Zoonotic pathogens from illegally traded wildlife justify adopting the One Health perspective in disease response

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ABSTRACT

Recent studies have described a direct relationship between the illegal wildlife trade (IWT) and the prevalence of zoonotic pathogens in human populations. In the Philippines, the Philippine Integrated Disease Surveillance and Response (PIDSR) framework outlines the monitoring, response, and management of disease outbreaks, but needs to be updated in the wake of zoonoses from IWT. Here, we identified zoonotic pathogens that may be introduced to human populations through the IWT, pinpointed potential outbreak hotspots, and provided recommendations on how to improve the Philippines' public health response while considering One Health. Using seizure data from the Biodiversity Management Bureau (DENR-BMB) covering the period from 2010 to 2016, we found that birds (32.3% of volume) and reptiles (63.3% of volume) were the most frequently seized by law enforcement in terms of incidence and volume. About 54% of seized wildlife could potentially host zoonotic pathogens with bacteria (78.3%), protozoa (34.8%), and viruses (27.5%) being the most represented pathogen groups. Three cities in Metro Manila together accounted for 30% of all seizures in the country followed by Palawan province which accounted for about 28% of seizures. Of the twelve epidemic prone diseases identified in the PIDSR, five diseases were found to have causative agents that could potentially be hosted by the traded wildlife. These findings will not only enhance the approach to surveillance in the PIDSR but will also aid in identifying opportunities to improve policies on agriculture and food security, public health and disease surveillance, and biodiversity conservation.

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INTRODUCTION

The Philippines is one of the world's mega diversity countries, which altogether hold two-thirds of the Earth's biological diversity (Posa et al. 2008; DENR-BMB 2014). The country is

KEYWORDS

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characterized by high endemism; nearly half of its vertebrates and 45% to 60% of its vascular plants are unique to the islands (Posa et al. 2008). However, the Philippines is currently facing some of the greatest losses of biodiversity. Overexploitation through the illegal wildlife trade (IWT) is one of the principal pressures to Philippine biodiversity. The country is a known source, transit point, and destination for trafficked wildlife, and it is estimated that the total value of IWT is as much as PhP 50 billion per year (Enano 2019). One consequence of the IWT is the introduction of zoonotic disease agents into human populations. While zoonotic diseases have been around for a long time, their recent emergence has greatly impacted public health because of their penetration across more biogeographic barriers, wider host or vector ranges, and the expanding host species reservoir (Wang and Crameri 2014). Zoonotic diseases make up an estimated 70% of emerging infectious diseases (EIDs) and the increasing human population allows for pathogens to have several entry points into the population, including trade and consumption of animals (Woolhouse et al. 2005; Karesh et al. 2012). The consumption of wildlife in Wuhan, China has been implicated as the origin of SARS coronavirus 2 (SARS-CoV-2), the causative agent of the COVID-19 pandemic. Bats and pangolins have been particularly highlighted as vectors (Lam et al. 2020; Xu et al. 2020). The possibility that the virus originated from and was transmitted through wildlife trade and consumption led to a reexamining of national and international-level wildlife trade policies and the links between biodiversity and health.

As activities like the IWT increase the interactions between humans and wildlife and create more opportunities for the spread of disease, the need for a One Health approach in public health response becomes even more imperative. The One Health approach brings together partners in the health and environment sectors to examine changes in the interactions between humans, wildlife, and the environment. It links biodiversity to food security, nutrition, shelter, sanitation, mental health and well-being, and infectious diseases. It also identifies ways to manage this landscape through the development and implementation of policies and programs that ensure optimal health outcomes for all (WHO 2017; CDC 2018). Consistent patterns have shown that biodiversity loss tends to increase pathogen transmission and disease incidence. Keesing and Ostfeld (2021) provide an updated review of the literature on the link between biodiversity and zoonotic diseases, emphasizing the need for studying the richness and abundance of particular taxa that are likely carriers of zoonotic disease, such as rodents, bats, primates, and artiodactyls among mammals.

Several legislations exist in the Philippines to address zoonoses. In 2011, the Philippine Inter-Agency Committee on Zoonoses (PhilCZ) was established through Administrative Order (AO) No. 2011-10, which stipulates that the PhilCZ will develop a national strategy on the prevention, control, and elimination of zoonoses and establish a functional mechanism for the effective prevention, control, and elimination of zoonotic diseases. In 2017, the Department of Health (DOH) launched the Emerging and Re-emerging Infectious Disease program and through it has sought to manage specific zoonoses like the Zika Virus, Ebola Virus, and A(H5N6) in tandem with other government agencies in the country like the Department of Agriculture (DA) and the Department of Environment and Natural Resources (DENR). The program applies the One Health approach in that it considers the social determinants of health and environmental changes as contributing factors to the emergence or resurgence of infectious diseases. For disease surveillance and disease outbreak management, the Philippines is guided primarily by the Philippine Integrated Disease Surveillance and Response (PIDSR) framework, which began implementation in 2008. Aside from identifying priority diseases, it also outlines the roles of local and national government entities in disease surveillance and management. However, gaps in disease surveillance persist resulting in outbreaks like the 2014 Henipavirus outbreak in Sultan Kudarat that was suspected, based on the ecology of henipaviruses, to have originated from fruit bats found in the concerned villages (Ching et al. 2015) and the recurring Ebola Virus outbreak—the most recent of which was detected in 2015 in monkeys bound for export (Peñas et al. 2019).

As IWT continues to facilitate the emergence and penetration of zoonotic diseases into human populations, it is necessary to know what other diseases of zoonotic origin could cause outbreaks in the country. As a known source, transit point, and destination for IWT, the Philippines would highly benefit from an updated PIDSR. This study determined 1) what pathogens from traded wildlife can possibly lead to zoonoses in the Philippines, 2) the animal hosts of these zoonotic disease agents, and 3) possible disease hotspots. These findings can lead to recommendations on the improvement of the PIDSR, particularly surveillance.

MATERIALS AND METHODS

To identify the zoonotic disease agents that may be introduced to populations through the IWT, wildlife seizure data from the DENR-Biodiversity Management Bureau (DENR-BMB) were obtained. The data provided by the DENR-BMB was in the form of a tabular dataset in Microsoft Excel and was a consolidation of seizure reports from the DENR regional offices. The information in the datasets, which covered the period from January 2010 to June 2016, included common names of wildlife, species taxonomy, place of seizure including the region, quantity confiscated, apprehending office, and the date of seizure. From this, a new dataset was constructed showing the taxonomic classes of the confiscated wildlife and their associated zoonotic pathogens in addition to the aforementioned information in the DENR-BMB datasets. Only partial data for 2016 was available when the request was made for the seizure records.

