

Diverse pathogens in animals
involved in the wild meat trade:
implications for public health



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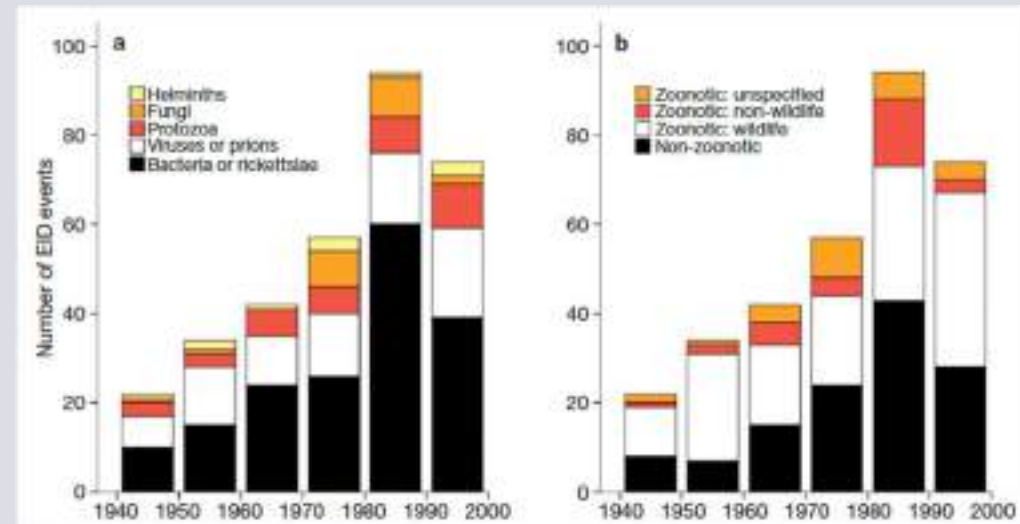
All animals have parasites

- Every animal species has >1000 different species of virus, bacteria, helminths and other parasites that can infect them
- → more parasite species than non-parasitic species
- Some parasites may be transmitted to other species, e.g. humans.



Emerging Infectious Diseases

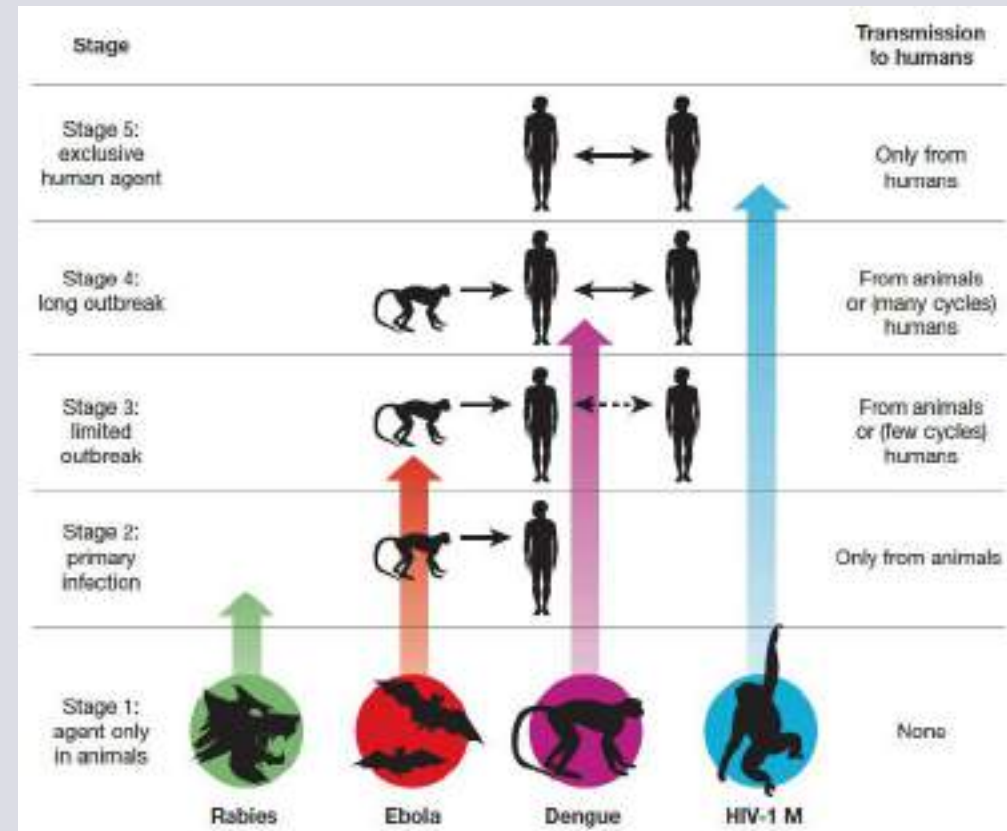
- New infections (re-)arising in human populations, or with increasing prevalence
- Mostly antibiotic resistant bacterial strains and viruses
- Many, especially viruses, originate from wildlife: ZONOOSES



Jones et al., 2008 *Nature*

Zoonoses

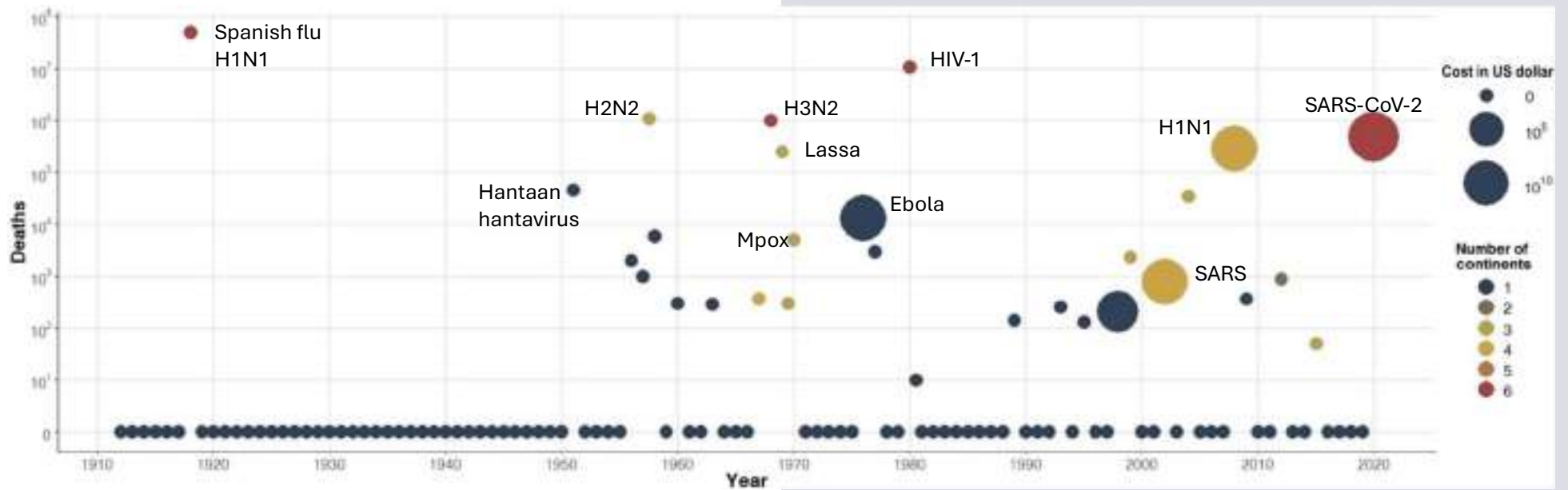
- Zoonoses can either repeatedly spill over from animal **reservoir**, without further transmission
 - Often goes undetected
- Or lead to further transmission among humans
 - Epidemic, pandemic



