PROPOSALS FOR THE PREVENTION AND DETECTION OF EMERGING INFECTIOUS DISEASES IN GUATEMALA

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Executive Summary

From the Plague of Justinian to the recent COVID-19 pandemic, infectious diseases have caused some of the largest death tolls in history. While many pathogens have existed for millennia, changes in human behavior have facilitated their spread. Human population growth, globalization, and environmental damage contribute to the development and spread of dangerous new human diseases known as emerging infectious diseases (EID), such as severe acute respiratory syndrome (SARS), AIDS, Ebola, dengue or yellow fever. In fact, between 1940 and 2004, at least 335 EIDs have been identified. According to WHO data, a steady increase of EIDs has been observed during this period, indicating an upward trend that is expected to continue in the future.

In recent years, most emerging human diseases have been transmitted by zoonotic pathogens – that is, those transmitted between animals and humans. Approximately 60.3% of EIDs in recent decades are estimated to have a zoonotic origin. That represents a significant challenge for public health.

In this context, Guatemala emerges as a country of particular interest for our analysis since it has a combination of factors that favor the appearance of epidemiological hotspots.[1] Among these factors are its warm climate, tropical forests, and wide variety of wild species, as well as the proximity of human population centers to natural habitats. That is in addition to rapid urbanization, unsustainable agricultural development, and high population density. Indeed, Central America is one of the fastest growing urban regions in the world and Guatemala stands out with an annual urban population growth rate of 3.4%, making it one of the main drivers of this trend.

In turn, outbreaks of diseases such as dengue fever, Chagas disease, and avian influenza have been reported in Guatemala. This dynamic is partly fostered by livestock and poultry farming, both common in the Guatemalan rural population. 60% of the animal protein consumed by Guatemalans comes from local poultry farming, which is at risk of known diseases such as avian influenza or the West Nile virus. These outbreaks have been aggravated by poor health infrastructure in some areas. For example, poor access to sanitation services, especially in rural areas and among indigenous groups, contributes to the spread of infectious diseases. According to WHO and UNICEF data, approximately 44% of the Guatemalan rural population does not have access to basic sanitation, and almost half of the population in the country lacks access to improved sanitation.

[1] These *hotspots* are geographic areas with a high risk for the emergence and spread of infectious diseases (K. E. Jones et al., 2008a).

Finally, in terms of investment in public health, Guatemala shows relatively low per capita spending compared to other countries in the region. In 2022, public expenditure on health stood at 82 euros per capita, while Costa Rica and Panama had per capita spending of 634 and 590 euros, respectively. Mexico spent 246 euros per capita, while other Central American countries ranged between 99 and 169 euros.

Considering these factors, we identify opportunities for improvement and offer recommendations to prevent and detect the development or spread of infectious diseases. As for prevention, we propose four objectives: first, improving sanitation through interventions in essential infrastructure, such as public water and waste services, as well as through sanitary measures when coming into contact with domesticated animals or wildlife; second, curbing the illegal wildlife trade; third, halting deforestation and other forms of environmental degradation; and fourth, avoiding the abuse of antibiotics in the animal agriculture industry.

Regarding detection, we propose greater articulation of epidemiological surveillance systems — including improved coordination between the Ministry of Public Health and Social Assistance (MSPAS) and the Ministry of Agriculture, Livestock, and Food (MAGA) — as well as the increased participation of local communities. We also suggest implementing a proactive approach to detecting pathogens through systematic monitoring in high-risk populations and mobile testing clinics that carry out broad-spectrum tests in rural communities. Finally, we recommend improving the transparency and accessibility of the gathered data and implementing technological solutions such as genomic sequencing and natural language processing to track sources of infection on social media.

All these proposals are grounded in scientific literature and the interviews we conducted with experts in the field. Their implementation is feasible in the Guatemalan context and would result in notable benefits to public health and other sectors without incurring excessive costs.

Area	Objective	Proposals
Prevention	Implement interventions to improve sanitation	1. Improvements in essential infrastructure and public services 2. Sanitary practices for human-animal contact
	Curb illegal wildlife trade	1. Interinstitutional coordination, control, and monitoring 2. Education, awareness, and training 3. Participation of civil society
	Stop deforestation and other forms of environmental degradation	1. Forest governance 2. Sustainable agricultural intensification 3. Urban planning 4. Other ecological interventions
	Halt antibiotic abuse in animal food production	1. Restricting non-therapeutic uses of antibiotics in animals
Detection	Design systems of epidemiological surveillance	1. Coordination between human and animal health sectors
	Adopt a proactive approach to pathogen detection	1. Monitoring pathogens present in wildlife 2. Frequent testing of high-risk populations
	Ensure transparency and accessibility of epidemiological data	1. Networks to share data between departments 2. Effective communication with the international community
	Implement technological solutions	1. Boosting laboratories with genomic sequencing and natural language processing programs

1. Introduction

The emergence of global catastrophic biological risks has posed a series of unprecedented challenges in the contemporary world. These wide-ranging events, including pandemics and biological disasters, pose an imminent threat to public health, socioeconomic stability, and security around the world. Their ability to transcend national borders and simultaneously affect multiple regions and countries highlights the need to manage these risks in a coordinated and global manner.

Aspects of our modern world such as increasing human mobility, international trade, climate change, and accelerated urbanization have created an environment conducive to the spread of infectious diseases and other biological hazards on a global scale (Gottdenker et al., 2014a). The COVID-19 pandemic has been a reminder of the vulnerability of nations and the need for a coordinated global response to catastrophic biological risks. Its socioeconomic and humanitarian effects have stressed the importance of preparedness and resilience in public health and crisis management. Managing these risks requires a comprehensive vision and active cooperation between countries, international organizations, research institutions, health professionals, and civil society (Destoumieux-Garzón et al., 2018; Ghai et al., 2022).

In this context, Guatemala and the global community face the challenge of preparing for and effectively responding to biological risks. Early detection, rapid response, and coordination between government agencies and international organizations are essential to mitigating the devastating effects of these events and protecting the lives and well-being of the Guatemalan population. In particular, the Guatemalan health system faces significant challenges in terms of capacity and resources. Health infrastructure — including the availability of medical personnel, diagnostic equipment, and medicines — is limited in rural areas and marginalized communities (WHO, 2017), which hinders early detection, control, and proper management of infectious diseases.

This report aims to explore the challenges that Guatemala faces in managing biological risks related to emerging infectious diseases (EIDs) and to discuss potential measures and strategies to prepare for and respond to these threats. To do this, it begins with an exhaustive analysis of the factors that contribute to the appearance and spread of EIDs in the country, reviewing the human activities that favor the emergence of these risks, such as deforestation, poor agricultural practices, and the illegal wildlife trade. Subsequently, we examine the existing health and surveillance systems and describe the procedures and guides currently implemented for an effective response. Finally, we explore opportunities for improvement in the prevention and detection of biological risks in Guatemala, proposing specific recommendations to strengthen health and surveillance systems, increase the likelihood of early detection of outbreaks, and promote collaboration between relevant actors.

2. Emerging infectious diseases

Emerging infectious diseases (EIDs) are defined as those whose incidence has increased in the past two decades or threatens to increase in the near future (World Health Organization, 2005). This category includes diseases that have not previously affected humans, have affected only small isolated populations, or have recently been associated with an infectious agent (Tabish, 2009). EIDs are often categorized alongside reemerging infectious diseases (RID). The latter are diseases that had a notable rate of incidence at some point in the past and reappear in a population after a period of inactivity (Tabish, 2009).

At least 335 EIDs have been identified between 1940 and 2004 (K. E. Jones et al., 2008a). In this period, the number of EIDs per decade increased steadily, indicating an upward trend that is expected to continue in the future, mainly due to anthropogenic causes (Baker et al., 2022). According to one study, the annual probability of an "extreme epidemic"[2] could triple in the coming decades (Marani et al., 2021).

In 2019, infectious diseases caused approximately 7.9 million deaths worldwide, i.e. 102 deaths per 100,000 people.[3] Guatemala suffered about 14,540 deaths, equivalent to 82 deaths per 100,000 inhabitants. Infections constituted 13.9% of all deaths globally and 15.3% in Guatemala. In this country, respiratory infections were the most common cause of death (10.9%), followed by enteric infections (3.1%) (Institute for Health Metrics and Evaluation, 2020).

EIDs pose a significant risk to public health because the affected populations are not prepared to face them. As there has been no exposure to the pathogen, individuals have not developed antibodies, and society does not have a specific treatment for it. For this reason, EIDs have caused the outbreaks with the highest morbidity and mortality rates[4] (Spernovasilis et al., 2022). Recent examples include the various variants of the coronavirus family, the human immunodeficiency virus (HIV), influenza A, and Ebola, among others (McCloskey et al., 2014). Pandemics, alongside major

[2] The authors define "extreme epidemics" based on three criteria: (1) the epidemics that occurred in the same period merge into one; (2) epidemics are only considered if they are not currently active; and (3) epidemics that ended with the introduction of effective vaccines or treatments are excluded.
[3] In this context, respiratory infections, enteric infections, malaria and neglected tropical diseases, HIV/AIDS and other infectious diseases are included.
[4] Morbidity is the 'number of people who fall ill in a given population and period,' while mortality is the 'number of deaths in a given population and period.' (Fundéu RAE, 2023)

wars and famines, have been responsible for the episodes of human history with the highest mortality rates. The Black Death (1346-1353), the Influenza A pandemic (1918-1920), the HIV pandemic (1981-present), the Justinianic plague (541-750), and the COVID-19 pandemic (2019-2023) all left behind tens of millions of deaths (Castañeda Guillot et al., 2021).

