel restrictions so far [9], the local government in Wuhan has announced the suspension of public transportation on 23 January 2020, with closure of airports, railway stations, and highways in the city, to prevent further disease transmission [10]. In China, passenger volume of railway presented a decreasing trend from 27 January 2020 to 2 February 2020 and is down about by 62.2%~74.4% year on year. Passenger volume of civil aviation, highway and waterway has also declined with more than 70%, 85.6% and 90.2% on a year-on-year basis on 29 January 2020 (Fig.S5). Emigration ratio from Wuhan to other provinces presented a decreasing trend after 23 January 2020 (Fig.S6). The suspension of transportation helped a lot to prevent the virus spread from person to person, with the number of newly confirmed cases presented a decreasing trend both in and outside of Hubei Province of China (Fig. S7).

The impacts of such an epidemic on social economy will be huge [11], especially on services such as transportation, cultural tourism, hotel and catering and entertainment (Fig.S8-S9). The mismatch between supply and demand in the market caused by infectious diseases has led to huge employment consequences [12]. Uncertainty about the future of the epidemic and fear of its international spread could also reduce confidence in economic development [13]. The SARS event led to a decline in consumption, imports, exports and investment (Fig.S10-S12), and many enterprises faced liability crisis (Fig.S13). It was estimated that the SARS outbreak costed China between \$12.3 billion and \$28.4 billion, with GDP estimated to have fallen by 2% in the second quarter of 2003 and 1% for the whole year (Fig.S14). At the same time, global economic loss was estimated to be between \$30 billion and \$100 billion [14]. The H7N9 had a milder economic impact than SARS, and China's poultry industry suffered more than 40 billion yuan from the outbreak. However, the economic impact was minimal on a global scale [14].

Similar with SARS, COVID-19 also started at the end of the year, but it attracted the governmental attention relatively earlier. Since the Chinese New Year is early February in 2020, the impact on the real economy is likely to begin in the first quarter. Travel rush after the Spring Festival holiday has postponed, however, the number of passengers carried by all kinds of transportation means has dropped sharply. Revenues of film box office, tourism and catering industries have also dropped significantly due to the restricts. According to the China Movie Data Information Network [15], the total revenue of film box office during the 2019 Spring Festival season was 5.86 billion Chinese yuan, accounting for 9% of the whole year. However, due to the impact of the epidemic, the demand for watching movies in 2020 Spring Festival dropped sharply, and all the large cinemas have suspended business due to the COVID-19 outbreak, which will cause a huge loss of the revenues from film box office during the 2020 Spring Festival. It was reported that more than 20,000 employees of Xibei Restaurant Group were unemployed, and daily revenue was only 5-10% of a normal level. At present, various departments of the Chinese government have worked out emergent policies and measures to hedge against the impacts of the epidemic, especially to help the affected enterprises and workers (Table S1). In order to solve the problems occurred in the course of epidemic prevention and control, the Chinese government has fostered new areas of economy, such as online shopping, online food order and delivery, online entertainment and other forms of digital economy.

Since such an epidemic is associated with consumption of wild animals and has frequently happened in China recent years, it is essential to take precautionary actions to cut off or reduce human exposure to novel virus. In addition to the prevention and control measures recommended by WHO and National Health Commission of the People's Republic of China (NHCPC), more efficient regulatory actions should be taken for prevention at source.

Increase social awareness of hazards in eating wild animals. An announcement about bans on the trading of wild animals, including warning about the health risk of eating wild animals, was released by the State Administration for Market Regulation, Ministry of Agriculture and Rural Affairs, and National Forestry and Grassland Administration on 26 January 2020 in China. However, this announcement was only valid before the end of this outbreak. It was exactly the same way to deal with the SARS event in 2003, so such a tragedy occurred again 17 years later. The painful lesson of eating wild animals has not prevented some Chinese people from changing the notion that wild animals, especially rare ones, are tonic medicines for human body. In fact, most of the zoonosis were caused by viruses from wild animals and passed into humans through the process of killing and eating infected animals. Social awareness of hazards in eating wild animals, reducing contacts with wild animals, and respecting wildlife as an equal living being as human life in the natural ecosystem, should be further enhanced. As internet and social media applications have skyrocketed nowadays, social media could be useful tools for promoting public awareness and health education to completely eradicate the risks from eating wild animals.

Put prohibition of eating wild animals on legislation agenda, making it clear about serious punishment of the legal violation, including sentence to life prison. The currently effective Law of the People's Republic of China on the Protection of Wildlife (2018) was formulated for the purpose of protecting the rare and endangered terrestrial and aquatic wildlife, as well as important terrestrial wildlife with ecological, scientific or social values, whereas general wildlife, which was an integral part of the natural ecosystem, was not included in the scope of protection. While hunting, killing, purchasing, transporting and selling of the rare and endangered wildlife were addressed as illegal according to the Criminal Law of the People's Republic of China (2017), eating and consumption of wildlife was not mentioned. However, great demands for wild animals can stimulate the trading market, and the whole process should be suppressed and controlled at source. It should be amended in the Criminal Law and the Law on the Protection of Wildlife that eating and consumption of all the wild animals is related to alleged criminal behavior and should be seriously punished or be sentenced to prison. Criminal liabilities for eating, killing, processing, transporting, and selling the unauthorized animals should be defined clearly. Only severe penalty exceeds the pleasure and vanity acquired by eating wild animals, the general public, especially those who have such a weird consumption hobby, will be awaken to the alarm signals from SARS and the current event, and such a public health incident of global impacts will be prevented and avoided.

Improve the standards for food safety, including regulatory standards for ill and dead livestock transactions. The primary risk factor for humans is exposure to infected wild animals, dead and ill poultry, or contaminated environment such as poultry markets. Slaughtering, defeathering, handling carcasses and preparing for consumption will pose health risks to humans through contacts with affected poultry or wild animals. While food safety was stressed repeatedly during the spread of this outbreak, preventive actions should be taken earlier. A major food safety bill signed into law in January 2011 gave the U.S. Food and Drug Administration new powers and aims to shift the focus from response to prevention of food-borne illness [16]. However, consumption of live poultry and livestock, and epidemic prevention of wild animals were not included in the current Food Safety Law (2018) and Animal Epidemic Prevention Law (2015) of the People's Republic of China, which should be further updated and specified in detail. Moreover, marketing, processing, transportation and trading of animals that are sick or dead unexpectedly should be legally prohibited. Zoonotic disease prevention can be achieved by the enhanced and standardized surveillance and control in animal quarantine, production and processing, and storage and transportation. Slaughtering and primary processing of the livestock and poultry can be centralized in slaughtering houses authorized by a marketing supervision organization. Improved legal enforcement, real-time online monitoring, and enhanced processing technology will help to ensure food safety.

Strengthen market supervision and monitoring mechanism. It is difficult to completely ban the consumption of wild animals solely through the improvement of people's awareness, an effective and feasible market supervision system is needed to ban the possibility of eating wild animals. Wild animals may enter the circulation market because there is no specific law currently. To completely eradicate the circulation of wild animals in the market, a list of permitted edible animals should be developed first. For the animals that are authorized to be sold in the market should have an identification code, which can be checked by online monitoring in the whole process of slaughtering, processing, transporting, selling and consumption so that the sources can be easily identified and controlled in case of any emergencies. Regular and flight inspection should be taken especially for agricultural products and seafood markets. The administrative supervision department should take the initiative to investigate any illegal activities in the market, and bear the responsibility for malfeasance. All-round supervisions from public consumers, business, governmental departments, and non-governmental organizations should be strengthened as an entity for improvement of public health.

Since such an epidemic could break out and spread in any country, and once it happens, the impacts on the global health and socio-economic development are extremely large. International communication, cooperation, collaboration, and even convention should be further reviewed and strengthened for the conservation of wildlife, prevention of epidemic disease, construction and effective operation of public health system, and improvement of relevant policies and regulations. Interdisciplinary science including conservation biology, ecosystem ecology, epidemiology, public health, medical research and development, social sciences, law, and crisis management need to be integrated to provide an integrated cycle of prevention, preparation, response and recovery [17]. Only in this way can the ecosystem and human health be well ensured and such a global epidemic be prevented.

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References

1. C. Huang, Y. Wang, X. Li *et al.*, Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*, (2020). https://doi.org/10.1016/S0140-6736 (20)30183-5

2. F. Wu, S. Zhao, B. Yu *et al.*, A new coronavirus associated with human respiratory disease in China. *Nature* (2020). https://doi.org/10.1038/s41586-020-2008-3

3. P. Zhou, X. Yang, X. Wang *et al.*, A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature* (2020). https://doi.org/10.1038/s41586-020-2012-7

4. B. Hu, L. Zeng, X. Yang, X. Ge, W. Zhang, B. Li *et al*, Discovery of a rich gene pool of bat SARS-related coronaviruses provides new insights into the origin of SARS coronavirus. *PLoS Pathog* **13**(11), e1006698 (2017).

5. W. Li *et al.*, Bats Are Natural Reservoirs of SARS-Like Coronaviruses. *Science* **310**, 676-679 (2005).

6. J. F.-W. Chan *et al.*, A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *The Lancet*, (2020). https://doi.org/10.1016/S0140-6736(20)30154-9

7. N. S. Zhong, B. J. Zheng, Y. M. Li *et al.*, Epidemiology and cause of severe acute respiratory syndrome (SARS) in Guangdong, People's Republic of China, in February, 2003. *The Lancet* **362** (9393), 1353-1358 (2003).

8. C. Wang, P. Horby, F. Hayden, G. Gao, A novel coronavirus outbreak of global health concern. *The Lancet*, (2020). https://doi.org/10.1016/ S0140-6736(20)30185-9

9. WHO, Statement on the meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV). Geneva, World Health Organization, Jan 23, 2020. https://www.who.int/news-room/detail/23-01-2020-statement-on-themeeting-of-the-internatio nal-health-regulations-(2005)-emergencycommittee-regarding-the-outbreak-of-novel-coronav irus-(2019-ncov) (accessed Jan 24, 2020)

10. People's Government of Hubei Province, Announcement No. 1, Headquarter of prevention and control for the novel coronavirus pneumonia in Wuhan City, 23 January 2020. http://www.gov.cn/xinwen/2020-01/23/content_5471751.htm (in Chinese)

11. P. Sands, A. El Turabi, P. A. Saynisch, V. J. Dzau, Assessment of economic vulnerability to infectious disease crises. *The Lancet* **388**, 2443-2448 (2016).

12. G. O. M. Lee, M. Warner, The impact of SARS on China's human resources: implications for the labour market and level of unemployment in the service sector in Beijing, Guangzhou and Shanghai. *The International Journal of Human Resource Management* **17**, 860-880 (2006).

13. R. D. Smith, Responding to global infectious disease outbreaks: lessons from SARS on the role of risk perception, communication and management. *Soc Sci Med* **63**, 3113-3123 (2006).

