Food and Agriculture Organization of the United Nations

CIFOR

cirad

WCS

SWM WHITE PAPER SERIES: OCTOBER 2020

WHITE PAPER

SWM SUSTAINABLE WILDLIFE MANAGEMENT PROGRAMME

Build back better in a post-COVID-19 world – Reducing future wildlife-borne spillover of disease to humans

Required citation:

FAO, CIRAD, CIFOR and WCS. 2020. *White paper: Build back better in a post-COVID-19 world – Reducing future wildlife-borne spillover of disease to humans: Sustainable Wildlife Management (SWM) Programme*. Rome, FAO. https://doi.org/10.4060/cb1503en

FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org

CIFOR information products are available on CIFOR website (https://www.cifor.org/library/). Any enquiries regarding CIFOR publications can be emailed to CIFOR Data and Information Services Manager, Sufiet Erlita, via CIFOR-library@cgiar.org or CIFOR-Publications@cgiar.org

CIRAD information products are available on CIRAD Agritrop website https://agritrop.cirad.fr/ and also on Dataverse

WCS publications and bibliographies, working papers, and datasets are available on the WCS website (https://library.wcs.org/Scientific-Research.aspx)."

ISBN 978-92-5-133458-4

This document was produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

Cover photo: The Sustainable Wildlife Management Programme is working to improve food security and the conservation and sustainable use of wildlife in and around the Makira Natural Park, which is Madagascar's largest protected area. ©FAO/David Mansell-Moullin

Contents

Foreword

COVID-19 has infected millions of people all over the world, challenging public health systems and negatively impacting economic growth. The global health crisis and economic recession will have long-term socio-economic consequences around the world.

We need to learn from this pandemic, to better understand the root causes of zoonotic diseases, prevent future outbreaks and support a green recovery to "build back better". Given the scale of direct and indirect costs caused by such emerging zoonotic diseases, both health, safety and sustainable development solutions are needed.

The SARS-COV-2 pandemic has once again highlighted our close relationship with nature, as well as issues related to the use of wildlife for food. Wild meat is an important and traditional source of protein, fat and micronutrients for millions of Indigenous Peoples and rural communities, particularly in tropical and subtropical regions. However, around 70 percent of emerging infectious diseases and almost all recent epidemics originate from animals, in particular wildlife. Furthermore, the trade in wildlife, especially in large urban areas, is increasing the risk of zoonotic disease transmission.

Measures to immediately restrict or ban (e.g. hunting, use or trade of wildlife products) could have serious adverse impacts on families with no other option but to eat wild meat. However, failing to take into consideration the increasing risk of zoonotic spillover may lead to more frequent pandemics in the future.

This complex situation calls for a sound risk assessment and for appropriate measures adapted to each country. These must be combined with global measures and coordinated efforts to efficiently address the question of why infectious diseases are emerging and re-emerging. At the same time, we must improve how we prepare for, and respond to future zoonotic disease outbreaks.

The white paper you have in your hands presents an invaluable and timely overview of state-of-the-art current knowledge on the transmission of wildlife-borne diseases to humans. It also provides concrete recommendations on how to prevent and respond to future zoonotic events based on the views and experiences of experts in various disciplines from the organisations involved in the Sustainable Wildlife Management (SWM) Programme. This Programme, a seven-year initiative from the Organisation of African, Caribbean and Pacific States (OACPS), funded by the European Union, is playing an important role in tackling these complex and interrelated issues.

Mr Koen Doens
Director-General
Directorate-General for International Cooperation and Development
European Commission

Mr Georges Rebelo Pinto Chikoti
Secretary General
Organisation of African, Caribbean and Pacific States (OACPS)

Purpose

This white paper aims to provide Northern and Southern Development partners and decision- makers with a better understanding of:

a) why spillover of disease from wildlife to humans occurs, and why these zoonotic disease outbreaks can spread and become epidemics and pandemics such as COVID-19;

b) what they can do to prevent, detect and respond to future spillover events, with a special focus on priority interventions at the human–wildlife–livestock interfaces.

It has been produced as part of the Sustainable Wildlife Management (SWM) Programme, which will deliver critical lessons on how to prevent, detect and respond to future spillover events with appropriate national and transboundary policies and practices in the context of the SWM partner sites.

The **SWM Programme** is a major international initiative to improve the conservation and sustainable use of wildlife in forest, savannah and wetland ecosystems. Field projects are being implemented in 13 African, Caribbean and Pacific countries. The aim is to: improve how wildlife hunting is regulated; increase the supply of sustainably produced meat products and farmed fish; strengthen the management capacities of indigenous and rural communities; and reduce demand for wild meat, particularly in towns and cities. It is being implemented by a dynamic consortium of four partners with expertise in wildlife conservation and food security:

- Food and Agriculture Organization of the United Nations (FAO)
- Center for International Forestry Research (CIFOR)
- French Agricultural Research Centre for International Development (CIRAD)
- Wildlife Conservation Society (WCS)

Acknowledgments

This white paper was developed within the framework of the SWM Programme by (in alphabetical order): Badi Besbes, Hubert Boulet, Carmen Bullon, Blaise Kuemlangan, Jeffrey LeJeune, Yingjing Li, Markus Lipp, David Mansell-Moullin, Scott Newman, Bruno Portier, Sandra Ratiarison, Kristina Rodina, Eugenio Sartoretto, Keith Sumption, Tiina Vähänen, Sophie Von Dobschuetz, Sheila Wertz-Kanounnikoff and Mette Løyche Wilkie (FAO); J. E. Fa, Robert Nasi and Nathalie van Vliet (CIFOR); Sandy Andelman, Chris Walzer, Michelle Wieland and David Wilkie (WCS); and Alain Billand, Daniel Cornélis, Ferran Jori and Marisa Peyre (CIRAD).

Introduction

The COVID-19 pandemic has had a rapid and massively unequal impact on public health and on the economic wellbeing of families and countries throughout the world. It has pushed governments to consider policies that their citizens would never have supported in the past, but that now seem to them unavoidable. In this context, much discussion has arisen within and between the scientific and development communities on the ways national governments and international organisations should react to this global threat, especially to prevent future emerging disease outbreaks, and mitigate against the risk of them causing another pandemic. The possibility that the COVID-19 virus spilled over to humans from wildlife species – potentially a bat, a pangolin or another animal species (Andersen *et al.*, 2020) – has rekindled debates around the trade in wildlife for human consumption. Similarly, outbreaks of avian influenza (H5N1), swine influenza (H1N1) and Middle East respiratory syndrome coronavirus (MERS-CoV) are increasing concerns about current livestock rearing practices and the risk that domesticated animals pose as a future source of zoonotic disease spillover to humans.

Wildlife is intimately linked to the food security, livelihood and cultural identity of numerous rural people, and to a lesser extent, to people in some relatively remote provincial towns, particularly in tropical and subtropical regions. In large cities located far from wildlife, wild meat is usually consumed for status or tradition (Fa *et al.*, 2015; van Vliet and Mbazza, 2011). In total, people eat an estimated 5 million tonnes of wild meat per year in Africa's Congo Basin, and around 1.3 million tonnes in the Amazon Basin (Nasi, Taber and Vliet, 2011). No regional estimates are available for Asia, but harvest and trade continue to be part of people's livelihoods for both Indigenous Peoples and local communities with forest-based livelihoods (Caldecott, 1987; Corlett, 2007; Pangau-Adam and Noske, 2012; Robinson and Bennett 2000; Rye, 2000), and modern hunters in oil palm dominated landscapes (Luskin *et al.*, 2014). As a source of income, wild meat is also a common component of household economies throughout the supply chain, from the hunter to urban markets and food stalls.

Wildlife trade has occurred for millennia. Colonial rulers industrialized the trade, for example blue duiker skins for luxury gloves in Europe, beaver felt hats from Canada/United States of America for the European consumer, passenger pigeons and bison tongues for eastern US consumers, elephant ivory for billiard balls and piano keys, etc. Today, the trade is both formal and informal, legal and illegal, and both national and international in scope. Also, wild meat markets typically evolve from selling large- to small-bodied species as unsustainable hunting depletes wild populations.

©FAO/David Mansell-Moullin

During the past 25 years, hunting of wildlife for food has been a growing concern for the following three main reasons (CBD, 2009):

Ecological impacts: In many ecosystems, the larger vertebrate fauna, especially frugivorous birds, primates, ungulates, and mammalian carnivores, have become locally extinct or been substantially reduced in numbers as a result of habitat loss and unsustainable hunting. Small species are typically more resilient to hunting than larger species, due to their higher reproductive rates (Cowlishaw *et al.*, 2005). Since the early 1990s, "defaunation" is often cited as the most evident impact of overhunting (Dirzo and Miranda, 1990), resulting in the "empty forest syndrome" (Redford, 1992) and, increasingly, the "empty savannah syndrome" as well (Lindsey *et al.*, 2013a). Examples of defaunation are numerous across the world, and an estimated 285 mammal species are threatened with extinction due to hunting for wild meat (Ripple *et al.*, 2016). Over-harvesting has not only direct effects on prey populations, but also cascading effects on the ecosystems as a whole (Abernethy *et al.*, 2013; Antunes *et al.*, 2016; Koerner *et al.*, 2017; Ripple *et al.*, 2016; van Vliet *et al.*, 2010). Yet the relative contribution of hunting versus other drivers, especially habitat loss, makes it difficult to attribute causation to hunting alone (Dirzo *et al.*, 2014; Hofman *et al.*, 2010; Roberts *et al.*, 2013; Simberloff *et al.*, 2013; Wilkie *et al.*, 2011).

Unsustainable levels of hunting to meet urban demand: Where wildlife is hunted to supply markets in distant, large cities, harvest rates are typically unsustainable, and income generated from this livelihood activity will likely be short-lived, following a boom-bust cycle (Fa *et al.*, 2019). The subsequent depletion of wildlife ultimately risks increasing malnutrition and poverty for rural populations who rely on this resource for their subsistence and cultural identity (Fa, Curriem and Meeuwig, 2003).

Health and zoonotic diseases: Approximately 70 percent of the pathogens causing emerging infectious diseases today are zoonotic, emerging from both wildlife and livestock (Newman, *et al.*, 2005; Woolhouse, 2002). Wild animal species are an important reservoir of potential zoonotic pathogens, but the diversity of these pathogens calls for increased multidisciplinary research efforts to understand the transfer dynamics of such infections (Siembieda *et al.*, 2011; Wolfe *et al.*, 2005). The list of infectious diseases thought to have their origin in wildlife encompasses some of the most virulent pathogens including Ebola virus, Lassa virus, hantavirus and human immunodeficiency virus (Weiss, 2001).

Research indicates that outbreaks of animal-borne diseases are on the rise, mostly due to environmental degradation and the intensification of livestock production and trade (Jones *et al.*, 2008; Paige *et al.*, 2014).

In the current context, responses such as China's intent to outlaw urban trade and consumption of all terrestrial wild animals to solve the wild meat-disease linkage have met with support from various quarters. In particular, the international conservation lobby is strongly in favour of this decision, calling for it to be extended and made permanent, and stressing the interconnectedness of public health risks and biodiversity conservation concerns. (e.g. Lion Coalition, 2020; WWF, 2020). Other groups, who favour regulated consumptive use of wildlife along short-range value chains, which are sustainably managed to meet populations' food and income needs, have proposed a more cautionary stance (e.g. Roe *et al.*, 2020).

These differences in opinion are not new, but the current situation has exacerbated them, raising important issues for development and conservation policy. All too often, attempts to reconcile these interests through public policy turn out not to satisfy either party. They fail to respect the important, albeit often unacknowledged, roles that the consumptive use of wildlife plays in the national economy and cultural identity. They are also unsuccessful in putting into practice effective integrated public and animal (including wildlife) health approaches addressing environmental drivers. Finally, they fail to secure the resource in ways that provide adequate long-term protection for fauna of global interest while guaranteeing their sustainable use.

Indeed, bans on wild meat trade and consumption have been legally adopted in many countries, but lack of political will and/or limited resource allocation have led to limited law enforcement. Non-compliance is one of the major obstacles to organize any health risk control and sustainable wildlife management. Furthermore, pathogen spillover events occur when people, live wildlife and domestic animals are concentrated in situations (primarily markets) where waste management, hygiene, biosafety, biosecurity and food safety measures may not be sufficiently practised, and where animals are often stressed and kept in holding facilities that do not meet adequate international standards, often mixing different animal species, domestic and wild.

To improve preparedness for, and early response to, the next zoonotic disease outbreak and subsequent spread, governments, policy makers and the international community should look at the bigger picture. It is crucial not just to consider the negative impacts of wild meat trade and consumption on biodiversity and health, but also socio-economic issues for the millions of people worldwide who depend on wildlife for food and livelihoods. According to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (FAO, 2019; IUCN, 2020), over 9 000 wild animal species (including invertebrates, amphibians, fish, reptiles, birds and mammals) are used as human food worldwide, corresponding to a very large variety of wild meats that are exploited by myriad cultures. Such diversity is found in contrasting socio-ecological contexts that require global and locally adapted structural solutions, including appropriate legal instruments and institutional coordination enabling socially acceptable management options. Ultimately, favourable solutions for humans and wildlife are only likely if all possible options and their total costs (both direct and opportunity costs) are considered and selected in close collaboration with stakeholders.

The purpose of this white paper is to summarise the information available on the causes of zoonotic disease spillover at the human-wildlife-livestock interface and subsequent spread through secondary transmission from person to person. We recommend interventions targeting the drivers of zoonotic disease emergence and provide suggestions on how to improve prevention, preparedness and response to future outbreaks. The Paper concludes with a discussion on the contribution that the Sustainable Wildlife Management (SWM) Programme can make in this context.

Note that this white paper does not consider zoonoses that have no secondary transmission from human to human, such as rabies. It focuses on *future* zoonotic risks at the human-wildlife-livestock interface. COVID-19 at its current stage is a disease primarily spread through human to human transmission. However, it likely had a zoonotic origin, and if the reservoir host species is still infected, then recurrence is possible. In addition, new species may be becoming endemically infected by humans following reverse zoonosis, i.e. transmission of the virus from humans to susceptible animals (OIE, 2020a; b; c; d).

1. Zoonotic disease pandemics – why they occur

For a pandemic event such as COVID-19 to take place, there are three steps that must occur, namely:

a) the pathogen must be successfully transmitted from the reservoir species (wild or domestic) to humans (spillover event);

b) the pathogen must be directly transmitted between humans (secondary transmission);

c) the pathogen must spread from a local context (epidemic) to the global population (pandemic).