In the past decades, approximately 60.3% of EIDs in humans have been caused by zoonotic pathogens — agents responsible for the transmission of disease between animals and humans (Jones et al., 2008). Although not all zoonoses are considered EIDs and vice versa, zoonoses undoubtedly have a considerable impact on public health, the economy, and security on a global scale (Jones et al., 2008). In Guatemala, high biodiversity and close interactions between humans and animals favor a greater probability of the emergence and transmission of this type of disease. That is why the following sections will be focused on zoonoses, with the objective of effectively identifying and controlling risk factors in the country, implementing preventive measures, and promoting the adoption of biosecurity practices that contribute to preventing future outbreaks.

2.1. Zoonoses

Zoonoses can be caused by bacteria, viruses, fungi, parasites, or other pathogens. Their transmission can occur through direct contact with infected animals, their products, or their fluids, as well as through exposure to vectors such as mosquitoes, ticks, or fleas. Transmission of zoonotic pathogens can occur by various routes: by ingestion of contaminated food and water (42% of all pathogens), by vectors (42%), by air (36%), by direct contact with the host (29%), and by contact with contaminated environments and objects (24%) (Loh et al., 2015).

It is estimated that 60.3% of the EIDs that emerged in recent decades were zoonotic, and 71.8% of these zoonoses originated in wildlife (K. E. Jones et al., 2008a). Some estimates point to the existence of approximately 1,670,000 unknown viruses already present in mammals and birds, of which between 631,000 and 827,000 have zoonotic potential (Carroll et al., 2018).

Zoonoses in Central America

Zoonoses represent a significant health problem in Central America. There is a wide variety of zoonotic pathogens, including bacteria, viruses, and parasites, as well as fungi and prions, to a lesser extent. However, epidemiological information is limited for many of them (Rasche, 2021). There have been cases of reemergence of certain arboviruses, such as the Mayaro virus, which together with the Zika, Chikungunya, and Dengue viruses is part of the epidemiological picture in the Western Hemisphere, including Central America (Patterson et al., 2016). There are also endemic diseases such as Chagas, which thrive mainly in rural areas with precarious socioeconomic conditions (Mosca Salvadore, 2020).

Zoonotic viruses such as dengue, Zika, yellow fever, and other arboviruses, as well as influenza A (H1N1), rabies virus, hantavirus, and hepatitis E virus are prevalent in the region and are mainly transmitted through arthropod vectors. Other diseases are caused by protozoa and other protists, as in the case of Chagas disease (*Trypanosoma cruzi*), leishmaniasis *(Leishmania* spp.), toxoplasmosis (*Toxoplasma gondii*), and malaria (*Plasmodium* spp.). In addition, there are zoonotic diseases caused by multicellular worms, such as filariasis, trichinellosis, gnathostomiasis, hymenolepsis, taeniasis, cysticercosis, and echinococcosis. These parasites are transmitted through various vectors or by direct contact with infected animals (Rasche, 2021).

Deforestation and land use change, such as the transformation of forests and jungles, also represent a risk of emerging zoonotic diseases transmitted by wild animals in tropical regions such as Central America. Landscape connectivity plays a key role in conserving biodiversity and maintaining ecological functions (G. Leija & Mendoza, 2021). Changes in climate can also affect the spread of these zoonotic diseases in the region, through patterns such as droughts (Tamayo et al., 2022; Zhao et al., 2022). In addition, political and economic crises can exacerbate public health problems by increasing the vulnerability of human populations to zoonoses and hindering efforts to control and prevent these diseases (Martí I Puig & Rodríguez Suárez, 2022).

Lastly, Central America and the Caribbean have been identified as the regions with the highest rates of zoonotic viruses in wild mammals (Olival et al., 2017). The risk associated with these pathogens is unclear and cannot be precisely measured. However, by studying pathogens present in related species in the animal kingdom, it is possible to assess the risk of transmission between different species and discover previously unknown host species in Central America (Rasche, 2021).

Category	Description
Zoonotic Pathogens	Bacteria, Viruses, Parasites, Fungi, Prions.
Arboviruses	Mayaro, Zika, Chikungunya, Dengue.
Protozoa and Protists	Chagas (Trypanosoma cruzi), Leishmaniasis (Leishmania spp.), Toxoplasmosis (Toxoplasma gondii), Malaria (Plasmodium spp.).
Multicellular Worms	Filariasis, Trichinellosis, Gnathostomiasis, Hymenolepsis, Teniasis, Cysticercosis, Echinococcosis.
Endemic diseases	Chagas.
Prevalent Viruses	Dengue, Zika, Yellow Fever, Influenza A (H1N1), Rabies, Hantavirus, Hepatitis E.
Risk factors	Deforestation, changes in land use, climate change, and political and economic crises.
Future Zoonotic Pathogens	Potential pathogens whose risk is unclear. By studying pathogens present in related species in the animal kingdom, it is possible to assess the risk of transmission between different species and discover unknown host species.

Table 1. Summary of zoonosis in Central America.

Zoonoses in Guatemala

Guatemala presents a series of important challenges with respect to biosecurity. As shown in Table 2, vector-borne diseases such as dengue, malaria, and Chagas, among others, are prevalent and pose a significant threat to health in the country (MSPAS, 2023). These diseases are not limited to remote areas but also occur in cities. In some cases, these diseases have resulted in deaths, especially when adequate resources for treatment are lacking (Appendix 1, interview with Paulina Paiz).

Disease	2018	2019	2020	2021	2022	Total
Dengue	7,523	50,957	6,011	2,918	8,505	75,914
Malaria	3,082	2,071	1,058	1,269	1,854	9,334
Chagas	355	470	303	349	397	1,874
Chikungunya	248	344	45	14	38	689
Zika	224	338	22	18	7	609
Total of cases	11,432	54,180	7,439	4,568	10,801	88,420

Table 2. Top 5 diseases most transmitted by vectors in Guatemala during 2018-2022.

The country has a diverse and growing population, and a number of socioeconomic and environmental factors which contribute to the emergence of epidemiological hotspots. These hotspots are geographic areas with a high risk of emergence and spread of infectious diseases (K. E. Jones et al., 2008b). Some common factors that define a hotspot are warm climate, tropical forests, wildlife biodiversity, and proximity between natural environments and human population centers (Allen et al., 2017). All of them are found in Guatemala.

In particular, the country has experienced outbreaks of diseases such as dengue fever, Chagas disease, and avian influenza (Patterson et al., 2016), aggravated by the lack of adequate sanitary infrastructure in some regions and combined with factors such as population density, urbanization, and unsustainable agricultural expansion in these areas (Matthys et al., 2006). In addition, rural areas present significant challenges, as inadequate agricultural and animal husbandry practices can foster the emergence of zoonotic diseases.

Management of these geographic areas is also hampered by disparities in access to health care, health infrastructure, and epidemiological surveillance capacity. In addition, there are various anthropogenic practices that can exacerbate risk in this country, such as agricultural expansion and intensification, urban sprawl, illegal trade in wildlife, and uncontrolled access to wilderness environments (G. Leija & Mendoza, 2021; Martí I Puig & Rodríguez Suárez, 2022; Tamayo et al., 2022; Zhao et al., 2022).

The emergence of hotspots can be aggravated by multiple factors, such as a lack of knowledge about the causes, transmission routes, symptoms, or consequences of the disease; as well as poor risk perception, lack of coordination between authorities and communities, and lack of equipment and infrastructure (Palomares Velosa et al., 2022a). This last factor is particularly problematic in low-income regions where health facilities and surveillance systems may be inadequate. The agricultural and livestock industries can contribute to the appearance of biosecurity hotspots by facilitating the spread of zoonotic diseases (B. A. Jones et al., 2013), as well as antimicrobial resistance (AMR). Currently, it is estimated that 25% of deaths associated with bacteria are due to this resistance (Murray et al., 2022).

2.1.1. Zoonoses from wildlife

Wild animals carry a wide variety of zoonotic pathogens, many of which could cause EID if transmitted to humans. The creation of new interfaces between wildlife and people or domesticated animals can facilitate the transmission of these diseases. As mentioned above, 72% of zoonotic EID comes from wildlife (K. E. Jones et al., 2008a).

The diversity of pathogens present in wild animal populations and the ability of these pathogens to jump to humans is an area of active research. Studies have shown that viruses, bacteria, and parasites can be transmitted from wild animals to humans (Rohr et al., 2019). These can cause a variety of illnesses, from mild infections to serious, life-threatening illnesses. Prevention and control of zoonoses from wild animals is challenging due to the complexity of ecosystems and interactions between species (Rohr et al., 2019).

2.1.1.1. Aggravating risk factors

Three anthropogenic dynamics that could accelerate the described process are identified below: loss of native vegetation, illegal wildlife trafficking, and irresponsible access to high-risk wild environments.

- **Loss of native vegetation**

The relationship between biodiversity and disease emergence is complex and often paradoxical. While it is true that a high level of biodiversity is a predictor of an epidemiological hotspot, abrupt changes in the nature and distribution of this biodiversity also imply a greater risk of zoonotic transmission (Keesing & Ostfeld, 2021). In this section, we outline several reasons why ecosystem alterations may increase human exposure to various diseases.

Urban and agricultural expansion into areas of native vegetation causes modifications in the trophic structure of the ecosystem and creates new interfaces between humans, domesticated animals, and wild animals (Hassell et al., 2017). Among the latter, the mammals that best adapt to anthropized ecosystems, such as bats and rodents, are also those that host the most pathogens (Gibb et al., 2020; McFarlane et al., 2012).

Various anthropogenic practices are also associated with the loss of predators and other competitors that help regulate host and vector populations (Glidden et al., 2021). For example, the construction of dams in various parts of Africa has blocked the proliferation of a native species of shrimp that consumes snails hosting the parasite causing schistosomiasis, an acute parasitic disease (Sokolow et al., 2017).

Finally, the fragmentation of the habitat in small patches can also affect the nutritional availability of the environment and increase the density of species in the same place (Glidden et al., 2021). For example, deforestation in Malaysia has been linked to increased contact between macaques — hosts of a malaria-causing parasite — and mosquitoes acting as vectors (Davidson et al., 2019).