14. W. Qiu, C. Chu, A. Mao, J. Wu, The Impacts on Health, Society, and Economy of SARS and H7N9 Outbreaks in China: A Case Comparison Study. *J Environ Public Health* **2018**, 2710185 (2018).

15. China Movie Data Information Network, https://zgdypw.cn/#/root.html (in Chinese)

16. E. Stokstad, Food Safety Law Will Likely Strain FDA Science. *Science* **331** (6015), 270 (2011).

17. J. Bedford, J. Farrar, C. Ihekweazu, G. Kang, M. Koopmans, J. Nkengasong, A new twenty-first century science for effective epidemic response. *Nature* **575**, 130-136 (2019).

Baby pangolins on my plate: possible lessons to learn from the COVID-19 pandemic

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Abstract

The Journal of Ethnobiology and Ethnomedicine (JEET), throughout its 15 years of existence, has tried to provide a respected outlet for scientific knowledge concerning the inextricable links between human societies and nature, food, and health. Ethnobiology and ethnomedicine-centred research has moved at the (partially artificial and fictitious) interface between *nature and culture* and has investigated human consumption of wild foods and wild animals, as well as the use of wild animals or their parts for medicinal and other purposes, along with the associated knowledge, skills, practices, and beliefs. Little attention has been paid, however, to the complex interplay of social and cultural reasons behind the increasing pressure on wildlife. The available literature suggest that there are two main drivers that enhance the necessary conditions for infectious diseases to cross the species barrier from wild animals to humans: (1) the encroachment of human activities (e.g., logging, mining, agricultural expansion) into wild areas and forests and consequent ecological disruptions; and, connected to the former, (2) the commodification of wild animals (and natural resources in general) and an expanding demand and market for wild meat and live wild animals, particularly in tropical and sub-tropical areas. In particular, a crucial role may have been played by the *bushmeat-euphoria* and attached elitist gastronomies and conspicuous consumption phenomena.

The COVID-19 pandemic will likely require ethnobiologists to reschedule research agendas and to envision new epistemological trajectories aimed at more effectively mitigating the mismanagement of natural resources that ultimately threats our and other beings' existence.

In memory of Dr. Javier Caballero, Autonomous University of Mexico and JEET board member, who passed away 12 March 2020.

Ethnobiology, gastronomy, and COVID-19

The COVID-19 pandemic poses to the scientific community and to its worldwide audience important open research questions in ethnobiology and ethnomedicine. Questions that have regularly reappeared during the past century with the spread of the various pathogenic viruses originally derived from animals (e.g., Spanish flu, Asian flu, AIDS, Nipah, Marburg, swine flu, SARS, MERS, and Ebola):

- Why does the intensification of the use of certain animal resources happen in certain places at certain times?
- Is this intensification happening in specific areas during a particular period due to commodification of Traditional/Indigenous/Local Ecological Knowledge (TILEK) or to which other socio-cultural factors?
- Is the search for an exclusive, elitist gastronomy "to blame"?
- How can we prevent such unsustainable intensifications?

The Journal of Ethnobiology and Ethnomedicine (JEET), throughout its fifteen years of existence, has tried to provide a respected outlet for scientific knowledge concerning the inextricable links between human societies and nature, food, and health. It has specifically covered these relationships from an ethno-scientific perspective, thus focusing on the complex systems of TILEK and their transformations across time and space.

In the past few decades, ethnobiology and ethnomedicine-centred research has moved at the (partially artificial and fictitious) interface between *nature and culture* and has tried to investigate the socio-cultural contexts in which domesticated and "wild" species and their ecosystems are perceived, used, and managed.

Specifically, JEET has published numerous papers addressing human consumption of wild foods and wild animals, as well as papers addressing the use of wild animals or their parts for medicinal and other purposes, along with the associated knowledge, skills, practices, and beliefs; less attention has been paid, however, to the reasons behind the intensification of the use of certain natural resources and, especially, to the links between their commodification and the emergence of new diseases from wildlife.

Zoonotic diseases constitute about 70% of all known emerging diseases and are Swords of Damocles hanging over global public health[1–3]. SARS-CoV-2 is the latest of several viruses that have emerged in wildlife, crossed the species barrier from animals (e.g., bats, civets, pangolins, apes) to humans, mutated, and then spread from human to human. These diseases often have multiple animal reservoirs and intermediate hosts as well as complex transmission pathways, but viral transmission often requires direct or indirect contact between humans and animals.

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A number of environmental and socio-economic factors are increasing contact rates between humans and wildlife: trade in wild animals for food and medicine, encroachment of humans and domestic animals into wildlife habitats, intensification of food systems and changes in land use in tropical and subtropical areas, globalization of agriculture and commerce, commodification of biodiversity and its traditional use, and consumption of bushmeat[4–6].

The complexities of the ecological, social, and economical dynamics of disease emergence, therefore, require interdisciplinary approaches, for which ethnobiology and human ecology are extremely well positioned. Given the key role that the dynamics occurring at the interface between the "wild" and the "domestic" have in the emergence of zoonotic diseases, ethnosciences need to reflect on the ongoing COVID-19 pandemic, its drivers, and implications. Many dozens of scholars have long investigated this interface both in terms of the dynamic relationships (based on knowledge, practices, rituals) that humans establish with the other living creatures and with local ecologies, and in terms of the impacts that human activities have on these ecologies and on other "webs of life." Because foods, food systems and food cultures play a key role in the emergence of zoonotic diseases, food studies explored through a truly trans-disciplinary gastronomic sciences-centred lens can further help to understand the processes and dynamics behind the consumption of "wild" animals, its commodification, and the system of beliefs and values that underpins it.

Here, we briefly discuss the COVID-19 pandemic within the broader socio-cultural and gastronomic context in which it originated and occurs now. First, we lay out the main human ecological drivers for increased contact between humans and (other) animals and the potential viral spillover: anthropogenic disturbance of forest ecosystems and increasing demand for meat and medicine derived from wildlife. We further discuss the reasons for the increased demand for bushmeat, both as a response to food insecurity and as a response to a demand for exclusive, elitist consumption. We then address the relations that occur between the commodification of wild animals and the traditional systems of knowledge and practices that have sustained continuity in wild animal use. Finally, we reflect on the ways in which COVID-19 relates to the Anthropocene idea, with the processes of intensification and commodification as underlying common drivers.

Bats: an exemplary case study

In order to prefigure these dynamics (and the line of argument below), we use bats as an example because their situation illustrates clearly the complex relationships between emerging zoonotic diseases, the intensification and commodification of wild animals, and the key role of foods and food systems in this emergence. Bats have been hunted for food and medicine since pre-historic times in all inhabited continents, especially in the Asia-Pacific region where big fruit bats of the genus *Pteropus* represent an important food source for some populations as well as an important element of local gastronomy, and are considered a delicacy in many places[7].

Bat meat is cooked in various ways, such as fried, roasted, stewed, grilled,

and stir-fried[8, 9]. Moreover, minced meat and whole bats cooked in hot pot (simmering flavored broth in which raw ingredients are cooked) are available in restaurants in Southern China[10]. The culinary use of bat meat is also widespread in other Southeast Asian and Pacific countries. In the Republic of Palau, whole fruit bats are boiled in a soup made with ginger, coconut milk, vegetables, and various spices. The dish is served in local restaurants[11]. In the Marianna Islands, the Chamorro people consider fruit bat, locally known as fanihi, a delicacy which they serve during social happenings. Bats are washed and cooked in a soup, and all parts, including the fur, viscera, and wing membranes are eaten[12].

Bats are also reservoirs of several viruses that can cause human diseases, including Nipah, Hendra, SARS, and probably MERS, Ebola, and COVID-19 as well[13– 18].

Cross-species transmission from bats to humans can be direct (through contact with infected bats or their excreta) or indirect through intermediate hosts (e.g., civets for SARS, camels for MERS, perhaps pangolins for COVID-19[19]). The SARS coronavirus, for example, was traced by Chinese scientists to cave-dwelling horse-shoe bats in Yunnan Province, but in the market of Guangdong, China, where the epidemic originated, the virus was isolated from masked civets (*Paguma* sp.), which acted as intermediate hosts[20,21].

In the last few decades, with increasing intensification of land use (e.g., logging, plantations agriculture) in areas where fruit bats live and with the commodification and widespread trade of live bats and bat meat, the ecology of fruit bats has been disrupted, as has the ecology of their viruses. Processes of land use change toward intensification have in many cases led to increased contact between fruit bats and domestic animals (e.g., while roosting in trees in and around livestock paddocks, feeding on fruits in orchards)and humans (e.g., bats drinking and urinating in open palm sap containers) as well as to increased opportunities for viral spillover. The disruption of bat ecology also results in increasing numbers of fruit bats seeking food in suburban and urban areas and increasing human and livestock contact with them or their fluids[22]. All this has largely increased the probability of viral spillover from bats to humans and/or to intermediate hosts (wild or domesticated) with which bats come into contact, with global connectivity then amplifying its human to human transmission. At the same time, the consumption of bats has spread to a wider pool of urban consumers, and in southern China bats are found regularly in markets[23], where they may be in cages in proximity to other wild animals. While bats were traditionally hunted and consumed within locally based and ecologically attuned systems of knowledge, and these systems of knowledge often have norms in place to avoid over-harvesting, the commodification of bats, as with many other wild animals, leads to a race for maximum extraction that will result in further loss of biodiversity, further loss of cultural diversity of all those populations relying on bats, and further disruption of the bat-dependent ecological cycles, with further ecological turbulence.

Intensification of the use of wild animals: why does it happen?

Understanding the drivers and dynamics that underpin intensification and commodification processes are of tremendous importance. The available literature points to two main drivers that enhance the necessary conditions for viruses to cross the species barrier from wild animals to humans: (1) the encroachment of human activities(e.g., logging, mining, agricultural expansion) into wild areas and forests and consequent ecological disruptions; and, connected to the former, (2) the commodification of wild animals (and natural resources in general) and an expanding demand and market for wild meat and live wild animals, particularly in tropical and sub-tropical areas. The globalization of the world economy (high human population densities, global transport and movement of people, spreading of information via the internet, including gastronomic information and recipes involving wild animals) has sustained these drivers and facilitates human-to-human transmission.

The emergence of new zoonotic diseases in the last century has occurred mostly at the African and Asiatic frontiers between forest and urbanization/ civilization. This can be understood as a reflection of the encroachment of human activities into forests and of the consequent disruption of local ecologies,including the ecology of viruses and their hosts. Indeed, changes in the ecology of reservoir species can have a great impact on the emergence of zoonotic diseases. Deforestation and urbanization have likely contributed to the emergence of the Ebola virus in West Africa. The encroachment of human activities into forests provides numerous paths for the transmission of viruses from bats to intermediate (including livestock) hosts. The Hindra viruses of East Australia originated from bats and

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horses sharing the same environment, i.e., a horse pasture. Bats adapted to roosting in trees in pastures after the forest in which they lived was logged and transformed to the point that it could no longer sustain bat populations. Similarly, the Nipah virus appeared in Malaysia in connection with a spike in intensive commercial pig husbandry, a condition that facilitated the transmission of the virus from the bat reservoir to a swine intermediate host, and from there to humans[24]. Bat populations, displaced by shrinking forests and forest ecosystems increasingly deprived of species, may turn to fruit orchards for food and roosting, thus increasing the chance of transmission to other animals and to humans when partially eaten fruits are subsequently consumed.