1.1 The ecological back drop

There is evidence that emerging zoonotic infectious disease risk is more likely in forested tropical regions experiencing land-use changes and where wildlife biodiversity (mammal species richness) is high (Allen *et al.*, 2017). Species richness in birds and mammals, and richness in human infectious diseases are also correlated (Dunn *et al.*, 2010; Morand and Figuié, 2018; Morand *et al.*, 2014). Both permanent and temporary landscape changes resulting from ecosystem fragmentation and degradation are major drivers of the emergence or re-emergence of zoonotic diseases such as malaria, dengue fever, Ebola and Lyme disease (Aguirre and Tabor, 2008; Olivero *et al.*, 2017; Rohr *et al.*, 2019). Different mechanisms may be involved (Cascio *et al.*, 2011; Plowright *et al.*, 2011; Plowright *et al.*, 2015), but landscape change and biodiversity loss are likely to cause major shifts in the ecology of pathogens. These factors favour the expansion of disease hosts or vectors and increase pressure for virulence/resistance

©FAO/David Mansell-Moullin

selection and/or for the evolution into more genetically diverse pathogen strains, which increases the probability that one of these strains can spill over to humans.

Several environmental factors such as climate change and extreme climatic events either brought about by global patterns such as global warming or El Niño–Southern Oscillation (ENSO), and/or by localized effects (e.g. flooding or drought) also increase the potential for zoonotic disease outbreaks. For example, outbreaks of malaria and hantavirus increase after intense rainfall and flooding, and after droughts, respectively (Cascio *et al.*, 2011; McMichael, 2015; Wang *et al.*, 2010).

These factors affect the timing and intensity of zoonotic disease outbreaks by creating optimal conditions for host species or vectors, leading to their congregation (e.g. wild migratory birds as hosts for zoonotic avian influenza viruses) or abundance (e.g. vectors such as flies, mosquitoes or ticks as hosts for vector-borne diseases) (Altizer *et al.*, 2013; Wang *et al.*, 2010; Wimberly *et al.*, 2008; Young *et al.*, 2017).

Environmental factors can also interact in synergy with land use/cover change, ecological changes and/or social inequities to influence disease patterns by creating new human–wildlife interfaces or leading to more intense interactions (Epstein, 2001; Gortazar *et al.*, 2014; Leaf, 1989; Patz *et al.*, 2004). In these cases, the mechanisms involved include modifications in the density and distribution of wildlife host species and disease reservoirs, including vector species (Wimberly *et al.*, 2008). In addition, climate change and global warming have led to altered conditions in areas previously free of certain vector species and associated pathogens, expanding the geographic occurrence of infectious diseases (Balogun *et al.*, 2016; Beugnet and Chalvet-Monfray, 2013; Caminade *et al.*, 2019).

1.2 Drivers of local disease emergence – the spillover phase

The frequency and duration of contact with wildlife are key elements in increasing the probability of disease spillover from wildlife to humans or wildlife to livestock to humans. There are several pathways to exposure – direct contact with a wild animal, indirect contact with the urine or faeces of a wild animal that were deposited on food or another surface, or through an intermediary host. Intermediary hosts include: other wildlife species (e.g. wild civets for SARS); livestock (e.g. dromedary camels for MERS-CoV); or poultry (e.g. for zoonotic influenza) (Lau *et al.*, 2017; Tu *et al.* 2004).

Closer proximity and easier access to wildlife habitats: Ecological degradation, land conversion and fragmentation of wildlife habitats by human settlements, agricultural intensification, infrastructure development, and road networks related to extractive industries all increase proximity and access to wildlife habitats. In these contexts, an increase of human-wildlife-livestock encounters within a given area, an expansion of the area where contacts can occur and/or changes in wildlife ranging patterns can be observed (Wolfe *et al.*, 2005; Paige *et al.*, 2014; Rulli *et al.*, 2017; Giles *et al.*, 2018). Subsequent alterations in the structure of ecological communities also disrupt pathogen ecology. These interacting mechanisms elevate contact rates among humans, livestock and wildlife species (Bloomfield *et al.*, 2020; Karesh *et al.*, 2012; Loh *et al.*, 2015; Plowright *et al.*, 2011), thus the likelihood of human and livestock exposure to wildlife and to the potential disease agents they carry, especially in untouched tropical forests areas, given their high biodiversity (Bauch *et al.*, 2015; Loh *et al.*, 2015; Murray and Daszak, 2013; Patz *et al.*, 2004; Rulli *et al.*, 2017). When rural population densities increase (e.g. when settlements become villages or even small towns), the likelihood of both spillover and spread also increases.

Proximity and access to wildlife habitats also amplify exposure to environmental contamination from a variety of sources that can indirectly result in pathogen spillover and exposure to potential zoonoses. Many diseases that affect humans are indeed transmitted by ingesting or handling faecal-contaminated food or water. Bats, rats or other pests may enter human dwellings and defecate inside accommodations or even on food left in the open. For example, serological evidence of bat SARS-Coronaviruses and related viruses was reported in 2.7 percent of people living near bat caves in China (Wang *et al.*, 2018). Dwellers and farmers have also been reported to be exposed to Nipah virus from bat urine or saliva, for example on fruits or in date palm sap (Rahman *et al.* 2012), or from pigs previously exposed to bats (Kurup, 2002).


©Brent Stirton-Getty Images for FAO, CIFOR, CIRAD, WCS

Dependence on wild meat for food and income: Wild meat represents the main source of protein, fat and micronutrients, but also a key element in diet and income diversification for millions of rural people across the tropics and subtropics (Nasi *et al.*, 2008; Nielsen *et al.*, 2018). In rural areas, most Indigenous Peoples and local communities depend on wild meat because they have no other source of meat or cannot afford alternative sources. Also, for families living in provincial towns located close to sources of wild animals, eating wildlife may still be a dietary necessity. Dependence on wild meat increases in both rural and urban areas at places and times where other food systems and sources of livelihoods are disrupted, such as during economic hardship, civil unrest or drought (Coad *et al.*, 2018).

Wild meat has a higher value-to-weight ratio than most agricultural crops, and when smoked and dried can be transported long distances without rotting. Moreover, wildlife is typically an open access resource that can be exploited by anyone. These factors, when combined, make it one of the few commodities that poor rural families can trade profitably, and is thus a valued source of income for people who live with wildlife.

Hunter-gatherer communities are typically in contact with wild animals a few times a week or more often. Where Ebola outbreaks could be traced back to a probable "case zero" or index case, Indigenous Peoples and local communities were exposed to the virus during subsistence hunting, or their children were exposed while playing close to wildlife (FAO, 2018). However, despite being relatively more exposed to pathogens of wildlife origin, an individual hunter's lifetime probability of contracting a deadly zoonotic disease such as Ebola still remains very low. This is because not all contact with wildlife exposes the hunter to disease agents, and not all disease agent transmissions result in the hunter contracting a disease. Due to the isolation of these remote rural communities, they also pose a small risk to global health. However, nowadays, if a hunter – or another individual operating upstream in a wild meat value chain – contracts a zoonotic disease from an animal, he or she may be more likely to carry it to areas of higher human population density, given the increased mobility and commercial flows of goods and peoples.

In cities, wild meat typically comprises less than 2 percent of the animal source foods eaten by urban families in the tropics and subtropics (Wilkie *et al.*, 2005). However, when thousands or millions of urban dwellers buy and eat wild meat, the probability that at least one individual will be exposed to a pathogen of wildlife origin and then infect other people increases substantially.

Not all zoonotic infections will result in disease or subsequent human-to-human spread. An investigation conducted by public health authorities in Guangdong Province, China found that 13 percent of animal traders (i.e. workers in live animal markets) had IgG antibodies against SARS-Coronavirus even though none of them had been diagnosed with SARS, compared to 1–3 percent of persons in three control groups (CDC, 2003).

Human behaviours and choices: There is also a large demand for wild meat in almost every major urban centre around the world. The cultural preference for this meat or for other wild animal body parts used as traditional medicinal products, and the associated socio-economic status of being able to afford this high-priced commodity, places wild meat and other wildlife by-products into a global value chain, accompanied by potential zoonotic pathogens.

In some ways complementary to unregulated movement of wild meat, the wildlife pet trade is also responsible for enabling wildlife to reach every corner of the globe within days, again travelling with potential pathogens and often bypassing standards that would help minimize disease spread (e.g. such as routine health checks or quarantine measures applied upon arrival of live animals) (Can, D'Cruze and Macdonald, 2019; Pavlin, Schloegel and Daszac, 2009).

In addition, of particular concern are some consumption practices that do not abide by good food safety standards, including consumption of raw wild meat, blood or body parts. Several studies also report a distinct lack of precautionary behaviour, resulting in hunters, butchers and consumers exposing themselves to zoonotic diseases. Combined with general lack of awareness among people who come into contact with wild meat, those behaviours increase the risk that new pathogens will spill over to humans (Kamins *et al.*, 2015; LeBreton *et al.*, 2006; Paige *et al.*, 2014).

Finally, another developing and expanding area is ecotourism, where groups of people, usually guided by locals, visit wildlife habitats to get close to, observe and even feed wild animals in their natural environment. Ecotourism has been hypothesized as a risk factor for the potential zoonotic spillover of pathogens from humans to great apes (Muehlenbein and Ancrenaz, 2009). In the context of the current COVID-19 pandemic, such close interaction between humans and wildlife could lead to new wildlife reservoirs being established for this virus when susceptible wildlife species such as great apes, cats or mink that are exposed to SARS-CoV-2 virus from humans are able to maintain the virus and thus become a new exposure source for humans, other wildlife and livestock (FAO, 2020a). However, further research is needed to confirm if ecotourism could provide opportunities for spillover from wildlife to humans and to assess the level of risks (Cascio *et al.*, 2011).

Management practices along wildlife value chains, including hunting, marketing, slaughtering and processing: As live animals, their meat or other body parts progress along wildlife value chains, the opportunity for human contact increases, including close direct contact with hunters, traders, butchers, cooks and consumers (Greatorex *et al.*, 2016).

In the wild, unsustainable hunting is thought to increase spillover risk by increasing hunting of higher zoonotic risk species (Koerner *et al.*, 2017). Indeed, when preferred large-bodied wildlife species are depleted by overhunting, hunters add smaller-bodied species to their hunting "diet breadth". Lower zoonotic risk ungulates are thus replaced in hunter captures, increasing direct contacts with higher zoonotic risk rodents, primates and bats.

At the time of harvest, animal restraint, exsanguination, dehairing, defeathering and evisceration result in direct contamination of meat at the time of slaughter. They may generate aerosols that can contaminate edible portions of carcasses prepared for food and infect workers and customers along wild meat value chains (Bertran *et al.*, 2017; Gao *et al.*, 2016; Gill, 1998). The variety of zoonotic pathogens that can be recovered from wildlife depends upon the animal species and the location of capture; it includes not only highly contagious viral pathogens such as Ebola virus and SARS, but also other bacterial pathogens with widespread morbidity and a large number of multicellular parasites, all typically not transmitted through secondary infection (Bachand *et al.*, 2012; Mann *et al.*, 2015; Pourrut *et al.*, 2011; Samsudin *et al.*, 2020; Swift *et al.*, 2007).

Moving from rural to urban areas, the contact with live wildlife and wildlife by-products occurs mostly in formal and informal market places, where many animal species – domestic and wild – are aggregated, and wildlife, livestock and people mingle. In sub-Saharan Africa, as much as 80 percent of all food types are traded in informal markets (Roesel and Grace, 2014). Here, also, much if not most of all wildlife is sold for food. Although informal markets are the primary source of food in rural settings, these markets are becoming increasingly common in urban centres where live animals and animal-derived food products are regularly sold (El Bizri *et al.*, 2020; Kogan *et al.*, 2019; Zhang *et al.*, 2008). SARS or SARS-CoV-2 spillover into humans likely occurred following exposure of people working in or visiting live animal markets ("wet markets"). Bats are presumed the original animal source; however, these pathogens are thought to have adapted in intermediate animal species, likely wild, such as Himalayan palm civets (Paguma larvata) for SARS (Li *et al.*, 2006) before being able to infect humans. Generally, any interaction between livestock and people in close contact with living rodents, bats and birds or other wildlife shedding viruses along the supply chains provides opportunities for intra- and inter-species transmission and potential recombination of viruses.

However, since evidence of virus circulation in wildlife is currently lacking, these risks have been rated as low for SARS-CoV-2; that is, exposure of humans to SARS-CoV-2 from wildlife in markets or congregation sites, wildlife ranches and farms is unlikely to occur. Spillover from the original animal reservoir or intermediate hosts to human populations may therefore be considered a rare event, unless future evidence suggests that this is occurring more frequently than currently thought. However, the ongoing pandemic involves millions of human cases who are in turn shedding the virus and thus creating new contaminated environments other than the original natural reservoir (FAO, 2020a). Confinement of wildlife in stressful, high-density conditions may result in increased viral shedding. Poorly regulated and organized markets (formal or not) are often managed without transparency; they frequently lack facilities such as clean water; traders are not encouraged to perform basic sanitary handling and processing; and there is often no environmental and equipment cleaning. Moreover, the lack of proper waste disposal and wastewater containment further increases the risk of cross-contamination, including from rodents (Ribas *et al.*, 2016).

General principles for the safe production of all foods Codex Alimentarius (FAO and WHO, 2009), including those of wildlife origin, and good biosecurity practices in live animal markets (e.g. FAO, 2015) have been established by international consensus. However, public health, biosecurity, and disease surveillance and response systems for emerging pathogens in the wild meat sector are at present al-

most completely absent (Maas *et al.*, 2016; Woods *et al.*, 2019). Unlike commercial-scale livestock, the killing and processing of wildlife and rural livestock are often performed outside of dedicated abattoirs by individuals with limited knowledge or awareness of food safety risks. The highly decentralized nature of these processes makes it challenging to establish effective systems along the wild meat value chains to control food safety hazards through governance and oversight, and to monitor zoonotic risks. In addition, there are also major technical and technological knowledge gaps that further complicate the issue. For example, for newly discovered and emerging diseases, knowledge about the epidemiology and microbiology may not be available to develop effective test or control strategies. In this context, it is imperative that the risks along the wild meat value chains are assessed so that interventions can be targeted and prioritized at the points that contribute to the risks and are the most effective at making the food safer. Verification of compliance with established risk mitigation strategies (the process) will be important since end product testing is resource-intensive, especially for products with an expected low prevalence of contamination. Among the largest barriers to enhancing food safety of wild meat products are:

a) the lack of robust risk assessments of foodborne hazards in the system (Gbogbo *et al.*, 2019; Pruvot *et al.*, 2019; Simons *et al.*, 2016);

b) poor knowledge, awareness and behaviours among workers in the wild meat value chains (Alhaji, Yatswako and Oddoh, 2018b; Friant, Paige and Goldbery, 2015; Nuno *et al.*, 2018);

c) lack of communication and adoption of evidence-based practices to enhance food safety across the entire value chain (Sheherazade, 2015).