Likewise, expanding human settlements could lead to more frontier habitats with increased human-wildlife interaction, causing an unprecedented contact with pathogen reservoirs and increasing the risk of zoonotic spillovers (Barbier, 2021; Wilkinson et al., 2018). Several studies show that the probability of Ebola outbreaks in West and Central Africa is higher in recently deforested areas (Olivero et al., 2017; Rulli et al., 2017). Hence, the loss of native vegetation seems to increase the likelihood of pathogen transmission (Gottdenker et al., 2014b).

Agricultural and livestock expansion and intensification

Agriculture is one of the main drivers of anthropogenic modification of natural environments. Of course, the agricultural sector is essential to ensure a country's food and economic security. However, the risk of zoonotic transmission could be aggravated by uncontrolled sector growth, specifically by the expansion of cultivated areas or the use of unsustainable technologies and practices.

Advancing the agricultural frontier can lead to habitat fragmentation and increased contact with wildlife. For example, the expansion of palm oil plantations has been closely linked to an increase in vector-borne diseases (Morand & Lajaunie, 2021). Guatemala has an area of 180,614 hectares in palm plantations (GREPALMA, 2021), some of which penetrate indigenous communities' lands and alter their ecosystems (Cuffe, 2021; Leonardo, 2023).

The redistribution of freshwater caused by irrigation has also been associated with increased vectors and hosts of human pathogens (Rohr et al., 2019b). Specifically, changes in water flow, river ecology and salinity, human proximity, and pollution may have increased the prevalence of schistosomiasis, malaria, encephalitis, hemorrhagic fevers, gastroenteritis, intestinal parasites, and filariasis in various locations around the world (Lerer & Scudder, 1999). In Guatemala, the development of large irrigation systems required by palm and sugarcane plantations has already altered public water use in rural settings, with severe socioeconomic consequences (Granovsky-Larsen, 2018).

Likewise, the excessive use of pesticides can lead to vector resistance, affect host susceptibility to parasites, and alter ecosystem composition (Rohr et al., 2019). In Guatemala, Chagas disease eradication campaigns based on the massive use of insecticides have been ineffective due to the resistance of the vectors *T. dimidiata* and *T. infestans* (Castro-Arroyave et al., 2020; Samuels et al., 2013).

Finally, cattle ranching also carries significant risks of zoonotic diseases due to the demand for large landholdings, in the case of *extensive* cattle ranching, and densified livestock management, in the case of *intensive* cattle ranching (Hayek, 2022). The first system is the most common in Latin America and has been identified as one of the leading causes of deforestation in Guatemala (Devine et al., 2020a) as well as other parts of the continent, such as the Amazon (Skidmore et al., 2021).

Urban sprawl

Central America is the second fastest urbanizing region in the world, behind Africa. With an annual growth rate of the urban population of 3.4%, Guatemala is one of the main drivers of this trend (Maria et al., 2018).

Unlike in other regions, this growth has not necessarily led to higher density in cities but to increased levels of low-density urban sprawl. In Central America, the total urbanized area tripled between 1975 and 2014, but much of this expansion is not attributable to capital cities and other large agglomerations (Maria et al., 2018). In Guatemala, secondary cities account for approximately two-thirds of the urban population, a proportion that has increased markedly over the past two decades. While the metropolitan area of Guatemala City has remained relatively stable over time, intermediate cities (those with between 50,000 and 250,000 inhabitants) and smaller cities (between 20,000 and 50,000) increased their population by 135% and 61%, respectively (UNDP, 2020).

This dispersion can be positive for the country's territorial balance but also entails risks. Some are associated with the emergence of "new ruralities" in which traditional agricultural activities are progressively replaced by dynamics linked to leisure or rural industrialization, among others (UNDP, 2020). This transformation can have negative consequences if land use changes occur haphazardly, as in many Guatemalan municipalities (Zurita et al., 2020).

For this report, one of the trends to be monitored more closely is the urbanization of the department of Petén. The Flores-San Benito conurbation has been identified as a strategic center for articulating cities at the national and regional levels. However, its growth has been spontaneous, under market logic, and puts pressure on natural resources (SEGEPLAN, 2013). The development of these and other municipalities, such as San José and San Andrés, could pose a threat to the ecosystems of Lake Petén Itzá and the Maya Biosphere Reserve.

Illegal wildlife trade (IWT)

Wildlife trafficking is one of the most lucrative illegal businesses in the world, with an estimated value of between $7 billion and $23 billion annually (Nellemann et al., 2016). Traded animals are mainly used for meat consumption, as exotic pets, for traditional medicine, or for fashion and decoration (Mozer & Prost, 2023).

This reality constitutes a threat to global health. Between 1990 and 2020, a total of 240 pathogens were reported in trafficked wild animals, of which five were transmitted to humans; however, it is estimated that the number would be much higher with proper monitoring (Rush et al., 2021). For example, transmission of viruses such as HIV, Ebola, or different coronavirus variants has been traced to bushmeat consumption. However, a lack of research precludes certainty in these cases (Karesh et al., 2005). As for the main hosts, various groups of mammals — primates, ungulates, carnivores, and bats — have been identified as accounting for 58% of all pathogens present in wildlife trafficking, while others — rodents and marsupials — could pose an equivalent or greater risk in the future (Shivaprakash et al., 2021).

The people most exposed to potential contagion are hunters, sellers, and consumers. An estimated 1 billion contacts between wild animals and humans or domesticated animals occur annually (Karesh et al., 2005). In the case of illegal trafficking, the lack of regulatory standards allows for inadequate sanitary conditions, exacerbating the risk (Bezerra-Santos et al., 2021).

In this context, Latin America has become one of the most important exporters of wild animals. The region combines extraordinary biodiversity with powerful criminal networks interested in the industry (Guynup, 2022). In Guatemalan legislation, the unauthorized collection and commercialization of wild fauna and flora are punishable by imprisonment of five to ten years and a fine of ten thousand to twenty thousand Quetzals. However, the capacities of the security forces have not been sufficient to eradicate trafficking, which is still very active (Ochoa López, 2022). Many animals are destined for East Asia, where they are highly valued (Guynup, 2022).

The most frequently exported animals are the parrot, macaw, and various reptile species (Ochoa López, 2022). Even so, between 2004 and 2018, 276 mammal specimens were seized, including mainly primates, procyonids, rodents, dasipodids, cervids, and leporids (Flores & CONAP, 2020).

Many of these species constitute a high risk of zoonotic transmission. For example, armadillos can transmit leprosy to humans (Sharma et al., 2015), coatis appear to play an important role in the rabies transmission cycle (Puebla-Rodríguez et al., 2023), and tepezcuintle (a rodent) can harbor parasites such as the worms which cause cystic echinococcosis (Mayor et al., 2015).

Irresponsible access to high-risk wilderness environments

Caves constitute a unique environment on Earth due to the absence of natural light and the constant temperature. These peculiarities influence the composition and distribution of fauna, generally favoring species identified as reservoirs of various diseases, such as bats, rodents, and arthropods (Igreja, 2011). Thus, people accessing caves are especially vulnerable to potential infections. In Guatemala, caves are commonly used for various cultural purposes, such as religious ceremonies, tourism, and shelter (L. Stevens et al., 2014).

There are several examples of outbreaks originating in caves. The natural host of the Marburg virus, one of the most lethal viruses for humans, is the Egyptian fruit bat, and there is strong evidence that its transmission to humans is associated with visits to caves in Kenya and Uganda (Kuzmin et al., 2010). In Guatemala, a new variant of influenza A was identified for the first time in bats (Tong et al., 2012), and other studies have identified the prevalence of *Bartonella* (Bai, 2011) and rabies in these animals (Ellison et al., 2014). However, awareness levels in at-risk populations remain low (Moran et al., 2015).

In addition to the viral and bacterial infections, Guatemalan caves also present a danger of fungal and parasitic diseases. Thus, histoplasmosis outbreaks have been reported originating in caves throughout the Americas, including one that began with an Australian expedition in Juan Flores Cave, Petén (Muhi et al., 2019). Cave use has also been associated with increased exposure to the insect *T. dimidiata*, one of the most important vectors of Chagas disease. The Santa Isabel cave in Petén and the Lanquín and Cahabón caves in Alta Verapaz, all frequented by humans, provide evidence of significant consumption of human blood in this insect (L. Stevens et al., 2014).

2.1.2. Zoonoses from domesticated animals

According to a study by Kock and Caceres-Escobar (2022), it is estimated that 28.2% of zoonotic diseases originate in domesticated animals that live closely with humans. This situation occurs when there is occasional or systematic coexistence with animals such as dogs, cats, poultry, pigs, cows, horses, and even less common species such as primates, rodents, reptiles, birds, and wild mammals, which represent potential sources of diseases transmissible to humans in the form of various zoonoses (Matamoros et al., 2000).

In particular, cattle ranching is a crucial economic activity in Guatemala, where many families depend on it for their livelihoods. For cattle ranching, family farms represent 94% of all cattle farms nationwide, a higher proportion than in the rest of the Central American region (MAGA, 2013). This increases the close and constant contact with livestock that exposes workers to various zoonotic diseases. In turn, poultry farming is common in the Guatemalan rural population. Currently, 60% of the animal protein consumed by Guatemalans comes from poultry farming (MAGA, 2019), which can be a reservoir for diseases such as avian influenza, Newcastle, or West Nile virus.

2.1.2.1. Aggravating risk factors

Three dynamics that tend to aggravate zoonoses from domesticated animals are identified as follows: lack of basic sanitation, overuse of antibiotics, and socio-cultural factors.

Lack of basic sanitation

Basic sanitation refers to conditions and practices that promote hygiene and prevent contamination of the environment, such as access to safe drinking water, adequate wastewater treatment, and proper solid waste management. When basic sanitation conditions are poor or non-existent, it creates an environment conducive to the proliferation of pathogens, which can be found in contaminated water, untreated or poorly managed human and animal waste, and other means of transmission.