Wolfe et al., 2007 *Nature*

Zoonoses

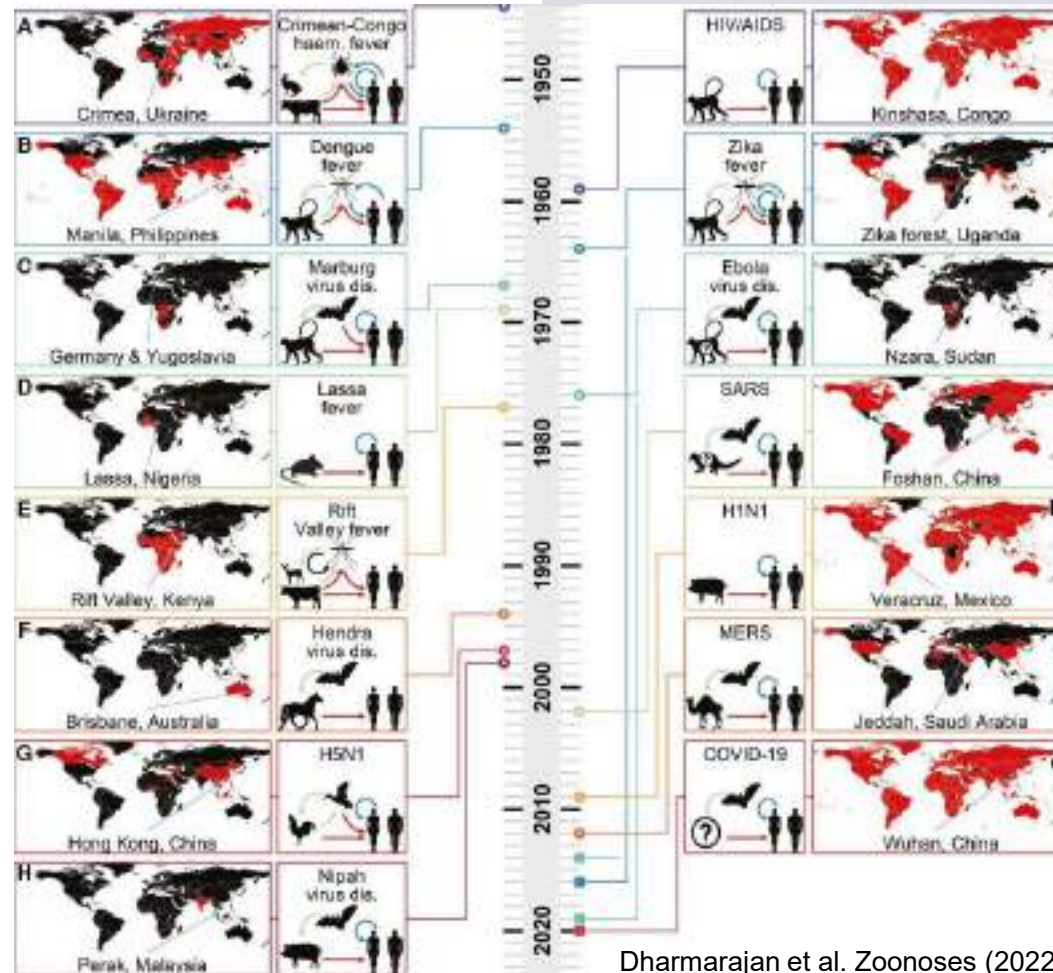
- Zoonoses have an enormous impact



Bernstein et al., 2022 *Science Advances*

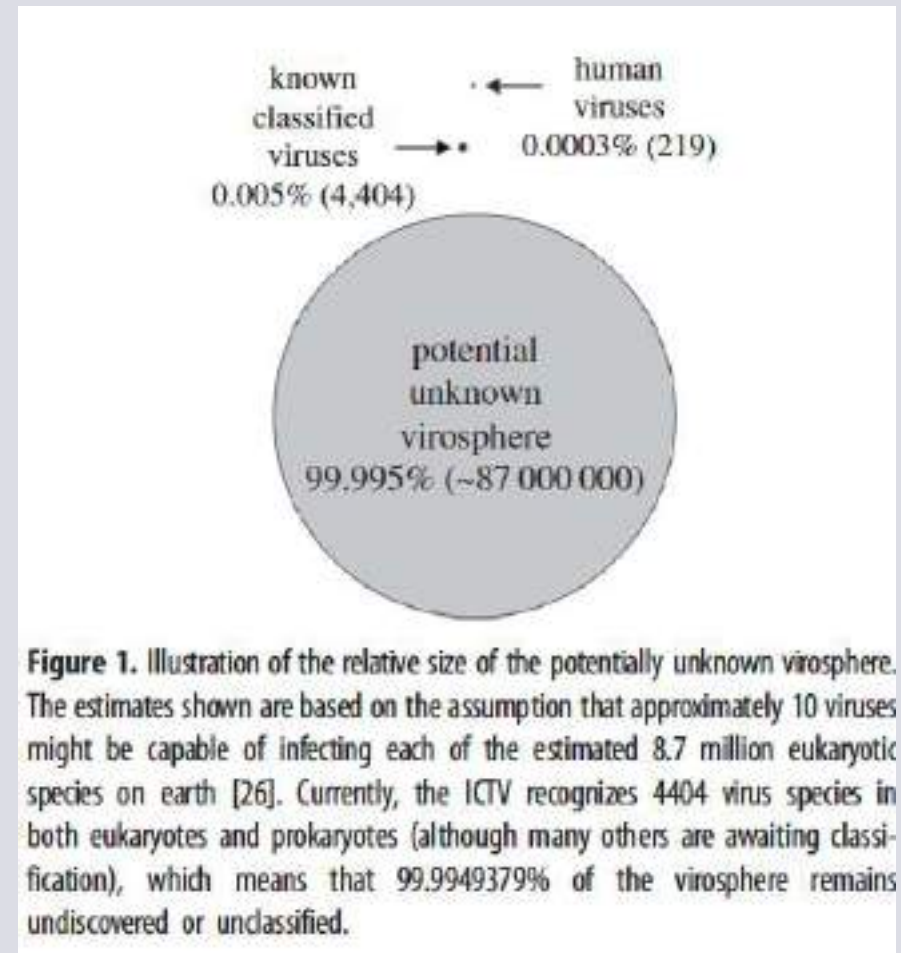
Zoonoses

Many zoonoses originate from the tropics, but not all.



