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All in all, acknowledging spatiobehavioral characteristics as a formal way of defining the epidemiology of new contagious diseases in the digital era is vital and holds important public health implications. It could make privacy-ensured data-sharing mechanisms and infrastructures better prepared in normal times and ready to use at the early stage of new contagious diseases, which otherwise can work only during the important public health emergencies [12]. Moreover, it could provide valid early-stage evidence, perhaps statutory authority as well in the future, for implementing precise protection (e.g., wearing face masks in public) and prevention measures (e.g., lockdown) (Figure 1). Such measures have been demonstrated as the most effective medicine during a pandemic for equally protecting everyone, anytime, anywhere in the world. Therefore, using spatial lifecourse epidemiological theories, methods, and tools to better understand and characterize the spatiobehavioral characteristics of individual cases of new contagious diseases at the early stage would enable us to start prevention strategies compulsorily at the first moment possible for stopping disease transmission, and to outpace the epidemic eventually [2].

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[1]West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, China
[2]State Key Laboratory of Remote Sensing Science, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China
[3]Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China
[4]International Institute of Spatial Lifecourse Epidemiology (ISLE), Hong Kong, China

*Correspondence:
jiapengff@hotmail.com (P. Jia).

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References

1. Lipsitch, M. *et al.* (2020) Defining the epidemiology of Covid-19 – studies needed. *N. Engl. J. Med.* 382, 1194–1196
2. Jia, P. and Yang, S. (2020) Are we ready for a new era of high-impact and high-frequency epidemics? *Nature* 580, 321
3. Budd, J. *et al.* (2020) Digital technologies in the public-health response to COVID-19. *Nat. Med.* 26, 1183–1192
4. Jia, P. and Yang, S. (2020) Early warning of epidemics: towards a national intelligent syndromic surveillance system (NISSS) in China. *BMJ Glob. Health* 5, e002925
5. Jia, P. and Yang, S. (2020) China needs a national intelligent syndromic surveillance system. *Nat. Med.* 26, 990
6. Hogan, C.A. *et al.* (2020) Sample pooling as a strategy to detect community transmission of SARS-CoV-2. *JAMA* 323, 1967–1969
7. Jia, P. (2020) Understanding the epidemic course in order to improve epidemic forecasting. *Geohealth* 4, e2020GH000303
8. Jia, P. (2019) Spatial lifecourse epidemiology. *Lancet Planet Health* 3, e57–e59
9. Jia, P. *et al.* (2020) Spatial lifecourse epidemiology and infectious disease research. *Trends Parasitol.* 36, 235–238
10. Apolloni, A. *et al.* (2013) Age-specific contacts and travel patterns in the spatial spread of 2009 H1N1 influenza pandemic. *BMC Infect. Dis.* 13, 176
11. Bengtsson, L. *et al.* (2015) Using mobile phone data to predict the spatial spread of cholera. *Sci. Rep.* 5, 8923
12. Jia, P. and Yang, S. (2020) Time to spatialise epidemiology in China. *Lancet Glob. Health* 8, e764–e765

Forum

Illegal Wildlife Trade: A Gateway to Zoonotic Infectious Diseases

Marcos A. Bezerra-Santos,[1] Jairo A. Mendoza-Roldan,[1] R.C. Andrew Thompson,[2] Filipe Dantas-Torres,[3] and Domenico Otranto[1,4,*]

The illegal wildlife trade (IWT) is a criminal practice bringing several ecological and public health consequences, such as the spreading of zoonotic pathogens and/or the introduction of exotic species of animals into new geographical areas. Here, we discuss potential risks of IWT on the spreading and emergence of zoonotic pathogens.

IWT as a Threat to Wildlife and Public Health

IWT is the unauthorized commerce of wild animals and plants as well as their derivatives (e.g., bushmeat, ivory, rhino horn, and fur), with a financial value estimated to be worth up to US$23 billion annually[i]. This criminal activity is widespread in several countries, being a concern for wildlife conservation as it is responsible for substantial losses in biodiversity due to uncontrolled capture and trade of endangered species (Box 1). The IWT, as well as the illegal importation of bushmeat, may also be a public health concern due to the spreading of zoonotic agents from the exporting areas (Box 1). For example, the illegal transportation of bushmeat to Europe, mainly from African countries, has been recorded in airports in France and Switzerland, with about 5.25 tons/week and 8.6 tons/year of wildlife meat arriving at Paris, Zurich, and Geneva airports, respectively [1]. The risk of acquiring zoonotic infections from wildlife is increased for the individuals directly involved in this activity (e.g., poachers, local market sellers, and consumers) due to the hazards associated with the incorrect manipulation and consumption of these animals, their products, or both. For example, the lack of appropriate hygiene conditions in the commercialization of wildlife meat and its products (e.g., hand-washing, promiscuous selling with other fresh products and unsanitized structures) are common practices observed in wildlife trade markets, and are regarded as important drivers for the thriving and transmission of infections caused by wildlife-associated pathogens [2].