The keywords "[taxon name]", "zoonotic", "zoonoses", "pathogen", and "disease" were used to identify the associated pathogens of the seized wildlife. A pathogen was included in the new dataset if it met all of the following criteria: 1) the pathogen must have been found on the traded animal host or the host was found to have had antibodies against the pathogen as a result of a previous infection, 2) the pathogen must have had documented transmission to humans from an animal host but not necessarily from a DENR-BMB listed seized wildlife, and 3) the pathogen must be able to cause a significant illness that may or may not lead to death (Pavlin et al. 2009). The zoonotic nature of the pathogens was then confirmed through a literature search on Google Scholar, the databases of the Center for Disease Control (CDC), and the appendix of zoonotic pathogens by Taylor et al. (2001) in Risk Factors for Human Disease Emergence.

RESULTS AND DISCUSSION

Trends in Wildlife Seizures

Between January 2010 and June 2016, the DENR-BMB recorded 187 wildlife seizures in the Philippines. Seizures halved between 2011 and 2013, followed an upward trend between 2013 and 2015, and decreased again in 2016 most likely due to the partial data available for that year (Fig. 1).

A total of 6,810 terrestrial and aquatic animals across 127 species were seized, with most species being either birds (47.7%) or reptiles (34.4%). Birds were more frequently seized (59.8% of incidents) than all other taxa, while reptiles accounted

Figure 1: Trend in wildlife seizures in the Philippines between January 2010 and June 2016.

for 63.3% of the volume of seized wildlife (Fig. 2). This is consistent with the trends derived from data on trade in Cartimar Market in Pasay from 2008 to 2019 (Cruz and Lagunzad 2021). Parrots (Psittacidae) are particularly heavily traded, especially in the tropics, where the trade has been happening for over a thousand years (Weston and Memon 2009; Pires 2012).

The hill myna *Gracula religiosa (Linnaeus, 1758)*, blue-naped parrot *Tanygnthus lucionensis (Linnaeus, 1766)* were the species most frequently seized by law enforcement, at 6% and 5% of all incidents, respectively. Meanwhile, the Tokay gecko *Gekko gecko (Linnaeus, 1758)* (27.6% of volume) and the Southeast Asian box turtle *Cuora amboinensis (Daudin, 1802)* (16.8% of volume) were the species most frequently seized by law enforcement and constituted a significant share in the volume of seized wildlife (Table 1). Of these, *T. lucionensis* is particularly problematic; it is considered Critically Endangered by the Philippine National Red List (Gonzalez et al. 2018, BCSP 2020). Also frequently seized was the Philippine pangolin *Manis culionensis (de Elera, 1915),* which is found only in the Palawan faunal region and is considered Critically Endangered by the International Union for the Conservation of Nature (IUCN). In the Philippine Red List, it is given the Endangered status (Gonzalez et al. 2018; BCSP 2020), which may need to be reassessed in the wake of the continued trade in this species, which is the most traded mammal in the country (Cruz and Lagunzad 2021). All trade in the species is prohibited by national and international laws as it is listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Table 1: Species most frequently seized by law enforcement and with largest volumes of seizures in the Philippines.

Top 5 Species by Incidence	Number of Seizures	Top 5 Species by Volume	Quantity (individual specimens)
Gracula religiosa	20	*Gekko gecko*	1,883
Tanygnathus lucionensis	16	*Cuora amboinensis*	1,148
Gekko gecko	11	*Gracula religiosa*	741
Manis culionensis	11	*Tanygnathus lucionensis*	494
Python bivittatus	11	*Siebenrockiella leytensis*	440

Turtles are heavily targeted by IWT. Accounting for 6% of the volume of seized wildlife was the Philippine Forest turtle *Siebenrockiella leytensis (Taylor, 1920)*. It is considered Critically Endangered in both the IUCN Red List and the National Red List. The most serious threat to it is illegal extraction from the wild for international trade (Sy et al. 2020).