Zoonoses

- When zoonotic viruses emerge in humans, it is often an unknown virus.
- Because most viruses (from wildlife) are not known.



Geoghegan & Holmes, 2017 *Open Biol*

Zoonoses

- Laboratory techniques to genetically characterize organisms (incl. viruses, bacteria) have recently greatly improved and become cheaper.
- Accelerated virus discovery rate in recent years.

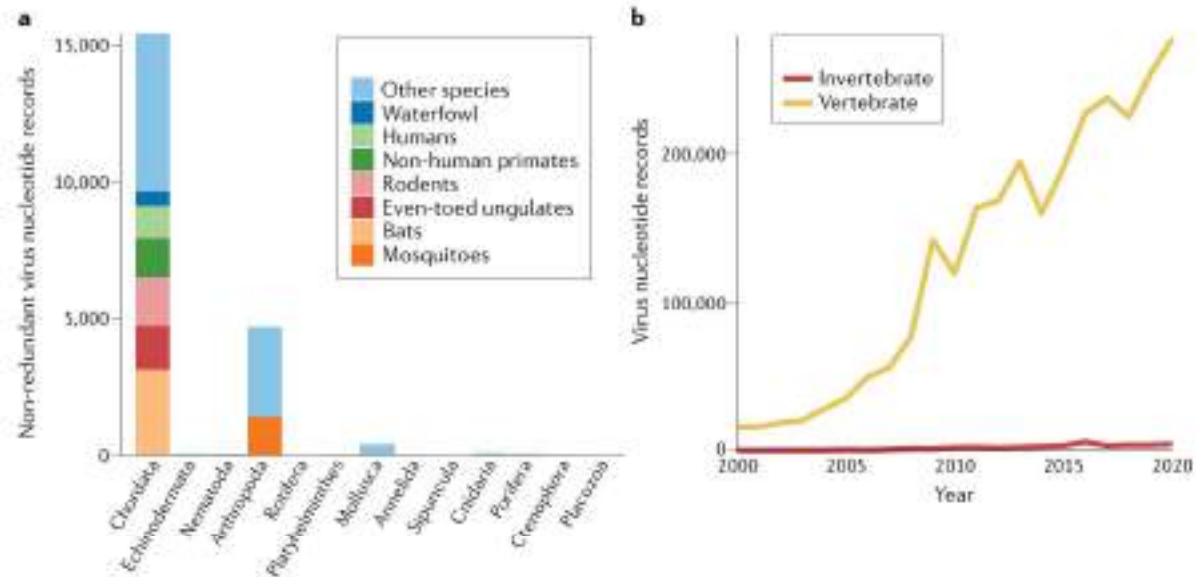
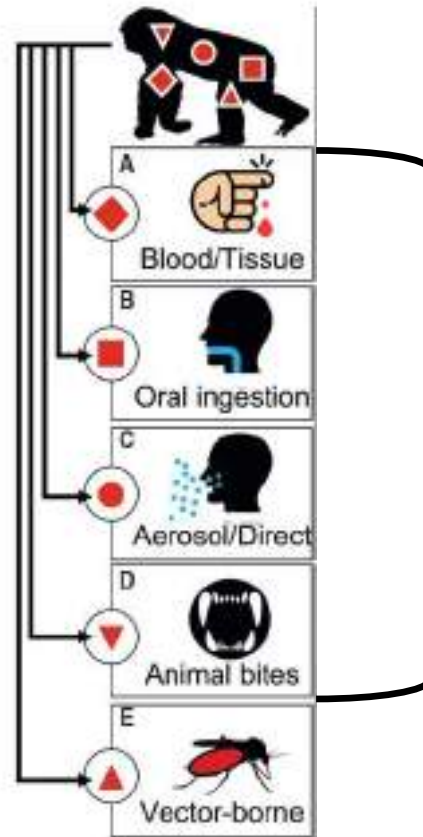


Fig. 2 | **Virome sequencing by animal phylum.** **a** | Graphical representation of the number of unique virus nucleotide entries in the US National Center for Biotechnology Information (NCBI) GenBank nucleotide sequence database sorted by virus species and host species showing that viruses associated with chordates far outnumber those from all other animal phyla. The proportions of these entries assigned to hosts of note are shown in different colours. Duplicate entries were excluded. **b** | Graphical representation of the rapid increase in vertebrate-associated virus entries in the NCBI GenBank sequence database over the past two decades and the comparatively low numbers of invertebrate-associated viruses identified over the same period.

Harvey & Holmes, 2022 *Nature Rev. Microbiol.*

How do people get infected from wildlife?



Dharmarajan et al. Zoonoses (2022)



Risk during wildlife hunting, butchering, trading, consumption



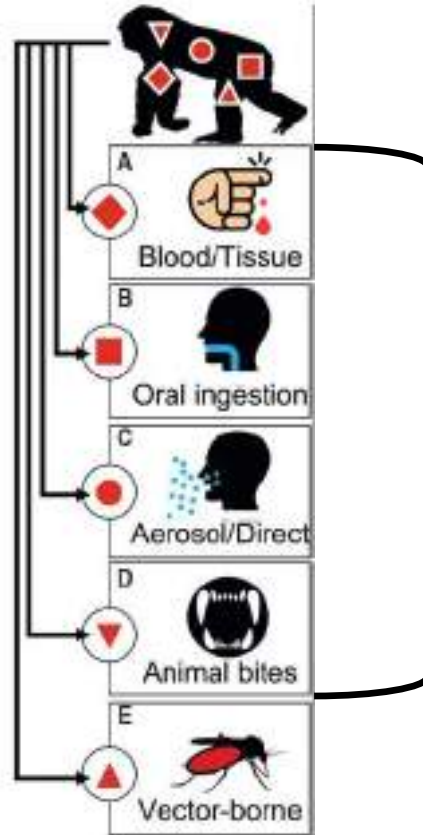
How do people get infected from wildlife?

A top virologist who visited a Wuhan market in 2014 said he found it to be a 'pandemic waiting to happen.'