To the extent that humans transform and occupy the forest ecosystem (e.g., palm oil or tea plantations, live-stock pastures), they disrupt the ecology of wild animals, which in turn may increase the likelihood of viruses finding their way into intermediate hosts (wild or domesticated) and eventually into humans. The MERS coronavirus, for example, appeared in Saudi Arabia in 2012, and has been shown to have bats as the original reservoir and camels as an intermediate host[25, 26]. Humans become infected after exposure to infected camels or consuming the raw milk and meat of camels. Although the dynamics of transmission from bats to camels are not yet understood, they may involve the increased contact that occurs between the two species in conditions of sedentary (versus nomadic) and stabled (versus open-air) camel husbandry, conditions in which bats could roost inside stables and spread viruses to the camels below with their urine, faeces, and droplets.

The bushmeat-euphoria

As subsistence needs and a globalized consumerist system pushes people (e.g., farmers, gatherers, and hunters, desperate for food and cash) into the forests, more is demanded and extracted from these areas, including wild animals used as food and medicine.

A diversity of local and seasonal wild animal-derived foods sustains the livelihood and economy of many American, African, and Asian communities. These products are materially and culturally important foods (e.g., providing nutrients, sustaining social cohesion, and cultural identity) as well as an integral part of the gastronomic basket of these communities. Wild food consumption, in many subsistence communities, is embedded into complex systems of traditional ethnobiological and ethnoecological knowledge about the species consumed, their biology and ecology, and ways of hunting, gathering or fishing, as well as traditional knowledge about processing, cooking, recipes and ways of consuming.
Wild food consumption is also often entrenched into systems of beliefs, rituals, and taboos that aim to regulate communities' engagement with wild natural resources and species.

In many parts of Africa, bushmeat (i.e., wild animals hunted/collected for food, such as mammals ranging from rodents to large species, reptiles) contributes substantially to the animal protein supply and often fetches a higher price in markets than livestock meat[27]. Roasted, boiled, smoked, or dried, bushmeat provides proteins and fat to rural and forest inhabitants, as well as cash from its commercialization[28]. The history of AIDS tells us today that HIV-1 and HIV-2 originated from SIV, a virus that was transmitted from non-human primates to humans in Central Africa at the beginning of the 20th century. The evidence that humans who participated in bushmeat hunting, trading, and butchering could easily acquire SIV, and that several transmissions of the virus from individual to individual in quick succession allowed it to mutate into HIV, is robust[29–31]. Some studies have postulated that high-risk transmission channels, allowing the virus to adapt to humans, emerged with colonialism and the growth of large African cities, in connection to a spread of prostitution[32, 33].

Bushmeat hunting is again on the rise today, particularly in those tropical and subtropical areas characterized by poverty and food insecurity. Hunters enter deep into forested areas following roads from logging and mining activities to source wild animals in response to a growing urban demand, with customers often regarding bushmeat as a delicacy and a prestige food. Indeed, it is not simply taste that is driving demand for bushmeat, as price, needs, familiarity, tradition, and prestige also play a role[34].

A striking example of the relationship between food insecurity and bushmeat hunting is provided by the lemurs of Madagascar. Borgerson et al.[35] have shown that most children in the households of wildlife hunters were malnourished. Bushmeat was often the only accessible food for these families, and under these circumstances, it is no wonder that hunters are lured into commercial bushmeat chains that provision hotel and restaurants with lemur meat as a prestige food[36]. Another study in Madagascar has predicted that the rate of childhood anaemia would increase 29% if access to bushmeat, including bat and lemur meat, was restricted, predominantly affecting the poorest households that could not afford to purchase meat from domesticated animals[37].

Poverty and food insecurity increase the demand for wild animals for consumption and trade, and thus contact between these animals and humans. Indeed, this is the socio-economic background for the Ebola and HIV epidemics. Interestingly, in a world that is ecologically and economically interconnected, causes and effects are complex and sometimes unexpected. It is therefore worth noting that in several parts of Africa the demand and consumption of bushmeat has increased as a consequence of the collapse of artisanal and small-scale fisheries due to industrial overfishing (from China, Korea, the EU) and fish population collapse along African coasts[38,39]1.

At the same time, livelihoods are increasingly being commodified (i.e., dependent on products and services obtained with cash), and this commodification and the increasing need for cash drives further commodification of wild foods and animals formerly hunted and consumed for subsistence. This, connected with a demand for these foods in growing towns and cities, has driven additional extraction and the national and international trade of live animals and their meat[40, 41]. This all results in high demand for animal-derived products

1. In a hypothetical blame game, we could also blame cheap squid and farmed salmon consumers in high-income countries for the next West African epidemic stemming from bushmeat consumption.

sold in formal and informal, rural and urban open-air markets as well as along streets and roadsides across many tropical and subtropical areas [42, 43]. The resulting market pressure on the species and on local communities often brings about the erosion of norms and taboos (e.g., regarding wild animal hunting and harvesting), the shifting of the economic value chain and of control over the resource from local producers to outsiders, the adoption of invasive technologies for harvesting, and an increase in wealth inequality within communities, thus threatening both social and environmental sustainability and resilience at multiple levels[41]. With increasing commodification of traditional and ecologically attuned systems of knowledge, these systems have often been bent to market imperatives for short-term gain, cheap resources, and cheap labor. Unsanctioned and poorly sanctioned processes of commodification (for some species all the way to wildlife farming) are threatening species previously consumed for subsistence, their population and habitat. For example, the mopane caterpillar, harvested from the mopane tree across southern Africa, has become a commodity sold in towns and cities as well as exported to Europe, and this has created stress and threats to local lives and livelihoods (as people witness the commodification of an important subsistence and seasonal resource), to the species itself (customary norms for sustainability discarded), to the mopane tree that hosts the caterpillar (trees are felled to reach caterpillars high up the canopy), and to the same savannah ecosystems of which the mopane tree is a keystone species (providing critical food to elephants, who in turn shape the ecosystem with their presence)[44]. With regard to mammals, the trade of live and recently slaughtered wild animals in "wet markets" (markets where live animals and freshly slaughtered meat are sold, and so named because of the large quantities of water used to slosh the floors) across many tropical and subtropical areas of the world (e.g., Peru, South-East Asia and China, Western Africa) has largely increased contact between different species of wild animals, and between them and humans. Much of this trade relates to the demand for products used in Traditional Chinese Medicine. Traditional Chinese Medicine makes large use of animal products, creating an environmental impact as well as health hazards[45]. Because this medicine is widespread and growing, there is increasingly higher demand for wildlife species and for the products obtained from them[46].

Wild meat in elitist gastronomies

Over one century ago, Veblen[47] theorized that *conspicuous consumption*, i.e., the elitist consumption of expensive and superfluous foods and drinks, is one of the ways in which affluent classes flaunt their wealth and power. As Bourdieu[48] suggested, however, this strategy turns these products into a status symbol which is copied by other strata of society in search of legitimation. While this process intensifies the actual consumption of products, the "new rich" are the ones that are the most eager in mimicking[49]. This phenomenon is more than ever evident today, in a global society that is highly unequal and confers prestige to wealthier people[50], in particular in China; a country that more than others has experienced fast economic growth and the rise of new affluent social groups[51, 52]. While the new social status is generally marked by purchasing houses and luxury goods [53–55], food and foodways are also transformed. It is not just a matter of eating out in fine-dining restaurants[56], but rather asking for exclusive foods traditionally associated with the old elites[52], such as wild meat.

Asia is an epicenter for wildlife trafficking and wild animal consumption. In countries like China, Myanmar, Vietnam, and Thailand, the social status, prestige, and gastronomic exclusivity deriving from *ye wei* (literally "wild taste") is the main driver of the demand for wild meat, particularly among the wealthiest and those aspiring to be. In the cuisine of Asian countries, *ye wei* refers to bushmeat and game including wild and exotic animals. Historically, members of the imperial courts in the dynastic eras used to request *ye wei*, including symbolic and magical animals or animal parts, for their meals. Nowadays, *ye wei* is widely sold in Asian wet markets, offered at restaurants, and requested by wealthy consumers because of their rarity and cost. In a recent survey conducted in China, almost a third of the respondents reported consuming wildlife, with consumers with higher incomes and higher education levels having higher wildlife consumption rates[57]. The rapid urbanization and shift to a market economy in these countries, and the subsequent emergence of hundreds of millions of potential middle-class consumers wanting to emulate elitist foodways, has boosted the demand for wild meat, trade of wild animals, attendance of wet markets, and food and medicinal consumption of wild animals. These animals are sourced legally or illegally, from the wild or from wildlife farms. A source for these species is the thousands of wildlife farms that have arisen in China during the last twenty years, which can be seen as attempts to intensify "wildlife production." These farms raise a number of animals for food, from peacocks to porcupines and civets, which are often believed to have powerful medicinal and magical/symbolic properties. Indeed, the SARS coronavirus has been shown to use farmed civets as intermediate hosts before jumping to humans[58, 59]. Rhino horns, tiger bones, civet and pangolin meat, porcupines, bamboo rats, totoaba bladder, shark fins' soup, and roasted bats are notable examples of this demand for wild luxury foods and/or medicinal items. Commercial chains run deep into forests to provision wealthy consumers by selling to restaurants, at "wet markets," or through online platforms,where consumers can also find recipes and cooking advice. In recent years, the trade of wildlife for food and medicine has spread via the Internet, where virtual platforms and ecommerce websites sell wild animals or products obtained from them.

This demand is driving widespread legal and illegal trade of wild animals. Wildlife trafficking profits are estimated at $26 billion per year and are pushing many species (often critical for ecosystem functioning and resilience, and for the services these ecosystems provide to humans) towards extinction. Humans are literally eating and drinking species into extinction[60]. In these circumstances, wild meat commodification and its associated activities are likely to enhance the conditions for zoonotic infectious diseases to jump to humans, while global connectivity and human population density and movement then help to spread the virus from human to human.

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Pangolins: from medicinal item to exclusive delicacy

A prime example is the pangolin, the most trafficked animal in the world, which is the likely intermediate host of SARS-CoV-2[61]. Pangolins are nocturnal insect eating mammals living in the forests of Asia and Africa. Pangolins have long been hunted for food and traditional medicine across Asia and West and Central Africa[62, 63]. In Ghana, for example, people traditionally use different parts (scales, bones, head, and meat) for different purposes including spiritual protection, rheumatisms, infertility, and convulsions, while the meat was used for preparing charms for chiefs or tribal leaders[64]. In Sierra Leone, the scales, head, meat, and tail are prevalently used for food as well as for spiritual protection and to treat skin diseases and digestive problems[65]. Pangolins and their scales are similarly used (e.g., to ward off evil spirits and witchcraft) in Nigeria[66–68] and in Benin[69], as well as across India and Pakistan[70, 71].