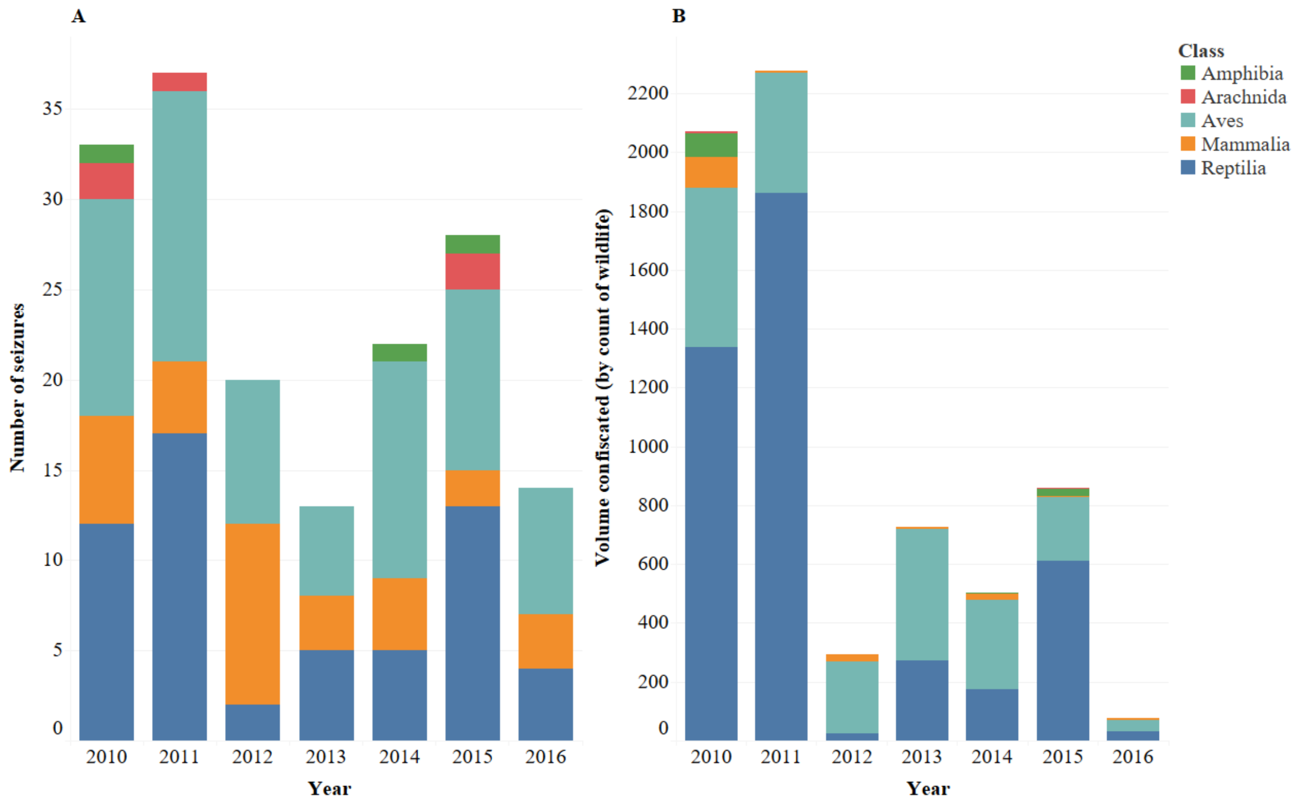

Figure 2: (A) More frequently seized wildlife by number of seizures and (B) the corresponding volumes seized by law enforcement.

Table 2: The wildlife species illegally traded in the Philippines based on seizure data from 2010 to 2016 and their associated zoonotic pathogens as determined through the literature search.

Scientific Name	Class	Associated Pathogens	Pathogen Type	Reference
Accipiter trivirgatus	Aves	*Aspergillus fumigatus*	Fungi	Jones MP and Orosz SE (2000)
Acerodon jubatus	Aves	*Coxiella burnetii*	Bacteria	Ioannou I et al. (2009)
	Aves	*Cryptosporidium parvum*	Protozoa	Reboredo-Fernandez A et al. (2015)
	Aves	West Nile Virus	Virus	Venter M and Swanepoel R (2010)
	Mammalia	Reston Ebola Virus	Virus	Jayme SI et al. (2015)
Acridotheres cristatellus	Aves	Influenza A Virus H5N1	Virus	Stallknecht DE and Brown JD (2008)
Agapornis fischeri	Aves	*Cryptosporidium spp.*	Protozoa	Zhang X et al. (2015
Agapornis fischeri	Aves	*Chlamydophila psittaci*	Bacteria	Suksai P et al. (2016)
Ahaetulla prasina	Reptilia	*Salmonella enterica*	Bacteria	Fasaei B and Tamai I (2018)
Amazona oratrix	Aves	*Aspergillus fumigatus*	Fungi	Boseret G et al. (2013)
	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
	Aves	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
	Aves	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
	Aves	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
	Aves	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013)
	Aves	Influenza A Virus H5N1	Virus	Boseret G et al. (2013)
	Aves	*Mycobacterium avium*	Bacteria	Boseret G et al. (2013)
	Aves	*Mycobacterium bovis*	Bacteria	Boseret G et al. (2013)
	Aves	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013)
	Aves	West Nile Virus	Virus	Jones MP and Orosz SE (2000)
Aonyx cinereus	Mammalia	*Giarda duodenalis*	Protozoa	Beck R et al. (2011)
Aratinga solstitialis	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
	Aves	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
	Aves	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
	Aves	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
	Aves	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013)
	Aves	Influenza A Virus H5N1	Virus	Boseret G et al. (2013)
	Aves	*Mycobacterium avium*	Bacteria	Boseret G et al. (2013)
	Aves	*Mycobacterium bovis*	Bacteria	Boseret G et al. (2013)
	Aves	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013)
	Aves	West Nile Virus	Virus	Boseret G et al. (2013)
Arctictis binturong	Mammalia	*Bacillus anthracis*	Bacteria	Hugh-Jones ME and De Vos V (2002)
	Mammalia	*Brugia malayi*	Helminth	Wicker LV et al. (2016)
	Mammalia	*Brugia pahangi*	Helminth	Edeson JFB and Wilson T (1964)
Boa constrictor	Reptilia	*Plesiomonas shigelloides*	Bacteria	Wicker LV et al. (2016)
Boa constrictor	Reptilia	*Cryptosporidium parvum*	Protozoa	Pedraza-Diaz S et al. (2009)
Boiga dendrophila	Reptilia	*Salmonella enterica*	Bacteria	Geue L and Löschner U (2002)
Boiga dendrophila	Reptilia	*Pseudomonas aeruginosa*	Bacteria	Colinon C et al. (2010); Foti M et al. (2013)
	Reptilia	*Aeromonas hydrophila*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Enterococcus faecalis*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Escherichia coli*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Klebsiella pneumoniae*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Morganella morganii*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Proteus mirabilis*	Bacteria	Jho YS et al. (2011)
	Reptilia	*Proteus vulgaris*	Bacteria	Jho YS et al. (2011)
Bubo philippensis	Aves	*Serratia marcescens*	Bacteria	Jho YS et al. (2011)