Wildlife farming practices: Wildlife farming has taken off mostly to feed luxury markets, first for economic reasons only, and then to mitigate the conservation impacts caused by wild meat harvesting (Lindsey *et al.*, 2013b; Turvey *et al.*, 2018; Wang *et al.*, 2019). For the last few decades, an increasing number of tropical animal species have been bred under intensive production systems, for example, antelopes, ostriches, large rodents in Africa (van Vliet *et al.*, 2016), and civets (Carder *et al.*, 2016) and pangolins (Challender *et al.*, 2019) in Asia. However, the animal health, welfare and food safety challenges faced in any intensive animal production system may be amplified in such systems where there is limited knowledge of animal needs, inadequate biosecurity and biosafety measures, as well as insufficient veterinary support. These challenges, together with the lack of knowledge of wildlife diseases, may facilitate the emergence of infections (Bekker, Jooste and Hoffman, 2012; Magwedere *et al.*, 2012). Moreover, wildlife farming may put wild populations at risk due to genetic pollution and disease transmission from the accidental or even deliberate release of captive animals into free ranging populations. (Grewe *et al.*, 2007; Mustin *et al.*, 2012).

1.3 Drivers of disease spread

It has been evidenced that more spillover events take place in contrast to the few pandemics that are documented. However, our constantly changing human societies create new risks and the conditions for the rapid spread of zoonotic disease among wildlife, livestock and humans, and between humans.

Human demography, urbanization and interconnection: The number of humans living in the world has increased from 1 billion in 1800 to the current 7.7 billion. By 2050, as much as 68 percent of the world's human population will be living in towns. The highest human demographic growth rates are concentrated in Asia and Africa, where urbanization and rural exodus have contributed to the rise of large cities and megacities (over ten million inhabitants). Since domestic road, rail and plane networks are multiplying, an infected person can easily transmit a disease to almost any large city in a matter of hours or days.

Human and animal mobility: In recent decades, global connectivity has dramatically increased with the development of global trade, international transport and changing human migration patterns (e.g. due to conflicts or political and environmental instability). This rise in global connectivity has been accompanied by an increase in the long-distance transport of animals and humans, their diseases (or vectors) and pathogens (Can, D'Cruze and Macdonald, 2019; Tatem, Hay and Rogers, 2006). The result is an increased risk of a global spread of zoonotic diseases.

Globalized food value chains of livestock and wildlife: With demographic growth, the frequency and volume of international trade, which influences the exchanges of agricultural products, has increased. The modernization and intensification of livestock production and trade during the last half century provided new opportunities for pathogens to travel quickly across the world. Several studies have shown that the risk of a country being infected increases with the number of live animals imported (Hautefeuille, Dauphin and Peyre, 2020; Trovão and Nelson, 2020). This is applicable to both livestock and wildlife trade. Furthermore, the large illegal movement of wildlife for high-end wild meat consumption, for the exotic pet industry, or for other uses (e.g. traditional medicine) occurs without any animal health or welfare controls, biosecurity measures, quarantine, veterinary support or food safety controls (Can, D'Cruze and Macdonald, 2019).

1.4 Past policy, regulatory and institutional failures

Policy and regulatory frameworks play a key role in minimising the impact of infectious diseases through prevention, detection, and response legislation. However, failures associated with weaknesses (including lenient enforcement), gaps and redundancy within or between existing policy and regulatory mechanisms can weaken the response to outbreaks of contagious and serious diseases at national and international levels.

Policy and regulatory frameworks that invest as a priority in prevention and preparedness are usually lacking. However, too often, emergency laws and measures do not or cannot take into full consideration their potential impacts. Emergency laws that restrict movement and require isolation during a pandemic are considered normal responses from a public health perspective. Yet, in addition to the other socio-economic impacts they generate, as currently observed with the COVID-19 pandemic, they may disrupt food systems and affect access to food and nutrition, especially by women and other marginalised groups.

Furthermore, the ability of governments and other actors to prevent, detect and respond appropriately to disease risks emerging from wildlife is frequently hampered by the lack of inter-sectoral cooperation and collaboration, as well as by overlapping or contradictory sectoral legislations that can create confusion in the sharing of roles and responsibilities between institutions. In particular, if the human and animal health sectors collaborate to some extent, then there is often only a minimal involvement of authorities and services in charge of natural resources management, including wildlife.

In most countries, the lack of up-to-date, cross-sectoral statistical databases and information systems allowing accurate risk assessment and the development of predictive models is also one of the critical factors leading to the adoption of inappropriate, disproportionate and/or cost-ineffective policies and laws to address the drivers of disease emergence and spread, and/or to deal with emergencies. Another challenge is that wildlife surveillance or wildlife health events investigations are often undertaken by non-governmental entities such as non-governmental organizations (NGOs) or research institutions. The data and information collected by these entities may not be systematically shared in a timely manner with government structures, and are thus not available for analysis and early warning.

At the sectoral level, a major barrier to the control of the use of wild animals for food and the surveillance of wildlife-borne disease is the lack of effective laws to regulate subsistence and commercial hunting practices. In many countries, wildlife legislation is often unclear on the definition of hunting for one's own food and for commercial purposes. The latter category primarily focuses on licensing systems linked to sport/recreational hunting, which merely list the species that can be hunted, imposed quotas, hunting seasons, and in some cases, the methods that can be deployed. These laws do not include any regulations of the health of wild animals if used for food, including wildlife farming, their condition during slaughter, or the processing and handling requirements for their consumption. As a result, wild meat value chains, which are usually informal or illegal, operate without any legal guidance of disease risk assessment or public health protection. These challenges are exacerbated by the fact that wildlife health is in the interest of multiple sectors and public agencies but not specifically under any of their mandates, leading to policy and funding gaps. The result is an ongoing debate over whether it is the government, producers, processors or consumers who should bear the financial cost of implementing and enforcing food safety regulations.

2. Recommended interventions to prevent spillover of zoonotic diseases

2.1 Enabling conditions

Human, animal, plant and environmental health are inextricably connected through the ecological realities governing life – we share land, air and water, and all of our food comes from the Earth. This means that human health is dependent on the health of all other components of the ecosystem. This context has led to the development of integrated approaches to health such as the "One Health" approach to ensure that the respective sectors in charge of the health of people, livestock, wildlife, the ecosystem and the environment as a whole, strengthen collaboration to overcome a sectoral ("silo") approach and rather work together in a coordinated manner at the local, national, regional and global levels. The effective implementation of this multi-sectoral collaboration and coordination is essential to succeed at building back better and preventing the next pandemic. This section introduces a non-exhaustive list of approaches needed to strengthen coordination at the country level, policy and legislation gaps, as well as implementation modalities that can be improved in order to properly develop and implement One Health programming at the national level.

2.1.1. Strengthening the One Health approach

There is a need to strengthen integrated, interdisciplinary and cross-sectoral approaches such as the One Health approach in order to better address the root causes of zoonotic spillover. The aim is to: reduce human exposure to wildlife and livestock disease agents; organize wildlife, livestock and human disease surveillance to detect and report disease outbreaks, perform joint, intersectoral risk assessment (JRA) for zoonotic disease threats arising at the wildlife-human-livestock interface (FAO, OIE and WHO, 2018); and support epidemic preparedness to respond rapidly and effectively in order to prevent the spread of a zoonotic disease.

Implementing this holistic and participatory approach requires smooth inter-institutional coordination and effective intersectoral collaboration. The One Health approach has changed the way of doing business, and it is moving in the right direction, but it is yet to be inclusive of the forestry, wildlife and environment sector. Natural resources management services and experts need to be more involved to ensure that interactions between ecosystems and agroecosystems are addressed. Intersectoral awareness of and training on the important role that natural resources managers and biologists can play in preventing emerging infectious diseases, allowing them to have an equal voice, with medical-based experts, on public health issues. This also requires the formulation and enforcement of appropriate legislation, with a clear allocation of roles, responsibilities and budget and regulations on access to data and public information by all state and non-state actors involved.

2.1.2. Strengthening sectoral policies and legislation

There is a need to encourage the development and implementation of sectoral policies and legislation in support of food safety and public as well as animal health, to enable implementation of prevention and mitigation strategies against disease emergence risks at various scales in line with supporting sustainable and safe food systems and livelihoods. Such legal mechanisms contribute to the long-term strengthening of a population's resilience to disease, as well as to minimising the impact of environmental or economic shocks. Policy and legislation development processes should ensure the participation of a broad stakeholder base, especially from the most vulnerable and/or marginalised groups and their rights, in order to shape laws and regulations that are realistic, have adequate technical content, and are socially acceptable.

Wildlife legislation: Traditionally, wildlife legislation regulates the hunting sector. It may also regulate human-wildlife conflicts but when this is the case zoonotic disease spillover risk should also be recognized as such. In recent years, wildlife legislation has witnessed innovative and dynamic trends by addressing also the non-consumptive uses and conservation of these resources and their habitats across sectors. Embedding law in participatory processes would further enable an ecosystem approach, thereby promoting a more diversified range of options to achieve the sustainable management of wildlife.

Prevention of wildlife-borne diseases is more likely to be possible if a broad array of wildlife-related legal instruments is effectively implemented. Developing the legal basis to control the use of wildlife is undoubtedly the first step, but these activities need to be accompanied by the protection of livelihoods of the communities that are still dependent on wild animals for food and income. Legislation that protects and regulates the sustainable use of wildlife must take into account the environmental and social needs and practices of user communities and health risks to humans and animals.

During a crisis, it is essential that the legal framework for the hunting sector (subsistence, sport or commercial) and the management system it supports (e.g. licensing systems and the determination of species targeted for hunting, quotas, seasons) are clear and allow a certain flexibility. This will allow governments to temporarily suspend consumption or trade in specific wildlife species within a given area, as well as to quickly extend hunting or fishing seasons to guarantee the food security of Indigenous Peoples and local communities. Similar considerations could also be applied to commercial hunting where it is legal and within the limits of sustainable resource use.

Experience has shown that illegal use of natural resources and poaching increase during emergencies (Swamy and Pinedo-Vasquez, 2014). Governments and their partners should continue to implement international binding and non-binding instruments, and to monitor and enforce them (e.g. measures to protect endangered species and their habitats); if not, poaching and other illicit activities may increase and threaten decades of conservation efforts.

©Brent Stirton-Getty Images for FAO, CIFOR, CIRAD, WCS

Animal health legislation: The interconnectedness between emerging infectious diseases in wildlife and livestock and human health, highlighted by the COVID-19 pandemic and other recent Ebola, Nipah and SARS outbreaks, stresses the need for a coordinated and fully legislated approach to disease prevention and control. In most countries, wildlife health is regulated within the framework of general animal health legislation and is the regulatory responsibility of the national veterinary authority. Developing strong animal health legislation that pays attention to all animal species including wildlife is thus essential to prevent the occurrence of animal disease and its transmission to humans. Such legislation should incorporate the standards and recommendations of the World Organisation for Animal Health (OIE), including its Terrestrial and Aquatic Animal Health Codes. It should provide the national veterinary authority with the mandate to regulate, control and foster animal health including, among others, the powers to develop a system of veterinary surveillance and control, and to adopt and implement sanitary measures, such as compartmentalisation, obligations of notification or movement control. Legislation should mandate the veterinary authority to declare an animal health emergency and to approve the sanitary measures necessary to respond to the emergency. The veterinary authority should then be responsible for coordinating emergency action in a functioning "chain of command" and for approving measures such as movement restrictions; measures to seize, treat or cull animals; destroy animal products; and/or strengthen powers for inspectors.

Laws for maintaining ecosystem integrity: The importance of policies and legislation that consider land management, including land use planning, in the prevention of wildlife and public health issues needs to be widely recognised. These legal instruments can significantly contribute to enable the sustainable use of natural resources, optimise land use, and reduce human–wildlife conflicts. They can also help address environmental drivers of zoonotic diseases and improve socio-economic conditions through a participatory multisectoral, multi-stakeholder and scale-dependent process. The application of responsible governance of tenure to guide the design of policy and regulatory frameworks on land use planning and occupancy should especially be supported. In areas where state administration has been absent and infrastructure is poor, customary tenure systems are often the primary means of enforcing rights and resolving tenure disputes (FAO, 2016). Recognizing local and customary tenure rights while ensuring a balance with provisions for gender equality through legislation, will be a first and essential step to help achieving a governance system that is flexible and locally responsive. This would help turning marginalized groups into a reliable asset for managing wildlife including for preventing and/or addressing the occurrence of pests and diseases.

Laws that enable governments to maintain and restore ecosystem integrity, especially by reducing the fragmentation and degradation of wildlife habitat, will undoubtedly decrease the probability of zoonotic disease emergence. Informed land use planning mechanisms thus allow for the creation and protection of conservation and restoration areas, also by formally recognising the territorial rights of Indigenous Peoples and local communities. Examples of devolution of responsibilities abound, such as the community-based forest management association system in Madagascar, allowing local communities to manage and benefit from the sustainable use of their natural resources.

Regulations of food safety, biosecurity and surveillance along meat value chains (including markets): Food hygiene and sanitation as well as market biosecurity are key factors in controlling zoonotic risks associated with wildlife meat consumption and trade. Food safety and quality legislation should provide guidelines on and approaches to reducing the transmission of wildlife pathogens and the risk of foodborne disease. For instance, regulations requiring that all traded wild meat is thoroughly dried/smoked could significantly reduce exposure to wildlife disease agents and the risk of zoonotic disease spillover from wildlife to humans. This legislation should also recognise that hunters and wild meat operators have a role and responsibility in maintaining the safety of their products. Legislation or plans that address emergency preparedness for potential food safety outbreaks, including recall from the market of products that could pose a food safety threat, can allow for quick response and mitigate the impact of adverse food safety and zoonotic disease risk. At the same time, while live animal markets continue to operate, it is imperative that those that remain are managed in a way that reduces the risk of infection of animals and humans with zoonotic pathogens. Implementation of adequate hygiene and biosecurity measures, e.g. separation of animal holding and slaughtering areas, no mixing of different animal species, regular market rest days with cleaning and disinfection, etc., is as important as appropriate decontamination of any equipment and vehicles that enter markets (FAO, 2015).

2.1.3. Promoting regional integration and international coordination

Regional and international collaboration and measures are needed, given that zoonotic diseases, as seen during the COVID-19 pandemic and the recent outbreaks of Ebola, do not respect national borders. Regional integration of regulations, capacity development and information sharing are needed, particularly in relation to diagnosis and research (e.g. in terms of technologies, equipment and expertise), control of flows of goods and peoples, and transboundary surveillance.

2.2 Pre-outbreak: Minimise the risks of zoonotic disease spillover from wildlife to humans by reducing the wildlife–livestock–human interface

2.2.1. Addressing risky practices involved along wildlife supply chains

It is necessary to support practical risk mitigation strategies based on changing behaviours and practices that are deemed risky as well as to verify compliance with established risk mitigation strategies. This is particularly important given the decentralised organisation of wildlife supply chains and the lack of tests and testing facilities to identify all potential zoonotic risks from the bush to consumers (e.g. from hunting, slaughtering, processing and handling, to storage and distribution in food markets).