The IWT is a gateway for the introduction of zoonotic and non-zoonotic exotic pathogens, the latter being of concern for the health and conservation of endemic wildlife. Although several species of zoonotic pathogens are commonly related to wildlife globally, reports on their occurrence associated with IWT are scanty (Table 1). These pathogens can be transmitted to

Box 1. IWT: Drivers and Consequences

The IWT is a global trend phenomenon (Figure I) due to the attractive prices, the low effort made by poachers to acquire wildlife, and the more lenient legal penalties applied for people involved in this activity[ii]. This criminal network is composed of people from several socioeconomic levels, from local subsistence poachers to transnational organized crime. People from local communities in developing countries highly influence the IWT due to factors such as low income, poverty, and illiteracy [14]. This trend has been observed on the illegal trade of pangolins in Nepal, where the low socioeconomic status of locals associated with the growing demand for this animal, particularly in China, facilitated its trading, directly impacting on its conservation [14]. In popular markets, several wildlife species are in contact with each other before being sold or shipped to other regions, this being a driver for the interspecies transmission of pathogens [2]. A study conducted in Laos assessed the potential transmission of zoonotic pathogens from wildlife traded in local markets, identifying 36 zoonotic agents being potentially transmitted. Increased human–wildlife contact, poor biosafety measures, and high-risk taxa for zoonoses were also accounted as risk factors for the presence and dissemination of pathogens in these markets [2].

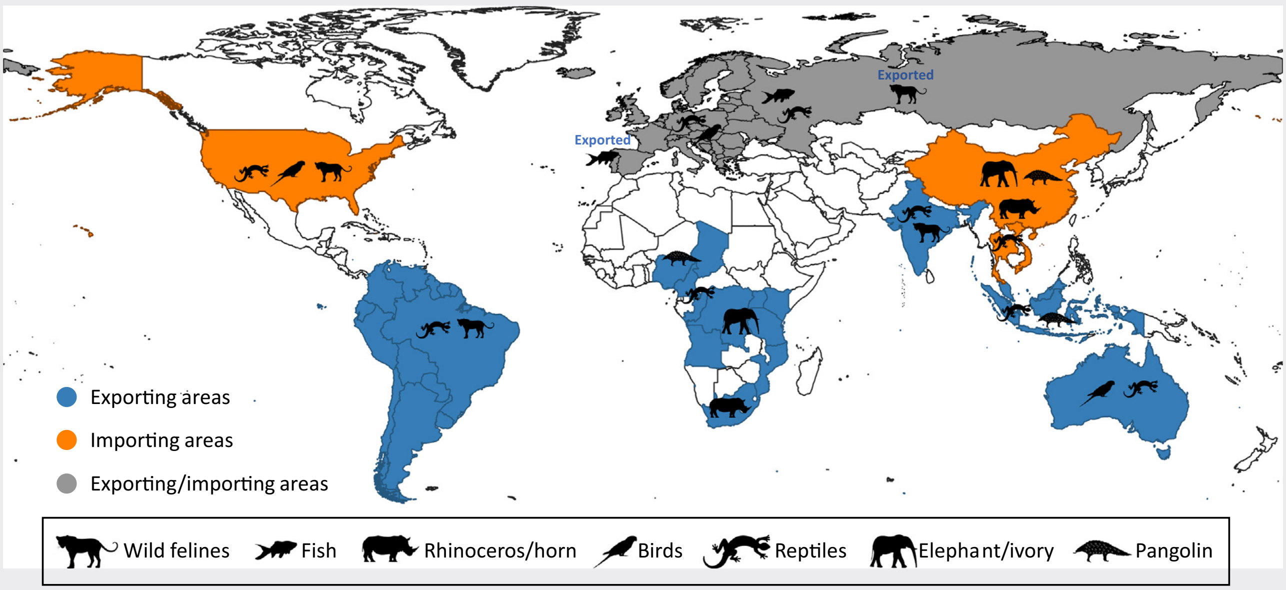

Figure I. The Main Source and Destination Areas of Endangered Wildlife Species Involved in the Illegal Trade Worldwide[iii–v]. Europe and Russia are mainly importing areas, but for some animal groups, such as fish (*Anguilla anguilla*) in Europe and wild felines in Russia, exportation is also recorded.