In China, pangolins are highly sought after for traditional medicine (Fig. 1) and as food[72]. This demand causes over-exploitation that, coupled with habitat loss, threatens the very survival of the species used. Pangolin scales are regarded as a medicinal panacea (like rhino horns, and like rhino horns they are made of keratin), and their meat is considered a delicacy. The demand for pangolins in China is met by an illegal trade that is lucrative and on the rise, lately attracting wildlife traffickers who used elephant ivory as their prime generator of profits. The demand for pangolin meat and scales, due to increasing conspicuous consumption by the Asian middleclass, has driven pangolins to the verge of extinction[73]. From all forested corners of the tropics, pangolins are transported to Asian markets, where stressed and likely immune depressed pangolins are caged with many other species, and also with their own pathogens. This has emptied forests of pangolins: a steady decrease of pangolins, and wildlife in general, in African forests has been reported by local hunters and traditional healers in studies in Southwestern Nigeria[67] and in Cameroon[74].

The pangolin is prized as a delicacy in China, especially in the Southern and Eastern part of the country[75]. According to Challender et al.[76], this culinary practice is attested to by historical sources dating back to the 12th century CE: in present-day Jiangxi Province, Chinese pangolin meat was common street food during wintertime, cooked in lees from fermented rice wine. A popular recipe from the mountain village of Zhu Yu, dating back to the 16th century CE, consisted of curing pangolin meat in salt for two days before boiling it in water[77]. Nowadays, pangolin is served in high-end restaurants in urban cities, mostly in Anuhi, Fujian, Jiangxi, Guangxi, Yunnan, Guizhou, Guangzhou, Guangdong, and Guangxi provinces. [75, 76, 78–80]. Once the order is placed, the animal may be hammered until it is unconscious and then slaughtered in front of the customers as a guarantee of the meat's freshness. Some other time instead the animal is smuggled to the restaurant already dead and preserved in ice. Blood is drained and usually given to the customer to bring home. The dead animal is placed in hot water to remove the scales and the meat is cut into small pieces[81], which then may be boiled, stewed, braised, or steamed.

Fig. 1 Pangolin wine.

Chopped pangolin meat is usually stewed with Chinese wine, other meat

Fig. 2 Pangolin soup.

Fig. 3 Pangolin fetus soup.

Fig. 4 Pangolin blood rice.

including chicken or pork, and medicinal herbs such as *Ligusticum striatum*, *Tetrapanax papyrifer*, *Stemmacantha*, and *Akebia* spp.[82]

In Shenzhen (Guangdong Province), pangolin meat is served in hot pot[81]. Pangolin meat is also an ingredient of “eight animal stew”, a dish made from animals like pangolin, swan, and snake simmered together for five hours, and a soup prepared with pangolin meat and caterpillar fungus (*Ophiocordyceps sinensis*)[83] (Fig. 2).

Several recipes including pangolin meat are prepared in Fujan gastronomy. In the western mountainous area, pangolin meat is steamed, simmered, and served/covered with a gelatinized sauce made with onion, soy sauce, ginger, Shaoxing wine, chicken soup, and Danggui (*Angelica sinensis* roots)[79]. A soup is also prepared by boiling the meat, which is served with pieces of pangolin tongue[84]. In the villages of the Yunnan–Guizhou Plateau (Yunnan and Guizhou provinces), a pangolin and chestnut stew is part of the local cuisine[80]. Besides meat, pangolin foetuses are eaten in soup (Fig.3).

Moreover, baby pangolins are boiled in rice wine to brew a tonic and the blood is used as an ingredient in pangolin-blood fried rice (Fig. 4)[85].

Self-regulating mechanisms mitigating potential overexploitation in TILEK systems

As subsistence-oriented populations are integrated into the global economy, processes of intensification and commodification of resources previously used for subsistence take place. These commodification processes often end up severing the links that existed between resource extraction and the carrying capacity and ecology of the surrounding environment. Populations lose their raw materials and spiritual attachment to their own restricted resource catchments, and these catchments become providers of both cash for hunters and highly-sought after products for global consumers. In the process, the same traditional knowledge, norms, and practices that have sustained a low-rate harvest of materially and culturally meaningful species change: while the knowledge and skills related to hunting and to the behavior of, for example, pangolins remain key to providing these animals to the market, the norms that regulated their harvest collapse under the pressure of demand, livelihood commodification, and the shift of decision-making from communities to individuals and outsiders. Indigenous and traditional knowledge, norms, and beliefs that regulate human access to different species in different places at different times are nonetheless central to biodiversity conservation[86]. Indeed, traditional knowledge, its nuanced understanding of ecological relationships, and the limits it sets to over-harvesting are of great importance for biodiversity conservation and for local livelihoods[87, 88], as well as being an attribute of communities with continuity in resource use practices.

By investigating the knowledge systems that different populations have in relation to the environment and its species, ethnobiology and ethnoecology help to understand and conceptualize the links between local populations, natural resources, and their management. Each use of a species does not have just a material significance, but rather it is embedded in cultural and social systems that give meaning to that use and put that meaning into the context of the wider ecology on which communities depend and about which have deep knowledge. When animals and their products are divorced from their cultural ecological context and commodified at the national and international level, then the place of these animals in the local culture and ecology becomes irrelevant if they do not contribute to cash generation and profit extraction. As seen repeatedly during the Anthropocene, the severing of the dynamic link (and its constraints) between human populations and the ecology of the places in which they live opens the way for all kinds of distortions, disruptions, and global threats, including the threat of pandemics.

One of the mechanisms through which populations and communities try to regulate access to and extraction of resources is through taboos. The enforcement of taboos may strike a dynamic balance between the biological and ecological characteristics of a species and its rate of extraction and use. This is often achieved through cultural and social mechanisms that may be effective as long as social and cultural integrity is not replaced with and substituted by commodified livelihoods. In this way, uses and traditions may lead to wildlife conservation, as shown in several studies[74, 89]. Culture and tradition regulate the use of certain species; the replacement of cultures and traditions with Western culture and a profit-based economic system breaks those regulations, with dire effects on the targeted species. In a study about taboos among rural communities of Cameroon, Bobo et al.[74] found that local culture regulates wildlife extraction and use through social norms and taboos. Four types of taboos that regulate

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resource extraction can be distinguished: (1) species specific, which regulate access (e.g., hunting, fishing, gathering) to specific wild species of ecological or cultural relevance (e.g., totem species); (2) habitat, which regulate (e.g., forbid during certain times of the year) access to specific habitats (e.g., sacred forests); (3)method, which regulate the culturally sanctioned time, place, means, and ways through which an activity (e.g., hunting) can be performed; and (4) segment taboos, which impose restrictions on the consumption of certain animals by certain social groups such as women or children[87, 90, 91]. Through taboos and social norms, resource-dependent communities regulate the rate of use of the species they depend upon for their survival, thus fostering resilience and cultural and social continuity.

Contemporary forms of wild animal extraction respond instead to the principles of intensification and maximization (versus optimization) of resource use for global trade and profit generation. This commodification of wild resources and their embedding in global commercial chains is sustained by a high demand for wild animals and their parts for conspicuous consumption by urban and high-income consumers, particularly in Asian countries.

Disconnected consumers and the importance of awareness

With the disconnection taking place between consumers on the one hand, and producers, biodiversity and local ecologies on the other hand, the knowledge that consumers need is no longer, or not only, about the ways of processing, cooking, and eating foods, but also and importantly about the consequences that their decisions about what to eat have on distant livelihoods and ecologies. Several scholars have argued, in this respect, for the important role of consumer education in food habits and choices to reduce demand for prestige meat[92]. For example, shark fin soup is a preferred dish for ostentatious wedding ceremonies, birthday parties, and business meetings in China, and the demand for shark fins (often obtained through the practice of finning, which involves cutting the shark's fin and throwing the shark back into the water) is pushing shark populations towards collapse[93, 94]. However, since about 2011, there has been an estimated 50–70% decrease in shark fin consumption in China, following many educational campaigns on the issue. In a survey about shark fin consumption conducted by WildAid, about 75% of the respondents did not even know the meat in the soup was from sharks, apparently because the name of the dish in Mandarin is "fish wing soup." This is encouraging in relation to the importance of education. In the wake of the COVID-19 pandemic, the Chinese government has shut down wet markets all over the country and has begun a campaign of awareness concerning the importance of protecting wild species for collective health. The banning of wet markets, wildlife trade, and wildlife farming, without driving down the demand for wild meat, risks causing the trade to move underground, with a potentially even worse impact on commercialized species. Rather, demand can be reduced by informing and educating consumers about the consequences of their food desires and habits; there is no prestige in driving species to extinction. At the same time, there is the need to support alternative livelihoods for hunters, traders, and wildlife farmers if and when banning wet markets and wildlife trade. In the absence of alternative means of subsistence, any ban on wildlife trade and consumption will have a disproportionate effect on their livelihoods, pushing many of them into poverty and illegality[95]. Questions on how to alleviate poverty, and what outcomes this would have on bushmeat consumption, are nonetheless open to debate[96].

At the same time, as zoonotic diseases emerge not only from wildlife trafficking for human consumption, but also, as discussed, from the encroachment of human activities into forests as a result of land use changes and the expansion of intensive husbandry systems, and also from the disruption that these processes bring to the forest and the ecology of its species (including that of viruses and bacteria), and as these changes are an integral part of the Anthropocene, there is the need to rethink both our relationships with the rest of Earth's community (materially and spiritually) and our global food system based on intensification and commodification, which creates profits for the few at the expense of everyone else and their health. Rethinking the global food system implies relocalizing food production, reconnecting it with the specific ecology of each place where food is produced, reconnecting producers and consumers, attuning each system to the local ecology of each place, creating value chains that empower all the stakeholders and not just a few at the expense of the many. Traditional and local knowledge, practices, norms, foods, and recipes would then again become tools of attuned engagement with the surrounding natural environment, rather than extrapolated elements of a commodified feeding frenzy.

A crucial role in this change can be played by food storytelling as well. The average conspicuous consumers buy the final product based on the story, not the animal itself (they can also be served a specially prepared chicken). One way to oppose that malpractice would be to widely acknowledge the illusion of the exclusiveness of such "wild foods" and to re-articulate the existing narratives.

In this respect, phenomena such as COVID-19 need to be framed within discourses that redefine the perceived boundaries between human and non-human, between what are considered cultural and natural realms. From this perspective, in the economy of wild foods, often presented as prestige dishes within global imaginaries of gastronomic exclusivity, the "wild" is loosing its significance, as the wild is not wild anymore. On the other hand, the same imaginary is undermining not only local economies, but also global health. Thus, the rhetoric of the wild is increasingly reducing spaces for wildlife as much as the livelihood of those who base their economy therein. In this sense, now, maybe more than ever, that *wilderness* yields the paradoxical result of making the already fuzzy boundary between domesticated and wild even more fragile.