More than half of Guatemalan people lack access to adequate sanitation, and significant inequalities exist between different geographic regions, with the rural population and indigenous groups often marginalized and underserved (World Bank, 2018). According to WHO and UNICEF data, 44% of the Guatemalan rural population lacks access to basic sanitation (WHO & UNICEF, 2022), and almost half of the Guatemalan population lacks access to improved sanitation.

Also, the gap between urban and rural areas is significant, with rural areas lagging 55% behind urban areas. Unimproved latrines or pits remain the most common form of sanitation, especially in rural areas. Although small positive changes have been achieved, such as decreasing open defecation and increasing sewerage coverage, much remains to be done to balance and improve the sanitation situation in the country (World Bank, 2018).

In turn, Guatemala still faces significant challenges regarding drinking water coverage. While there has been an overall increase in access to improved water since 1990, water coverage is mainly concentrated along the Pacific coast, while in the north and west of the country, it remains insufficient. As with basic sanitation, there is a disparity in water access between urban and rural areas, with rural areas being the most affected (World Bank, 2018).

According to the National Water and Sanitation Plan of the Ministry of Health in 2015, water quality remained an ongoing problem. In 2014, only 40% of the water samples analyzed for residual chlorine met the standards established by national regulations. Water is often drawn directly from rivers or lakes and distributed without treatment. As a result, the levels of bacteria in the coliform group and pathogenic bacteria are high (PAHO, 2015).

- **Excessive use of antibiotics and antifungal agents**

Antimicrobial resistance (AMR) is an evolutionary phenomenon when microorganisms exposed to antibiotics develop adaptive traits to these antimicrobials through natural selection mechanisms (Prestinaci et al., 2015). For years, the World Health Organization has considered AMR a serious global health threat (WHO, 2001).

Approximately 4.95 million deaths are currently associated with AMR, of which 1.27 million are directly attributable to that resistance (Murray et al., 2022). By 2050, it is estimated that annual deaths attributable to AMR could reach 10 million (The Review on Antimicrobial Resistance, 2014). In the long term, AMR could also lead to a general shortage of effective antibiotics, which would have a disastrous impact on modern medicine, as the safety of many medical interventions, such as surgeries and chemotherapy, depends on these antibiotics (Teillant et al., 2015).

One of the causes of AMR is the abuse of antibiotics in human medicine, either by overprescription or self-medication (Prestinaci et al., 2015). In the case of Guatemala, there is evidence of high rates of self-medication (Ramay et al., 2015), facilitated by the high availability of antibiotics in convenience stores, where these drugs are sold without prescription (Moreno et al., 2020).

However, AMR may be mainly driven by the use of antibiotics in animals, which is far more significant in volume. Global antibiotic use in cattle, sheep, chickens, and pigs was estimated to be 99,502 tons in 2020, which could rise to 107,472 tons by 2030 (Mulchandani et al., 2023). Much of the recent and future increase is due to the growing demand for meat, which requires intensification of animal production (Van Boeckel et al., 2019). In relative terms, an estimated 73% of all antibiotics sold worldwide are administered in animals (Van Boeckel et al., 2017).

The main controversy related to antibiotics in animals is that, in many cases, they have non-therapeutic uses, i.e., they serve purposes other than disease treatment, such as growth promotion. This abuse is considered one of the main drivers of the increase of AMR in animals, which can be transmitted to humans through the food chain or through contaminated water, air, soil, or manure in the environment (Ghosh & LaPara, 2007; Ma et al., 2021).

In Guatemala, AMR has been detected in *E. coli* strains isolated from pork marketed in municipal markets (Porras et al., 2022) and in pathogenic bacterial strains isolated from tilapia collected in various aquaculture production centers (García-Pérez et al., 2021).

Finally, a related phenomenon is antifungal resistance, the ability of fungi to adapt to antifungal agents. The discovery of Candida Auris, which forced Guatemala to issue an epidemiological alert, is a possible consequence of this (MSPAS, 2021). In this case, the excessive administration of anti-fungicides in agriculture is one of the main drivers of resistance (Brauer et al., 2019).

Sociocultural factors

Health and disease processes are related to two lines of interaction: risk factors and social determinants. This leads to dynamic and interactive processes between biological, physical, environmental, and human factors, such as population density, overcrowding, migrations and displacements, education, labor activity, and other socioeconomic factors.

Variations in human behavior profoundly affect the epidemiology of parasitic zoonoses and their emergence or re-emergence (Matamoros et al., 2000). The probability of disease transmission increases in contexts with more significant interaction between animals and humans, such as hunting, animal husbandry, markets, megacities, and pet ownership (Moutou, 2020). In addition, aspects such as diet, agricultural practices, animal handling, traditional medicine, and animal-related beliefs may influence exposure to zoonotic diseases.

In addition, recent and unprecedented movements of people, animals, and their parasites worldwide have introduced and mixed cultural aspects such as practices, customs, and behavioral patterns. Among these, an increase in the intake of raw or undercooked, smoked, pickled, or dried meat, fish, crabs, shrimps, mollusks, and shellfish has been observed. This has facilitated the spread of several parasites such as protozoa (*Toxoplasma*), trematodes (*Fasciola sp., Paragonimus spp., Clonorchis sp., Clonorchis sp., Opisthorchis spp, Nanophyetus sp.*), cestodes (*Taenia spp., Diphyllobothrum sp.*) and nematodes (*Trichinella spp., Capillaria spp., Gnathostoma spp., Anisakis sp., Parastrongylus spp.*) that can cause zoonoses (Matamoros et al., 2000).

In turn, other socioeconomic and cultural factors aggravate the risk of zoonotic transmission. For example, infrastructure is often of lower quality in impoverished areas, which aggravates the problem (Palomares Velosa et al., 2022b). In Guatemala, Chagas disease infestation at the household level has been associated with cracks in adobe, wattle, and daub constructions (Penados et al., 2020).

Another element to consider is lack of relevant education — more specifically, the low perception of risk and lack of knowledge about the causes, transmission routes, symptoms, and consequences of diseases (Palomares Velosa et al., 2022b). For example, in Guatemala, knowledge and language use gaps between rural communities and health sector professionals often impede the implementation of biosurveillance systems and other preventative measures (Cerón et al., 2016).

3. Institutions in Guatemala

Guatemala is a unitary democratic republic with a political system based on administrative centralism and division of powers. Executive power is held by the President of the Republic, who is considered the head of state and head of government. They are assisted by a council of ministers composed of the Vice President and the ministers of various departments. The Ministry of Public Health and Social Assistance (MSPAS) and the Ministry of Agriculture, Livestock and Food (MAGA) are the main ones in charge of epidemiological issues. The legislative branch should also be mentioned since Congress is responsible for enacting laws concerning public health, administrative organization, and the national budget, which may impact epidemiological issues. Lastly, the judiciary issues sentences and judicial directives aimed at guaranteeing the right to health of Guatemalans.

As shown in Figure 1, MSPAS, in particular, is the leading agency responsible for detecting, preventing, and responding to emerging infectious diseases, epidemics, and pandemics. Within MSPAS, the Department of Epidemiology is in charge of epidemiological surveillance. This Department of Epidemiology is, in turn, in charge of the National Epidemiological Surveillance System (SINAVE), which seeks to have a single, updated, and standardized system in the country. It also establishes a manual of norms and procedures that serve as a reference for all those offices and departments that carry out epidemiological surveillance activities in Guatemala.

The epidemiological surveillance system in Guatemala was established in 1945 with the creation of the Epidemiology Section within MSPAS. In its beginnings, it focused on infectious events. It achieved notable advances in public health, such as the eradication of smallpox in the 1970s and the detection of the last case of poliomyelitis in 1992. In the mid-1980s, surveillance of noncommunicable diseases began to be included, and mandatory telegraphic disease reporting was implemented (MSPAS, 2018).

Since the late 1990s, the system has undergone changes and reorganizations. In 2016, the Department of Epidemiology became defined as the system's main body, made up of two particular sections: Epidemiological Surveillance and Epidemiological Development. Four editions of the epidemiological surveillance protocols have been carried out, the last in 2018. The primary function of the Epidemiology Department is to review, evaluate, define, and update the National Public Health Surveillance System in order to informthe other five primary functions of the department (MSPAS, 2018).

SINAVE is functionally composed of four levels: the first corresponds to the minimum local community levels (civilian population); the second is made up of health centers, hospitals, and medical units of the Guatemalan Social Security Institute (IGSS), private sector care units and non-governmental organizations; the third corresponds to the Health Area Directorates; and the fourth is the central level (National Government).

On the other hand, MAGA plays a crucial role in detecting and preventing infectious diseases in animals, some of which may potentially spread to humans. This ministry has four vice ministries; for this report, the most relevant is the Vice Ministry of Agricultural Health and Regulations, which oversees the Department of Epidemiological Surveillance and Risk Analysis (DEVEAR) within the Directorate of Animal Health (DSA).

This Department of Epidemiological Surveillance and Risk Analysis, similar to that of MSPAS, is in charge of the Animal Health Epidemiological Surveillance Network (REVESA), the technical base for animal epidemiological risk detection and prevention activities. The REVESA structure is composed of three levels. The first level is local and community-based, including the participation of animal owners, MAGA extensionists, municipal authorities, licensed veterinarians, volunteers, community leaders, teachers, and NGOs. The second level is located in the department, where DSA epidemiologists and their assistants participate, as well as official veterinarians and field technicians in the poultry and swine programs. The third and last level is DEVEAR, in charge of filtering, analyzing, and interpreting the information and coordinating with departmental epidemiologists, depending on the severity of the notification and its impact on the animal population where the outbreak or event is detected.

As for passive surveillance, there is a network of active agents who report on outbreaks of animal diseases. If they make reports, monitoring is carried out, and other agencies, authorities, or local committees are consulted to obtain information on possible outbreaks or diseases (Appendix 1. Interview with Juan Carlos Moreira).