humans via arthropod vectors (e.g., ticks, fleas, mites, and lice) or by the ingestion of contaminated food and water (e.g., bacteria, protozoa) [1,3]. In addition, problems such as the emergence of antibiotic-resistant pathogens are among the concerns for the conservation of endemic wildlife populations and for public health [4]. For example, antibiotic-resistant strains of zoonotic bacteria (e.g., *Escherichia coli*, *Klebsiella* spp., *Salmonella* spp.) have been isolated from illegally traded wild birds in Brazil, suggesting potential public health risks associated with this illegal activity [4].

Ectoparasites may also be exported along with their hosts to new geographical areas through the illegal transport of live wildlife or their derivatives (e.g., wet hides). This has been observed in Europe, with several exotic tick species (e.g., *Hyalomma aegyptium* and *Amblyomma* spp.) being introduced via the illegal importation of reptiles, especially from African countries [3,5]. The introduction of exotic ectoparasites through the IWT may result in their spreading along with the zoonotic viruses, bacteria, helminths, and protozoa they transmit, resulting in serious consequences for public health. For example, *Rickettsia* spp. and *Ehrlichia* spp. with high similarity to human rickettsial and ehrlichial pathogens were molecularly detected in alien ticks parasitizing exotic reptiles and amphibians imported to Japan from Ghana, Jordan, Madagascar, Panama, Russia, Sri Lanka, Sudan, Suriname, Tanzania, Togo, Uzbekistan, and Zambia [6].

The transportation of infectious agents through IWT and their derivatives has also been recorded for zoonotic endoparasites, such as *Baylisascaris procyonis, Toxascaris* sp., and *Toxocara* sp. in racoons (*Procyon lotor*) illegally imported to Norway [7]. Both the above nematodes are associated with larva migrans in humans, with *B. procyonis* presenting an aggressive tissue migration and tropism for neurologic and ocular systems [7]. Moreover, *B. procyonis* is an exotic emerging species in Europe and was introduced into

Table 1. Pathogens of Public Health Concern Reported in Wildlife Illegally Traded Worldwide

Pathogen	Wildlife involved	Wildlife products	Trade type	Public health issues	Refs
Viruses					
Simian foamy virus (retrovirus)	Non-human primates	Bushmeat	International	Increase in pathogenicity following cross-species transmission	[11]
Cytomegalovirus (herpesvirus)	Non-human primates	Bushmeat	International	Concern for immunocompromised people	[11]
Lymphocryptovirus (herpesvirus)	Non-human primates	Bushmeat	International	B-cell tumors in immunocompromised individuals	[11]
Bacteria					
Escherichia coli	Birds, duiker	Live animals, bushmeat	National, international	Urinary-tract infection, meningitis, septicemia	[4,12]
Klebsiella pneumoniae	Birds	Live animals	National	Pneumonia, urinary-tract infection, septicemia	[4]
Salmonella enterica serovar Typhimurium	Birds	Live animals	National	Gastrointestinal infection	[4]
Listeria monocytogenes	Pangolin, red hog	Bushmeat	International	Meningitis, septicemia, and abortion in immunocompromised people	[12]
Staphylococcus aureus	Pangolin, duiker, red hog, fish	Smoked fish, bushmeat	International	Osteomyelitis, endocarditis, pneumonia, bacteremia, toxic shock syndrome	[12]
Parasites					
Baylisascaris procyonis (nematode)	Raccoons	Live animals	International	Neurological signs, visceral larva migrans	[7]
Toxocara sp. (nematode)	Raccoons	Live animals	National, international	Neurological signs, visceral larva migrans	[7]
Trichinella spp. (nematode)	Black bear, grizzly bear	Meat products	International	Intestinal, muscle, and neurological clinical signs	[1]
Cryptosporidium spp. (protozoan)	Non-human primates	Live animals	National	Intestinal clinical signs	[15]
Hyalomma aegyptium (tick)	Turtles	Live animals	International	Potential vector of zoonoses (e.g., *Borrelia turcica*; Crimean–Congo hemorrhagic fever virus)	[3]

the continent via imported racoons in the early 20th century, becoming subsequently endemic in some European countries [7]. The abovementioned examples suggest that wildlife could represent a source of zoonotic pathogens to previously free areas.