COVID-19 and the Anthropocene

We might eventually ask ourselves what the relationships between the Anthropocene and the COVID-19 pandemic are. Is COVID-19 a creature of the Anthropocene like climate change? The main traits of the Anthropocene, i.e., ecosystem and biodiversity loss, disrupted and turbulent ecologies, pervasive human activity, intensification of land use, commodification of traditional foods and knowledge, indeed also shape the conditions for the emergence of zoonotic diseases. The spread of zoonotic viruses in the last hundred years, more so in connection with attempts at wildlife farming, recalls what previously happened during the domestication process of livestock thousands of years ago. Continued contact between wild animal species and humans is known to be a source of zoonotic diseases. With increasing close contact during and after the domestication process, and with the increasing densities of human communities, zoonotic diseases like measles emerged at that time. The sanctioning of wildlife farming by the Chinese Government has probably improved the livelihoods and economic conditions of wildlife farmers, many of whom have been pushed out of the livestock sector and into wildlife farming at the forest's hedge during the1990s by the expansion of intensive livestock husbandry[97], but may have contributed in opening up an old Pandora's Box. Many of the diseases that have plagued humans over the last several thousand years derived from our close relationships with our domesticated species. In the same way that the historical process of livestock domestication has brought us new diseases, is it possible that contemporary attempts at wildlife farming are leading us down the same path? Indeed, both processes stem from the intensification of human-animal relations (e.g., the reliance, close-proximity and handling by humans of selected species, or their trade) which leads down a path that facilitates the crossing of the species barrier by viruses present in reservoir and intermediate hosts.

Lessons to learn: future ethnobiological research trajectories

Phenomena such as the COVID-19 pandemic are forcing ethnobiologists to readdress the schedule of their academic agendas and not only of their daily lives. This paper was drafted by authors who normally share the same physical space in a small university in NW Italy,but that at the moment can only work together and converse using online tools. COVID-19 is also requiring us to readdress our teaching strategies, our ways of intellectually interacting within the scientific arena, and, even more importantly, our research paths.

This pandemic will force us to rethink not only our "classic" priorities in ethnobiology but also to envision new epistemological trajectories aimed at more effectively mitigating the mismanagement of natural resources that ultimately threats our and other beings' existence.

Moreover, field studies will be more difficult during and after this pandemic, and, nevertheless, more work will need to be done in the near future along the following lines:

- Historical studies on epidemics and other zoonotic diseases linked to ethnography-based ethnobiological and ethnomedical studies;
- New trends in the intensification of use and commodification of specific living creatures and their ecosystems for food, medicinal, or other purposes;
- Research on the self-regulating systems (including commons and communal goods) that local communities put in place to avoid overexploitation of specific resources in TILEK systems;
- Ethnozoological and ethnobotanical research linked to robust ethnoecological and/or cultural anthropological analyses of the contexts of use, possibly addressing diachronic and spatial dynamics (and not merely lists of used species);
- Human ecological studies on how access to natural resources happens and how it changes in response to changing socio-cultural-political contexts;
- Surveys on the rising of new elitist gastronomies and conspicuous consumption;
- Eco-semiotic works dealing with models for understanding how representations of natural objects are constructed and function;
- Political ecological research on how governance systems at different levels may impact or mitigate these intensification processes;
- Environmental philosophical work aimed at (re)defining the Anthropocene in times of in security.

The next few months will tell us more about how COVID-19 will have impacted the way in which we look at the relationships among living creatures, ecosystems, and human societies, and how our awareness of the value of the "webs of life" will influence our future studies and related reflections.

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Authors' contributions

AP designed the overall logical framework and drafted the reflections on the future ethnobiological research directions; GV analysed in-depth the human ecology and the environmental anthropology of the increasing use of wild animals and drafted a first version of the manuscript; DMZ researched Asian pangolin and bat-centred cuisines and recipes; MFF and PG contributed to the overall anthropological discussion. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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References on following page.

References

1. Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. Philos T R Soc B 2001;356:983–989. https://doi.org/10.1098/rstb.2001.0888.

2. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P. Global trends in emerging infectious diseases. Nature 2008;451:990–993. https://doi.org/10.1038/nature06536.

3. Quammen D. 2012. Spillover: Animal Infections and the Next Human Pandemic. New York: W.W. Norton & Co.; 2012.

4. Daszak P, Cunningham AA, Hyatt AD. Emerging infectious diseases of wildlife – threats to biodiversity and human health. Science 2000;287:443–449. https://doi.org/10.1126/science.287.5452.443.

5. Daszak P, Cunningham AA, Hyatt AD. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Trop 2001;78: 103–116. https://doi.org/10.1016/s0001-706x(00)00179-0.

6. Weiss RA, McMichael AJ. Social and environmental risk factors in the emergence of infectious diseases. Nat Med 2004;10:S70–S76. https://doi.org/10.1038/nm1150.

7. Mildenstein T, Tanshi I, Racey PA. Exploitation of bats for bushmeat and medicine. In: Voigt CC, Kingston T, editors. Bats in the Anthropocene: Conservation of Bats in a Changing World. Cham: Springer International Publishing; 2016. p. 325–375. https://doi.org/10.1007/978-3-319-25220-9_12.

8. Chiew M Batty food. The Star [Internet]. 2010 Jun 7 [cited 2020 Mar 15]; Lifestyle [about 4 p.]. Available from: https://www.thestar.com.my/lifestyle/features/2010/06/07/batty-food.

9. Rodriguez A. 7 bizarre exotic meat dishes you can find in China. Alvinology. 2020 [cited 2020 Mar 15]; Food & Drink [about 2 p]. Available from: https://alvinology.com/2020/01/25/7-bizarre-game-meats-you-can-find-in-china.

10. Woo PCY, Lau SKP. Viruses and bats. Viruses 2019;11:884. https://doi.org/10.3390/v11100884.

11. Tasteatlas [Internet]. Fruit Bat Soup. London: AtlasMedia Ltd; 2020 [cited 2020 Mar 15]. Available from: https://www.tasteatlas.com/fruit-bat-soup.

12. Wilson DE, Graham GL, editors. Pacific island flying foxes: proceedings of an international conservation conference. Washington DC: US Department of the Interior Fish and Wildlife Service; 1992.

13. Li W, Shi Z, Yu M, Ren W, Smith C, Epstein JH. Bats are natural reservoirs of SARS-like coronaviruses. Science 2005;310:676–679. https://doi.org/10.1126/science.1118391.

14. Memish ZA, Mishra N, Olival KJ, Fagbo SF, Kapoor V, Epstein JH, Alhakeem R, Durosinloun A, Al Asmari M, Islam A, Kapoor A, Briese T, Daszak P, Al Rabeeah AA, L WI. Middle East Respiratory syndrome coronavirus in bats, Saudi Arabia. Emerg Infect Dis 2013;19:1819–1823. https://doi.org/10.3201/eid1911.131172.

15. Smith I, Wang LF. Bats and their virome: an important source of emerging viruses capable of infecting humans. Curr Opin Virol 2013; 3:84–91. https://doi.org/10.1016/j.coviro.2012.11.006.

16. Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, Si HR, Zhu Y, Li B, Huang CL, Chen HD, Chen J, Luo Y, Guo H, Jiang RD, Liu MQ, Chen Y, Shen XR, Wang X, Zheng XS, Zhao K, Chen QJ, Deng F, Liu LL, Yan B, Zhan FX, Wang YY, Xiao GF, Shi ZL. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020;579:270–273. https://doi.org/10.1038/s41586-020-2012-7.

17. Plowright RK, Eby P, Hudson PJ, Smith IL, Westcott D, Bryden WL, Middleton D, Reid PA, McFarlane RA, Martin G, Tabor GM, Skerratt LF, Anderson DL, Crameri G, Quammen D, Jordan D, Freeman P, Wang LF, Epstein JH, Marsh GA, Kung NY, McCallum H. Ecological dynamics of emerging bat virus spillover. P Roy Soc B-Biol Sci 2015;282:20142124. https://doi.org/10.1098/rspb.2014.2124.

18. Leendertz SAJ, Gogarten JF, Düx A, Calvignac-Spencer S, Leendertz FH. Assessing the evidence supporting fruit bats as the primary reservoirs for ebola viruses. Ecohealth 2016;13:18–25. https://doi.org/10.1007/s10393-015-1053-0.

19. Li X, Zai J, Zhao Q, Nie Q, Li Y, Foley BT, Chaillon A. Evolutionary history, potential intermediate animal host, and cross-species analyses of SARS-CoV-2. J Med Virol 2020;1–10. https://doi.org/10.1002/jmv.25731.

20. Li W, Shi Z, Yu M, Ren W, Smith C, Epstein JH, Wang H, Crameri G, Hu Z, Zhang H, Zhang J, McEachern J, Field H, Daszak P, Eaton BT, Zhang S, Wang LF. Bats are natural reservoirs of SARS-like coronaviruses. Science 2005;310: 676–679. https://doi.org/10.1126/science.1118391.

21. Lau SKP, Woo PCY, Li KSM, Huang Y, Tsoi HW, Wong BHL, Wong SSY, Leung SY, Chan KH, Yuen KY. Severe acute respiratory syndrome coronavirus-like virus in Chinese horseshoe bats. P Natl Acad Sci USA 2005;102:14040–14045. https://doi.org/10.1073/pnas.0506735102.

22. Markus N, Hall L. Foraging behaviour of the black flying fox (Pteropus alecto) in the urban landscape of Brisbane, Queensland. Wildlife Res 2004; 31:345–355. https://doi.org/10.1071/WR01117.

23. Mickleburgh S, Waylen K, Racey P. Bats as bushmeat: a global review. Oryx 2009;43:217–234. https://doi.org/10.1017/S0030605308000938.

24. Pulliam JR, Epstein JH, Dushoff J, Rahman SA, Bunning M, Jamaluddin AA, Hyatt AD, Field HE, Dobson AP, Daszak P; Henipavirus Ecology Research Group (HERG). Agricultural intensification, priming for persistence and the emergence of Nipah virus: a lethal bat-borne zoonosis. J R Soc Interface 2012;9:89–101. https://doi.org/10.1098/rsif.2011.0223.

25. Azhar EI, El-Kafrawy SA, Farraj SA, Hassan AM, Al-Saeed MS, Hashem AM, Madani TA. Evidence for camel-to-human transmission of MERS coronavirus. New Engl J Med 2014;370:2499–2505. https://doi.org/10.1056/NEJMoa1401505.

26. Zumla A, Hui DS, Perlman S. Middle East respiratory syndrome. Lancet 2015; 386: 995–1007. https://doi.org/10.1016/S0140-6736(19)33221-0.

27. Ntiamoa-Baidu Y. Wildlife and food security in Africa [Internet]. Rome: FAO; 1997. Available from: http://www.fao.org/3/w7540e/w7540e00.htm. [cited 2020 Mar 15].