Show full article



Recessed cages at Huanan Market in Wuhan, China, in 2014. © Alan Holmes



Dharmarajan et al. Zoonoses (2022)



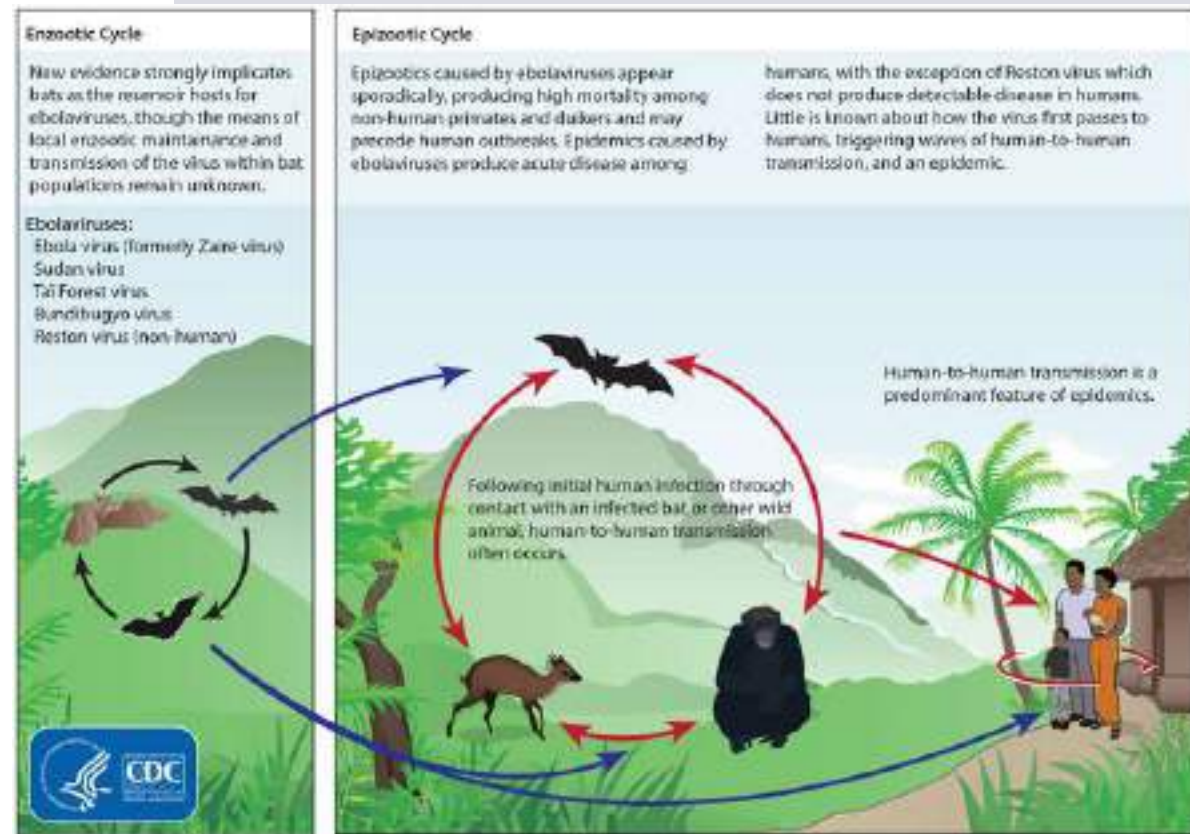
Risk during live wildlife trade



Recorded zoonotic spillover events due to wildmeat trade

- E.g. Ebola virus: 36% outbreaks linked to wildmeat consumption

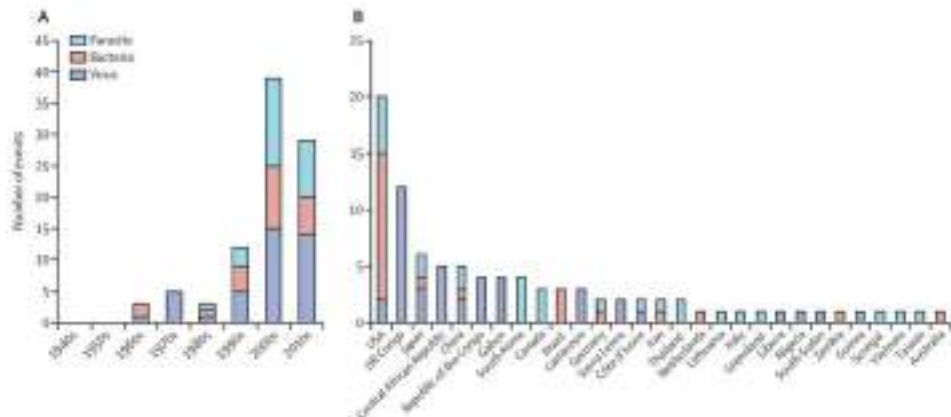
Judson & Munster 2023 *J. Inf. Dis.*



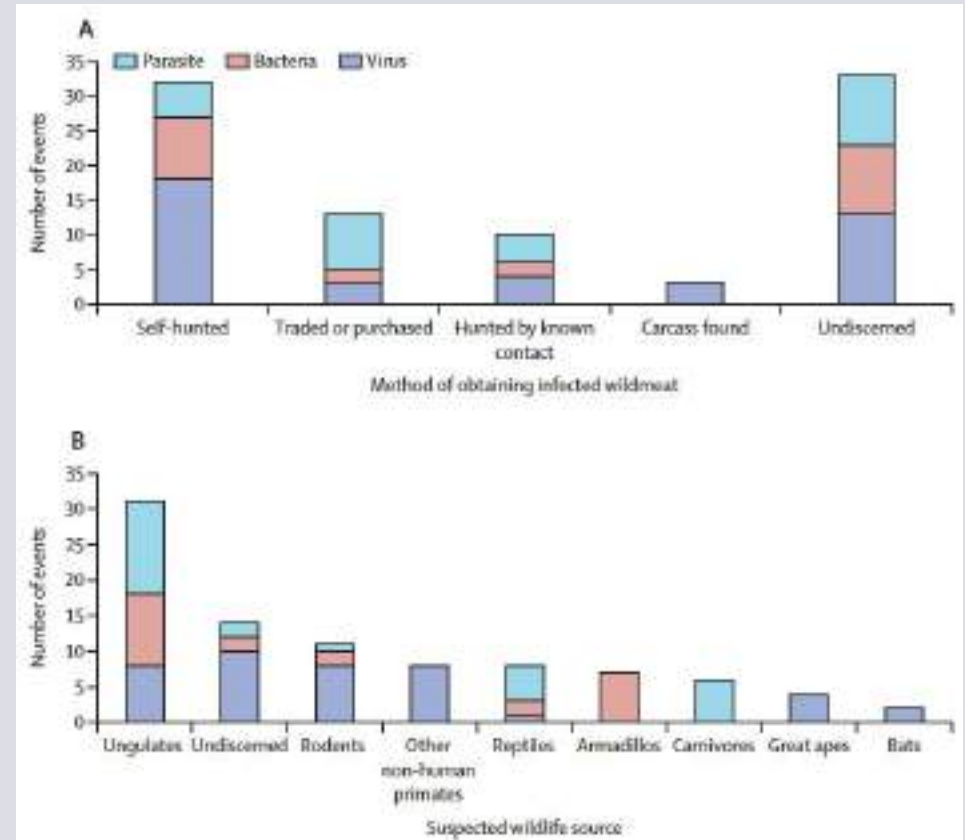
Recorded zoonotic spillover events due to wildmeat trade

Via wildmeat trade: 91 suspected spillover events of 25 zoonotic diseases

Milbank & Vira 2022 *Lancet Plan. Health*



Many more unrecorded....