Concerning the emergency response, the National Coordinator for Disaster Reduction (CONRED) plays a vital role at the national level. CONRED is structured in five levels. The National Level comprises all central institutions, including the National Council, the Executive Board, and the Secretariat for Disaster Reduction. The Regional Level is defined according to the regionalization of the country and includes regional public, private, and citizen organizations. The Departmental Level covers the jurisdiction of a department and includes the Departmental Coordinator for Disaster Reduction, composed of departmental organizations and relief corps. The Municipal Level covers the entire municipality and includes the Municipal Coordinator for Disaster Reduction, composed of municipal organizations and relief corps. Finally, the Local Level comprises the Local Coordination for Disaster Reduction, which includes local organizations and relief corps.

The National Council of Protected Areas (CONAP) may also have a role in biosurveillance, monitoring the health of fauna within protected areas, and collaborating with other institutions to detect emerging infectious diseases. CONAP has an organizational structure that includes several units and directorates, each of which is tasked with a particular group or issue, such as “Indigenous Peoples” or “Local Communities.” Regional directorates cover different regions of the country: Metropolitan (the capital), Central Highlands, South Coast, Western Highlands, Northwest, Verapaces, Petén, Northeast, Southeast, and East.

CONAP has an ongoing investigation on zoonosis financed with German cooperation, carried out in the Petén region and involving the participation of several entities such as the Ministry of Health, Ministry of Agriculture, and academia. There is also a regional project in the Maya Forest involving Mexico, Guatemala, and Belize, which recently received more funds for its expansion. It also receives international cooperation from various institutions and countries, including Germany (GIZ and KfW), USAID from the United States, the Brazilian cooperation agency, the Canadian fund, and the European Union. In addition, an upcoming project called "Ecological Transition of Petén" is planned, which also involves several Guatemalan institutions (Appendix 1. Interview with Merle Fernández).

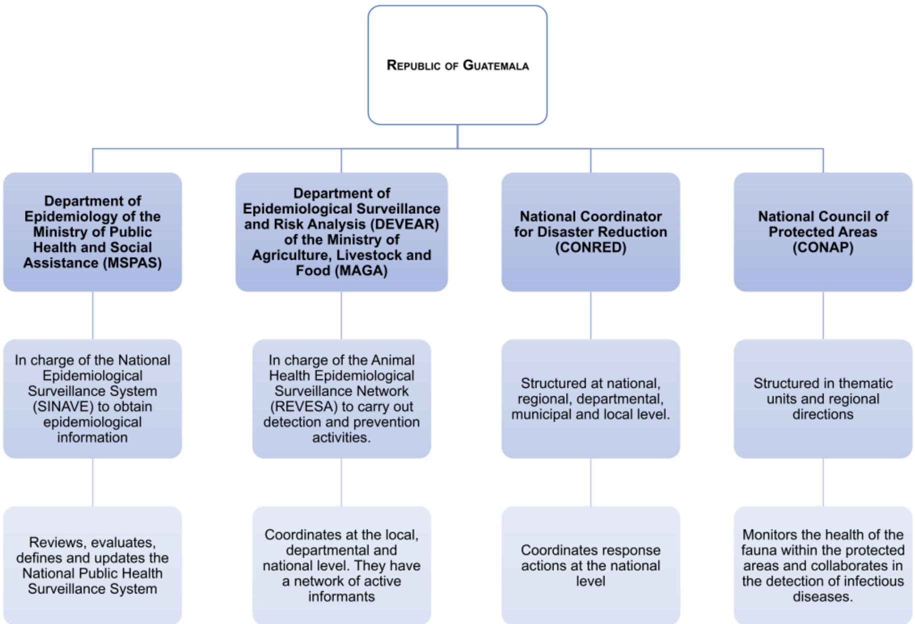

Figure 1. Institutional framework in Guatemala related to emerging infectious diseases and risk management of epidemics and pandemics.

Budget

Generally, biosurveillance in low- and middle-income countries is conducted primarily through passive case reporting and separately within the human and animal health sectors. These systems are limited by their reliance on individuals seeking medical care, untimely detection of events, lack of disease recognition, and selection bias in cases detected by health services (Grajeda et al., 2021).

Biosurveillance is a crucial strategy for preventing and controlling infectious disease outbreaks. Biosurveillance refers to collecting, integrating, interpreting, and communicating health data to detect and respond to disease threats (Toner et al., 2011a). As we saw earlier, biosurveillance is especially important in Latin America due to the diversity of zoonotic and emerging diseases in the region.

The budget allocated for biosurveillance is critical in determining the system's effectiveness. However, budget allocation varies significantly between countries. The report "Investing in Global Health Security: How to Build a Fund for Pandemic Preparedness in 2022" (NTI Bio & Pandemic Action Network, 2022) discusses the need for adequate investment in epidemiological surveillance to improve pandemic preparedness. This investment should be commensurate with the infectious disease threat in a country and is essential in order to prevent and respond to high-impact biological threats (Yassif et al., 2021).

In the particular case of Guatemala, public spending on health for 2022 was US$89 per capita, slightly higher than in Honduras, where it was US$76. In comparison, Costa Rica and Panama had per capita spending of US$688 and US$640, respectively. Mexico had a per capita expenditure of US$267, and the other Central American countries were between US$107 and US$183. As examples of more developed countries, the United States had an expenditure of 9,546 USD per capita, and Germany, France, and Spain, 5,517, 4,248, and 2,235 USD, respectively (Datosmacro.com, 2022).

Indicators

Indicators are essential tools for evaluating the effectiveness of biosurveillance systems. Indicators can include early detection capacity, speed of response, geographic coverage of the system, and the capacity to identify and characterize pathogens (Stoto, 2014). According to the Global Health Index 2021, the health situation in Guatemala presents a series of challenges that merit attention, summarized in Table 3.

Indicator	Guatemala's score	Global score	Comments
Overall	29.1	38.9	Guatemala ranked 142 out of 194 countries evaluated. The evaluation focuses on key aspects such as the prevention of the appearance of pathogens, the early detection and notification of epidemics, and the response to these events, as well as the strengthening of the health sector and the national capacity to face these threats.

Antimicrobial resistance	33	45.3	Need to strengthen antibiotic use policies and AMR supervision.
Zoonoses	14.2	19.8	Need to strengthen mechanisms for detection and prevention of diseases transmitted from animals to humans.
Laboratory systems	50	44.9	Acceptable quality and ability to perform relevant testing and analysis.
Laboratory supply chains	0	15.9	Deficiencies in the management of these chains, fundamental for the availability of reagents and equipment necessary for analysis.
Real-time surveillance and reporting	25	34.6	Challenges in the early detection of infectious diseases, the timely transmission of information, and the availability and transparency of health data.
Data accessibility and transparency	10	34.7	
Case-based investigation	0	16.9	Fundamental to understand and control infectious diseases
Epidemiology workforce	100	46.5	Good job at training and maintaining competent personnel in the field, crucial for surveillance, detection and response to infectious diseases.

Table 3. Summary of Guatemala's Global Health Security Index Scores.

In addition to the indicators mentioned above, other indicators such as laboratory analysis capacity, pathogen characterization capacity, and risk communication capacity are also important in assessing the effectiveness of biosurveillance systems (Miller & Hagan, 2017; Stoto, 2014; Yassif et al., 2021).

Actors

Actors in the surveillance and protection of biological risks include governmental institutions, international organizations, research laboratories, and local and indigenous communities. In addition, health professionals, veterinarians, and scientists play a crucial role.

It is essential to highlight the International Regional Organization for Plant and Animal Health (OIRSA), an international intergovernmental entity comprising nine member states with functions comparable to PAHO's in agricultural matters. OIRSA is financed mainly through delegated services, such as quarantine treatments at ports, airports, and land borders, which generate approximately 90% of its resources. In addition, it manages projects with international cooperation. The fee for these services is used to prevent the entry of pests and diseases. In the case of Guatemala, this income amounts to approximately US$10 million, of which 80% is reinvested in local projects and 20% is allocated to headquarters for regional programs. An emergency fund is also maintained in case of phytosanitary emergencies (Appendix 1. Juan Carlos Argueta and Abelardo De Gracia).

As for the private sector and academia, the work of Fundación para la Salud Integral de los Guatemaltecos (FunSalud), an organization started by Dr. Edwin Asturias, who was part of the COVID-19 response team in the country, stands out. FunSalud uses Oxford Nanopore technology for disease detection (Appendix 1. Interview with Paulina Paiz). The Universidad del Valle de Guatemala is also another critical player to consider. This university is conducting joint research with Washington State University, where samples are sent for sequencing (Appendix 1. Interview with Paulina Paiz). This university also has strong links with institutions such as the CDC and has received cooperation from Switzerland and USAID. The Universidad del Valle de Guatemala is recognized for its focus on technology, innovation, and science and has significantly influenced several government ministries, including the Ministry of Health. The university has recently upgraded its infrastructure and has innovative laboratories, including an aerospace laboratory and laboratories for physics, biology, mechanics, and food (Appendix 1. Interview with Daniela Ochaita).

Guides and procedures

Procedures and guides are essential to guide biosurveillance operations. For example, in Guatemala, the Protocol of the National Epidemiological Surveillance System and the Epidemiological Surveillance Manual for Animal Diseases provide guidelines on conducting surveillance for emerging infectious diseases.

Detection and reporting systems are equally critical components of biosurveillance. For example, Guatemala's integrated collaborative surveillance (ViCo) system has proven effective for disease detection and reporting (Jaramillo et al., 2022). In addition to the protocol and manual mentioned above, other documents, such as the Norms and Procedures of the National Epidemiological Surveillance System (MSPAS, 2007), also provide guidelines for biosurveillance.