28. Lindsey PA, Balme G, Becker M, Begg C, Bento C, Bocchino C, Dickman A, Diggle RW, Eves H, Henschel P, Lewis D, Marnewick K, Mattheus J, McNutt JW, McRobb R, Midlane N, Milanzi J, Morley R, Murphree M, Opyene V, Phadima J, Purchase G, Rentsch D, Roche C, Shaw J, van der Westhuizen H, Van Vliet N, Zisadza-Gandiwa P. The bushmeat trade in African savannas: impacts, drivers, and possible solutions, Biol Conserv 2013;106:80–96. https://doi.org/10.1016/j.biocon.2012.12.020.

29. Kalish ML, Wolfe ND, Ndongmo CB, McNicholl J, Robbins KE, Aidoo M, Fonjungo PN, Alemnji G, Zeh C, Djoko CF, Mpoudi-Ngole E, Burke DS, Folks TM. Central African hunters exposed to simian immunodeficiency virus. Emerg Infect Dis 2005;12:1928–1930. https://doi.org/10.3201/eid1112.050394.

30. Marx PA, Alcabes PG, Drucker E. Serial human passage of simian immunodeficiency virus by unsterile injections and the emergence of epidemic human immunodeficiency virus in Africa. Philos T Roy Soc Lond B. 2001;356:911–920. https://doi.org/10.1098/rstb.2001.0867.

31. Apetrei C, Robertson DL, Marx PA. The history of SIVS and AIDS: epidemiology, phylogeny and biology of isolates from naturally SIV infected non-human primates (NHP) in Africa. Front Biosci 2004;9:225–254. https://doi.org/10.2741/1154.

32. de Sousa JD, Müller V, Lemey P, Vandamme AM. High GUD incidence in the early 20th century created a particularly permissive time window for the origin and initial spread of epidemic HIV strains. PLOS One 2010;5:e9936. https://doi.org/10.1371/journal.pone.0009936.

33. Chitnis A, Rawls D, Moore J. Origin of HIV type 1 in colonial French Equatorial Africa? AIDS Res Hum Retrov 2000;16:5–8. https://doi.org/10.1089/088922200309548.

34. Schenck M, Effa NE, M Starkey, Wilkie D, Abernethy KA, Telfer P, Godoy R, Treves A. Why people eat bushmeat: results from two-choice, taste tests in Gabon, Central Africa. Hum Ecol. 2006;34:433–445. https://doi.org/10.1007/s10745-006-9025-1.

35. Borgerson C, McKean MA, Sutherland MR, Godfrey LR. Who hunts lemurs and why they hunt them. Biol Conserv 2016;197:124–130. https://doi.org/10.1016/j.biocon.2016.02.012.

36. Reuter K, Randell H, Wills AR, Sewall BJ. The consumption of wild meat in Madagascar: drivers, popularity and food security. Environ Conserv 2016;43: 273–283. https://doi.org/10.1017/S0376892916000059.

37. Golden CD, Fernald LCH, Brashares JS, Rasolofoniaina R, Kremen C. Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. P Natl Acad Sci USA 2011;08: 19653–19656. https://dx.doi.org/https://doi.org/10.1073/2Fpnas.1112586108.

38. Brashares JS, Arcese P, Sam MK, Coppolillo PB, Sinclair ARE, Balmford A. Bushmeat hunting, wildlife declines, and fish supply in West Africa. Science 2004:306:1180–1183. https://doi.org/10.1126/science.1102425.

39. Wilkie D, Starkey M, Abernethy K, Effa E, Telfer P, Godoy R. Role of prices and wealth in consumer demand for bushmeat in Gabon, Central Africa. Conserv Biol 2005;19:268–274. https://doi.org/10.1111/j.1523-1739.2005.00372.x.

40. Brashares J, Goldena C, Weinbauma K, Barrettc C, Okello G. Economic and geographic drivers of wildlife consumption in rural Africa. P Natl Acad Sci USA 2011;108:13931–13936. https://doi.org/10.1073/pnas.1011526108.

41. Barnett R. Wild meat utilisation in the east and southern Africa region. In: Mainka S, Trivedi M, editors. Links between Biodiversity Conservation, Livelihoods and Food Security: The sustainable use of wild species for meat. Glan: IUCN; 2002. p. 55–60.

42. Wilkie DS, Bennett EL, Peres CA, Cunningham AA. The empty forest revisited. Ann NY Acad Sci 2011;1223:120–128. https://doi.org/10.1111/j.1749-6632.2010.05908.x.

43. Chaber A, Allebone-Webb S, Lignereux Y, Cunningham AA, Marcus Rowcliffe J. The scale of illegal meat importation from Africa to Europe via Paris. Conserv Lett 2010;3:317–321. https://doi.org/10.1111/j.1755-263X.2010.00121.x.

44. Illgner P, Nel L. The geography of edible Insects in Sub-Saharan Africa: a study of the Mopane Caterpillar. Geogr J 2000; 166:336–351. https://doi.org/10.1111/j.1475-4959.2000.tb00035.x.

45. Still J. Use of animal products in traditional Chinese medicine: environmental impact and health hazards. Complement Ther Med 2003;11: 118–122. https://doi.org/10.1016/S0965-2299(03)00055-4.

46. Kirkpatrick RC, Emerton L. Kill tiger to save them: Fallacies of the farming argument. Conserv Biol. 2010. 24:655–659. https://doi.org/10.1111/j.1523-1739.2010.01468.x.

47. Veblen T. The theory of the leisure class an economic study of institutions. New York: The Macmillan Company; 1899.

48. Bourdieu P. Distinction: a social critique of the judgement of taste. London: Routledge; 1984.

49. Le Wita B. French bourgeois culture. Cambridge: Cambridge University Press; 1994.

50. Halkett EC. The sum of small things. A theory of aspirational class. Princeton, Princeton University Press; 2017.

51. Goodman DSG, editor. The new rich in China: future rulers, present lives. London: Routledge; 2008.

52. Osbung J. Anxious wealth. Money and morality among China's new rich. Stanford: Stanford University Press; 2013.

53. Tomba L, Tang B. The Forest City: homeownership and new wealth in Shenyang. In: Goodman DSG, editor. The New Rich in China: Future Rulers, Present Lives. London: Routledge; 2008. p. 171–86.

54. Cartier C. The Shanghai-Hong Kong Connection: fine jewelry consumption and the demand for diamonds. In: Goodman DSG, editor. The New Rich in China: Future Rulers, Present Lives. London: Routledge; 2008. p. 187–200.

55. Gerth K Lifestyles of the rich and infamous: the creation and implications of China's new aristocracy. Comp Sociol 2011;10:488–507. https://doi.org/10.1163/156913311X590592.

56. Ma H, Huang J, Fuller F, Rozelle S. Getting rich and eating out: consumption of food away from home in urban China. Can J Agr Econ 2006;54:101–119. https://doi.org/10.1111/j.1744-7976.2006.00040.

57. Zhang L, Yin F. Wildlife consumption and conservation awareness in China: a long way to go. Biodivers Conserv 2014;23:2371–2381. https://doi.org/10.1007/s10531-014-0708-4.

58. Guan Y, Zheng BJ, He YQ, Liu XL, Zhuang ZX, Cheung CL; Luo SW, Li PH, Zhang LJ, Guan YJ, Butt KM, Wong KL, Chan KW, Lim W, Shortridge KF, Yuen KY, Peiris JS, Poon LL. Isolation and characterization of viruses related to the SARS coronavirus from animals in Southern China. Science 2003;302: 276–278. https://doi.org/10.1126/science.1087139.

59. Webster RG. Wet markets–a continuing source of severe acute respiratory syndrome and influenza? Lancet 2004;363:234-236. https://doi.org/10.1016/S0140-6736(03)15329-9.

60. Newman L. Lost feast: culinary extinction and the future of food. Toronto: ECW Press; 2019.

61. Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF. The proximal origin of SARS-CoV-2. Nat Med. 2020.

62. Gaski AL, Johnson KA. Prescription for extinction: endangered species and patented oriental medicines in trade. Washington DC; Traffic USA; 1994.

63. Sodeinde OA, Adedipe SR. Pangolins in south-west Nigeria—current status and prognosis. Oryx 1994;28:43–50. https://doi.org/10.1017/S0030605300028283.

64. Boakye MK, Pietersen DW, Kotzé A; Dalton DL; Jansen R. Knowledge and uses of African pangolins as a source of traditional medicine in Ghana. PLOS ONE. 2015;10:e0117199. https://doi.org/10.1371/journal.pone.0117199.

65. Boakye MK, Pietersen DW, Kotzé A, Dalton DL, Jansen R. Ethnomedicinal use of African pangolins by traditional medical practitioners in Sierra Leone. J Ethnobiol Ethnomed 2014;10:76. https://doi.org/10.1186/1746-4269-10-76.

66. Soewu DA, Ayodele IA. Utilisation of Pangolin (Manis sps) in traditional Yorubic medicine in Ijebu province, Ogun State, Nigeria. J Ethnobiol Ethnomed 2009;5:39. https://doi.org/10.1186/1746-4269-5-39.

67. Soewu DA, Adekanola TA. Traditional-medical knowledge and perception of pangolins (Manis sps) among the Awori People, Southwestern Nigeria. J Ethnobiol Ethnomed 2011;7:25. https://doi.org/10.1186/1746-4269-7-25.

68. Jansen R, Sodeinde O, Soewu D, Pietersen DW, Alempijevic D, Ingram DJ. White-bellied pangolin Phataginus tricuspis (Rafinesque, 1820). In: Challender DWS, Nash HC, Waterman C, editors. Pangolinis. Science, Society and Conservation. Cambridge MA: Academic Press; 2020. p. 139–156. https://doi.org/10.1016/B978-0-12-815507-3.00009-5.

69. Akpona HA, Djagoun CAMS, Sinsin B. Ecology and ethnozoology of the three-cusped pangolin Manis tricuspis (Mammalia, Pholidota) in the Lama forest reserve, Benin. Mammalia 2008;72:198–202. https://doi.org/10.1515/MAMM.2008.046.

70. Altaf M, Javid A, Umair M, Iqbal KJ, Rasheed Z, Abbasi AM. Ethnomedicinal and cultural practices of mammals and birds in the vicinity of river Chenab, Punjab-Pakistan. J Ethnobiol Ethnomed 2017;13:41. https://doi.org/10.1186/s13002-017-0168-5.

71. Vijayakumar S, Prabhu S, Yabesh JM, Prakashraj R. A quantitative ethnozoological study of traditionally used animals in Pachamalai hills of Tamil Nadu, India. J Ethnopharmacol 2015;171:51–63. https://doi.org/10.1016/j.jep.2015.05.023.

72. Bräutigam A, Howes J, Humphreys T, Hutton J. Recent information on the status and utilization of African pangolins. TRAFFIC Bulletin. 1994;15(1):15–22.

73. Challender DWS, Hywood L. African pangolins: under increased pressure from poaching and intercontinental trade. TRAFFIC Bulletin. 2012;24:53–5.