Reducing urban consumers' demand for wildlife as food: Where alternative animal source food to wild meat is already available and dependence for wild meat for food and livelihoods is limited, the reduction of wild meat trade and consumption needs to be actively organised by discouraging the significant and growing demand for wild meat in urban areas. This requires implementing a combination of social marketing and increased access to alternative sources of proteins, especially in provincial towns where few alternatives to wild meat may be on offer. Attempts to reduce consumption of wildlife by raising awareness of the disease risks only had no impact on consumer attitudes and behaviours in Central Africa (Wilkie, 2006), given that the lifetime risk of contracting and dying from a disease spillover from wildlife is actually low. To identify the most promising approaches to changing behaviour,

consumer surveys should be conducted on the most salient non-price demand drivers of wild meat in urban areas. The outcomes of these surveys can be used to design and undertake education and awareness-raising campaigns to discourage the consumption of wild meat, as well as to identify preferred domestic animal-source food (ASF) to be promoted and supported.

Reinforcing controls of wildlife trade in urban areas: Permanent blanket bans on trade and consumption of all wild species may be unwarranted and could decrease acceptance of the overall measures. However, under critical circumstances, blanket bans on all species could still be considered a temporary and/or localised emergency measure where pathogen spillover risks are assessed as particularly high.

Where wildlife trade is legal, an effective balance between enforcement and regulatory approaches should be considered in order to:

- stop illegal wildlife trafficking;
- improve legal trade management, especially in "wet markets";
- enforce selective bans on the sale of live or fresh wildlife, targeting species assessed as representing a higher risk of harbouring pathogens with zoonotic potential, such as bats, primates and rodents.

Any appraisal of the effects of withdrawing wild meat from food supply chains to mitigate both health risks and the risks of wildlife over-exploitation should be based on a robust understanding of the importance of wild meat in terms of its contribution to the food security, cultural value and the livelihoods of many Indigenous Peoples and local communities who depend on it and, more broadly, to national economies. The context in which zoonotic diseases thrive in a wet market can only be understood as part of a reasoned and unbiased examination of hunting, wild meat trade, its use and marketing practices throughout the world.

Introducing and enforcing good hunting practices, hygiene and food safety measures in remote hunting communities and nearby provincial towns in a One Health approach: The application of general principles of food hygiene, such as those described in international Codex texts, will reduce the likelihood that foods and actors involved along the wild meat supply chains become contaminated with any pathogen that might cause foodborne illnesses. This has proven efficient during past Ebola outbreaks to prevent both primary and secondary infections. The uptake of those practices requires a good buy-in of the priority for action by the different actors at all levels of wild meat value chains. Increasing hunters' awareness of the risk of touching and consuming wildlife found dead has proven effective in northern Republic of the Congo (Doshi *et al.*, 2018; Kelly *et al.*, 2017; Kuisma *et al.*, 2019; Munster *et al.*, 2018). However, awareness, although considered necessary for risk communication, especially in a context of information deficit, is not sufficient to result in behaviour change (Alhaji, Yatswako and Oddoh, 2018a). The knowledge-to-practice gap is a major hurdle to overcome to enhance the adoption of food safety practices at all levels of the wild meat value chains. There is empirical evidence that providing education and training, motivating behaviour change and fostering enabling environments for change can lead to improved practices in live markets that reduce environmental pathogen loads and lower health risks, especially if programmes are tailored to target audiences (Dipeolu and Alonso, 2019; Jones *et al.*, 2008; Roesel and Grace, 2014; Shi *et al.*, 2020; Zhou *et al.*, 2018; Wang *et al.*, 2020). The adoption of good practices will also require strengthening the capacities (including facilities) of all actors to use appropriate personal hygiene, regular handwashing, respiratory etiquette, and environmental sanitation at all stages of food processing and preparation.

Risk assessment: Decision-making in relation to the application of the measures mentioned above should be based on a risk-based approach accounting for the likelihood of pathogen spillover outcomes and not just pathogen absence or presence. Such an approach to addressing wildlife trade and consumption, and associated food safety issues, often requires more data and agreement among stakeholders on how to deal with risks. However, it carries with it the advantage of limiting food loss and waste of products that are valuable to society and impacts on nutrition and economics that this waste entails (Barlow *et al.*, 2015). In addition, despite the obstacles, live wildlife and wildlife products intended for food are not necessarily dangerous, or at least do not have to be. Roesel and Grace (2014) demonstrate and emphasise that hazards do not always translate into risks. In this context, it is imperative that more efforts be invested in risk assessment along the wildlife value chains so that interventions can be targeted and prioritised at the points that contribute to the risks and are the most effective at reducing zoonotic risks.

Developing practical approaches to zoonotic risks assessment could be achieved by:

- spatially locating, characterising and mapping key interfaces for zoonotic virus spillover within a given area (e.g. areas with wildlife farming, wildlife trade, bat guano activities and cave mining);
- identifying socio-demographic patterns of the actors engaged in these activities, their reliance on income from them, and their trusted sources of information.

2.2.2. Supporting conservation and restoration of intact ecosystems

In order to decrease human-wildlife-livestock interfaces, there is an urgent need to decrease the fragmentation and degradation of natural ecosystems. The rate of net forest loss is estimated to have been 4.7 million ha per year in 2010–2020 (FAO, 2020b). Of the remaining global forest cover, 70 percent is within 1 km of the forest's edge, subject to the degrading effects of fragmentation (Haddad *et al.*, 2015).

Priority measures to slow the further degradation of habitats, especially forests, should include:

- halting new road opening of intact ecosystems with abundant wildlife;
- restoring fragmented landscapes that still host wildlife such as selectively logged areas;
- promoting land and natural resource tenure regimes that increase community stewardship to ensure a better buy-in of sustainable management measures by communities and their involvement in surveying degradations caused by external actors.

All of these priorities could be addressed in a comprehensive One Health approach to land use planning aimed at reconciling development objectives and mitigation of zoonotic disease risks according to the location of public services, demographic pressures and landscape features that can influence disease patterns and health risks. The geographic targeting of these measures with the objective of disease prevention needs to be explored, especially through modelling.

2.2.3. Research on wildlife pathogens and disease ecology

While several research projects like PREDICT[1] and the Emerging Pandemic Threats (EPT) programme[2] have profiled wildlife-human-livestock interfaces, assessed associated risks and predicted geographic areas with increased spillover risk (Allen *et al.*, 2017), many aspects of wildlife pathogens and disease ecology, including the mechanisms and dynamics involved in pathogen spillover and disease spread, still remain unknown or poorly known. Additional strong investment on research is thus required. To allow for more targeted and proportionate preparedness for, and response to, the next zoonotic disease epidemic, research should primarily focus on: developing practical tools and methods to identify high-risk areas, countries or regions, and to set up efficient surveillance systems; and increasing the knowledge and understanding of all elements determined to be drivers of disease emergence, including identifying countries with low capacity to detect and respond to outbreaks. In this respect, the following research areas are of particular interest to be supported:

- the characterisation of pathogen diversity, in order to develop accurate risk assessment models predicting pathogen transmission to exposed human hosts and animal hosts, and then to develop and implement the most appropriate surveillance, prevention and risk communication strategies;
- the study of the taxonomic and interface-level risk factors that lead to amplification, viral sharing, co-infection and subsequent recombination opportunities of pathogens;

1 https://ohi.vetmed.ucdavis.edu/programs-projects/predict-project
2 http://www.fao.org/3/ca6341en/ca6341en.pdf

- the development of spatio-temporal risk models and scenarios based on epidemiological data, wildlife trade data and wildlife trade chain analyses to test local and national-scale interventions at different points along the wildlife trade value chain and other spillover interfaces.

2.2.4. Strengthening and diversifying local food systems and livelihoods

Decreasing wildlife populations and increasing zoonotic risks highlight the urgent need to support the diversification of the food and income sources of wildlife-dependent communities, in order to both reduce future zoonotic risks and build resilience. Except where hunting is a full-time occupation (Fa, Garcia Yuste and Castelo, 2000), wild meat tends to be the product of a system of farm/forest management that collectively offers high returns directly to the hunters from a range of activities (agriculture, timber and non-timber forest products gathering) (Mendelson, Cowlishaw and Rowcliffe, 2003; Ntiamoa-Baidu, 1998; Brown and Williams, 2003). Where wildlife is scarce, the enforcement of legal and regulatory frameworks relating to wildlife-based food systems to reach sustainable wildlife management may succeed only if wildlife-dependent communities are provided with sufficient, affordable and safe livestock animal source foods (ASF), and alternative sources of income.

In this context, investments should be targeted at developing local ASF systems. Indeed, dependence solely on imported ASF can put communities, especially in remote rural areas and small towns, at risk of increased malnutrition, food starvation and poverty when supply chains are disrupted. Access to affordable and diversified ASF produced locally remains an important nutritional and resilience need for rural and poor urban populations, since they provide a safety net for nutritionally vulnerable groups during times of hunger or crisis (Randolph *et al.*, 2007; Gibson, 2011). Local ASF also represent important economic activities and sources of income for many, generating new employment and entrepreneurial opportunities for women and men.

Different small livestock products can be reared and provide viable alternative sources of ASF for household consumption and income, with low inputs and investments (e.g. bees, poultry, pigs, small ruminants). However, the following key challenges to developing local ASF systems may need to be overcome:

- enabling conditions (e.g. access to inputs, markets and veterinary care) for small-scale profitable breeding enterprises will be extremely variable between countries and sites;
- livestock breeding initiatives can create new types of zoonotic risks (involving livestock as intermediate species) when developed in close proximity to natural habitats;
- access to land and water can be a limiting factor to developing farms in some areas.

This option thus needs to be carefully planned and designed through feasibility studies and pilot projects with local communities, taking into consideration the different opportunities for men and women, and seen as a long-term process. This option may also involve key enabling conditions such as appropriate tenure regimes to ensure easy and secured access to land to initiate community-based, small-scale farming businesses.

Furthermore, introducing livestock into wildlife-dependent communities requires an assessment of the value of wild meat to local livelihoods. The assessment should consider absolute levels of food and income as well as other livelihood issues and the role of wild meat in risk mitigation strategies. In relative terms, the local wild meat trade can be highly inclusive because there are generally few barriers to entry, markets are dominated by the poor, and hunting equipment is generally simple and affordable. Gender equality in wildlife-dependent communities is also positive. Men typically hunt while women are in charge of processing and sales in urban markets and restaurants.

Raising awareness among national and local authorities will be key to ensuring successful implementation of the above-mentioned actions given the long-time frames involved. National development and investment plans should include the needs of these wildlife-dependent communities within national food security and poverty reduction strategies in order to safeguard future human and environmental health.

2.3 Local disease emergence and pandemic: Reduce risks of disease spread by improving epidemic preparedness

Actions to reduce human exposure to potential disease agents in wildlife will reduce the risk of the next zoonotic disease spillover to humans, but it will not completely stop future spillovers. If a spillover occurs that does not result in secondary transmission from human to human (e.g. rabies), then there is little or no risk of an epidemic or pandemic. But if the spillover disease is transmitted efficiently through secondary infection, from human to human, then only robust epidemic preparedness and the capacity to respond rapidly and effectively to a zoonotic disease outbreak will prevent or slow the spread of the disease. For example, the Republic of Korea has demonstrated, in the case of COVID-19, how epidemic preparedness and a speedy and robust response to an outbreak can dramatically reduce both the human and economic toll of an epidemic or pandemic (Tang et al., 2020).

Epidemic preparedness involves taking actions that prepare for, detect, report and respond to disease outbreaks. In the outbreak phase, systems need to be able to detect, assess and report the outbreak. Moreover, contact tracing, quarantine and isolation as well as risk communications, community engagement and behaviour change efforts should be implemented. Importantly, those infected should be cared for and treated.

In the spread phase, health agencies and countries need to publicly declare a disease outbreak and potential epidemic, as well as continue outbreak phase efforts, including physical distancing. At this stage, vaccines should also be developed, if vaccines do not exist.

Two particular aspects of the epidemic preparedness involve the wildlife sector:

Surveillance and reporting (including development of wildlife surveillance systems to monitor circulating pathogens): Early detection of a spillover event is still a key limitation in the ability to provide appropriate and timely response to emerging infectious disease threats. There are still significant gaps in the implementation and maintenance of effective surveillance mechanisms that support early threat identification. While behavioural interventions and policy changes are vital to address the root causes of the risk of spillover and emergence, effective frontline surveillance systems can work to both monitor the impact of interventions and guardrail in case measures have been ineffective or insufficient. Supporting the development of sustainable national wildlife disease surveillance programmes is, therefore, an essential ingredient in a country's preparedness for, and response to, future zoonotic disease epidemics.

With respect to the particular case of wild bird-related zoonotic diseases in sub-Saharan Africa, it has been shown that gaps in epidemiological knowledge and within-country surveillance preclude definitive inferences about the geographical/spatial and temporal pattern of avian influenza virus infection (Khomenko *et al.*, 2018). Better surveillance of waterfowl at the crossroads of migratory flyways to wintering areas would inform on epidemiological risk and provide early warning of specific highly pathogenic avian influenza (HPAI) threats to poultry, and potentially human, health (Lycett *et al.*, 2016).

Building national and regional capacities in all aspects relevant to the effective implementation of a One Health approach: To address issues at human-wildlife-livestock-ecosystem interface and risk factors for emerging/future pandemics through the One Health approach, technical representatives (e.g. from Ministries of Health and Agriculture/Veterinary Services, Forestry, Wildlife, Rural Development, Environment, Livestock and Trade) and relevant professions (e.g. ecologists, biologists, veterinarians and physicians) need to be trained in the approach and on research, risks assessment, surveillance and reporting. Cross-sectoral executive training is also needed at the national and regional levels to support regional integration where relevant.

2.4 Geographic targeting of interventions

Overseas Development Aid for epidemic preparedness and spillover risk reduction should be:

a) targeted at the relatively small set of countries assessed as having a high risk of wildlife disease spillover and that rank lowest in the World Bank's epidemic preparedness assessment (Madhav *et al.*, 2017);

b) provided at a monetary scale sufficient to put in place the public health infrastructure needed to rapidly and effectively respond to the next zoonotic disease outbreak (Madhav *et al.*, 2017).

Without this targeted investment, there is a significant risk that the next zoonotic spillover, with secondary transmission from human-to-human, will become an epidemic or pandemic. The following criteria can be used to assess whether there is a high risk of a country experiencing a wildlife disease spillover:

- high levels of interactions between wildlife, livestock and people;
- many degraded or at-risk (deforested) ecosystems;
- dependency on wild meat as a protein-source food and live animal markets;
- limited control of wildlife trade.

3. Sustainable Wildlife Management Programme contribution

3.1 Regionally and nationally applicable models and tools

The Sustainable Wildlife Management (SWM) Programme aims to improve wildlife conservation and the food security of rural communities that rely on wild meat. This will be achieved by:

- improving how wildlife hunting is regulated;
- building governance and management capacities for sustainable subsistence hunting/fishing of Indigenous People and local communities;
- supporting the diversification and supply of local and safe animal-sourced foods;
- reducing demand for wild meat, particularly in towns and cities.