Despite progress, there are still opportunities for improvement. Improving early detection capability and expanding the geographic coverage of the biosurveillance system could significantly improve responsiveness to disease threats (Cameron et al., 2020). Another crucial aspect is detection capability, which refers to the ability of a system to identify a disease outbreak quickly (Stoto, 2014).

International cooperation

International cooperation is an essential component in the fight against biological threats and biosurveillance. Infectious diseases recognize no borders, and an outbreak in any corner of the world can quickly become a global threat. Cooperation between nations is, therefore, essential for an effective response to disease threats. International cooperation also plays a vital role in improving and developing biosurveillance, which goes beyond disease detection, prevention, and response. This principle of global collaboration has been particularly relevant in the fight against zoonotic EIEs, as evidenced by the World Organisation for Animal Health (Hamilton, 2021).

International organizations are critical for multilateral cooperation. These entities can facilitate cooperation among countries, coordinate responses to disease outbreaks, and promote international standards and guidelines for biological risk management (World Health Organization et al., 2019). Of note is the Global Early Warning System (GLEWS), which is a collaboration between the World Health Organization (WHO), the World Organization for Animal Health (WOAH), and the Food and Agriculture Organization of the United Nations (FAO). This system combines and coordinates the warning and response mechanisms of the three organizations and assists in predicting, preventing, and controlling animal disease threats, including zoonoses.

Also noteworthy is WHOA’s Biological Terrain Reduction Strategy, which focuses on five essential areas: policies, standards, operations, intelligence, and training. This organization assists countries in modernizing veterinary legislation, aligning it with international frameworks, and supporting the creation and implementation of national disease control plans. It also sets animal health standards through four fundamental documents that are updated annually, including laboratory procedures and communication protocols. In operations, the organization has a network of experts, including collaborating centers and reference laboratories, that support disease management and improving veterinary services. Biological risk intelligence requires disease and outbreak reporting through the WAHIS platform, complemented by risk scanning and active search activities at a global level. Finally, it offers training on critical topics for biological risk reduction and emergency management, tailoring its content to the needs of each country by pre-surveying participants (Appendix 1, interview with Ian Peter Busuulwa).

This global cooperation can take various forms, such as information sharing, research collaboration, development of new medical solutions, and mutual relief in response to disease outbreaks. A multisectoral approach that embodies the 'One Health' principle can effectively address zoonotic diseases in different countries (World Health Organization et al., 2019).

This information exchange includes sharing data on disease outbreaks, scientific research and findings, and best practices in biorisk management. This circulation of information allows countries to learn from each other and optimize their biosurveillance systems (Stoto, 2014). Countries can likewise collaborate on research into new diseases, developing vaccines and treatments, and improving detection and diagnostic technologies. This collaboration can drive scientific progress and improve global capacity to prevent and control infectious diseases (Yassif et al., 2021). Countries can provide mutual assistance in a disease outbreak by providing resources, expertise, and logistical support. Such assistance can be instrumental in controlling an outbreak and minimizing its impact (NTI Bio & Pandemic Action Network, 2022).

Despite its importance, international cooperation faces challenges. These include differences in countries' capabilities and priorities, legal and regulatory barriers, and difficulties in coordinating efforts globally (Haines & Gronvall, 2023). Overcoming these challenges is critical to optimizing international cooperation in biological risk management. As infectious diseases evolve and new threats emerge, international cooperation will become increasingly essential to protect health globally. This cooperation will require continued commitment from countries and a willingness to work together to prevent and control infectious diseases (Cameron et al., 2020).

4. Recommendations

This section presents a series of recommendations to enhance the prevention and detection of emerging infectious diseases in Guatemala. Prevention measures aim to prevent a disease from being transmitted to humans in the first instance and, therefore, seek to mitigate the aggravating factors of zoonotic risk. Detection measures aim to find outbreaks quickly or even anticipate them to ensure an early response.

The prevention area includes four objectives: i) carry out interventions to improve sanitation, ii) stop illegal wildlife trafficking, iii) stop deforestation and other forms of environmental degradation, and iv) prevent the abuse of antibiotics in the animal industry. The detection area includes four more: i) designing comprehensive epidemiological surveillance systems, ii) adopting a proactive approach to pathogen detection, iii) ensuring transparency and accessibility of data, and iv) implementing technological solutions. All proposals are presented in order of priority. Finally, the achievement of the objectives is broken down into specific proposals. Table 4 provides a summary of the recommendations.

All proposals are in line with existing literature (Vora et al., 2023) and expert interviews (Appendix 1). Their implementation is affordable for Guatemala and would benefit public health and even other sectors, making them cost-effective. One study estimates that the total cost of the proposed preventive measures[5] would be between $22 billion and $31 billion per year globally, a much lower figure than, for example, the $5 trillion in losses caused by COVID-19 in 2020 (Dobson et al., 2020). Another study determines that the total cost of the proposed measures[6] would be about $20 billion per year, less than one-twentieth of the annualized value of lives lost to emerging zoonoses worldwide (Bernstein et al., 2022).

Area	Objective	Proposals
Prevention	Implement interventions to improve sanitation	1. Improvements in essential infrastructure and public services 2. Sanitary practices for human-animal contacts
	Curb illegal wildlife trade	1. Interinstitutional coordination, control, and monitoring 2. Education, awareness, and training 3. Participation of civil society
	Stop deforestation and other forms of environmental degradation	1. Forest governance 2. Sustainable agricultural intensification 3. Urban planning 4. Other ecological interventions
	Halt antibiotic abuse in animal food production	1. Restrict non-therapeutic uses of antibiotics in animals
Detection	Design integral systems of epidemiological surveillance	1. Coordination between human and animal health sectors
	Adopt a proactive approach to pathogen detection	1. Monitoring pathogens present in wildlife 2. Frequent testing of high-risk populations
	Ensure transparency and accessibility of epidemiological data	1. Networks to share data between departments 2. Effective communication with the international community
	Implement technological solutions	1. Boosting laboratories with genomic sequencing and natural language processing programs

[5] These measures include reducing deforestation, monitoring and governing wildlife trafficking, improving agricultural practices, and strengthening biosurveillance systems for early detection.
[6] These measures can be classified into the same categories as in the previous study.

Table 4. Summary of recommendations to strengthen prevention and detection.

Prevention

- **Carrying out interventions to improve sanitation**

The spread of many diseases is often linked to inappropriate practices in interaction with the environment. In this section, we list several interventions in domestic environments and public services that can help people actively prevent the transmission of various pathogens to humans.

Essential infrastructure improvements

Local infrastructure conditions are essential in disease prevention and have economic and health benefits that justify improvements. We propose several interventions to **improve water and sanitation services, waste management, and domestic environments**.

Access to piped water increases the quality of life. Also, it eliminates the need to store water in containers in domestic environments, helping to curb the proliferation of vectors such as *Aedes aegypti*, the mosquito that transmits dengue fever (Telle et al., 2021). In this context, it is essential to improve and expand the coverage of public drinking water and sanitation services, one of the main objectives of the National Water Policy. Likewise, when access to piped water is unfeasible, periodically cleaning water containers and covering them with airtight lids can help reduce the presence of *Aedes aegypti* and, consequently, of Zika and other diseases transmitted by this vector (Pinchoff et al., 2021).

In addition, waste management in urban environments is also crucial to prevent solid waste from accumulating and attracting vectors and hosts of zoonotic diseases (Krystosik et al., 2020). In this sense, we celebrate and call for full compliance with the Regulation for the Integrated Management of Common Solid Waste and Solid Waste, which regulates the collection, transfer, treatment, and final disposal of solid waste and solid waste in Guatemala.

Other low-cost interventions can be implemented at the household level. A project conducted between 2001 and 2008 in the Guatemalan village of La Brea succeeded in reducing infestation levels of *T. dimidiata*, the main vector of Chagas disease, with relatively simple measures: covering cracked walls, covering dirt floors with a cement-like substance, or building open-air wire chicken coops to keep animals out of houses. Infestation rates dropped from 41.8% in 2001 to 2.2% in 2022, many years after the end of the intervention, indicating high long-term effectiveness (Pereira et al., 2022).

Sanitary practices in human contact with animals

It is important that **people who are regularly in contact with animals due to their professional activities adopt good practices in the handling of these animals**. We highlight the Central American Technical Regulation on Products Used in Animal Feed: Good Manufacturing Practices. Specifically, we emphasize the importance of properly designing, maintaining, and sanitizing facilities and equipment, including proper spatial distribution, ventilation and wastewater and waste disposal systems, and cleaning and disinfection processes for work surfaces.

In turn, training personnel in food handling techniques, food safety and quality principles, and personal hygiene is crucial. In this case, we recommend expanding training programs beyond the large production centers, since most cattle farms in Guatemala are family farms.

It would also be positive to standardize these sanitary practices and implement animal product quality and safety certification schemes (Appendix 1. Interview with OIRSA). Public institutions could explore incentive programs and other economic support for certified farmers, including subsidies for equipment purchase and preferential credit.

Finally, it is essential to monitor the human-wildlife interface. It has already been explained above how people in contact with caves are particularly exposed to zoonotic diseases. Authorities should educate the public and require those accessing caves to wear appropriate clothing, masks, and other protective equipment (Petrovan et al., 2021). Also, access to the highest-risk areas should be restricted to professional cavers whose preparation should include vaccination and necessary preventative medications (Igreja, 2011).

- **Stopping illegal wildlife trafficking**

As explained above, illegal wildlife trafficking (IWT) is associated with an increased risk of zoonotic transmission. Likely, some significant outbreaks in recent history — e.g., Ebola, HIV/AIDS — are due to trafficking, so trafficking could have indirectly resulted in the loss of millions of lives and billions of dollars (Doody et al., 2021). In contrast, it is estimated that the global budget allocated to IWT monitoring and management to prevent pandemics effectively should be between $250 million and $750 million annually[7] (Dobson et al., 2020).