Illegal Importation of Exotic Pets and the Risk of Zoonotic Pathogens

The illegal importation of exotic pets is a growing activity worldwide, posing public health risks for the transmission of zoonotic pathogens. In addition, this practice may lead to environmental issues such as the invasion and establishment of exotic animal populations in local ecosystems, potentially threatening indigenous species due to the risk of introduction of novel pathogens. Exotic pets (e.g., small mammals, reptiles, amphibians, fish, and birds) may be carriers of several zoonotic viruses (e.g., Crimean–Congo hemorrhagic fever virus, West Nile virus, arenaviruses), bacteria (e.g., *Salmonella* spp., *Yersinia pestis*), and parasites (e.g., *Giardia duodenalis*, *Cryptosporidium parvum*, *Toxoplasma gondii*, *B. procyonis*) [5,8]. For example, zoonotic *Salmonella enterica* serotypes, previously associated with human outbreaks of reptile-related salmonellosis, were detected in tortoises (*Testudo graeca*) illegally imported from North Africa to Italy, bringing risks of human infection with pathogenic *Salmonella* [9]. In another study performed in Japan, a zoonotic genotype of *Cryptosporidium* (i.e., horse genotype) was detected in a four-toed hedgehog (*Atelerix albiventris*), a popular exotic pet frequently traded to that country [10]. This genotype was also associated with severe diarrhea in humans, one of them being an employee from a pet shop involved in the care of exotic pets [10]. These reports confirm the importance of controlling the illegal trade of exotic pets and raises awareness regarding the environmental and public health risks associated with releasing these animals in local environments.

Zoonotic Pathogens Transmitted through Consumption of Meat from Illegally Traded Wildlife

Food-borne zoonotic pathogens have also been associated with the consumption of illegally traded wildlife meat. This practice poses serious public health risks due to the lack of sanitary inspection and inadequate manipulation, which may facilitate zoonotic parasite transmission to hunters, sellers, and consumers [5]. Bushmeat-related activities have been linked to viral disease outbreaks [e.g., Ebola virus, HIV-1, monkeypox virus, and severe acute respiratory syndrome (SARS)], further highlighting the risks associated with this practice [2]. For example, zoonotic viruses (i.e., simian foamy virus, cytomegalovirus, and lymphocryptovirus) have been detected in the bushmeat of non-human primates illegally imported from Guinea, Nigeria, and Liberia, and seized at international airports in the USA [11]. Similarly, bacteria of public health concern (i.e., *E. coli*, *Listeria monocytogenes*, *Staphylococcus aureus*) have been detected in illegally imported African wildlife bushmeat seized at Charles de Gaulle airport, Paris, France [12]. Zoonotic parasites have also been linked with the illegal importation of wildlife meat and its products. This is the case in Ireland, Germany, and Denmark where the consumption of fraudulently mixed sausages (domestic pigs and infected wild boar), illegally imported from Poland to those countries via personal baggage, was associated with human cases of trichinellosis [1,13]. The abovementioned examples highlight the importance of monitoring borders to avoid the introduction of exotic parasites through the illegal trade.

Concluding Remarks

The IWT brings several challenges regarding the conservation of endangered species (e.g., outbreaks of exotic diseases), transmission of zoonotic pathogens, and introduction of exotic infectious agents into a new region, representing a potential threat to the local wildlife, domestic animals, and humans. Moreover, the concerns related to this activity may also be applied to the legal wildlife trade, as the IWT exacerbates already emerging problems such as the transportation of pathogens in formal commerce worldwide. Several infectious agents, such as zoonotic viruses, bacteria, and parasites, have been detected in traded wildlife and their products. Despite existing regulations regarding the wildlife trade, the illicit commerce of many species is still strong in many parts of the world, bringing greater public health risks due to the lack of monitoring on their health status. Moreover, pathogens might silently circulate among these animals and their derivatives prior to becoming a detectable problem. Due to the lack of monitoring of wildlife and their products in the frame of the IWT, this activity represents a serious 'One Health' issue that may threaten the health of local wildlife, livestock, domestic animals, and/or humans. Therefore, the IWT is a gateway to zoonotic infectious diseases and measures for combating this illicit activity (e.g., increased public awareness, improved surveillance at ports and airports, constant inspection of wildlife trade markets, and enforcement of national and international regulations) are advocated to avoid the public health, environmental, and economic problems that may be caused as a result of the IWT.