Diverse viruses found in animals in the wild meat chain

Review Article
Investigating Infectious Organisms of Public Health Concern Associated with Wild Meat

Georgia Kate Maloney^{1,2}, Philippe Gambert^{3,4}, Sophie Grosset^{5,6}, Erik Vorhees^{7,8} and Anne-Lise Chamber^{9,10}

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² Viral Zoo Health Alliance, PO Box 102, Nairn Lakes Drive, SA 5021, Australia
³ Université de Liège, SART Tilman, Belgium (2020), IGD-D24139, University, Toulouse FR 9401400, Toulouse, France
⁴ Centre for Infectious Disease Research, University of Queensland, St. Lawrence, Queensland, Australia
⁵ Veterinary Microbiology and Immunology, University of Liverpool, Leahurst, Neston, Merseyside, UK
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⁸ Veterinary Microbiology and Immunology, University of Liverpool, Leahurst, Neston, Merseyside, UK
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¹⁰ Veterinary Microbiology and Immunology, University of Liverpool, Leahurst, Neston, Merseyside, UK

- High diversity of viruses and bacteria reportedly found in animals involved in the wild meat chain
 - Similar as in wildlife representatives of those species
- Viruses of risk for spillover to humans
- High prevalences in some instances
- Underestimation due to targeted detection techniques

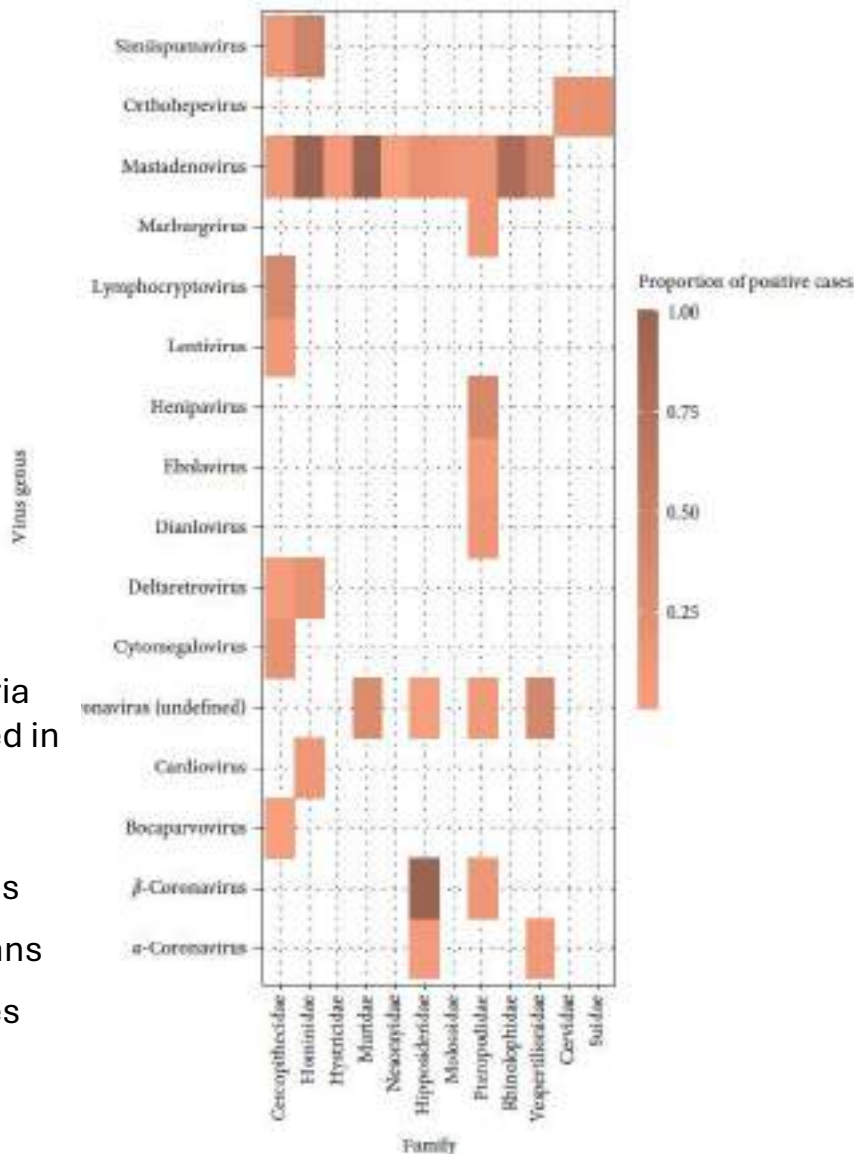


Table 1: Complete list of pathogen genera identified in wild meat samples, or from animals derived from the wild meat chain.

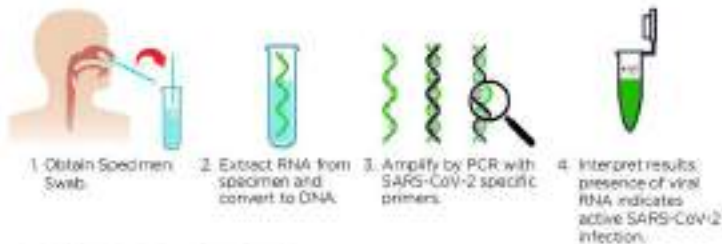
Viruses (n = 36)		
*γ-coronavirus	*Deltaretrovirus	*Lymphocryptovirus
*β-coronavirus	*Dianlovirus	*Marburgvirus
*Bocaparvovirus	*Ebolavirus	*Mastadenovirus
*Cardiovirus	*Henipavirus	*Orthohepevirus
Cytomegalovirus	*Lentivirus	*Senilspumavirus
Bacteria (n = 28)		
Acinetobacter	Klebsiella	Peptostreptococcus
Aeromonas	Lactococcus	Proteus
*Bacillus	*Legionella	Providencia
*Brevibacterium	*Listeria	Pseudomonas
*Campylobacter	Lyssibacterium	Ralstonia
Carnobacterium	Macrococcus	Salmoneella
Cetobacterium	Micrococcus	Serratia
Citrobacter	Moraxella	Staphylococcus
Clostridium	Morganella	Streptococcus
*Clostridium	*Mycobacterium	Treponema
Enterobacter	Mycoplama	Wohlfahrtiimonas
*Enterococcus	Myroides	*Yersinia
*Erysipelothrix	Paenibacillus	
*Escherichia	Pantoea	
Parasites (n = 19)		
Eukaryotes		
Ancylostoma	*Entamoeba	Desophogostomum
*Armillifer	Eimeria	Panophytomum
Ascariida	Fasciola	Prototstrongylus
Ascaris	*Giardia	Schistosoma
*Balantidium	Globocephalus	Spirura
Bertiella	Haemonchus	*Stomoxys
Bunostomum	Heligmosomoides	*Taenia
Capillaria	Helminthosys	*Toxocara
Cooperia	Hymenolepis	*Toxoplasma
*Cryptosporidium	Iodamoeba	*Trichinella
Dicrocoelium	Metadavimeia	Trichostrongylus
*Echinococcus	Metastrongylus	Trichuris
Eimeria	Monilia	Trypanosoma
Endolimax	Mosliiformis	Trypanoxyuris
Ectoparasites		
Amblyomma	Dermanyssus	Polypax
Bosophilus	Geniocotes	Rhincophalus
Bovicola	Harmaphysalis	Spirospira
Dermacentor	Isoxys	*Xenopsylla
Fungi (n = 1)		
Aspergillus	Mucor	Penicillium
Candida	Paecilomyces	