[7] In the context of the study, this budget would mainly be used to finance bodies such as the World Organization for Animal Health or the Wildlife Enforcement and Compliance Networks, one of which works in Central America.

In addition to health considerations, stopping IWT can benefit ecosystem services (Cardoso et al., 2021) and promote economic activities as tourism. A study in Namibia estimated that the country's efforts to curb IWT cost US$2 billion over ten years[8], but brought about US$5,345 million in benefits compared to a no-action scenario. Likewise, an additional investment of $550 million could yield benefits of $3.69 billion (Briceno & Perche, 2021).

However, discerning which investments are genuinely effective is a challenge. IWT is an intricate and multipronged issue, so banning it outright without regard for nuance may be counterproductive (Bonwitt et al., 2018; Roe et al., 2020). Solutions, then, must be comprehensive.

Guatemala has considered this complexity in policy development. CONAP has already developed a National Strategy against Illegal Wildlife Trafficking (ENTIVS) for the period 2020-2029, which has three strategic lines: i) inter-institutional coordination, control, and surveillance; ii) education, awareness and training; and iii) facilitating access to legal harvesting mechanisms and linking with civil society (Flores & CONAP, 2020). The initiative has an initial budget of 18,828,000 Quetzals. This section presents several recommendations that fit into the three lines of action proposed.

Inter-institutional coordination, control, and surveillance

Ensuring compliance with the law is the central objective in stopping IWT and the state's primary responsibility. However, it is also a challenge that requires resources and coordination. In this section, we propose two groups of actions to stop illegal wildlife trafficking: **monitoring of high-risk species and control of borders and markets**. In this way, the aim is to detect and prevent both the beginning of the process (the capture of the animal) and the end (national or international commercialization).

Firstly, we recommend that, together with the relevant conservation statuses — the CITES Appendices and the LEA Index — zoonotic risk be considered in the prioritization of species to be monitored. This would involve increased monitoring of different mammal species, including rodents, procyonids and dasipodids. Primates would also enter the group to be closely monitored, although protection levels are already generally high.

[8] This figure includes salaries of workers in wildlife protection and nature park offices, costs of patrolling and border control, 1% of the budget of the Ministry of Justice, and the allocated budget of NGOs such as the World Wildlife Fund and the Namibia Nature Foundation, among others.

Additionally, we call for the strengthening of patrols. DIPRONA has 19 delegations and 540 professionals (MINGOB, 2020), which seem insufficient to guarantee adequate wildlife protection (Ochoa López, 2022). We recommend strengthening the work of DIPRONA with more human and technical resources or even support from other divisions such as DEIC or DAIA. To reduce costs, we suggest prioritizing efforts to focus on Petén, Alta Verapaz, and Izabal departments, which suffer from more registered cases of IWT (Flores & CONAP, 2020). This prioritization should be reassessed over time and reallocated when necessary.

To facilitate monitoring tasks, we propose to explore the use of satellites and drones, which can be a good alternative for remote areas where research is complex (LaRue et al., 2017). The three mentioned departments, regions with high levels of biodiversity and crime, seem a good target to start the project (Yazici, 2022). Guatemala already has experience with satellite technology for monitoring illegal logging (British Embassy Guatemala City, 2017) and with spatial monitoring and reporting tools (SMART) in northern Petén (GIZ, 2021). We recommend that the results of these data collection and processing systems be integrated to monitor the protected species closely.

As stated in the ENTIVS, CONAP should do this follow-up and coordinate patrolling with an inter-institutional protocol adapted to each region. Judicialization in several departments has also increased attention to cases linked to IWT (Flores & CONAP, 2020), so we suggest that national judicial bodies become more actively involved in the cause. Finally, we call for exploring all possible avenues of cooperation with countries in the region, as well as the rest of the world, and attracting initiatives such as the International Consortium on Combating Wildlife Crime.

On another front, we recommend strengthening border control to prevent the consequences of IWT from being magnified. In this regard, the situation is particularly delicate at the road borders. The problematic accessibility of the border with Belize, characterized by political tensions, makes it easy for wildlife trafficking taking place in the area to go unnoticed by the authorities (Soberanes, 2018). The same is true for the northwestern border with Mexico, which is highly controlled by so-called *narco-ganaderos* (Devine, Wrathall, et al., 2020a). Finally, the border with El Salvador is also cited as one of the most common (Ochoa López, 2022), with Anguiatú being a crossing point for wildlife from the Motagua Valley (Flores & CONAP, 2020).

However, airports are the main point of international traffic (Utermohlen & Baine, 2018). Guatemala has two major international airports: La Aurora (Guatemala) and Mundo Maya (Petén). In this case, the work of DIPAFRONT should be coordinated with all personnel involved in the airline industry, who should follow training programs and develop protocols for action in line with ROUTES guidelines.

Regarding maritime transport, the ports of Santo Tomás de Castilla and Quetzal, the country's leading shipping ports in the Caribbean and Pacific, stand out (TRAFFIC, 2009). However, it is also essential to carry out controls in other points with less infrastructure, as well as less transited ports, such as Puerto Barrios and Santo Tomás de Santo in the Caribbean, and San José and Champerico in the Pacific. This is because, as wildlife traffickers become more professional, they also become more undetectable. To circumvent controls, they make unofficial border crossings on land and sea, moving wildlife at night through rivers, forests, human settlements, and maritime routes (Gluszek et al., 2021).

Finally, municipal markets should be the primary target for ensuring responsible consumption of wildlife products. Several Guatemalan markets commercialize wildlife species, including those of Flores, Poptún, Huehuetenango, Sayaxché, Chimaltenango, Retalhuleu, and El Guarda, among many others (Flores & CONAP, 2020). Regular inspections must be made in these markets to ensure that illegally traded wildlife can be seized and to verify compliance with sanitary standards for legally traded products.

Education, awareness, and training

Guatemala's role in the illegal trade of wild animals is not significantly linked to consumption but rather to the economic benefits of exportation. However, certain habits and traditions in the country encourage this activity. An example is consuming wild meat such as the armadillo chojineado or tepezcuintle (Flores & CONAP, 2020). To raise awareness of the risks associated with these habits, we recommend that protecting wildlife from illegal trafficking be one of the main axes of **education and awareness campaigns for the population** in environmental education. The National Environmental Education Policy, approved in 2017, does not include this element. However, we suggest introducing it in the new 2024-2028 implementation plan under negotiation (MARN, 2023) or creating a parallel national policy focused on wildlife. Both proposals are included in the ENTIVS, but neither has been implemented. Nor is there evidence of systematic campaigns beyond initiatives such as #ViveYDejaVivir or calls to report instances of IWT to the authorities. None of these sources emphasizes the risk of disease, an additional persuasive factor.

Lastly, there is an urgent need to **train all security forces**. We recommend that DIPRONA, DIPAFRONT, and DEIC be prepared to identify and handle wildlife species at high zoonotic risk, which should be subject to specific protocols.

Linking civil society

Wildlife trafficking provides a livelihood for many people and, in some cases, contributes to food security (Booth et al., 2021). In Guatemala, many local communities without alternative livelihoods are drawn into trafficking networks, primarily trapping (IIED & IUCN-SULi, 2019).

To reverse the situation, Guatemala can be guided by a theory of change with three potential courses of action: i) disincentivize illegal behaviors, ii) incentivize protection, and iii) support alternative livelihoods (Biggs et al., 2015).

Disincentivizing illegal behavior involves local communities in patrolling and law enforcement efforts. Civil society collaboration is crucial where authorities' capacity is lower, and communities might be tempted to facilitate trafficking, as in the case of the Guatemala-Belize border (Cremona et al., 2018). Projects such as Fundaeco's Genesis Group patrol the Maya Forest to detect illegal activities (Melgoza & Papadovassilakis, 2022). These initiatives could be reinforced through monetary or social incentives, as with payments for environmental services.

Incentivizing protection is offering financial and non-financial benefits linked to sustainable wildlife management. In this case, local tourism is one of the most common solutions (Roe & Booker, 2019). In Guatemala, the NGO Zootropic managed to restrict lizard trafficking through the creation of the Heloderma Nature Reserve, located in Arenal, which has become a tourist center and hires local villagers as rangers, guides, and other employees (IIED & IUCN-SULi, 2019).

Finally, supporting alternative livelihoods involves promoting non-wildlife-dependent economic activities. For example, a scarlet macaw conservation project in Guatemala and Belize offered dozens of women the opportunity to manage agroforestry plots and community-based micro-enterprises such as bakeries and chicken farms (IIED & IUCN-SULi, 2019).

The above examples demonstrate that all three courses of action can be successful in Guatemala. We recommend supporting NGO activities that have proven to be effective. We also suggest that, when necessary, public institutions develop a coordinated action plan to **integrate communities into patrolling efforts and provide alternative livelihoods to trafficking**. Community Development Councils should be more active in defining this strategy.

- **Halting deforestation and other forms of environmental degradation**

Globally, the annual cost of reducing deforestation to 40% in areas with the highest risk of zoonotic spread is estimated to be between $1.5 billion and $9.6 billion (Dobson et al., 2020). The link between deforestation and disease emergence suggests that efforts to maintain intact forest cover would reduce the risk of zoonotic transmission. Additionally, these actions would positively affect carbon sequestration and thus help to mitigate climate change (Busch & Engelmann, 2017).

This section presents several proposals for regulating land use change and protecting Guatemalan ecosystems. None of these recommendations is particularly novel; in some cases, Guatemala is already on the right track. However, this section intends that public health be added as an essential factor to underpin the creation and maintenance of these initiatives.

Governance of forest areas

The Guatemalan territory has extensive forest areas, primarily concentrated in the department of Petén, which various governance models administer with mixed results.

One of the most successful models has been the forest concessions in the Multiple Use Zone (ZUM) of the Maya Biosphere Reserve (RBM). Through the concessions, the state grants sustainable use and harvesting rights of the forest to the community that inhabits it. Since the protection of the forest resides in the interest of the community that manages it, these concessions can effectively reduce deforestation (Barsimantov & Kendall, 2012; Oldekop et al., 2019; Stevens et al., 2014).