To this end, the SWM Programme is developing and testing tools and practices at eight field sites (SWM sites) in 13 different countries (Chad, Democratic Republic of the Congo, Egypt, Gabon, Guyana, Madagascar, Mali, Papua New Guinea, Republic of the Congo, Senegal, Sudan, Zambia and Zimbabwe), encompassing a range of management settings and animal-based product value chains. The SWM Programme aims to develop innovative models for wildlife management and human development that can be replicated and upscaled elsewhere.

The SWM Programme objectives, hypotheses and social safeguards already consider various aspects that are relevant to address zoonotic risks associated with wildlife and wild meat.

3.1.1. A community rights-based approach and social safeguards

The SWM Programme has been designed and is implemented following a community-rights-based approach (CRBA) and other social safeguards. The CRBA puts people's rights at the centre of wildlife management, ensuring that a suitable balance can be found between conservation and the use of wildlife resources for food security and nutrition.

To achieve this objective, the CRBA emphasises the importance of public participation and consultation, and focuses on the rights of excluded, marginalised and most-at-risk individuals and groups. All of this is central to understanding the role of culture, power dynamics, and responsible governance to ensure that no one is left behind, especially in the development of intersectoral regulation. For example, the SWM Guyana project ensures that local, sustainable use of wildlife activities, which are initiated and led by local leaders on Indigenous-titled lands, are supported by institutions and regulations at the national level. The integration of these two levels is achieved through information sharing, capacity building, platforms and agreements that allow for the participation of people and communities in the development of policies and regulations.

The consideration of not only the strengthening of the technical/regulatory aspects, but also the process of technical/legislative review and implementation helps increase ownership and buy-in by those who will apply those regulations. Efforts to promote best practices along the wild meat value chains will thus have stronger and longer-term benefits. This will be of particular interest to ensure the uptake of better practices related to food safety or other aspects contributing to reduce the risks of disease spillover.

3.1.2. Wildlife value chains – from bush to bowl: Building management models and tools that integrate ecological, cultural, socio-economic and zoonotic risks

The SWM Programme aims to improve the understanding of the wild meat sector and raise awareness of the importance of this sector to the poor. By applying a value chain approach from the hunter to the consumer, or from "bush to bowl", the SWM Programme could support the identification of food safety and disease spillover risks and formulate conditions for integrated wildlife management. Value chain analyses (VCAs) are used to analyse the technical, institutional and financial dimensions of the wild meat sector (hunting, transport, sale and consumption). The approach identifies the actors involved in the trade, the structure of the market and the distribution of benefits (and power), and pinpoints areas where disease spillover risks could occur. It will thus contribute to identifying food safety issues and zoonotic risks in order to better manage the slaughtering, processing and handling of wild meat. Pragmatic solutions are needed, given that testing all wild meat for pathogens is impossible and it is not possible to be 100 percent sure which animal viruses pose a real threat to humans. Accordingly, the SWM Programme focuses on:

- training hunters and other wild meat processors to minimise their exposure to diseases;
- promoting efficient ways to preserve (cook, smoke or dry) meat to render potential pathogens harmless;
- supporting regular health inspections along the value chain.

3.1.3. Behaviour changes

The SWM Programme emphasises the importance of reducing consumer demand for wildlife in urban areas where wildlife is not a dietary necessity. Social marketing campaigns are being designed to shift consumer demand away from wild meat to sustainably produced livestock and farmed fish. Targeted social marketing in Pointe-Noire, Republic of the Congo has been effective in shifting consumers away from eating wildlife while reinforcing consumers' sense of what it means to be Congolese (J. Wright, pers. com.). The SWM Programme aims to learn from these experiences and develop locally appropriate campaigns at SWM sites in order to:

- reduce the amount of wild meat consumed in towns and cities, and in turn the potential exposure of urban dwellers to pathogens in wild meat;

- define and promote practical solutions that can be replicated in other OACPS countries around the world;
- raise awareness of these issues among policymakers, government staff and implementing agencies.

3.1.4. A local approach to strengthen food systems and food security

In most tropical forest areas, the only available local, animal-based food products come from the forest and rivers (i.e. wild meat and fish). Local livestock production is limited. In contrast, in most savannah areas, the production of livestock has evolved over time, and local food security incorporates both wild sources of animal food and livestock. With increased market access and political support, many of these regions are now flooded with cheap, industrially produced, imported animal-based food products that are of lower nutritional value (Amuna and Zotor, 2008).

Fragmentation has dramatically increased access to wild habitats, allowing hunters to supply distant markets with wildlife products, sometimes putting unsustainable pressure on wildlife populations, particularly where no food and income alternatives exist. In contrast, where there is access to international markets, pressure on wildlife has decreased or remained stable, but the transition from traditional food systems to industrialised food systems has caused and continues to cause severe impacts on people's health (Bosu, 2015; de Jesus Silva *et al.* 2017; Piperata *et al.* 2011; Piperata *et al.* 2011; Vorster, Kruger and Margetts, 2011).

The SWM Programme supports the diversification of animal-based food products, including the supply of locally produced sustainable livestock and farmed fish, and wild meat/fish coming from sustainable use designated areas. The balance between different sources of animal-based products differs between SWM sites depending on the social, economic and ecological context. For example, in Republic of the Congo and the Democratic Republic of the Congo, the SWM Programme aims to increase the supply of sustainably farmed and healthy livestock and farmed fish in large, expanding provincial towns in order to reduce the pressures on wildlife. In Gabon and Guyana, two countries with low human population densities, SWM supports the development of a legal, safe and sustainable wild meat trade as part of a diversified food system. In both scenarios, food safety aspects are considered to ensure compliance with safe and nutritious food standards.

©Brent Stirton-Getty Images for FAO, CIFOR, CIRAD, WCS

3.2 Strengthening the legal and institutional framework

3.2.1. Effective advocacy on policy and legal frameworks

Supporting legal reform processes that are participatory and tailor-made for the country, and that respect its legal tradition, is complex. Ensuring effective implementation and enforcement of legislation poses even greater challenges, especially when the people and places are distant from centres of national or local government. However, the SWM Programme partnership (i.e. one inter-governmental organisation, two research centres and an NGO) is well structured to offer effective support to governments to strengthen legal and institutional frameworks. The SWM partnership is also well placed to provide constructive engagement and dialogue at different levels and in different forms with the national stakeholders (e.g. including government, civil society and academia). The government focal points in each SWM Programme country are an important entry point to raise awareness about this kind of support in different ministries and agencies.

3.2.2. Participatory and evidence-based learning to strengthen policy, legal and institutional frameworks

The SWM Programme has developed a variety of tools and methodologies to facilitate the assessment of existing legislation and the formulation of appropriate legislative responses. Five diagnostic tools, which are founded on a community rights-based approach, have been developed to:

- assess the structural consistency of the statutory law framework;
- assess the compliance with international conventions and guidelines;
- analyse the consistency across sectoral legislations and identify potential gaps;
- understand the relationship between statutory and customary law;
- assess the degree to which laws are implemented and enforced.

These SWM Programme tools help identify gaps and inconsistencies between sectoral legislation and the implementation of international treaties. They can also be used to identify disconnects between statutory law and customary law, and current practices that result in a weak implementation. The tools can be used to develop a comprehensive understanding of current legislation (and its strengths and weaknesses) as a basis for a review or revision of normative frameworks. In addition, the findings from the SWM field projects will provide needed data, knowledge and evidence to support these processes.

New tools and methodologies could be added to the set of tools to improve the review and revision of food security and human/animal health-related legislation, as part of the One Health approach to strengthen public health and help reduce future wildlife-borne spillover of disease to humans.

3.3 Knowledge management and information systems to guide decision-making

The SWM Programme is organised both geographically (SWM sites) and in thematic results (SWM results), as follows:

- Result 1 (R1): Legal and regulatory framework
- Result 2 (R2): Sustainable hunting and fishing
- Result 3 (R3): Alternative protein supply
- Result 4 (R4): Sustainable consumption
- Result 5 (R5): Monitoring, evaluation and learning
- Result 6 (R6): Knowledge management.

New information and knowledge are generated by the SWM site teams and by the SWM result teams. The result teams support the site teams with methodological recommendations and data management tools. Information systems at the SWM sites are based on tools (e.g. KoBoToolbox) that enable simple and standardised data acquisition, automated processing and aggregation of indicators. Decision-making is underpinned by an adaptive management approach, theory of change models and associated indicators.

This SWM knowledge management system is well suited to design, generate and integrate pilot health surveillance data flows into national preparedness systems and cross-sectoral risk assessments, feed alert systems, and develop information services to guide decision-making. In this respect, working at both field and national levels at the interface of multiple sectors, the SWM Programme is well positioned to assess and address issues related to data access for timely decision-making, that are a major barrier to an efficient One Health implementation.

In this respect, the field methods and tools developed and tested by the SWM programme to assess wildlife-based food systems (hunting practices, commodity chain analyses, consumption behaviour, etc.) across contrasting socio-ecosystems provide a valuable source of information and knowledge needed by the stakeholders of the One Health sector. As part of the One Health integration process, a participatory epidemiological surveillance approach associating the local stakeholders involved in the wild meat sector will be designed and tested within SWM sites.

The issues addressed by the SWM programme are cross-cutting; hence, the intervention sites contribute to the strengthening of intersectoral dialogue and cooperation at both local (intervention sites) and national levels. At the local level, the programme facilitates stakeholder platforms involving decentralised state services of multiple sectors. At the national level, the programme provides support in various forms, for example in Gabon through support and participation in inter-ministerial thematic working groups (hunting, marketing and health) involving technicians and lawyers. Data collected in the field provide first-hand information to inform decision-making at both local and national levels.

3.4 Opportunities for extended contributions

The SWM Programme is well positioned to develop and support strategies at the human–wildlife interface to strengthen preparedness, prevention and response to future zoonotic disease outbreaks, provided additional funding can be made available.

3.4.1. One Health surveillance at SWM sites

A One Health surveillance approach combines:

a) the characterisation of the modalities and networks of contacts between wildlife, livestock and humans at different interfaces;

b) the assessment of interspecies transmission risk based on contacts and behaviours;

c) the establishment of user-centred surveillance and early warning systems for wildlife health events to be developed together with local and national stakeholders, including local communities and hunters;

d) the collection of samples and testing to identify the most frequent zoonoses that are locally present;

e) the integration of the field data into national preparedness systems and cross-sectoral risk assessments.

Significant work has been carried out during the past 20 years on participatory health surveillance (e.g. in the context of Ebola) as well as along animal value chains and markets (linked with high-impact animal diseases such as avian influenza and African swine fever) (Calba *et al.*, 2016, 2015; Delabouglise *et al.*, 2015; Goutard *et al.*, 2015). Collaboration and the exchange of tools and strategies among disciplines and countries should be promoted. One key area of interest in the context of the SWM Programme for these cross-disciplinary exchanges includes the mapping and characterisation of wild animal or meat value chains to develop targeted risk reduction strategies (Baudon *et al.*, 2017).

For over a decade, SWM partners in close collaboration with national authorities have helped build wildlife health surveillance and early disease detection systems to allow for timely response to outbreaks of Ebola and other emerging high-impact pathogens, including those with pandemic potential (MERS-CoV, avian influenza) (Funk *et al.*, 2016). Traditional hunters are well aware of the health status of the animals they hunt and can therefore provide actionable intelligence on wildlife disease event occurrence to public and animal health agencies (Schulz *et al.*, 2016). These approaches can be replicated and strengthened across all SWM sites.

Building on the multi-disciplinary monitoring teams set up during the 2006 avian influenza crisis, existing waterbird monitoring systems and mechanisms (e.g. International Waterbird Census coordinated by Wetlands International with support from the SWM Programme/RESSOURCE Project) could be used to develop and/or test procedures to monitor wild waterbird populations and avian zoonotic diseases (avian influenza). Routine virus surveillance in wild birds used as sentinels, particularly migratory waterfowl, could offer an efficient early warning system. In addition, waterbirds also play a role as bio-indicators for the health of wetlands (Green and Elmberg, 2013; Newman *et al.*, 2007). Setting up or strengthening waterbird monitoring by local communities by promoting adapted tools and methods can also play an important role in addressing the environmental drivers of zoonotic risks. Finally, describing major waterbird markets and value-chains could contribute to identifying/mapping risk areas for spillover of bird-related zoonotic diseases; this would be particularly relevant in Mali (Inner Niger Delta) and Chad (Fitri Lake).

Setting up these wildlife field surveillance and reporting systems will have an immediate positive and boosting effect on national epidemic preparedness. In addition, these systems offer opportunities to collect samples over a relatively long period of time and at different sites during this process to contribute to research on wildlife pathogens and risk assessment carried out by potential research partners.

3.4.2. Developing tools to predict zoonotic risk

In partnership with the University of Malaga (UMA), SWM partners will use biogeographic modelling to understand the occurrence of diseases affecting wildlife, livestock and humans. The first phase will focus on two specific SWM areas and diseases (Ebola-virus disease outbreaks in Gabon and West Nile fever in the Sahel). This work will provide models that could be adapted/extrapolated to other human-wildlife-livestock interface disease situations in other SWM sites and extended to other ACP countries in a second phase. These models will ultimately serve as a basis for predictive tools that can support decision-making in development planning, and policy and regulation reforms that address zoonotic disease prevention and mitigation (Mangiarotti *et al.*, 2020, 2016, Paul *et al.*, 2016; Tran and Roger, 2018).

3.4.3. Capacity building for One Health implementation

Information, training and capacity building for all stakeholders involved at the SWM sites to address priorities proposed above. The topics targeted would include:

- One Health and integrated health approaches;
- disease ecology;
- food safety and personal protection;
- wildlife health event investigation and reporting;
- risk assessment, management and mitigation;
- crisis management in a context of sustainable exploitation of wild animal populations/development of livestock production in vulnerable habitats in transformation.

Addressing the capacity gaps of the One Health approach within the Ministries of Forestry and Wildlife: To date, from a global to a national level, the One Health approach is still largely dominated by the medical and veterinary professions with significantly less engagement and contribution by the natural resources management professionals working on ecosystems, biodiversity and wildlife. One Health also focuses predominately on zoonotic disease surveillance, diagnosis and response, but does not address upstream work to prevent disease emergence. Finally, in-service, professional training programmes are in place for Ministries of Health and Veterinary Services, but there is currently no in-service training programme for the Ministries of Wildlife, Forestry and Natural Resources Management to support One Health work related to prevention, surveillance and response.