Scientific Name	Class	Associated Pathogens	Pathogen Type	Reference
Cacatua alba	Aves	*Staphylococcus aureus*	Bacteria	Jho YS et al. (2011)
Bubo philippensis *Cacatua alba*	Aves	*Salmonella enterica*	Bacteria	Hydeskov HB et al. (2013) Perez JM (2012)
	Aves	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013) Boseret G et al. (2013)
	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
	Aves	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013) Boseret G et al. (2013)
	Aves	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013) Boseret G et al. (2013)
	Aves	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
	Aves	*Escherichia coli*	Bacteria	Boseret G et al. (2013)
	Aves	*Giarda duodenalis*	Protozoa	
	Aves	Influenza A Virus H5N1	Virus	
	Aves	*Mycobacterium avium*	Bacteria	
	Aves	*Mycobacterium bovis*	Bacteria	
Cacatua galerita	Aves	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013)
Cacatua haematuropygia	Aves	West Nile Virus	Virus	Flammer K Drewes LA (1988)
Cacatua galerita	Aves	*Chlamydophila psittaci*	Bacteria	Maluping R et al. (2007)
Cacatua sulphurea	Aves	*Giarda duodenalis*	Protozoa	Mcdonnell P et al. (2003); Upcroft JA et al. (1997)
Cacatua haematuropygia	Aves	*Chlamydophila psittaci*	Bacteria	Kaleta EF and Taday E (2003)
Carettochelys insculpta	Reptilia	*Escherichia coli*	Bacteria	Flammer K and Drewes LA (1988)
Ceratophrys ornata	Amphibia	*Chlamydophila psittaci*	Bacteria	Kaleta EF and Taday E (2003)
Chelonoidis carbonaria	Reptilia	Newcastle Disease Virus	Virus	Kawamura M et al. (1987)
Carettochelys insculpta	Reptilia	*Paecilomyces lilacinus*	Fungi	Lafortune M et al. (2005)
Chelonia mydas	Reptilia	*Staphylococcus aureus*	Bacteria	Santoro M et al. (2006) Santoro M et al. (2006)
	Reptilia	*Bacillus cereus*	Bacteria	Santoro M et al. (2006)
	Reptilia	*Aeromonas hydrophila*	Bacteria	
Corvus macrorhynchos	Aves	*Enterobacter cloacae*	Bacteria	Santoro M et al. (2006)
	Aves	*Escherichia coli*	Bacteria	Santoro M et al. (2006) Santoro M et al. (2006)
	Aves	*Klebsiella pneumoniae*	Bacteria	
Crocodylus johnstoni	Reptilia	*Proteus mirabilis*	Bacteria	Santoro M et al. (2006)
Cuora amboinensis	Reptilia	*Proteus vulgaris*	Bacteria	Santoro M et al. (2006)
Eclectus roratus	Aves	*Pseudomonas aeruginosa*	Bacteria	Santoro M et al. (2006)
	Aves	*Serratia marcescens*	Bacteria	Santoro M et al. (2006) Santoro M et al. (2006)
	Aves	*Vibrio alginolyticus*	Bacteria	
Chelonoidis carbonaria	Reptilia	*Campylobacter fetus*	Bacteria	Wang CM et al. (2013)
Chelus fimbriata	Reptilia	*Aeromonas hydrophila*	Bacteria	George RH (1996)
Geochelone elegans	Reptilia	*Escherichia coli*	Bacteria	George RH (1996)
Gonyosoma oxycephalum	Reptilia	*Mycobacterium avium*	Bacteria	George RH (1996)
Goura victoria	Aves	*Vibrio alginolyticus*	Bacteria	George RH (1996)
Corvus macrorhynchos	Aves	*Clostridium perfringens*	Bacteria	Tanimura N et al. (2006)
Crocodylus johnstoni *Eclectus roratus*	Aves	*Coxiella burnetii*	Bacteria	Asaoka Y et al. (2003) To H et al. (1998)
Gallicolumba luzonica *Gekko gecko*	Aves	Influenza A Virus H5N1	Virus	Roh YS et al. (2010) Quist EM et al. (2011)
Geochelone elegans	Reptilia	*Mycobacterium szulgai*	Bacteria	Maluping R et al. (2007)
Gonyosoma oxycephalum	Aves	*Histoplasma capsulatum*	Fungi	Flammer K and Drewes LA (1988) Maricopa County Department of Public Health (2003)
Goura victoria *Gracula religiosa*	Aves	*Chlamydophila psittaci*	Bacteria	Casey C (2007)
	Aves	*Escherichia coli*	Bacteria	Wang CM et al. (2013)
	Aves	West Nile Virus	Virus	Foti M et al. (2013) De Camps S et al. (2008)
	Reptilia	*Edwardsiella tarda*	Bacteria	Jones MP and Orosz SE (2000)
	Reptilia	*Campylobacter fetus*	Bacteria	

Scientific Name	Class	Associated Pathogens	Pathogen Type	Reference
	Reptilia	*Pseudomonas aeruginosa*	Bacteria	
	Aves	*Toxoplasma gondii*	Protozoa	
	Aves	*Aspergillus fumigatus*	Fungi	
Graptemys geographica	Reptilia	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
	Reptilia	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
	Reptilia	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
	Reptilia	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
Haliastur indus	Aves	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013)
Hoplobatrachus rugulosus	Amphibia	Influenza A Virus H5N1	Virus	Boseret G et al. (2013)
	Amphibia	*Mycobacterium avium*	Bacteria	Boseret G et al. (2013)
Hydrosaurus pustulatus	Reptilia	*Mycobacterium bovis*	Bacteria	Boseret G et al. (2013)
Iguana iguana	Reptilia	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
Indotestudo elongata	Reptilia	*Pasteurella multocida*	Bacteria	Petersen KD et al. (2001)
Leucopsar rothschildi	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013)
Lonchura oryzivora	Aves	West Nile Virus	Virus	Boseret G et al. (2013)
Graptemys geographica	Reptilia	*Aeromonas hydrophila*	Bacteria	George RH (1996)
Lorius garrulus	Aves	*Escherichia coli*	Bacteria	George RH (1996)
Lorius lory	Aves	*Mycobacterium avium*	Bacteria	George RH (1996)
Haliastur indus	Aves	*Vibrio alginolyticus*	Bacteria	George RH (1996)
	Aves	*Chlamydophila psittaci*	Bacteria	Maluping R et al. (2007)
Hoplobatrachus rugulosus	Amphibia	*Bacillus cereus*	Bacteria	Cho H et al. (2010)
Hydrosaurus pustulatus	Mammalia	*Spirometra erinaceieuropaei*	Helminth	Jongthawin J et al. (2014)
	Reptilia	*Campylobacter fetus*	Bacteria	Wang CM et al. (2015)
Iguana iguana	Reptilia	*Escherichia coli*	Bacteria	Sylvester WRB et al. (2014)
Indotestudo elongata	Reptilia	*Enterobacter cloacae*	Bacteria	Ahmed AM et al. (2007))
Leucopsar rothschildi	Aves	*Toxoplasma gondii*	Protozoa	De Camps S et al. (2008)
Lonchura oryzivora	Aves	Influenza A Virus H5N1	Virus	Brooks-Moizer F et al. (2008)
Lorius garrulus	Aves	*Toxoplasma gondii*	Protozoa	Laveran M (1900)
Lorius lory	Aves	*Salmonella typhimurium*	Bacteria	Shima A and Osborn K (1989)
	Aves	*Chlamydophila psittaci*	Bacteria	Chahota R et al. (2006)
	Aves	*Cryptococcus neoformans*	Fungi	Raso TF et al. (2004)
Morelia viridis	Reptilia	West Nile Virus	Virus	Komar N (2003)
Macropus rufogriseus	Mammalia	*Angiostrongylus cantonensis*	Helminth	Bermudez R et al. (2009)
Manis culionensis	Aves	*Leptospira weilii*	Bacteria	Roberts MW et al. (2010)
Melopsittacus undulatus	Aves	*Toxoplasma gondii*	Protozoa	Prociv P and Carlisle MS (2001)
	Mammalia	*Brugia malayi*	Helminth	Mohapatra RK et al. (2016)
	Aves	*Necator americanus*	Helminth	Chin SC et al. (2016)
	Aves	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
	Aves	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
	Aves	*Encephalitozoon cuniculi*	Fungi	Boseret G et al. (2013)
	Aves	*Escherichia coli*	Bacteria	Boseret G et al. (2013)
	Aves	Influenza A Virus H5N1	Virus	Boseret G et al. (2013)
	Aves	*Toxoplasma gondii*	Protozoa	Boseret G et al. (2013)
Morelia viridis	Reptilia	*Salmonella enterica*	Bacteria	Geue L and Löschner U (2002)
Nymphicus hollandicus	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
Panthera tigris	Mammalia	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
	Mammalia	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
	Mammalia	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
	Mammalia	*Encephalitozoon cuniculi*	Fungi	Boseret G et al. (2013)
				Boseret G et al. (2013)
				Boseret G et al. (2013)
				Boseret G et al. (2013)
				Boseret G et al. (2013)