74. Bobo KS, Aghomo FFM, Ntumwel BC. Wildlife use and the role of taboos in the conservation of wildlife around the Nkwende Hills Forest Reserve; South-west Cameroon. J Ethnobiol Ethnomed 2015;11:2. https://doi.org/10.1186/1746-4269-11-2.

75. Wu S, Liu N, Zhang Y, Ma GZ. Assessment of threatened status of Chinese pangolin (Manis pentadactyla). Chinese J Appl Environ Biol. 2004;04.

76. Challender DW, Harrop SR, MacMillan DC. Understanding markets to conserve trade-threatened species in CITES. Biol Conserv, 2015;187: 249–259. http://dx.doi.org/https://doi.org/10.1016/j.biocon.2015.04.015.

77. Challender DW, Nash HC, Waterman C, editors. Pangolins: Science, Society and Conservation. Cambridge MA: Academic Press; 2019. https://doi.org/10.1016/C2017-0-02849-5.

78. Koerner N Chinese cookbook for happiness and success [Internet]. Berlin: Epubli GmbH; 2014 [cited 2020 Mar 15]. Available from: https://www.amazon.it/Chinese-cookbook-happiness-success-English-ebook/dp/B01GFYKGEO.

79. Wei M. Fujian Cuisine [Internet]. DeepLogic; 2019 [cited 2020 Mar 15]. Available from: https://www.kobo.com/ie/en/ebook/fujian-cuisine-1.

80. Wei M. Yunnan and Guizhou Cuisine [Internet]. DeepLogic; 2019 [cited 2020 Mar 15]. Available from: https://www.kobo.com/ie/en/ebook/yunnan-andguizhou-cuisine.

81. Watts J 'Noah's Ark' of 5,000 rare animals found floating off the coast of China. The Guardian [Internet]. 2007 May 26 [cited 2020 Mar 15]; Environment [about 2 p.]. Available from: https://www.theguardian.com/environment/2007/may/26/china.conservation.

82. Xing S, Bonebrake TC, Cheng W, Zhang M, Ades G, Shaw D, Zhou Y. Meat and medicine: historic and contemporary use in Asia. In: Challender DW, Nash HC, Waterman C, editors. Pangolins: Science, Society and Conservation. Cambridge MA: Academic Press; 2019. p. 227–239. https://doi.org/10.1016/B978-0-12-815507-3.00014-9.

83. Nuwer RL. Poached: inside the dark world of wildlife trafficking. Cambridge MA: Da Capo Press; 2018.

84. Coggins C. The tiger and the pangolin: nature, culture, and conservation in China. Honolulu: University of Hawaii Press; 2003.

85. Lo K Probe launched into latest case of man boasting about 'delicious pangolin soup. South China Morning Post [Internet]. 2017 Feb 13 [cited 2020 Feb 15]; Society [about 2 p.]. Available from: https://www.scmp.com/news/china/society/article/2070384/chinese-authorities-probe-eatingendangered-species.

86. Gadgil M, Berkes F, Folke C. Indigenous knowledge for biodiversity conservation. Ambio. 1993;22:151–6 www.jstor.org/stable/4314060.

87. Berkes F, Colding J, Folke C. Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 2000;10:1251–1262. https://doi.org/10.2307/2641280.

88. Alves RR, Rosa IL. Why study the use of animal products in traditional medicines? J Ethnobiol Ethnomed 2005;1:5. https://doi.org/10.1186/1746-4269-1-5.

89. Kideghesho JR. Co-existence between the traditional societies and wildlife in western Serengeti, Tanzania: its relevancy in contemporary wildlife conservation efforts. Biodivers Conserv 2008;17:1861–1881. https://doi.org/10.1007/s10531-007-9306-z.

90. Colding J, Folke C. The relations among threatened species, their protection and taboos. Conserv Ecol. 1997;1:6 http://www.consecol.org/vol1/iss1/art6/.

91. Colding J, Folke C. Social taboos: "invisible" systems of local resource management and biological conservation. Ecol Appl 2001;11:584–600. https://doi.org/10.2307/3060911.

92. Chausson AM, Rowcliffe JM, Escouflaire L, Wieland M, Wright JH. Understanding the Sociocultural Drivers of Urban Bushmeat Consumption for Behavior Change Interventions in Pointe Noire, Republic of Congo. Hum Ecol 47:179–191. https://doi.org/10.1007/s10745-019-0061-z.

93. Verlecar XN, Snigdha SR, Dhargalkar VK. Shark hunting: an indiscriminate trade endangering elasmobranchs to extinction. Curr Sci India. 2007;92: 1078–82 http://drs.nio.org/drs/handle/2264/602.

94. Jacquet J, Alava JJ, Pramod G., Henderson S, Zeller D. In hot soup: sharks captured in Ecuador's waters. Environm Sci 2008;5:269–283. https://doi.org/10.1080/15693430802466325.

95. Felbab-Brown V. The extinction market: wildlife trafficking and how to counter it. Oxford: Oxford University Press; 2017.

96. Robinson J, Bennett E. Will alleviating poverty solve the bushmeat crisis? Oryx 2002;36:332–332. https://doi.org/10.1017/S0030605302000662.

97. Fearnley L. Wild Goose Chase: The Displacement of Influenza Research in the Fields of Poyang Lake, China. Cult Anthropol 2015;30:12–35. https://doi.org/10.14506/ca30.1.03.

The legal proposals shaping the future of wildlife in China

April 3, 2020

BY WANG CHEN & JIANG YIFAN

The coronavirus has propelled China's Wildlife Protection Law up the legislative agenda. China Dialogue assesses six plans for its revision.

Proposals discussed in this article:

- Nine suggestions on the revision of the Wildlife Protection Law. China Law Society Administrative Law Research Group, 12 February.
- 10 key points for the 2020 revision of the Wildlife Protection Law. The SEE Foundation, 17 February.
- Opinions and suggestions on the revision of the Wildlife Protection Law. Peking University Centre for Nature and Society, Shanshui Conservation Centre and eight other groups, 18 February.
- Six legislative suggestions for strengthening wildlife protection, ensuring biosafety and protecting public health. From 14 environmental law experts, including Chang Jiwen, 22 February.
- Several opinions and suggestions on the revision of the Wildlife Protection Law. China Law Society Environment and Resource Law Research Group, 24 February.
- 10 suggestions for the revision of the Wildlife Protection Law. The China Biodiversity Conservation and Green Development Foundation, 24 February.

Covid-19, and its suspected origin in wildlife consumption, has caused China to look again at how it treats the natural world. With unprecedented public demand for a ban on the eating of wild animals, China's highest legislative body is moving quickly to avoid a similar public health crisis from happening again.

On 10 February, the Legislative Affairs Commission of the National People's Congress Standing Committee added a revision of the Wildlife Protection Law to its agenda for 2020. Then to protect public health, the Standing Committee announced on 24 February a "complete ban of illegal wildlife trade and the elimination of the unhealthy habit of indiscriminate wild animal meat consumption". The decision will allow measures to be taken before the revision of the Wildlife Protection Law comes into effect.

The revised law could change the fate of wild animals not just in China, but worldwide. For over a month, conservation groups and scientists have worked together to propose changes. The variety of the proposals highlights disagreements regarding wildlife protection in China: over aims, methods and interests. But a new consensus is also emerging from the public health emergency. The outcome of the revision process will depend on how the disagreements and the consensus are reflected in the language of the updated law.

China Dialogue has analysed the most influential proposals, listed at the bottom of the article, across four key themes: biodiversity, public health, wild-animal farming and utilisation, and calls for deeper reform.

Restoring biodiversity

The Wildlife Protection Law, which first came into effect in 1988, is the legislative basis for management and protection of wildlife in China. It has been revised four times: in 2004, 2008, 2016 and 2018. But language permitting the "use" of wild animals has always been present, even after the bitter lessons of the 2003 SARS epidemic. A major debate over the 2016 revision centred on whether wild animals should be "used" or "protected", with the principle of "regulated use" written into the law, consolidating the idea that wildlife is to be treated as a "resource".

The law, orientated towards use, limits protections to two categories of wild animal: those that are "rare and endangered land and aquatic animals" and those "land wild animals with important ecological, scientific or social value". The two lists of animals are supposed to be updated regularly. For wild animals not on the lists, the law has no clear rules on their domestication, breeding, trade or consumption.

The China Law Society's Environment and Resource Law Research Group points out in its proposal that protection of animals not included in either category is currently implemented piecemeal across various laws and regulations, that there are "difficulties in resolving conflict between use and protection, and the protection-first principle cannot be implemented".

The existing law leaves plenty of scope for the use of wild animals. It establishes a licensing system for artificial breeding of wild animals under special state protection: both the animals and their products can be

A farmer checks a bamboo rat bred in Qinzhou, south China (Image: Alamy)

bought, sold and used if quarantine certificates and approvals are in place. Other animals can be sold and used if they're acquired legally. In reality, there are numerous issues with licensing, approvals, quarantine inspection and law enforcement.

Meanwhile, local and regional governments promote the farming of wild animals as a way to reduce poverty and stimulate rural economies. Accordingly, the wildlife farm industry has been steadily expanding.

Many animals that should be protected by the current law are not, as updates to the short lists of protected species are long overdue. The SEE Foundation pointed out the problem in its proposal: according to the regulations, the forestry and grassland authorities submit land animals to be listed and the fishery authorities do the same for aquatic animals. Once agreed, the lists are submitted to the State Council for approval. However, the two authorities have failed to reach agreement for some years. Many of the proposed revisions examined by China Dialogue aim to create a scientific mechanism for making these decisions, ensuring the lists are updated regularly and kept in line with international treaties such as CITES (the Convention on International Trade in Endangered Species) and the CBD (Convention on Biological Diversity). This is to ensure that certain animals receive priority protection, whilst more animals acquire protection status through the expansion of the legal definition of "wildlife".

Taken together, the narrow legal definition of "wild animals", fragmented oversight mechanisms and the failure to update lists of animals given special state protection means that many animals are not adequately protected, exposing the public to the risk of disease.

Several proposals call for the scope of protections to be widened. In a joint proposal, ten organisations including Shanshui Conservation Centre, Peking University Centre for Nature and Society, and Friends of Nature suggest expanding protections for "wild animals with important ecological, scientific or social value" to cover all as-yet unprotected species as "ordinary protected animals". The thinking here is to change the current approach of valuing animals according to rarity and utility toward one of protecting biodiversity and acknowledging that all animals have their place in the ecosystem. This "biodiversity principle" features in five of the six proposals examined. Four also call for stronger protection of wildlife habitats to preserve biodiversity.

On this, the China Law Society's Environment and Resource Law Research Group proposal particular care be taken to ensure the revised law links up with the Nature Reserve Law, The National Park Law, and the Yangtze River Protection Law, all currently being drafted, and the ongoing revision of the Fisheries Law. This would avoid conflict between these laws on how habitats, protected areas and nature reserves are listed, and prevent administrative powers overlapping or conflicting across agencies.

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Protecting public health

With the revision of the law being prompted by concerns about disease, health was a focus of the proposals we reviewed, with each calling for the protection of public health to be included as a purpose of the legislation.