In order for the One Health approach to truly move further upstream from early detection of spillover pathogens, and to be able to appropriately prevent pandemics and prevent the emergence of infectious diseases, there is a need to invest in capacity development to foster biodiversity considerations in the One Health approach, notably by:

a) building the capacities of forestry, wildlife, and natural resource management government sectors to allow proper engagement in One Health programming and implementation, with emphasis on preventing the next pandemic. The natural resources managers at the national level need to be trained on how to play an essential and vital role in the One Health approach. To achieve this, and based on an assessment of knowledge gaps, a training programme could be developed to build the capacities of natural resources managers in One Health, focusing on actions addressing the main risk factor categories on which the forestry, wildlife and environment sectors should have a leading role:
    - Preventing encroachment via land use planning
    - Addressing climate change & water management
    - Preserving and restoring habitat, biodiversity & ecosystems
    - Improving management of wildlife farming & wildlife trade as food/pets/display animals.

b) developing and strengthening the capacities of traditional One Health stakeholders (e.g. public and animal health) on links with forestry, habitat degradation, climate change, ecosystem and biodiversity loss, and disease emergence.

c) carrying out joint trainings with the actors of the forestry, wildlife and environment, animal health and human health sectors on how to address these areas together:
    - Facilitating sustainable, climate-smart, ecofriendly agricultural development
    - Contributing to Food Safety along wildlife value chains, especially informal trade & markets.

3.4.4. Assessing, renovating and expanding the One Health approach for improved institutional coordination

All the work carried out as part of the above priorities would be linked to in-country One Health platforms, zoonotic disease steering committees or other One Health mechanisms in place. The aim is to enable cross-sectoral collaboration, information sharing and the development of joint press releases, fact sheets and recommendations regarding the findings. Implementing an integrated, all-society approach to health is essential to foster early warning and build resilience. Decision-making mechanisms are complex and influenced by strong socio-economic drivers (Delabouglise *et al.*, 2017). Challenges increase for inter-sectorial decision-making approaches. Early detection programmes for zoonotic or other high-impact diseases have the greatest impact when they bring about immediate and targeted action to prevent spillover and further disease spread and provide early warning for the pandemic potential of pathogens.

There is an urgent need to carefully assess the current One Health country programmes in order to: (i) highlight gaps in One Health programming; (ii) ensure that natural resource management and wildlife sectors are adequately represented in One Health programming, coordination and other mechanisms; and (iii) facilitate expansion of national One Health programmes to be inclusive of drivers of disease emergence and measures to prevent future disease emergence. This assessment through the “natural resource management lens” goes beyond the current One Health assessments, including the Joint External Evaluation supporting Global Health Security and the International Health Regulations, and requires an innovative One Health assessment that moves into the context of preparedness and prevention, rather than focusing on detection and response. Such a tool could be developed and tried out in SWM countries, then rolled out to other countries.

References

Abernethy, K.A., Coad, L., Taylor, G., Lee, M.E. & Maisels, F. 2013. Extent and ecological consequences of hunting in Central African rainforests in the twenty-first century. *Philosophical Transactions of the Royal Society of London B. Biological Sciences,* 368:20120303.

Aguirre, A.A. & Tabor, G.M. 2008. Global Factors Driving Emerging Infectious Diseases: Impact on Wildlife Populations. *Annals of the New York Academy of Sciences,* 1149:1–3.

Alhaji, N., Yatswako, S. & Oddoh, E. 2018a. Knowledge, risk perception and mitigation measures towards Ebola virus disease by potentially exposed bushmeat handlers in north-central Nigeria: Any critical gap? *Zoonoses and Public Health,* 65:158–167.

Alhaji, N.B., Yatswako, S. & Oddoh, E.Y. 2018b. Knowledge, risk perception and mitigation measures towards Ebola virus disease by potentially exposed bushmeat handlers in north-central Nigeria: Any critical gap? *Zoonoses and Public Health,* 65.

Allen, T., Murray, K.A., Zambrana-Torrelio, C., Morse, S.S., Rondinini, C., Di Marco, M., Breit, N., Olival, K.J. & Daszak, P. 2017. Global hotspots and correlates of emerging zoonotic diseases. *Nature communications,* 8:1–10.

Altizer, S., Ostfeld, R.S., Johnson, P.T., Kutz, S. & Harvell, C.D. 2013. Climate change and infectious diseases: from evidence to a predictive framework. *Science,* 341:514–519.

Amuna, P., & Zotor, F. 2008. Epidemiological and nutrition transition in developing countries: Impact on human health and development: The epidemiological and nutrition transition in developing countries: Evolving trends and their impact in public health and human development. *Proceedings of the Nutrition Society,* 67:82–90.

Andersen, K.G., Rambaut, A., Lipkin, W.I., Holmes, E.C. & Garry, R.F. 2020. The proximal origin of SARS-CoV-2. *Nature Medicine,* 26:450–45.

Antunes, A.P., Fewster, R.M., Venticinque, E.M., Peres, C.A., Levi, T., Rohe, F. & Shepard, G.H. 2016. Empty forest or empty rivers? A century of commercial hunting in Amazonia. *Science Advances,* 2:e1600936.

Bachand, N., Ravel, A., Onanga, R., Arsenault, J.& Gonzalez, J-P. 2012. Public health significance of zoonotic bacterial pathogens from bushmeat sold in urban markets of Gabon, Central Africa. *Journal of wildlife diseases,* 48:785–789.

Balogun, E.O., Nok, A.J., Kita, K. 2016. Global warming and the possible globalization of vector-borne diseases: a call for increased awareness and action. *Tropical Medicine and Health,* 44:38.

Barlow, S.M., Boobis, A.R., Bridges, J., Cockburn, A., Dekant, W., Hepburn, P., Houben, G.F., König, J., Nauta, M.J. & Schuermans, J. 2015. The role of hazard-and risk-based approaches in ensuring food safety. *Trends in Food Science & Technology,* 46:176–188.

Bauch, S.C., Birkenbach, A.M., Pattanayak, S.K. & Sills, E.O. 2015. Public health impacts of ecosystem change in the Brazilian Amazon. Proceedings of the National Academy of Sciences, 112:7414–7419.

Baudon, E., Fournié, G., Hiep, D.T., Pham, T.T.H., Duboz, R., Gély, M., Peiris, M., Cowling, B.J., Ton, V.D., Peyre, M., 2017. Analysis of Swine Movements in a Province in Northern Vietnam and Application in the Design of Surveillance Strategies for Infectious Diseases. *Transboundary and Emerging Diseases,* 64:411–424.

Bekker, J.L., Jooste, P.J. & Hoffman, LC. 2012. Wildlife-associated zoonotic diseases in some southern African countries in relation to game meat safety: A review. *Onderstepoort Journal of Veterinary Research,* 79:1–12.

Bertran, K., Balzli, C., Kwon, Y.-K., Tumpey, T.M., Clark, A. & Swayne, D.E. 2017. Airborne transmission of highly pathogenic influenza virus during processing of infected poultry. *Emerging Infectious Diseases,* 23:1806.

Beugnet, F. & Chalvet-Monfray, K. 2013. Impact of climate change in the epidemiology of vector-borne diseases in domestic carnivores. *Comparative Immunology, Microbiology and Infectious Diseases.* 36:559–566.

Bloomfield, L.S.P., McIntosh, T.L. & Lambin, E.F. 2020. Habitat fragmentation, livelihood behaviors, and contact between people and nonhuman primates in Africa. *Landscape Ecology.* 35:985–1000.

Bosu, W.K. 2015. An overview of the nutrition transition in West Africa: implications for non-communicable diseases. *Proceedings of the Nutrition Society.* 74:466–477.

Brown, D. & Williams, A. 2003. The case for bushmeat as a component of development policy: issues and challenges. *International Forestry Review,* 5:148–155.

Calba, C., Goutard, F.L., Vanholme, L., Antoine-Moussiaux, N., Hendrikx, P. & Saegerman, C. 2016. The Added-Value of Using Participatory Approaches to Assess the Acceptability of Surveillance Systems: The Case of Bovine Tuberculosis in Belgium. *PLOS ONE* 11:e0159041.

Calba, C., Antoine-Moussiaux, N., Charrier, F., Hendrikx, P., Saegerman, C., Peyre, M. & Goutard, F.L. 2015. Applying participatory approaches in the evaluation of surveillance systems: A pilot study on African swine fever surveillance in Corsica. *Preventive Veterinary Medicine.* 122:389–398.

Caldecott, J. 1988. *Hunting and wildlife management in Sarawak*. World Wildlife Fund, Washington, D.C.

Caminade, C., McIntyre, K.M. & Jones, A.E. 2019. Impact of recent and future climate change on vector-borne diseases. *Annals of the New York Academy of Sciences* 1436: 157–173.

Can, Ö.E., D'Cruze, N. & Macdonald, D.W. 2019. Dealing in deadly pathogens: Taking stock of the legal trade in live wildlife and potential risks to human health. *Global Ecology and Conservation,* 17:e00515.

Carder, G., Lambert, H.S., Schmidt-Burbach, J. & D'Cruze, N. 2016. The animal welfare implications of civet coffee tourism in Bali. *Animal Welfare,* 25:199–205.

Cascio, A., Bosilkovski, M., Rodriguez-Morales, A.J., Pappas, G. 2011. The socio-ecology of zoonotic infections. *Clinical Microbiology and Infection,* 17:336–342.

CBD. 2009. Report of the Liaison Group Meeting on Bushmeat. Liaison Group on Bushmeat First Meeting, Buenos Aires, 15-17 October 2009.

CDC. 2003. Prevalence of IgG Antibody to SARS-Associated Coronavirus in Animal Traders --- Guangdong Province, China, MMWR reported by D. Yu, M.D., H. Li, R. Xu, M.P.H., J. He, J. Lin, L. Li, W. Li, H. Xu, S. Huang & J. Huang, October 17, 2003. 52:986–987.

Challender, D.W.S., Sas-Rolfes, M., Ades, G.W.J., Chin, J.S.C., Sun, N.C.-M., Chong, J.L., Connelly, E. *et al*. 2019. Evaluating the feasibility of pangolin farming and its potential conservation impact. *Global Ecology and Conservation,* 20:e00714.

Chang, S.L., Harding, N., Zachreson, C., Cliff, O.M. & Prokopenko, M. 2020. Modelling transmission and control of the COVID-19 pandemic in Australia. *Nature Communications*.

Coad, L., Fa, J.E., Abernethy, K., van Vliet, N., Santamaria, C., Wilkie, D., El Bizri, H.R., Ingram, D.J., Cawthorn, D.-M. & Nasi, R. 2018. Towards a sustainable, participatory and inclusive wild meat sector. Bogor, Indonesia, CIFOR, 216 pp.

Collignon, P. & Beggs, J. J. 2020, preprint. Covid-19 Fatality Risk: Why Is Australia Lower Than South Korea? In: medRxiv: The preprint server for health sciences [online]. [Cited 12 October 2020]. https://doi.org/10.1101/2020.05.14.20101378

Corlett, R.T. 2007. The Impact of Hunting on the Mammalian Fauna of Tropical Asian Forests. *Biotropica,* 39:292–303(212).

Cowlishaw, G., Mendelson, S. & Rowcliffe, J.M. 2005. Evidence for post-depletion sustainability in a mature bushmeat market. *Journal of Applied Ecology,* 42:460–468 (469).

de Jesus Silva, R., Garavello, M. E. D. P. E., Nardoto, G. B., Mazzi, E. A., & Martinelli, L. A. 2017. Factors influencing the food transition in riverine communities in the Brazilian Amazon. *Environment, Development and Sustainability,* 19:1087–1102.

Delabouglise, A., Dao, T.H., Truong, D.B., Nguyen, T.T., Nguyen, N.T.X., Duboz, R., Fournié, G. *et al*. 2015. When private actors matter: Information-sharing network and surveillance of Highly Pathogenic Avian Influenza in Vietnam. *Acta Tropica* 147:38–44. https://doi.org/10.1016/j.actatropica.2015.03.025

Dirzo, R. & Miranda, A. 1990. Contemporary neotropical defaunation and forest structure, function, and diversity – A sequel. *Conservation Biology,* 4:444–447.

Dirzo, R., Young H.S., Galetti M., Ceballos G., Isaac N.J. & Collen B. 2014. Defaunation in the Anthropocene. *Science,* 345:401–406.

Doshi, R.H., Guagliardo, S.A.J., Dzabatou-Babeaux, A., Likouayoulou, C., Ndakala, N., Moses, C., Olson, V., McCollum, A.M. & Petersen, B.W. 2018. Strengthening of surveillance during monkeypox outbreak, Republic of the Congo, 2017. *Emerging Infectious Diseases,* 24:1158.

Dunn, R.R., Davies, J.T., Harris, N.C., Gavin, M.C. 2010. Global drivers of human pathogen richness and prevalence. *Proceedings of the Royal Society B,* 277:2587–2595.

El Bizri, H.R., Morcatty, T.Q., Valsecchi, J., Mayor, P., Ribeiro, J.E., Vasconcelos Neto, C.F., Oliveira, J.S., Furtado, K.M., Ferreira, U.C. & Miranda, CF. 2020. Urban wild meat consumption and trade in central Amazonia. *Conservation Biology,* 34:438–448.

Epstein, P.R. 2001. Climate change and emerging infectious diseases. *Microbes and Infection* 3:747-754.

Evans, T., Olson, S., Watson, J., Gruetzmacher, K., Pruvot, M., Jupiter, S., Wang, S., Clements, T. & Jung, K. 2020. Links between ecological integrity, emerging infectious diseases originating from wildlife, and other aspects of human health – An overview of the literature. New York, USA.

Fa, J.E., Curriem D. & Meeuwig, J. 2003. Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future. *Environmental Conservation,* 30:71–78.

Fa, J.E., Olivero, J., Farfan, M.A., Marquez, A.L., Duarte, J., Nackoney, J., Hall, A., Dupain, J., Seymour, S. & Johnson, P.J. 2015. Correlates of bushmeat in markets and depletion of wildlife. *Conservation Biology,* 29:805–815.

Fa, J.E., Wright, J.H., Funk, S.M., Márquez, A.L., Olivero, J., Farfán, M.Á., Guio, F., Mayet, L., Malekani, D. & Louzolo, C.H. 2019. Mapping the availability of bushmeat for consumption in Central African cities. *Environmental Research Letters,* 14:094002.

Fa, J.E., Garcia Yuste, J.E. & Castelo, R. 2000. Bushmeat markets on Bioko Island as a measure of hunting pressure. *Conservation Biology,* 14:1602–1613.

FAO. 2015. Biosecurity guide for live poultry markets. FAO Animal Production and Health Guidelines No. 17. Rome.

FAO. 2016. Responsible governance of tenure and the law. A guide for lawyers and other legal service providers. Governance of tenure - Technique guide No.5. Rome. 136 pp.

FAO. 2018. Addressing Zaire Ebolavirus (ebov) outbreaks: Qualitative entry and exposure assessment update. Animal health risk analysis – Assessment No.6. Rome.

FAO. 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp.

FAO. 2020a. Exposure of humans or animals to SARS-Cov-2 from wild, livestock, companion and aquatic animals: Qualitative risk assessment. Rome. 88 pp.