Scientific Name	Class	Associated Pathogens	Pathogen Type	Reference
	Mammalia	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013) Boseret G et al. (2013) Yilmaz R and Yumusak N (2015)
	Mammalia	*Mycobacterium avium*	Bacteria	
	Mammalia	*Mycobacterium bovis*	Bacteria	
	Mammalia	*Mycobacterium genavense*	Bacteria	
	Mammalia	*Salmonella typhimurium*	Bacteria	
	Mammalia	West Nile Virus	Virus	
	Mammalia	*Bacillus anthracis*	Bacteria	
Pantherophis guttatus	Reptilia	*Brugia pahangi*	Helminth	Edeson JFB and Wilson T (1964)
Paradoxurus hermaphroditus	Mammalia	*Clostridium perfringens*	Bacteria	Zeira O et al. (2012) Acharjyo LN (2004) Carvallo FR et al. (2010) Shrivastav AB et al. (2011) Sykes JM and Ramsay EC (2007)
	Mammalia	*Dirofilaria immitis*	Helminth	
	Mammalia	*Escherichia coli*	Bacteria	
	Mammalia	*Gnathostoma spinigerum*	Helminth	
	Mammalia	*Microsporum canis*	Fungi	
Pelodiscus sinensis *Paradoxurus hermaphroditus*	Reptilia	*Mycobacterium avium*	Bacteria	Cho HS et al. (2006) Cousins D (2004) Fagiolini M et al. (2010) Fagiolini M et al. (2010) Thiangtum K et al. (2006) Mingrone MG and Fantasia M (1988) Edeson JFB and Wilson T (1964) Edeson JFB and Wilson T (1964)
	Reptilia	*Mycobacterium bovis*	Bacteria	
	Reptilia	*Strongyloides stercoralis*	Helminth	
	Reptilia	*Toxocara cati*	Helminth	
	Reptilia	*Toxoplasma gondii*	Protozoa	
	Reptilia	*Yersinia enterocolitica*	Bacteria	
	Mammalia	*Brugia malayi*	Helminth	
	Reptilia	*Brugia pahangi*	Helminth	
Petaurus breviceps	Mammalia	*Giarda duodenalis*	Protozoa	Oronan R et al. (2013) Wicker LV et al. (2016)
	Mammalia	*Leptospira interrogans*	Bacteria	
Pithecophaga jefferyi	Aves	*Toxoplasma gondii*	Protozoa	Wicker LV et al. (2016)
Pelodiscus sinensis	Reptilia	*Aeromonas hydrophila*	Bacteria	Sugita H and Deguchi Y (1983)
Probosciger aterrimus	Aves	*Citrobacter freundii*	Bacteria	Sugita H and Deguchi Y (1983)
Psittacula eupatria *Petaurus breviceps* *Pithecophaga jefferyi* *Prionailurus bengalensis* *Probosciger aterrimus*	Aves	*Edwardsiella tarda*	Bacteria	Xu T and Zhang XH (2014) Sugita H and Deguchi Y (1983) Sugita H and Deguchi Y (1983) Guangzhou HU et al. (2010) Sugita H and Deguchi Y (1983) Oros J et al. (2003) Nichols M et al. (2014) Barrows M (2006) Keymer IF (1972) Chen JC et al. (2015) Oros J et al. (1998)
	Aves	*Enterobacter aerogenes*	Bacteria	
	Aves	*Enterobacter cloacae*	Bacteria	
	Aves	*Enterococcus hirae*	Bacteria	
	Aves	*Klebsiella pneumoniae*	Bacteria	
	Aves	*Mycobacterium kansasii*	Bacteria	
	Mammalia	*Listeria monocytogenes*	Bacteria	
	Aves	*Toxoplasma gondii*	Protozoa	
	Aves	*Aspergillus fumigatus*	Fungi	
	Mammalia	*Toxoplasma gondii*	Protozoa	
	Aves	*Chlamydophila psittaci*	Bacteria	
Psittacula eupatria	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013) Boseret G et al. (2013) Boseret G et al. (2013) Boseret G et al. (2013)
	Aves	*Chlamydophila psittaci*	Bacteria	
	Aves	*Cryptococcus neoformans*	Fungi	
	Aves	*Cryptosporidium parvum*	Protozoa	
Psittacus erithacus	Aves	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013) Boseret G et al. (2013) Boseret G et al. (2013) Boseret G et al. (2013)
	Aves	Influenza A Virus H5N1	Virus	
	Aves	*Mycobacterium avium*	Bacteria	
	Aves	*Mycobacterium bovis*	Bacteria	
Psittrichas fulgidus	Aves	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
Pyrrhura molinae *Psittacula krameri* *Psittacus erithacus*	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013) Boseret G et al. (2013) Mancianti F et al. (2001)
	Aves	West Nile Virus	Virus	