Resources

[i] https://wedocs.unep.org/bitstream/handle/20.500.11822/9120/-The%20environmental%20crime%20crisis%3A%20threats%20to%20sustainable%20development%20from%20illegal%20exploitation%20and%20trade%20in%20wildlife%20and%20forest%20resources-2014RRAcrimecrisis.pdf?sequence=3&isAllowed=y

[ii] www.gfintegrity.org/wp-content/uploads/2017/03/Transnational_Crime-final.pdf

[iii] www.unodc.org/documents/data-andanalysis/wildlife/2020/World_Wildlife_Report_2020_9July.pdf

[iv] www.traffic.org/site/assets/files/13031/brazil_wildlife_trafficking_assessment.pdf

[v] www.wildlifetourism.org.au/blog/events/illegal-wildlife-trafficking-attacking-on-all-fronts/

[1]Department of Veterinary Medicine, University of Bari, Valenzano, Italy
[2]Division of Veterinary Biology, School of Veterinary Studies, Murdoch University, Murdoch, Western Australia, 6150, Australia
[3]Aggeu Magalhães Institute, Fundação Oswaldo Cruz (Fiocruz), Recife, Brazil
[4]Department of Pathobiology, Faculty of Veterinary Science, Bu-Ali Sina University, Hamedan, Iran

*Correspondence:
domenico.otranto@uniba.it (D. Otranto).
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References

1. Pozio, E. (2015) *Trichinella* spp. imported with live animals and meat. *Vet. Parasitol.* 213, 46–55
2. Greatorex, Z.F. *et al.* (2016) Wildlife trade and human health in Lao PDR: An assessment of the zoonotic disease risk in markets. *PLoS One* 11, e0150666
3. Brianti, E. *et al.* (2010) Risk for the introduction of exotic ticks and pathogens into Italy through the illegal importation of tortoises, *Testudo graeca*. *Med. Vet. Entomol.* 24, 336–339
4. Matias, C.A.R. *et al.* (2016) Frequency of zoonotic bacteria among illegally traded wild birds in Rio de Janeiro. *Braz. J. Microbiol.* 47, 882–888
5. Mendoza-Roldan, J.A. *et al.* (2020) Zoonotic parasites of reptiles: A crawling threat. *Trends Parasitol.* 36, 677–687
6. Andoh, M. *et al.* (2015) Detection of *Rickettsia* and *Ehrlichia* spp. in ticks associated with exotic reptiles and amphibians imported into Japan. *PLoS One* 10, e0133700
7. Davidson, R.K. *et al.* (2013) Illegal wildlife imports more than just animals – *Baylisascaris procyonis* in raccoons (*Procyon lotor*) in Norway. *J. Wildl. Dis.* 49, 986–990
8. Roon, A.V. *et al.* (2019) Live exotic animals legally and illegally imported via the main Dutch airport and considerations for public health. *PLoS One* 14, e0220122
9. Percipalle, M. *et al.* (2011) *Salmonella* Infection in illegally imported spur-thighed tortoises (*Testudo graeca*). *Zoonosis Pub. Health* 58, 262–269
10. Abe, N. and Matsubara, K. (2015) Molecular identification of *Cryptosporidium* isolates from exotic pet animals in Japan. *Vet. Parasitol.* 209, 254–257
11. Smith, K.M. *et al.* (2012) Zoonotic viruses associated with illegally imported wildlife products. *PLoS One* 7, e29505
12. Chaber, A. and Cunningham, A. (2016) Public health risks from illegally imported African bushmeat and smoked fish. *Ecohealth* 13, 135–138
13. Schmiedel, S. and Kramme, S. (2007) Cluster of trichinellosis cases in Germany, imported from Poland, June 2007. *Euro Surveill.* 12 pii=3240
14. Sharma, S. *et al.* (2020) People's knowledge of illegal Chinese pangolin trade routes in Central Nepal. *Sustain* 12, 4900
15. Carvalho Filho, P.R. *et al.* (2006) View of intestinal protozoa in apprehended New World nonhuman primates. *Braz. J. Vet. Res. Anim. Sci.* 43, 354–361