FAO. 2020b. *Global Forest Resources Assessment 2020 – Key findings*. Rome. https://doi.org/10.4060/ca8753en

FAO & WHO. 2009. *Codex Alimentarius*: food hygiene (Basic texts). Fourth edition. Rome. 136 pp.

FAO, OIE & WHO. 2018. Conducting national joint risk assessment – a tripartite operational tool. Rome.

Friant, S., Paige, S.B. & Goldberg, T.L. 2015. Drivers of bushmeat hunting and perceptions of zoonoses in Nigerian hunting communities. *PLoS Neglected tropical diseases* 9.

Funk, A.L., Goutard, F.L., Miguel, E., Bourgarel, M., Chevalier, V., Faye, B., Peiris, J.S.M., Van Kerkhove, M.D., Roger, F.L. 2016. MERS-CoV at the Animal–Human Interface: Inputs on Exposure Pathways from an Expert-Opinion Elicitation. *Frontiers in Veterinary Science,* 3.

Gao, X.-L., Shao, M.-F., Luo, Y., Dong, Y.-F., Ouyang, F., Dong, W.-Y. & Li, J. 2016. Airborne bacterial contaminations in typical Chinese wet market with live poultry trade. *Science of The Total Environment,* 572:681–687.

Gbogbo, F., Rainhill, J.E., Koranteng, S.S., Owusu, E.H. & Dorleku, W.-P. 2019. Health Risk Assessment for Human Exposure to Trace Metals Via Bushmeat in Ghana. Biological Trace Element Research.

Gibson, R.S. 2011. Strategies for Preventing Multi-micro nutrient Deficiencies: a Review of Experiences with Food-based Approaches in Developing Countries. In: Thompson, B. & Amoroso, L. (eds). (eds). *Combating micronutrient deficiencies: food-based approaches*. Pp. 7-27. Rome, FAO, and Wallingford, UK, CABI.

Giles, J.R., Eby, P., Parry, H., Peel, A.J., Plowright, R.K., Westcott, D.A. & McCallum, H. 2018. Environmental drivers of spatiotemporal foraging intensity in fruit bats and implications for Hendra virus ecology. *Scientific Reports,* 8:1–18.

Gill, C. 1998. Microbiological contamination of meat during slaughter and butchering of cattle, sheep and pigs. The microbiology of meat and poultry. London, Blackie Academic and Professional:118–157.

Gortazar, C., Reperant, L.A., Kuiken, T., de la Fuente, J., Boadella, M., Martínez-Lopez, B., Ruiz-Fons, F., Estrada-Peña, A., Drosten, C. & Medley, G. 2014. Crossing the interspecies barrier: Opening the door to zoonotic pathogens. *PLoS Pathogens,* 10.

Goutard, F.L., Binot, A., Duboz, R., Rasamoelina-Andriamanivo, H., Pedrono, M., Holl, D., Peyre, M.I. *et al*. 2015. How to reach the poor? Surveillance in low-income countries, lessons from experiences in Cambodia and Madagascar. *Preventive Veterinary Medicine* 120:12–26. https://doi.org/10.1016/j.prevetmed.2015.02.014

Grace, D., Dipeolu, M. & Alonso, S. 2019. Improving food safety in the informal sector: nine years later. *Infection Ecology & Epidemiology* 9:1579613.

Greatorex, Z.F., Olson, S.H., Singhalath, S., Silithammavong, S., Khammavong, K., Fine, A.E., Weisman, W., Douangngeun, B., Theppangna, W. & Keattsk L. 2016. Wildlife trade and human health in Lao PDR: an assessment of the zoonotic disease risk in markets. *PLOS ONE* 11.

Grewe, P.M., Patil, J.G., McGoldrick, D.J., Rothlisberg, P.C., Whyard, S., Hinds, L.A., Hardy, C.M., Vignarajan, S. & Thresher, R.E. 2007. Preventing Genetic Pollution and the Establishment of Feral Populations: A Molecular Solution. In: Bert T.M. (eds). *Ecological and Genetic Implications of Aquaculture Activities. Methods and Technologies in Fish Biology and Fisheries*, Vol 6. Springer, Dordrecht.

Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Hol, R.D., Lovejoy, T.E. *et al*. 2015. Habitat fragmentation and its lasting impact on earth's ecosystems. *Science advances,* 1:e1500052

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, A., Thau, D., Stehman, V. *et al*. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science,* 342:850–853

Hautefeuille, C., Dauphin, G. & Peyre, M. 2020. Knowledge and remaining gaps on the role of animal and human movements in the poultry production and trade networks in the global spread of avian influenza viruses – A scoping review. *PLOS ONE,* 15:e0230567

Hofmann, T., Ellenberg, H. & Roth, H.H. 1999. Bushmeat: A natural resource of the moist forest regions of West Africa. With particular consideration of two duiker species in Côte d'Ivoire and Ghana. Tropenökologisches Begleitprogramm (TÖB) publication F-V/7e. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn

Huang, Y., Tu, M.. Wang, S., Chen, S., Zhou, W., Chen, D., Zhou, L., Wang, M., Zhao, Y. & Zeng, W. 2020. Clinical characteristics of laboratory confirmed positive cases of SARS-CoV-2 infection in Wuhan, China: A retrospective single center analysis. Travel medicine and infectious disease.

IUCN. 2020. The IUCN red list of threatened species. Version 2020-2. https://www.iucnredlist.org. Downloaded on 09 June 2020.

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: 990–993.

Kamins, A.O., Rowcliffe, J.M., Ntiamoa-Baidu, Y., Cunningham, A.A., Wood, J.L &, Restif, O. 2015. Characteristics and risk perceptions of Ghanaians potentially exposed to bat-borne zoonoses through bushmeat. *EcoHealth,* 12:104–120.

Karesh, W.B., Dobson, A., Lloyd-Smith, J.O., Lubroth, J., Dixon, M.A., Bennet, M., Aldrich, S., Harrington T., Formenty, P. & Loh, E.H. 2012. Ecology of zoonoses: Natural and unnatural histories. *The Lancet,* 380:1936–1945.

Kelly, T.R., Karesh, W.B., Johnson, C.K., Gilardi, K.V., Anthony, S.J., Goldstein, T., Olson, S.H., Machalaba, C., Mazet, J.A. & Consortium, P. 2017. One Health proof of concept: Bringing a transdisciplinary approach to surveillance for zoonotic viruses at the human-wild animal interface. *Preventive Veterinary Medicine,* 137:112–118.

Khomenko, S., Abolnik, C., Roberts, L., Waller, L., Shaw, K., Monne, I., Taylor, J., et al. 2018. 2016–2018 Spread of H5N8 highly pathogenic avian influenza (HPAI) in sub-Saharan Africa: epidemiological and ecological observations. FAO, Rome, *Focus On*, 12:20 pp.

Koerner, S.E., Poulsen, J.R., Blanchard, E.J., Okouyi, J. & Clark, C.J. 2017. Vertebrate community composition and diversity declines along a defaunation gradient radiating from rural villages in Gabon. *Journal of Applied Ecology,* 54:805–814.

Kogan, N.E., Bolon, I., Ray, N., Alcoba, G., Fernandez-Marquez, J.L., Müller, M.M., Mohanty, S.P. & de Castañeda, R.R. 2019. Wet Markets and Food Safety: TripAdvisor for Improved Global Digital Surveillance. *JMIR Public Health and Surveillance,* 5:e11477.

Kuisma, E., Olson, S.H., Cameron, K.N., Reed,P.E., Karesh, W.B., Ondzie, A.I., Akongo, M.-J., Kaba, S.D., Fischer. R,J. & Seifert, S.N. 2019. Long-term wildlife mortality surveillance in northern Congo: a model for the detection of Ebola virus disease epizootics. *Philosophical Transactions of the Royal Society B* 374:20180339.

Kurup, A. 2002. From bats to pigs to man: The story of Nipah Virus. *Infectious Diseases in Clinical Practice,* 11:52–57.

Lau, S.K., Wong, A.C., Lau, T.C. & Woo, P.C. 2017. Molecular evolution of MERS coronavirus: dromedaries as a recent intermediate host or long-time animal reservoir? *International Journal of Molecular Sciences,* 18:2138.

Leaf, A. 1989. Potential health effects of global climatic and environmental changes. *New England Journal of Medicine,* 321:1577–1583.

LeBreton, M., Prosser, A.T., Tamoufe, U., Sateren, W., MpoudiNgole, E., Diffo, J.L., Burke, D.S. & Wolfe, N.D. 2006. Patterns of bushmeat hunting and perceptions of disease risk among central African communities. *Animal Conservation,* 9:495–495.

Li,W., Wong, S.-K., Li, F., Kuhn, J.H., Huang, I.-C., Choe, H. & Farzan, M. 2006. Animal origins of the severe acute respiratory syndrome coronavirus: insight from ACE2-S-protein interactions. *Journal of Virology,* 80:4211–4219.

Lindsey, P.A., Balme, G., Becker, M., Begg, C., Bento, C., Bocchino, C., Dickman, A., Diggle, R.W., Eves, H. & Henschel, P. 2013a. The bushmeat trade in African savannas: Impacts, drivers, and possible solutions. *Biological Conservation,* 160:80–96.

Lindsey, P.A., Barnes, J., Nyirenda, V., Pumfrett, B., Tambling, C.J., Taylor, W.A. & Rolfes, M.t.S. 2013b. The Zambian wildlife ranching industry: Scale, associated benefits, and limitations affecting its development. *PLOS ONE* 8:e81761.

Lion Coalition, 2020. Open letter to World Health Organisation https://lioncoalition.org/2020/04/04/open-letter-to-world-health-organisation/.

Loh, E.H., Zambrana-Torrelio, C., Olivalm K.J., Bogich, T.L., Johnson, C.K., Mazet, J.A., Karesh, W. & Daszak, P. 2015. Targeting transmission pathways for emerging zoonotic disease surveillance and control. *Vector-Borne and Zoonotic Diseases,* 15:432–437.

Lycett, S., Bodewes, R., Pohlmann, A., Banks, J., Bányai, C., Boni, M., & Kuiken, T. 2016. Role for migratory wild birds in the global spread of avian influenza H5N8. The Global Consortium for H5N8 and Related Influenza Viruses. *Science,* 354:6309.

Maas, M., Gröne, A., Kuiken, T., Van Schaik, G., Roest, H. & Van Der Giessen, J. 2016. Implementing wildlife disease surveillance in the Netherlands, a One Health approach. *Revue scientifique et technique/Office International des Epizooties,* 35:863–874.

Madhav, N., Oppenheim, B., Gallivan, M., Mulembakani, P., Rubin, E. & Wolfe, N. 2017. Pandemics: risks, impacts and mitigation. In Jamison, D.T., Gelband, H., Horton, S., Jha, P., Laxminarayan, R., Mock, C.N. & Nugent R, eds. Disease Control Priorities (Vol. 9): Improving Health and Reducing Poverty. The World Bank, Washington DC, USA.

Magwedere, K., Hemberger, M.Y., Hoffman, L.C. & Dziva, F. 2012. Zoonoses: a potential obstacle to the growing wildlife industry of Namibia. *Infection Ecology & Epidemiology,* 2:18365.

Mangiarotti, S., Peyre, M., Zhang, Y., Huc, M., Roger, F., Kerr, Y. 2020. Chaos theory applied to the outbreak of COVID-19: an ancillary approach to decision making in pandemic context. *Epidemiology & Infection,* 148:e95.

Mangiarotti, S., Peyre, M., Huc, M. 2016. A chaotic model for the epidemic of Ebola virus disease in West Africa (2013–2016). *Chaos: An Interdisciplinary Journal of Nonlinear Science,* 26:113112.

Mann, E., Streng, S., Bergeron, J. & Kircher, A. 2015. A review of the role of food and the food system in the transmission and spread of Ebolavirus. *PLoS Neglected Tropical Diseases,* 9.

McMichael, A.J. 2015. Extreme weather events and infectious disease outbreaks. *Virulence,* 6:543-547.

Mendelson, S., Cowlishaw, G. & Rowcliffe, J.M. 2003. Anatomy of a Bushmeat commodity chain in Takoradi, Ghana. *Journal of Peasant Studies,* 31:73–100.

Morand, S. & Figuié, M. 2018. Emergence of infectious diseases: Risks and issues for societies. Versailles: Ed. Quae, 128 pp.

Morand, S., Jittapalapong, S., Suputtamongkol, Y., Abdullah, M.T. & Huan, T.B. 2014. Infectious Diseases and Their Outbreaks in Asia-Pacific: Biodiversity and Its Regulation Loss Matter. *PLOS ONE,* 9:e90032.

Muehlenbein, M.P. & Ancrenaz, M. 2009. Minimizing pathogen transmission at primate ecotourism destinations: the need for input from travel medicine. *Journal of Travel Medicine,* 16:229-232.

Munster, V.J., Bausch, D.G., de Wit, E., Fischer, R., Kobinger, G., Muñoz-Fontela, C., Olson, S.H., Seifert, S.N., Sprecher, A. & Ntoumi, F. 2018. Outbreaks in a rapidly changing Central Africa—lessons from Ebola. *New England Journal of Medicine,* 379:1198–1201.

Murray, K.A. & Daszak, P. 2013. Human ecology in pathogenic landscapes: two hypotheses on how land use change drives viral emergence. *Current Opinion in Virology,* 3:79–83.

Mustin, K., Newey, S., Irvine, J., Arroyo, B. & Redpat, S. 2012. Biodiversity impacts of game bird hunting and associated management practices in Europe and North America. The James Hutton Institute, 72 pp.

Nasi, R., Brown, D., Wilkie, D., Bennett, E., Tutin, C., von Tol, G. & Christophersen, T. 2008. Conservation and use of wildlife-based resources: The bushmeat crisis, Montreal.

Nasi, R., Taber, A. & Vliet, N.V. 2011. Empty forests, empty stomachs? Bushmeat and livelihoods in the Congo and Amazon Basins. *International Forestry Review,* 13:355–368.

Newman, S.H., Epstein, J.H., Schloegel, L.M. 2005. The nature of emerging zoonotic diseases: ecology, prediction, and prevention. *Medical Laboratory Observer,* 37:10–21.

Newman, S.H., Chmura, A., Converse, K.A., Kilpatrick, A.M., Patel, N., Lammers E. & Daszak P. 2007. Aquatic bird disease and mortality as an indicator of changing ecosystem health. M*arine Ecosystem Progress Series,* 352:299–309.

Nielsen, M.R., Meilby, H., Smith-Hall, C., Pouliot, M. & Treue, T. 2018. The importance of wild meat in the global south. *Ecological Economics,* 146:696–705.

Ntiamoa-Baidu, Y. 1998. Sustainable harvesting, production and use of bushmeat. Vol. 6. Accra, Ghana: Wildlife Department, Ministry of Lands and Forestry.