Targeted versus unbiased detection of microbes

- Targeted: specific molecular binding to known virus molecules

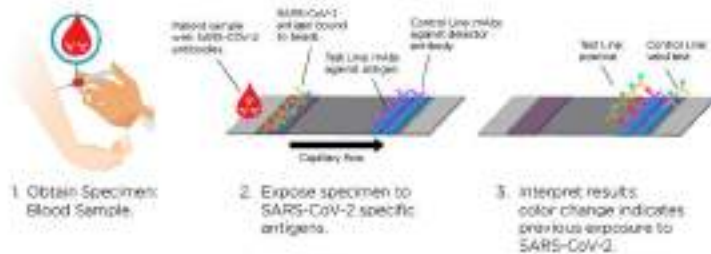
Molecular Tests (Nucleic Acid Detection)

Diagnose active SARS-CoV-2 infections

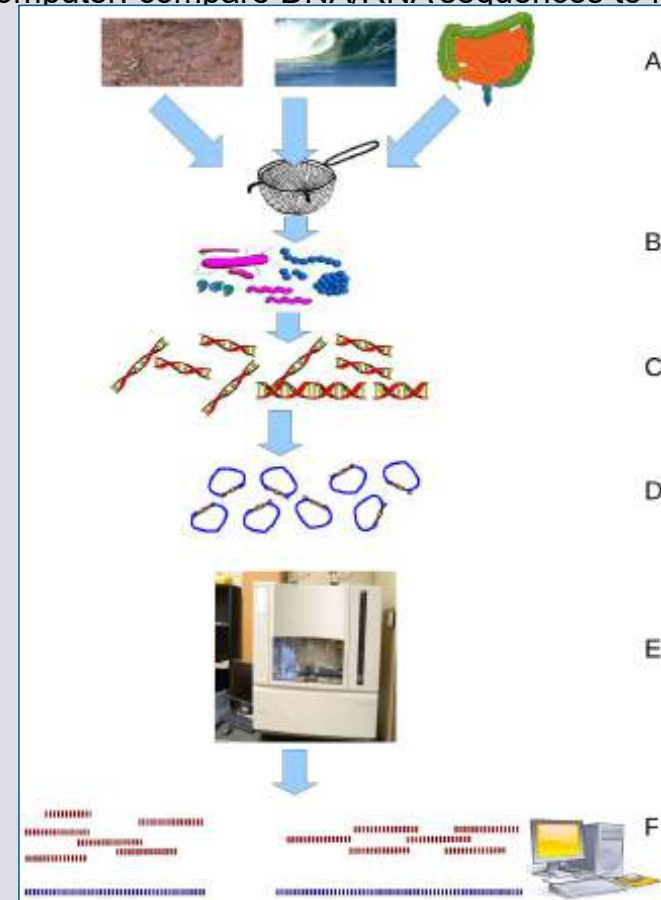


Antibody Tests (Serology)

Detect immune response to SARS-CoV-2 exposure



- Untargeted; metagenomic sequencing: determine the DNA/RNA sequence of all DNA/RNA in a sample
- Computer: compare DNA/RNA sequences to known



Diverse viruses found in animals in the wild meat chain: new study



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A wide diversity of viruses detected in African mammals involved in the wild meat supply chain

Posted November 30, 2024.

Marc Gerserts, Sophie Gomber, Casimir Nebeste, Douglas Akaike, Dudu Akaike, Pascal Bsofo, Anne-Lise Chaber, Guy-Crispin Gembu, Philippe Gaubert, Léa Joffrin, Anne Laidsoit, Nicolas Laurent, Herwig Leirs, Claude Mande, Joachim Mariën, Steve Ngoy, Jana Tešková, Ann Vanderheyden, Rianne van Vredendaal, Erik Verheyen, Sophie Gryseels