Scientific Name	Class	Associated Pathogens	Pathogen Type	Reference
Psittrichas fulgidus	Aves	*Candida albicans*	Fungi	Maluping R et al. (2007)
	Aves	*Chlamydophila psittaci*	Bacteria	Raso TF et al. (2004)
	Aves	*Cryptococcus neoformans*	Fungi	Hinney B et al. (2016); Kašičková D et al. (2009)
	Aves	*Encephalitozoon cuniculi*	Fungi	Jones MP and Orosz SE (2000)
	Aves	*Aspergillus fumigatus*	Fungi	Raso TF et al. (2004)
	Aves	*Cryptococcus neoformans*	Fungi	Lee SY et al. (2011)
	Aves	*Encephalitozoon cuniculi*	Fungi	Flammer K and Drewes LA (1988)
	Aves	*Escherichia coli*	Bacteria	Long P et al. (1983)
	Aves	*Nocardia asteriodes*	Bacteria	
Pyrrhura molinae	Aves	*Campylobacter jejuni*	Bacteria	Boseret G et al. (2013)
Python regius	Reptilia	*Chlamydophila psittaci*	Bacteria	Boseret G et al. (2013)
Python reticulatus	Reptilia	*Cryptococcus neoformans*	Fungi	Boseret G et al. (2013)
Spilopelia chinensis	Aves	*Cryptosporidium parvum*	Protozoa	Boseret G et al. (2013)
	Aves	*Giarda duodenalis*	Protozoa	Boseret G et al. (2013)
	Aves	Influenza A Virus H5N1	Virus	Boseret G et al. (2013)
	Aves	*Mycobacterium avium*	Bacteria	Boseret G et al. (2013)
Spilornis cheela	Aves	*Mycobacterium bovis*	Bacteria	Boseret G et al. (2013)
Streptopelia tranquebarica	Aves	*Mycobacterium genavense*	Bacteria	Boseret G et al. (2013)
	Aves	*Salmonella typhimurium*	Bacteria	Boseret G et al. (2013)
Sula leucogaster	Aves	West Nile Virus	Virus	Boseret G et al. (2013)
Python bivittatus	Reptilia	Arenavirus	Virus	Latney LV and Wellehan J (2013)
Python regius	Reptilia	*Chlamydia pneumoniae*	Bacteria	Cope I et al. (2014)
Python reticulatus	Reptilia	*Chlamydia pneumoniae*	Bacteria	Samaniego C et al. (2015)
Spilopelia chinensis	Aves	*Chlamydophila psittaci*	Bacteria	Gilbert M et al. (2012)
Trichoglossus moluccanus	Aves	Influenza A Virus H5N1	Virus	Phong SF et al. (2006)
	Aves	*Toxoplasma gondii*	Protozoa	Chen JC et al. (2015)
Tropidophorus grayi	Reptilia	West Nile Virus	Virus	Pedersen K et al. (2016)
Spilornis cheela	Aves	*Toxoplasma gondii*	Protozoa	Chen JC et al. (2015)
Streptopelia tranquebarica	Aves	Far eastern Tick-borne encephalitis virus	Virus	Stallknecht DE and Brown JD (2008)
	Mammalia	Influenza A Virus H5N1	Virus	Xing Y et al. (2017)

Among marine species, green sea turtles *Chelonia mydas (Linnaeus, 1758)* and hawksbill turtles *Eretmochelys imbricata (Linnaeus, 1766)* were implicated in the greatest number of seizures at 11 and 10 seizures, respectively. The operations led to the retrieval of 194 green sea turtles and 877 hawksbill turtles. In the National Red List, *C. mydas* and *E. imbricata* are considered Endangered and Critically Endangered, respectively (Gonzalez et al. 2018, BCSP 2020).

With the exception of *C. mydas*, all of the aforementioned species are recognized by the DENR-BMB as the most traded species in the Philippines (ADB 2019).

Zoonotic Pathogens in Traded Wildlife

There were 65 zoonotic pathogens with which the traded wildlife was found to be associated (Table 2). About 54% of traded wildlife species were found to be associated with zoonotic pathogens, with birds accounting for over half of wildlife positive for zoonotic disease agents. Bacteria (78.3%), protozoa (34.8%), and viruses (27.5%) were the largest pathogen groups represented, with *Chlamydophila psittaci* (9.2%), *Toxoplasma gondii* (6.0%), and Influenza A(H5NI) (5.5%) being the most frequently associated with the seized wildlife (Table 2). *C. psittaci* and the A(H5N1) virus primarily infect birds (Sims et al. 2005; Knittler and Sachse 2015). It was expected that pathogens of avian and reptilian origin would figure largely in the dataset as birds and reptiles were the most seized wildlife in terms of both incidence and volume. Also concerning is that *C. psittaci* and *T. gondii* are not in the PIDSR list of endemic-prone diseases despite the high potential of transmission from traded wildlife. Psittacosis outbreaks caused by *C. psittaci* have occurred several times in the past, such as one that occurred among poultry slaughter plant workers in two US states in 2018 (National Center for Immunization and Respiratory Diseases 2018). Though the symptoms of toxoplasmosis are mild, approximately 30% of humans are infected with *T. gondii* and it is likely that clinical disease is more common than reported (Dubey 2021). Water contaminated by *T. gondii* oocysts is a known source of toxoplasmosis and may possibly be the route of infection in the wildlife trade, aside from consumption of the meat.

The PIDSR identified twelve epidemic-prone diseases, of which five were found to have causative agents that were zoonotic in nature and were also harbored by the traded wildlife based on the results of the literature search (Table 3). Of these, Influenza A H5N1 viruses are the most problematic, being found in 12 traded species confiscated from 34 operations, mostly (13) conducted in Metro Manila. Six of these seizures were in Manila, but three were in Pasay City, likely (though not certainly) in

Cartimar given its reputation for IWT. Palawan is also a common site for the trade of the host species. These species include *G. religiosa*, one of the most traded species in the Philippines (ADB 2019). Though there are two cases of seizure of this species in Metro Manila (including Pasay City), it is largely a Palawan-based trade (six operations).

Table 3: Cross-referencing the causative agents of epidemic prone diseases in the PIDSR with the pathogens found associated with the wildlife seized in the Philippines.

Epidemic Prone Diseases	Causative Agents*	Associated with Seized Wildlife?
Acute Viral Hepatitis	Hepatitis A	No
	Hepatitis B	No
	Hepatitis C	No
Anthrax	*Bacillus anthracis*	Yes
Bacterial Meningitis	*Escherichia coli*	Yes
	Group B Streptococcus	No
	Neisseria meningitidis	No
	Haemophilus influenzae	No
	Listeria monocytogenes	Yes
	Streptococcus pneumoniae	No
Cholera	*Vibrio cholerae*	No
Dengue	—	—
Human Avian Influenza	Influenza A H5 Viruses	Yes
	Influenza A H7 Viruses	No
	Influenza A H9 Viruses	No
Influenza-like Illness	—	—
Leptospirosis	*Leptospirosis* sp.	Yes
Meningococcal Disease	*Neisseria meningitidis*	No
Paralytic Shellfish Poisoning	—	—
Severe Acute Respiratory Syndrome (SARS)	SARS-CoV	No
Typhoid and Paratyphoid Fever	—	—

* Determined through the CDC
"—": The causative agents for these epidemic prone diseases cannot be identified.