These concerns have brought new ideas on management of wildlife, and, like biodiversity protection, provide motivation to expand the scope of the law. Preventing the spread of disease from the consumption of wild animals was a regular feature of the proposals. The joint proposal from Shanshui Conservation Centre and eight other groups, and the proposal from the China Biodiversity Conservation and Green Development Foundation (CBCGDF), both included a ban on eating wild animals as a first principle. CBCGDF went further, suggesting a ban on domestication and breeding of wild animals.

Public health is also offered as a rationale for habitat protection. The joint proposal from Shanshui et al. suggested, in accordance with a UN assessment, that habitat change can lead to "changes in the number of vector breeding sites or reservoir host distribution". Therefore, the revised law "should explicitly stress the protection of both wild animals and their habitats, giving habitat protection higher status and designating it as a purpose of the legislation".

Public health worries have even triggered unusually extreme proposals for bans on eating wild animals at the local level. In late February, the Shenzhen People's Congress published a consultation draft of rules to ban the eating of captive-bred and raised Chinese softshell turtles, due to the risk of disease. This led to opposition from businesses and huge public debate, until the Ministry of Agriculture clarified that rules for management of aquatic animals still applied.

However, policies driven by public health concerns could easily overlook the trade in non-food and sterilised products, such as medicines and ornaments, particularly from animals captured or farmed and then processed from overseas.

In the proposals examined by China Dialogue, all from Chinese organisations, there was little mention of the medicinal use of wild animals. The CBCGDF talks of "cautious use of wild animals", only "in the public interest of the whole society". Those interests include medicinal use (alongside scientific research and education). But the proposal also suggests encouraging Chinese medicine manufacturers to develop alternatives, so use of wild animals and wild animal products is reduced and eventually eliminated. Another proposal, from 14 environmental law experts, said that where alternatives are available, a timetable should be set for the reduction and elimination of the use of wild animals in medicine. An immediate halt to medicinal usage was not seen as feasible.

For international conservation groups, banning the medicinal use of wild animals is more pressing.

In late February, the Environmental Investigation Agency (EIA) published its own proposal for the revised law, raising the issue of controlling the use of animals such as the elephant, tiger, pangolin and rhinoceros, and their products. It also called for the law to explicitly ban use of wildlife under special state protection in medicine, health products and ornaments. In 2018, the EIA published a report into the use of leopard bones in Chinese medicine, finding that a 1993 ban on the trade in tiger bones had resulted in widespread use of leopard bones as an alternative. The EIA estimated that more than 5030 leopards – including carcasses and skins – were seized in Asia since 2000, raising this to a minimum of 5332 in a March update to the report. The EIA's proposal is opposed to the existing dual-track approach of protecting wild populations while making use of captive-bred animals, saying that "Whether wildlife is consumed as food, medicine, a healthcare tonic or as a decorative item, this consumption poses risks to both the conservation of the species and public health". It therefore says: "the revised Law should make it clear that wildlife consumption of any kind is unacceptable."

A related matter, and one which the domestic groups again paid less attention to, is how the law should treat imported wild animal products. Only the proposal from the 14 environmental law experts called for "a ban on the import for food use of captive-bred or wild-caught land wild animals and aquatic mammals, and products of these." Again, the focus here is on public health and food use.

Aron White, China specialist with the EIA, doesn't want to see non-food use overlooked. He notes the decision of the NPC's Standing Committee only bans the trade in wild animals for food, but that if endangered animals around the world are to be protected, there is an urgent need to remove demand for their products from China's markets.

In a message to China Dialogue, White wrote: "Continuing to allow a legal trade in threatened wild animal species for use in traditional medicine is irresponsible on a global scale – both in terms of legitimising and perpetuating demand for species already under huge threat in other countries due to primarily China-based demand, and the public health risks inherent in the harvesting, collection, storage, processing and consumption of wild animals for any reason."

A breeding whitelist

The existing law's resource-utilisation approach means a huge wild-animal farming industry worth hundreds of billions of yuan has developed, providing over 14 million jobs nationwide. Debate has also focused on the tricky issue of how the law should treat that industry.

The CBCGDF has taken the hardest line, calling for a ban on all commercial breeding of wild animals. The other proposals want to see a "whitelist" to regulate and reduction in the practice.

The Shanshui Conservation Centre-led proposal includes the idea of a special whitelist of animals that could be bred in captivity, with offspring permitted to be used for non-food commercial purposes. Alongside this it suggests the use of captive-bred animals as stock for breeding programmes; the maintaining of genealogical data, breeding files and data on individual animals; and traceability of breeding animals with microchips.

The SEE Foundation suggests a more relaxed approach. This would see wild animals reclassified as either "special animals" or "ordinary protected animals". The first category would be sub-divided into rare and endangered animals to be protected, and wild animals that could be farmed after scientific assessment and under strict controls. The second category would cover all other wild animals.
On the utilisation of wild animals, the SEE Foundation calls for "a ban on the illegal eating of wild animals and wild animal products". The expression "illegal eating" corresponds to its call for a whitelist of wild animals that could be legally eaten. The proposal also makes clear that it

A pangolin to be released back into the wild in southern China is pictured after being rescued in Qingdao, east China. (Image: Alamy)

"does not exclude the use of wild animals for purposes such as scientific research or fur farming". But research has found fur farming to be the biggest single sector in China's wild animal industry.

Despite differing in the broadness of their whitelists, SEE and the joint proposal from the Shanshui Conservation Centre both say quarantine inspections for whitelisted animals must be a priority. Shanshui suggests quarantine standards for a species be a prerequisite for inclusion on the white list; the SEE Foundation admits that the entry criteria of the whitelist will be the key, and that quarantine standards will need to be improved before animals can be listed.

Zhao Xiang, director of the Shanshui Conservation Centre, told China Dialogue that establishing such an animal quarantine system will be difficult, requiring dedicated laboratories, veterinarians, species-specific standards, and careful ongoing management.

But those organisations proposing a whitelist do want to limit and reduce the size of the industry step by step, rather than maintain the status quo. Gradually cutting down the number of animals on the whitelist will send a signal to the industry that it is time to change. "We hope the list will shrink over time," said Liu Jinmei, chief legal consultant to Friends of Nature, speaking to China Dialogue. She also stressed that great caution should be used in creating the whitelist, and any business unable to meet the standards should exit the industry.

Calls for deeper reform

Several groups pointed out that fixing the inherent contradictions of the existing Wildlife Protection Law, and practical problems in enforcement, will require deeper reform.

The China Law Society's Administrative Law Research Group proposes changing China's administrative system for protecting wild animals. It writes that China's forestry authority has long been responsible for protection of wildlife on land – but that authority has been downgraded over time, from ministerial to bureau status, and lacks the resources to undertake such a complex task. It suggests a new wildlife protection bureau be established under the Ministry of Natural Resources, ensuring the necessary status and resources. The SEE Foundation made a similar suggestion.

The Shanshui Conservation Centre-led proposal pointed out that the forestry and grassland authorities are responsible for protection of wild animals on land, while the Ministry of Agriculture's fisheries department handles aquatic wild animals – and disagreements between the two have long hampered protection of wild animals in China. It agrees that these functions should be brought under the Ministry of Natural Resources, as above, but adds a supervisory role for the Ministry of Ecology and Environment.

Consolidating administrative powers won't be enough to ensure protection measures are implemented effectively, as issues with information gathering remain. There are many wild animal species and they exist in large numbers. What's more, crimes against them are generally well-hidden so more administrative staff and resources alone cannot identify problems.

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A street seller on an overpass displays tiger paws and animal products for sale in Guangzhou, China. (Image: Alamy)

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Because of this, several proposals advocate for greater public rights to information on wildlife protection and to exercise oversight of the authorities, which should, in turn, ensure transparency and allow public participation. Both the SEE Foundation and the CBCGDF want to see "public participation" made a principle of the revised law, giving the public and organisations the right to oversight, including to report illegal behaviour and administrative failures, or to expose such cases in the media and bring public interest lawsuits; and for public consultations and hearings to be held when construction projects may damage wildlife habitats.

When it comes to public interest lawsuits, Zhao Xiang thinks social organisations will be able to play a positive role in assessing damages and cause and effect in future cases. Meanwhile, Liu Jinmei has seen how such cases have an effect far beyond the matters under discussion in the courtroom, shaking up established interests and power structures. The Environmental Protection Law of 2015 gave social organisations the right to bring lawsuits as representatives of the public interest. This breakthrough has become an important channel for resolving environmental disputes.

But the existing system for environmental public interest lawsuits doesn't allow cases against government actions. The CBCGDF therefore suggests "establishing a system for social organisations to bring administrative public interest lawsuits". This would allow these groups to bring cases against the government on matters of wildlife protection and keep power in check. The 2017 revisions of the Civil Procedure Law and the Administrative Litigation Law only allowed for environmental public interest cases against government bodies to be pursued by public prosecutors.

Several organisations also noted that improvements to the Wildlife Protection Law alone will not be enough to improve wildlife protection – coordinated change is needed across several laws.

The China Law Society's Administrative Law Research Group suggests parallel changes to the articles on wildlife in China's Criminal Law, and to add a crime of mistreating wild animals.

The SEE Foundation, meanwhile, hopes the revision will expand into a more comprehensive process: "Use the revision of the Wildlife Protection Law as a starting point for ongoing revision of other laws and regulations, departmental rules and local legislation on wildlife protection." This would see a chain reaction of revisions to regulations on protection of land animals and laws on fishing, animal health, animal import and export, environmental protection, and the civil and criminal laws.

As Aron White commented to China Dialogue: "The Covid-19 pandemic has demonstrated in the starkest of terms how no one country's biodiversity and wildlife trade policies exist in isolation. The link to wildlife trade in China, whether legal or illegal, shows the urgent need for stronger laws and enforcement to close markets for wild animal products."

Will this unprecedented pandemic mean the fifth revision of the Wildlife Protection Law is different? We may find out at this year's Two Sessions (Lianghui) – although those meetings have also been delayed.

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TASMANIAN CHINESE BUDDHIST ACADEMY OF AUSTRALIA

30 May this year, Buddhists worldwide are celebrating the 2564th Holy Birthday of the Great Holy Sakyamuni Buddha. This day is known as the Bathing Buddha Festival, or Vesak Day in the Southern Transmission of Buddhism.

2564 years ago, Madam Mahamaya gave birth to Prince Siddhartha Gautama under a tree at Lumbini Grove in ancient India.

The prince later observed the endless sufferings of sentient beings, and vowed to help all sentient beings in the Universe by realising the truth of the universe. He embarked on a path of seeking the Truth which ultimately led him to enlightenment becoming the Buddha - the Enlightened Being.

Buddha's birthday is a day to commemorate His birth, and more importantly, Buddha's mother for her role in delivering the Buddha to the world. The day is also a reminder for all, that everyone can become a buddha, and possess a pure heart full of compassion, benevolence and wisdom.