doi: <https://doi.org/10.1101/2024.11.28.625648>

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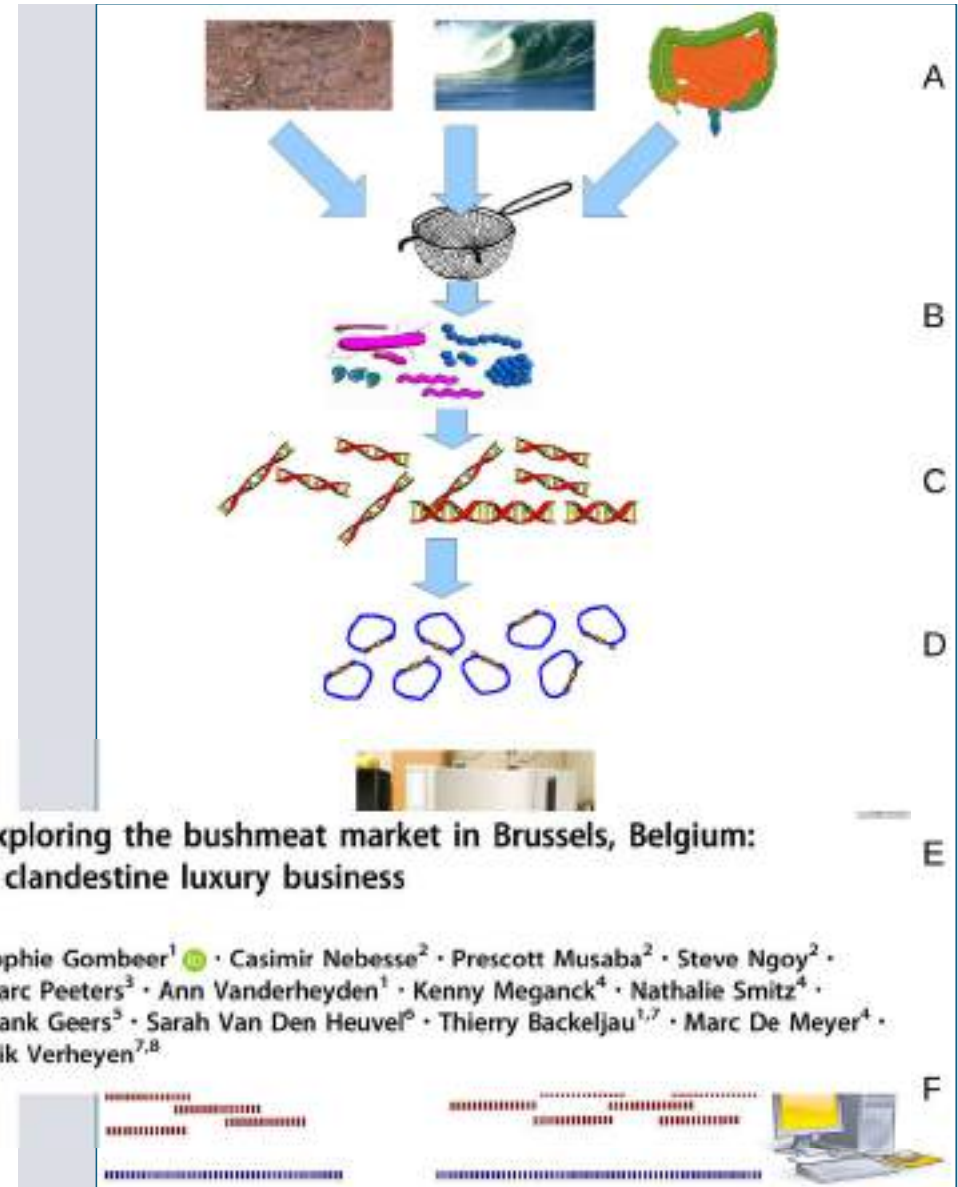
France

Methods

- 165 samples from various collections
- Metagenomic RNA sequencing
 - RNA viruses
 - + unbiased recovery of known and unknown viruses
 - - expensive: samples pooled

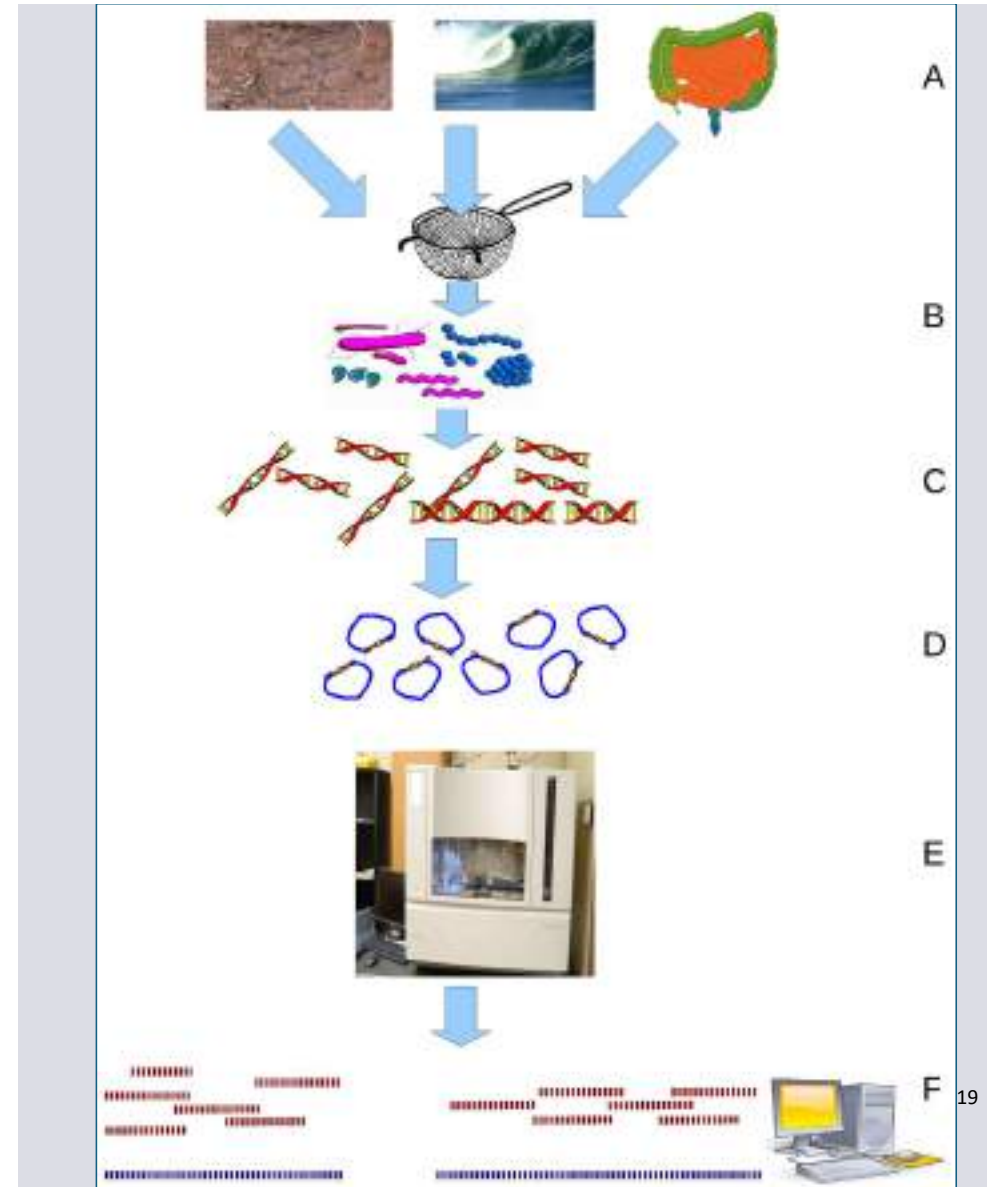


Figure 1. Map showing the provinces in the DRC and Belgium where samples were collected. On the left, a map of mainland Africa and Europe, with the DRC and Belgium marked in red. The provinces where samples were collected are shaded in dark grey in each country. The main course of the Congo River in blue.