E. coli, a causative agent of bacterial meningitis, has been documented in 11 of the traded species, including several species of Psittacidae (parrots), the most highly traded bird family. Most of the seizures (11 of 22) of the hosts have been in Metro Manila, most commonly (5) in Quezon City but twice in Pasay City. The other three are less commonly encountered in seized animals, but all of them as well as *E. coli* are also identified by Allen et al. (2017) as emerging infectious diseases (EID) from wildlife.

Previous studies have shown that wildlife in markets can cause the transmission of disease to humans. In 2016, Greatorex and colleagues conducted market surveys in Lao PDR and identified traded mammals that had the potential to host 36 zoonotic pathogens. In 1995, De Schrijver reported on how a team of customs officials in Belgium developed psittacosis after coming into contact with parakeets that were infected with *C. psittaci*. The parakeets had been illegally imported into the country by a sailor from India. The customs officials were admitted to the hospital for atypical pneumonia (De Schrijver 1995). As a key trade hotspot, the situation in the Philippines is similar: contact with illegally traded wildlife that have the potential to host zoonotic pathogens increase one's risk of getting sick with disease that may or not may be debilitating.

The information on zoonotic pathogens that humans can possibly derive from traded wildlife is dependent on the data available from the DENR-BMB, which is only from 2010 onward. Given the illicit nature of the activity, seizure records are the only major source of data available on IWT (Rosen and Smith 2010). This certainly imposes a limitation in the determination of reservoirs for zoonoses, particularly among taxa whose trade is not adequately reported, and highlights the need to improve surveillance of diseases that can infect humans. Many of the species reported in the seizure records, especially marine turtles and birds, have been traded since before the Spanish colonial period (Cruz and Lagunzad 2021).

Seizure Hotspots

Three cities in Metro Manila together accounted for 30% of all wildlife seizures in the country: Pasay City (13.9%), Manila (10.2%), and Quezon City (7.4%) (Table 4). Cartimar Market, a fixture in Pasay City, is a retail center that sells various items from clothes and shoes to pets and sometimes protected or endangered wildlife. Over 10% of all seizures in the country occurred here. Of the five causative agents that were found to be associated with the seized wildlife based on the literature search, Influenza A(H5N1) and *Escherichia coli* may have had the greatest number of occurrences. All five causative agents of epidemic prone diseases may have been harbored by wildlife that were seized in Metro Manila suggesting that Metro Manila is not only a seizure hotspot but also potentially a disease outbreak hotspot.

Table 4: Top 10 cities or municipalities by number of seizures.

Province	City/Municipality	Number of Seizures	% Share in Total Seizures
Metro Manila	Pasay City	15	13.9
Metro Manila	Manila	11	10.2
Metro Manila	Quezon City	8	7.4
Palawan	Puerto Princesa	6	5.6
Palawan	Taytay	5	4.6
Palawan	Rizal	4	3.7
Palawan	Quezon	4	3.7
Palawan	Narra	4	3.7
Palawan	El Nido	3	2.8
Palawan	Aborlan	3	2.8

The same can be said for Palawan province that saw the occurrence of three of the five causative agents (Influenza A(H5N1), *E. coli*, and *Bacillus anthracis*) (Table 5). Palawan province also accounted for 27.8% of all seizures in the Philippines, with cities and municipalities like Puerto Princesa City (5.6%), Taytay (4.6%), and Narra (3.7%) accounting for the most operations. General Santos City accounted for 29.8% of the volume of seized wildlife followed by Pasay City (10.6% of the total volume), and the municipalities of Rizal (8.0%) and Narra (7.0%) in Palawan. While General Santos City accounted for the largest volume of seized wildlife, it was only implicated in two seizure incidents with one operation leading to the seizure of over 1,600 Tokay geckos.

The identification of Metro Manila and Palawan as hotspots is important not only in the context of curbing IWT but also in identifying potential origins of zoonoses. The significant trade in implicated hosts of epidemic-prone pathogens in these areas, which are centers of trade and tourism, is concerning and should be taken into account in epidemic monitoring. In the context of the One Health framework, these should be considered as hotspots not only by the DENR-BMB but also by the DOH and other health-related institutions. Additionally, Metro Manila is also a common seizure site for *C. psittaci* and *T. gondii*, the most common zoonoses identified from traded wildlife but neither of which is identified by the PIDSR as pathogens of concern. It might be a critical preemptive step for the potential of these pathogens to become epidemics to be studied, especially because of the high rate of emergence of infectious diseases in recent years (Allen et al. 2017). Allen et al. (2017) identify the Philippines as being a high-risk area for EID from wildlife.

CONCLUSION

The consideration of the impacts of wildlife trade on public health invites a rethinking of disease surveillance activities in the Philippines that rely primarily on the reporting of local health units and routine collection and analysis of data from DENR and the DOH among other agencies (Manual of Procedures for the Philippine Integrated Disease Surveillance and Response 2014). This approach to surveillance can be enhanced with baselines on what zoonotic agents may be introduced to populations through trade as opposed to responding to diseases that may potentially cause outbreaks as they come. Pathogens of avian origin such as *C. psittaci* and A(H5N1) were the most frequently associated with seized wildlife. Some of the seized wildlife that were found to be associated with some zoonotic pathogens were also wildlife of conservation concern—like the Philippine pangolin *M. culionensis* and the Luzon bleeding heart *Gallicolumba luzonica* (Scopoli, 1786). Five of the pathogens associated with epidemic-prone diseases are found in traded wildlife, including *G. religiosa*, one of the most heavily traded in the Philippines. There was a concentration of seizures in the provinces of Metro Manila and Palawan, but more importantly most of the causative agents of the identified epidemic prone diseases in the PIDSR may have also occurred here, making them hotspots not only for IWT but also potentially for EID outbreaks This emphasizes the need for a One Health perspective in the understanding of IWT and zoonotic outbreaks as the consequences of the IWT will contribute to economic and public health problems through its impacts to local wildlife, livestock, and human health (Bezerra-Santos et al. 2021).

Knowing the disease agents, animal hosts, and possible disease outbreak hotspots leads to the following recommendations with the One Health approach in mind:

1. The PIDSR could be updated. The last known assessment of the framework was in 2015 when Gallardo et al. published their evaluation of the surveillance systems of Eastern Visayas 16 months after the region was hit by Typhoon Haiyan. They found that, post-Haiyan, no outbreaks were reported because of the irregular reporting by the surveillance units. As the Philippines grapples with the COVID-19 pandemic and its effects, the PIDSR will move surveillance units to identify opportunities to improve disease surveillance activities, particularly for diseases that are zoonotic in origin. The additional disease agents, animal hosts, and possible disease outbreak hotspots that were identified through the literature review and analysis of DENR-BMB seizure data will prove helpful as a baseline in this regard, particularly from a preemptive standpoint.