Nuno, A., Blumenthal, J.M., Austin, T.J., Bothwell, J., Ebanks-Petrie, G., Godley, B.J.& Broderick, A.C. 2018. Understanding implications of consumer behavior for wildlife farming and sustainable wildlife trade. *Conservation Biology,* 32:390–400

OIE. 2020 a. Follow up report N°2. COVID-19 (SARS-COV-2), Hong Kong (SAR - PRC). 16/03/2020. https://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=33629

OIE. 2020 b. Immediate notification. COVID-19 (SARS-COV-2), Hong Kong (SAR - PRC). 20/03/2020. https://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=33684

OIE. 2020 c. Immediate notification. COVID-19 (SARS-COV-2), Russia. 26/05/2020. https://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=34443&newlang=en

OIE. 2020 d. Immediate notification. SARS-CoV-2/COVID-19, United States of America. 06/04/2020. https://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=33885

Olivero, J., Fa, J.E., Real, R., Márquez, A.L., Farfán, M.A., Vargas, J.M., Gaveau, D., Salim, M.A., Park, D. & Suter, J. 2017. Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Scientific Reports,* 7:1–9.

Paige, S.B., Frost, S.D., Gibson, M.A., Jones, J.H., Shankar, A., Switzer, W.M., Ting, N. & Goldberg, T.L. 2014. Beyond bushmeat: animal contact, injury, and zoonotic disease risk in Western Uganda. *EcoHealth,* 11:534–543.

Pangau-Adam, M. & Noske, R. 2012. Wildlife hunting and bird trade in northern Papua (Irian Jaya), Indonesia. pp 95–108. *Ethno-ornithology*. Routledge.

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. 2004. Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. *Environmental health perspectives,* 112:1092–1098.

Paul, M.C., Goutard, F.L., Roulleau, F., Holl, D., Thanapongtharm, W., Roger, F.L., Tran, A. 2016. Quantitative assessment of a spatial multicriteria model for highly pathogenic avian influenza H5N1 in Thailand, and application in Cambodia. *Scientific Reports,* 6:31096.

Pavlin, B.I, Schloegel, L.M. & Daszac P. 2009. Risk of Importing Zoonotic Diseases through Wildlife Trade, United States. *Emerging Infectious Diseases,* 15:1721–1726.

Piperata, B. A., Ivanova, S. A., Da-Gloria, P., Veiga, G., Polsky, A., Spence, J. E., & Murrieta, R. S. 2011. Nutrition in transition: dietary patterns of rural Amazonian women during a period of economic change. *American Journal of Human Biology,* 23:458–469.

Piperata, B. A., Spence, J. E., Da-Gloria, P., & Hubbe, M. 2011. The nutrition transition in Amazonia: rapid economic change and its impact on growth and development in Ribeirinhos. *American Journal of Physical Anthropology,* 146:1–13.

Plowright, R.K., Eby, P., Hudson, P.J., Smith, I.L., Westcott, D., Bryden, W.L., Middleton, D., Reid, P.A., McFarlane, R.A. & Martin, G. 2015. Ecological dynamics of emerging bat virus spillover. *Proceedings of the Royal Society B: Biological Sciences,* 282:20142124.

Plowright, R.K., Foley, P., Field, H.E., Dobson, A.P., Foley, J.E., Eby, P. & Daszak, P. 2011. Urban habituation, ecological connectivity and epidemic dampening: the emergence of Hendra virus from flying foxes (*Pteropus* spp.). *Proceedings of the Royal Society B: Biological Sciences,* 278:3703-3712.

Pourrut, X., Diffo, J., Somo, R., Bilong, C.B., Delaporte, E., LeBreton, M. & Gonzalez, J.-P. 2011. Prevalence of gastrointestinal parasites in primate bushmeat and pets in Cameroon. *Veterinary Parasitology,* 175:187–191.

Pruvot, M., Khammavong, K., Milavong, P. & Philavong, C. 2019. Toward a quantification of risks at the nexus of conservation and health: The case of bushmeat markets in Lao PDR. *The Science of the Total Environment,* 676.

Rahman, M.A., Hossainm M.J., Sultana, S., Homaira, N., Khan, S.U., Rahman, M., Gurley, E.S., Rollin, P.E., Lo, M.K &, Comer, J.A. 2012. Date palm sap linked to Nipah virus outbreak in Bangladesh, 2008. V*ector-Borne and Zoonotic Diseases,* 12:65–72.

Randolph, T.F., Schelling, E., Grace, D. *et al*. 2007. Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science,* 85:2788–2800.

Redford, K.H. 1992. The empty forest. *Bioscience,* 42:412–422.

Ribas, A., Saijuntha, W., Agatsuma, T., Prantlová, V. & Poonlaphdecha, S. 2016. Rodents as a source of Salmonella contamination in wet markets in Thailand. *Vector-Borne and Zoonotic Diseases,* 16:537–540.

Ripple, W.J., Abernethy, K., Betts, M.G., Chapron, G., Dirzo, R., Galetti, M., Lev,i T., Lindsey, P.A., Macdonald, D.W., Machovina, B. 2016. Bushmeat hunting and extinction risk to the world's mammals. *Royal Society Open Science,* 3:160498.

Roberts, P., Hunt, C., Arroyo-Kalin, M., Evans, D., & Boivin, N. 2017. The deep human prehistory of global tropical forests and its relevance for modern conservation. *Nature Plants,* 3:17093

Robinson, J.G. & Bennett, E.L. 2000. Hunting for sustainability in tropical forests. Columbia University Press, New York.

Roe, D., Dickman, A., Kock, R., Milner-Gulland, E.J., Rihoy, E., Sas-Rolfes, M. 2020. Beyond banning wildlife trade: COVID-19, conservation and development. *World Development,* 136: 105121.

Roesel, K., & Grace, D. 2014. Food safety and informal markets: Animal products in sub-Saharan Africa. Routledge.

Rohr, J.R., Barrett, C.B., Civitello, D.J., Craft M.E., Delius, B., Deleo, G.A., Hudson, P.J. *et al*. 2019. Emerging human infectious diseases and the links to global food production. *Nature Sustainability,* 2:445–456.

Rulli, M.C., Santini, M., Hayman, D.T. & D'Odorico, P. 2017. The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks. *Scientific Reports,* 7:41613.

Rye, S. 2000. Wild pigs,'pig-men'and transmigrants in the rainforest of Sumatra. Natural enemies: people-wildlife conflicts in anthropological perspective. Routledge, London, 104–123.

Samsudin, S., Saudi, S.N., Masri, N.S., Ithnin, N.R., TZMT, J., Hamat, R.A., Wan Mohd, Z.W., Nazri, M.S., Surianti, S. & Daud, A.B. 2020. Awareness, Knowledge, Attitude and Preventive Practice of Leptospirosis Among Healthy Malaysian and Non-Malaysian Wet Market Workers in Selected Urban Areas in Selangor, Malaysia. *International Journal of Environmental Research and Public Health,* 17:1346.

Schulz, K., Calba, C., Peyre, M., Staubach, C. & Conraths, F.J. 2016. Hunters' acceptability of the surveillance system and alternative surveillance strategies for classical swine fever in wild boar - a participatory approach. *BMC Veterinary Research,* 12:187.

Sheherazade, S.M.T. 2015. Quantifying the bat bushmeat trade in North Sulawesi, Indonesia, with suggestions for conservation action. *Global Ecology and Conservation,* 3.

Shi, N., Huang, J., Zhang, X., Bao, C., Yue, N., Wang, Q., Cui, T., Zheng, M., Huo, X. & Jin, H. 2020. Interventions in Live Poultry Markets for the Control of Avian Influenza: A Systematic Review and Meta-analysis. *The Journal of Infectious Diseases,* 221:553–560.

Siembieda, J.L., Kock R.A., McCracken T.A. & Newman, S.H. 2011. The Role of Wildlife in Transboundary Animal Diseases. *Animal Health Research Reviews*. 12:95–111

Simberloff, D., Martin, J.-L., Genovesi, P., Maris, V., Wardle, D.A., Aronson, J., Courchamp, F., Galil, B., García-Berthou, E. & Pascal, M. 2013. Impacts of biological invasions: What's what and the way forward. *Trends in Ecology & Evolution,* 28:58–66.

Simons, R.R., Horigan, V., Gale, P., Kosmider, R.D., Breed, A.C. & Snary, E.L. 2016. A Generic Quantitative Risk Assessment Framework for the Entry of Bat-Borne Zoonotic Viruses into the European Union. *PLOS ONE,* 11.

Swamy, V. & Pinedo-Vasquez, M. 2014. Bushmeat harvest in tropical forests: Knowledge base, gaps and research priorities. Occasional Paper 114. Bogor, Indonesia, CIFOR.

Swift L, Hunter P, Lees A, Bell D. 2007. Wildlife Trade and the Emergence of Infectious Diseases. *EcoHealth,* 4:25–30(26).

Tang, B., Xia, F., Bragazzi, N.L., Wang, X., He, S., Sun, X., Tang, S., Xiao, Y. & Wu, J. 2020. Lessons drawn from China and South Korea for managing COVID-19 epidemic: Insights from a comparative modeling study. medRxiv.

Tatem, A.J., Hay, S.I. & Rogers, D.J. 2006. Global traffic and disease vector dispersal. *Proceedings of the National Academy of Sciences,* 103:6242–6247.

Tran, A., & Roger, F. 2018. Strengthening health decision-making at the territorial level: Operational support for spatial multi-criteria evaluation. *Perspective* - Cirad:1–4.

Trovão, N.S. & Nelson, M.I. 2020. When Pigs Fly: Pandemic influenza enters the 21st century. *PLoS Pathogens,* 16:e1008259.

Tu, C., Crameri, G., Kong, X., Chen, J., Sun, Y., Yu, M., Xiang, H. *et al*. 2004. Antibodies to SARS coronavirus in civets. *Emerging infectious diseases,* 10:2244–2248.

Turvey, S.T., Chen, S., Tapley, B., Wei, G., Xie, F., Yan, F., Yang, J., Liang, Z., Tian, H. & Wu, M. 2018. Imminent extinction in the wild of the world's largest amphibian. *Current Biology,* 28:R592-R594.

van Vliet, N., Cornelis, D., Beck, H., Lindsey, P., Nasi, R., LeBel, S., Moreno, J., Fragoso, J. & Jori, F. 2016. Meat from the wild: extractive uses of wildlife and alternatives for sustainability. pp 225–265. Current Trends in Wildlife Research. Springer.

van Vliet, N. & Mbazza, P. 2011. Recognizing the multiple reasons for bushmeat consumption in urban areas: a necessary step toward the sustainable use of wildlife for food in central Africa. *Human Dimensions of Wildlife,* 16:45–54.

van Vliet, N., Milner-Gulland, E.J., Bousquet, F., Saqalli, M. & Nasi, R. 2010. Effect of Small-Scale Heterogeneity of Prey and Hunter Distributions on the Sustainability of Bushmeat Hunting. *Conservation Biology,* 24:1327–1337.

Vorster, H. H., Kruger, A., & Margetts, B. M. 2011. The nutrition transition in Africa: can it be steered into a more positive direction? *Nutrients,* 3:429–441.

Wang, G., Minnis, R.B., Belant, J.L. & Wax, CL. 2010. Dry weather induces outbreaks of human West Nile virus infections. *BMC Infectious Diseases,* 10:38.

Wang, N., Li, S.-Y., Yang, X.-L., Huang, H.-M., Zhang, Y.-J., Guo, H., Luo, C.-M., Miller, M., Zhu, G. & Chmura, A.A. 2018. Serological evidence of bat SARS-related coronavirus infection in humans, China. *Virologica Sinica,* 33:104–107.

Wang, W., Artois, J., Wang, X., Kucharski, A.J., Pei, Y., Tong, X., Virlogeux, V., Wu, P., Cowling, B.J. & Gilbert, M. 2020. Effectiveness of Live Poultry Market Interventions on Human Infection with Avian Influenza A (H7N9) Virus, China. *Emerging Infectious Diseases,* 26:891.

Wang, W., Yang, L., Wronski, T., Chen, S., Hu, Y. & Huang, S. 2019. Captive breeding of wildlife resources—China's revised supply-side approach to conservation. *Wildlife Society Bulletin,* 43:425–435.

Weiss, R.A. 2001. Animal origins of human diseases. *Philosophical Transactions of fthe Royal Society B*: *Biological Sciences,* 351: 957-977.

Wilkie, D. 2006. Bushmeat: A disease risk worth taking to put food on the table? *Animal Conservation,* 9:370–371.

Wilkie, D.S., Bennett, E.L., Peres, C.A. & Cunningham, A.A. 2011. The empty forest revisited. *Annals of the New York Academy of Sciences,* 1223:120–128.

Wilkie, D.S., Starkey, M., Abernethy, K., Effa Nsame, E., Telfer, P. & Godoy, R. 2005. Role of prices and wealth in consumer demand for bushmeat in Gabon, Central Africa. *Conservation Biology,* 19:1–7.

Wimberly, M.C., Yabsley, M.J., Baer, A.D., Dugan, V.G. & Davidson, W.R. 2008. Spatial heterogeneity of climate and land-cover constraints on distributions of tick-borne pathogens. *Global Ecology and Biogeography,* 17:189–202.

Wolfe, N.D., Daszak, P., Kilpatrick, A.M & Burke, D.S. 2005. Bushmeat hunting deforestation, and prediction of zoonoses emergence. *Emerging Infectious Diseases,* 11:1822–1827.

Woods, R., Reiss, A., Cox-Witton, K., Grillo, T. & Peters, A. 2019. The importance of wildlife disease monitoring as part of global surveillance for zoonotic diseases: the role of Australia. *Tropical Medicine and Infectious Disease,* 4:29.

Woolhouse, M.E. 2002. Population biology of emerging and re-emerging pathogens. *Trends in Microbiology,* 10:s3–s7.

WWF. 2020. Opinion survey on COVID-19 and wildlife trade in 5 Asian markets. Findings from survey in March 2020. WWF Report. 14 pp.

Young, H.S., Wood, C.L., Kilpatrick, A.M., Lafferty, K.D., Nunn, C.L. & Vincent, J.R. 2017. Conservation, biodiversity and infectious disease: Scientific evidence and policy implications. The Royal Society.

Zhang, L., Hua, N. & Sun, S. 2008. Wildlife trade, consumption and conservation awareness in southwest China. *Biodiversity and Conservation,* 17:1493–1516.

Zhou, X., Wang, Y., Liu, H., Guo, F., Doi, S.A., Smith, C., Clements, A.C., Edwards, J., Huang, B. & Soares Magalhães, R.J. 2018. Effectiveness of market-level biosecurity at reducing exposure of poultry and humans to avian influenza: a systematic review and meta-analysis. *The Journal of Infectious Diseases,* 218:1861–1875.

SWM SUSTAINABLE WILDLIFE MANAGEMENT PROGRAMME

SWM-programme@fao.org
www.swm-programme.info

Supported by

Funded by the European Union