Methods

- 165 samples pooled in 52 pools
 - Quality too low for 22 pools
 - tissue samples stored in ethanol at room temperature or (semi-)cooked or smoked specimens from the Brussels market
- Metagenomic sequencing of 30 pools



Results – DR Congo samples

- viruses detected in 10/24 pools
- 12 distinct strains (11 unknown)
- 6 pools (5 strains) possible zoonotic

Number of specimens-	Species	Mammal order	Sample type	Viruses detected	
1	Giant otter shrew	Afrosoricida	Liver from fresh carcass		
2	African palm civet	Carnivore	Liver from fresh carcasses 		
2	African palm civet		Swabs from fresh carcasses	Unknown strains of orthoreovirus, percaivirus and herpesvirus	
1	Long-nosed mongoose		Swabs from fresh carcass		
2	Checked elephant shrew	Elephant shrew	Liver from fresh carcasses		
2	Checked elephant shrew		Swabs from fresh carcasses		
9	Four-toed elephant shrew		Liver from fresh carcasses		
1	Tree hyrax	Hyrax	Liver from fresh carcass	Unknown strain of hepadnavirus (hepatitis B)	
1	Tree pangolin	Pangolin	Liver from fresh carcass		
2	Allen's swamp monkey	Primate 	Swabs from fresh carcasses: 	Unknown strain A of spumavirus	
4	Allen's swamp monkey			Unknown strain A of spumavirus	+ unknown strain B of picobirnavirus
4	Mona monkey			Unknown strain B of spumavirus	
8	Red-tailed monkey			Unknown strain C of spumavirus	+ unknown strain A of picobirnavirus
2	Red-tailed monkey			Unknown strain C of spumavirus	+ unknown strain of Rotavirus
1	Thomas's bushbaby				
1	Unidentifiable pottoo species			Liver from fresh carcass	
2	Yellow baboon			Muscle from smoked carcasses	
13	African brush-tailed porcupine	Rodent	Swabs from fresh carcasses		
5	African brush-tailed porcupine + Emin's pouched rat		Muscle from smoked carcasses; liver from fresh carcasses		
5	Rope squirrel		Liver from fresh carcasses	Kunsagivirus cetanba (Picornavirus)	
6	Three rodent species		Organs from fresh carcass		
14	African brush-tailed porcupine + unidentifiable pouched rat		Swabs from fresh carcasses	Unknown strain C of picobirnavirus	
2	Blue duiker	Ungulate	Swabs from fresh carcasses	Unknown strain of macavirus (herpesvirus)	
2	Unidentifiable duiker species				

Results – Brussels samples

Viruses are co-transported with their hosts
Still infectious?

- viruses detected in 1/6 pools
- 1 arterivirus strain
- possible zoonotic

Number of specimens in pool	Species	Mammal order	Sample type	Viruses detected
1	Chimpanzee	Primate	Muscle and bone marrow from a smoked carcasses	
2	De Brazza's monkey			De Brazza's arterivirus
1	Red-tailed monkey			
2	Cow	Ungulate	Muscle and bone marrow from a smoked carcasses	
2	River hog			
2	Unidentifiable duiker species			



Similar studies

OPEN ACCESS Freely available online



Zoonotic Viruses Associated with Illegally Imported Wildlife Products

Kristine M. Smith^{1,2,3*}, Simon J. Anthony^{2,4*}, William M. Switzer⁵, Jonathan H. Epstein², Tracie Seimon^{1,4}, Hongwei Jia², Maria D. Sanchez^{2,4}, Thanh Thao Huynh², G. Gale Galland¹, Sheryl E. Shapiro³, Jonathan M. Sleeman⁶, Denise McAloose¹, Margot Stuchin^{4,7}, George Amato⁷, Sergios-Orestis Kolokotronis⁷, W. Ian Lipkin⁴, William B. Karesh^{1,2*}, Peter Daszak², Nina Marano³

¹Wildlife Conservation Society, Bronx, New York, United States of America, ²EcoHealth Alliance, New York, New York, United States of America, ³Centers for Disease Control and Prevention, Atlanta, Georgia, United States of America, ⁴Columbia University, New York, New York, United States of America, ⁵Cornell University School of Veterinary Medicine, Ithaca, New York, United States of America, ⁶United States Geological Survey National Wildlife Health Center, Madison, Wisconsin, United States of America, ⁷Sackler Institute for Comparative Genomics, American Museum of Natural History, New York, New York, United States of America

- 60 confiscations at JFK airport, New York
- 21 primates, 35 rodents
- Targeted PCR tests for various pathogens
- 12 primates positive for herpesvirus and/or simian foamy virus



Similar studies

Transboundary and Emerging Diseases

Transboundary and Emerging Diseases

ORIGINAL ARTICLE

Screening for Viral Pathogens in African Simian Bushmeat Seized at A French Airport

Sarah Timmam¹, Bernard Davoust¹, Anne-Lise Chaber^{2,3}, Yves Lignereux^{4,5}, Caroline Michelle¹, Sonia Montell-Bouchard¹, Didier Raoult¹ and Christelle Danuen¹

¹ UMRI 1063, CNRS 7238, INSERM 1095, Faculté de Médecine de la Timone, Aix-Marseille Université, Marseille, France

² Research Unit of Epidemiology and Risk Analysis applied to veterinary sciences (ERIAS-Ug), Fundamental and Applied Research for Animals and Health (FARAH), Faculty of Veterinary Medicine, University of Liège, Liège, Belgium

³ Wildlife Consultant L.L.C, Al Ain, United Arab Emirates

⁴ National Veterinary School, BP, Toulouse Cedex 03, France

⁵ Natural History Museum, Toulouse, France

- Four primate specimens Toulouse airport
- Metagenomic screening
- No viruses found
- Low depth sequencing



Next step: INTERCEPT samples

- samples of sufficient quality for metagenomic sequencing

	species	species common name	N individuals pooled	Meat state	RNA concentration (ng/uL)	DNA concentration (ng/uL)
pool1	Varanus niloticus	Nile monitor lizard	4	raw	7.82	4.61
pool2	Gallus gallus	Chicken	5	cooked	15.22	7.48
pool3	Bos taurus	Cattle	5	cooked	5.70	13.85
pool4	Bos taurus	Cattle	5	raw	6.91	7.68
pool5	Capra hircus	Goat	5	cooked	3.96	3.37
pool6	Atherurus africanus	African brush-tailed porcupine	5	cooked	81.94	595.2
pool7	Atherurus africanus	African brush-tailed porcupine	4	raw	19.09	16.21
pool8	Thryonomys swinderianus	Greater cane rat	5	cooked	5.68	15.15
pool9	Nandinia binotata	African palm civet	4	cooked	13.84	13.05

Next step: INTERCEPT samples

- Largest sample set of (imported) wild meat samples ever tested
- Metagenomics for unbiased screening
 - viruses + bacteria
- Different risks between
 - mammal taxa?
 - geographical origins?
 - domestic versus wild meat?
 - cooked versus fresh meat

➔ Better understanding of true risk



Conclusion

- High diversity of (mostly still unknown) viruses in wild mammals of all taxa
- Virus (and likely other microbe) natural diversity reflected in wildlife implicated in wild meat trade
- The origin of several epidemics in humans started with wild meat chain
 - Only small proportion documented
- Primates more often carry viruses that can spillover to humans → most risky for transport
- Viruses are co-transported with their host
 - Although unlikely to survive cooking
- More data needed to estimate real risk of importing dangerous pathogens