2. Identify priority species for conservation and improve wildlife law enforcement. Among the animal species identified by the DENR-BMB as the most traded, four (Southeast Asian box turtle, hawksbill turtle, Tokay gecko, and Palawan pangolin) have been identified as carriers of pathogens. Identifying target species for

Table 5: Causative agents of epidemic prone diseases in the PIDSR and their occurrence in confiscated wildlife and seizure locations.

Associated Pathogens	Confiscated Wildlife Species	Province	City/ Municipality
Bacillus anthracis	*Arctictis binturong*	Palawan	Quezon
	Panthera tigris	Metro Manila	Quezon City
Escherichia coli	*Boiga dendrophila*	Misamis Oriental	Laguindingan
	Boiga dendrophila	Palawan	El Nido
	Cacatua alba	Davao del Sur	Davao City
	Cacatua alba	Metro Manila	Manila
	Cacatua alba	Rizal	Cainta
	Cacatua haematuropygia	Metro Manila	Manila
	Cacatua haematuropygia	Palawan	Rizal
	Cacatua haematuropygia	Palawan	Puerto Princesa City
	Cacatua haematuropygia	Palawan	Narra
	Cacatua haematuropygia	Palawan	El Nido
	Chelus fimbriata	Metro Manila	Quezon City
	Eclectus roratus	Davao del Sur	Davao City
	Eclectus roratus	Metro Manila	Pasay City
	Graptemys geographica	Metro Manila	Quezon City
	Iguana iguana	Metro Manila	Quezon City
	Iguana iguana	Metro Manila	Pasay City
	Melopsittacus undulatus	Metro Manila	Quezon City

Associated Pathogens	Confiscated Wildlife Species	Province	City/ Municipality
	Melopsittacus undulatus	Metro Manila	Manila
	Panthera tigris	Metro Manila	Quezon City
	Psittacus erithacus	Metro Manila	Manila
	Psittacus erithacus	Rizal	Cainta
	Sula leucogaster	Palawan	Rizal
Influenza A Virus H5N1	*Acridotheres cristatellus*	Davao del Norte	Carmen
	Acridotheres cristatellus	Laguna	Calamba
	Acridotheres cristatellus	Metro Manila	Quezon City
	Acridotheres cristatellus	Metro Manila	Manila
	Acridotheres cristatellus	Nueva Ecija	Cabanatuan City
	Amazona oratrix	Metro Manila	Manila
	Aratinga solstitialis	Cavite	Dasmarinas City
	Aratinga solstitialis	Metro Manila	Pasay City
	Aratinga solstitialis	Rizal	Cainta
	Cacatua alba	Davao del Sur	Davao City
	Cacatua alba	Metro Manila	Manila
	Cacatua alba	Rizal	Cainta
	Corvus macrorhynchos	Metro Manila	Quezon City
	Corvus macrorhynchos	Rizal	Cainta
	Gracula religiosa	Batangas	San Luis
	Gracula religiosa	Batangas	Batangas City
	Gracula religiosa	Davao del Norte	Carmen
	Gracula religiosa	Metro Manila	Pasay City
	Gracula religiosa	Metro Manila	Manila
	Gracula religiosa	Palawan	Rizal
	Gracula religiosa	Palawan	Quezon
	Gracula religiosa	Palawan	Puerto Princesa City
	Gracula religiosa	Palawan	Narra
	Gracula religiosa	Palawan	El Nido
	Gracula religiosa	Palawan	Aborlan
	Gracula religiosa	Quezon	Lucena City
	Lonchura oryzivora	Metro Manila	Quezon City
	Melopsittacus undulatus	Metro Manila	Quezon City
	Melopsittacus undulatus	Metro Manila	Manila
	Psittacula eupatria	Cavite	Dasmarinas City
	Pyrrhura molinae	Metro Manila	Manila
	Spilopelia chinensis	Camarines Sur	Libmanan

Associated Pathogens	Confiscated Wildlife Species	Province	City/ Municipality
	Spilopelia chinensis	Davao del Norte	Carmen
	Streptopelia tranquebarica	Metro Manila	Pasay City
Leptospira sp.	*Paradoxurus hermaphroditus*	Cavite	Dasmarinas City
	Paradoxurus hermaphroditus	Metro Manila	Pasay City
	Macropus rufogriseus	Sarangani	Glan
	Macropus rufogriseus	Surigao del Norte	Surigao City
Listeria monocytogenes	*Petaurus breviceps*	Davao del Sur	Davao City
	Petaurus breviceps	Metro Manila	Quezon City
	Petaurus breviceps	Metro Manila	Pasay City

conservation will also require stricter implementation of wildlife laws—ensuring that pet shops and other wildlife facilities have the necessary permits to operate and are compliant with health and safety regulations. Funding and support for wildlife law enforcement and rangers is also necessary to ensure that poaching activities are immediately detected and stopped, and general access to wild habitats is lessened.

3. Strengthen the role of the Bureau of Animal Industry (BAI) in the regulation of wild animal consumption and fund research to provide baseline data on wildlife food markets. As the primary government agency tasked with conducting livestock disease research, regulating and inspecting the import, export, and movement of livestock, and enforcing food safety standards, the Bureau will play a central role in reinvigorated strategies that address the increasing interface between human communities and wildlife, particularly in the form of wildlife consumption. It should synergize its efforts with the DENR-BMB and the DOH. At present, research on wildlife food markets in the Philippines is sparse. Their role in the Philippine wildlife trade and potential to be origins of disease outbreaks remains largely unclear or unknown.

4. Include One Health in biology and public health curricula. In the general curriculum of biology and public health programs in Philippine universities, which are traditionally taken as preparatory programs for careers in biological research and medicine, there is no explicit integration of the interface between human health and environment health. Certain fundamental courses can be enriched with modules that highlight this connection, particularly through examples of zoonoses from wildlife and their increasing spread the more that human activity encroaches on natural habitats. Special electives can be developed that combine concepts, theories, and applications from these and allied courses in environmental and health sciences. Public health courses like environmental health and health service management can also be so enhanced.

Building on the commendable work that the government has done, the Philippines will greatly benefit from enhanced and strategies that revisit the tight links between public health and environmental health to ensure that no one gets left behind.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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