Between 1994 and 2002, CONAP granted twelve concessions for a 25-year cycle to community forest enterprises. Between 2000 and 2013, deforestation rates in the nine active concessions were practically 0% (Hodgdon et al., 2015). This contrasts with the figures for the surrounding areas of the RBM — between 1% and 5.5% — and even more so with those for the entire Petén region: 31% total deforestation and 23% in primary rainforest between 2002 and 2022, according to Global Forest Watch data.

Between 2020 and 2023, CONAP extended all existing contracts, granted two new concessions, and announced the processing of two more, totaling 617,878 hectares granted or 73% of the entire ZUM (Larios, 2023). We welcome the institution's commitment to maintaining the concessions and support efforts to consolidate the model. We also recommend that **the concession system be maintained and expanded in the ZUM or even outside**, exploring the feasibility of implementing it in areas close to diverse ecosystems and with long-established local communities.

Another noteworthy policy is the incentive scheme made up of the Forestry Incentives Program for Holders of Small Tracts of Land with a Forestry or Agroforestry Vocation (PINPEP), established in 2005, and the PROBOSQUE program, established in 2017. Both initiatives aim to promote the country's forestry development through sustainable forest management by providing grants for environmental services to the community sector, in the case of PINPEP, and to large landowners, in the case of PROBOSQUE. Between the two, 59,330 projects have already been financed throughout the country, of which 46,158 are focused on forest protection, totalling 263,033 hectares.

Payment for environmental services programs have also demonstrated their potential to reduce deforestation and conserve biodiversity (Jayachandran et al., 2017; Schirpke et al., 2018; Vorlaufer et al., 2017), also in the case of Guatemala (vonHedemann, 2020). We recommend that **the design of future payments for environmental services integrate public health considerations and incentivize activities such as the protection of ecosystems and water resources.**

Finally, in contrast to the systems mentioned above, the western part of the RBM presented high deforestation rates in recent years (Figure 1). According to satellite studies, this deforestation was mainly caused by illegal ranches in Laguna del Tigre (87%) and Sierra del Lacandón (67%) national parks (Devine, Currit, et al., 2020b). Much of the extensive cattle ranching in this area is closely linked to drug trafficking, which is why it is known as “narco-livestock ranching.” The attraction of this activity is twofold: to launder money by buying cattle in cash to sell to licit buyers in Mexico or Guatemala, and to territorially control pastures to turn them into strategic sites and blind spots (Devine, Wrathall, et al., 2020b).

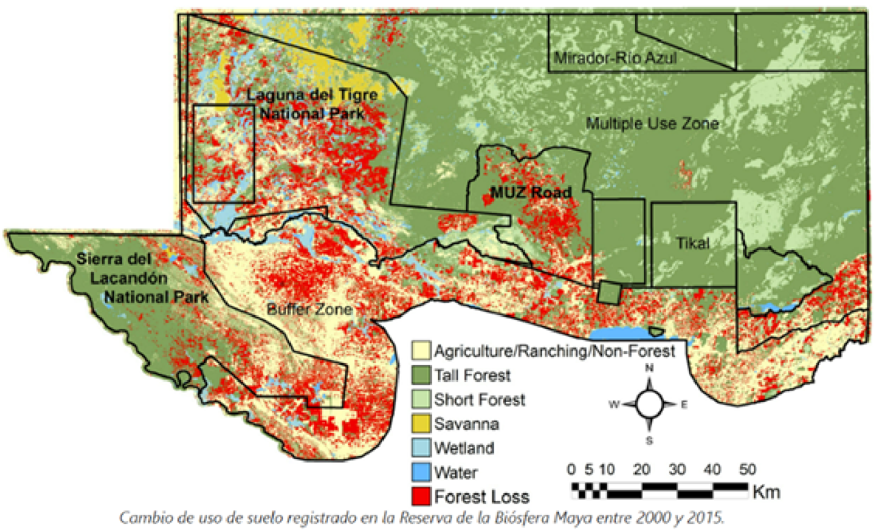

Figure 1. Retrieved from Devine et al. (2020b).

To address this challenge, we recommend **prioritizing funding, training and coordination of CONAP, INAB, and DIPRONA**. The protection of Laguna del Tigre Park is undermined by the lack of budget and professionals working there and often relies on non-governmental organizations such as the Wildlife Conservation Society (Radwin, 2019).

However, security forces are unlikely to be able to solve the problem on their own. Narco-rancher activity is made possible by their impunity and the intimidation most local communities suffer (Devine, Wrathall, et al., 2020b). This reality is widely recognized by authorities, who point to ungovernability as one of the main threats to the management of the Maya Biosphere Reserve (CONAP, 2016). The presence of security forces and other state institutions could even be counterproductive if they do not trust local communities (Appendix 1. Paula Prist interview). For this reason, we recommend **designing any policy in line with local interests and preferences** and propose exploring ways to empower communities by reconsidering the model of these protected areas. Expanding the eastern fringe of Laguna del Tigre, commonly called "the shield," might be a first step in this direction.

Sustainable agricultural intensification

According to MAPA data, the largest crops grown in Guatemala are corn (1,160,351 hectares), coffee (539,000 ha), sugarcane (323,688 ha), beans (208,771 ha), oil palms (180,000 ha), cardamom (169,429 ha), and rubber (131,000 ha). Together, they occupy approximately a quarter of the national territory.

Agriculture is a socioeconomic pillar of the country. Crops such as corn and beans are fundamental for the food security of a large part of the population, whose diet depends on these two foods. Others, such as palm oil and cardamom, are an essential source of income for Guatemala, which is among the world's leading exporters of these products.

However, uncontrolled agricultural expansion can have negative consequences on ecosystems. The cultivation of basic grains was responsible for 31% of deforestation in Guatemala for the period 2001-2010, although the coverage of these crops has decreased and is closely linked to subsistence (GCI, 2018). For these cases, we propose **investing in sustainable agricultural intensification techniques**. Technological intensification[9] saves soil and can reduce pressure on forests (Byerlee et al., 2014). This solution could be an excellent way to ensure food security while

[9] In this context, technological intensification refers to the process by which technical changes in a crop allow more production per unit of land for the same level of inputs.

reducing deforestation, but many Guatemalan farmers do not have the resources to implement it (Shriar, 2002).

Another relevant crop is African palm, responsible for 4% of deforestation between 2001 and 2010[10]. There are reports of communities affected by expansions of this crop in the Franja Transversal del Norte (Gamazo, 2017), the department of Escuintla (Del Cid & Figueroa, 2021) and the municipality of Sayaxché (Santiago, 2018), among others. In addition, this agricultural activity has been associated with the contamination of the La Pasión River in 2015, a severe example of an ecological crisis (Barreto, 2018). We suggest **offering technical and financial support to the Gremial de Palmicultores de Guatemala in implementing its Environmental and Climate Change Policy.** In particular, water management (Strategic Axis 1), soil management and conservation (Axis 4), and biodiversity conservation and restoration (Axis 5) are important.

Finally, it is necessary to consider the cultivation of coffee (18% of deforestation), cardamom (3%), and rubber (3%). However, these crops are considered more sustainable because they involve tree species with less of an impact on forest resources (GCI, 2018). Ninety-eight percent of Guatemala's coffee is grown in agroforestry systems with shade trees, in line with the Forestry Law (Alvarado, 2022). Similarly, cardamom is in the hands of small producers who form a system of agroforestry production chains in harmony with the environment (Lobera, 2020). Finally, rubber is a sustainable plantation that can reduce the negative impact of illegal logging and pressure on forest resources (INAB, 2020). We recommend **continuing to promote these crops to consolidate an economically and environmentally sustainable agricultural system.**

Municipal ordinance

In Guatemala, it is essential to ensure sustainable urban expansion, as there are numerous emerging urban centers close to wilderness environments. Flores (Petén), San Pedro Soloma (Huehuetenango), Cobán (Alta Verapaz), El Estor (Izabal), Gualán (Zacapa) and Santa Lucía Cotzumalguapa (Escuintla) are just a few examples. The growth of these cities beyond recognized boundaries poses two severe threats to public health: the occupation and degradation of ecosystems and the difficulty of providing public services such as water or waste management in peripheral areas. This is especially important given mosquitoes' persistence and proliferation in steeply sloping marginal areas.

[10] According to estimates by the palm sector itself, deforestation between 1989 and 2020 was considerably lower, at 0.67% (GREPALMA, 2021).

In this context, we recognize the effort invested in strengthening the Municipal Development and Land Management Plans (PDM-OT in Spanish), mostly updated until 2032. We also welcome the involvement of national authorities in urban development, as exemplified in the Guide for the Implementation of the PDM-OT. We recommend that the implementation of the PDM-OTs of localities near wild ecosystems be monitored to **avoid changes in land use that involve the undue occupation of these environments**.

Other ecological interventions

With the above recommendations, we have outlined ways to halt the advance of agricultural and urban frontiers and other forms of environmental degradation. Here, we present possible ways to **reverse and mitigate alterations already caused in ecosystems** to reduce the risk of zoonoses.

One of these possibilities is reforestation. Although the effects of reforestation on the risk of zoonotic transmission have not been empirically determined, some studies suggest a relationship. For example, it is estimated that restoring the Atlantic Forest in Brazil could reduce the presence of rodents that host Hantavirus, thereby reducing the risk of transmission by 45% (Prist et al., 2021). In recent years, Guatemala has developed progressive reforestation plans, with 550,000 trees planted in 2020, 3,100,000 in 2021 and 5,660,000 estimated in 2022 (MARN, 2022).

Other interventions attempt to impact wildlife through natural processes[11][3] directly. For example, it has been shown that ecosystem alterations can cause food chain disruptions. In this sense, the reintroduction of rodent predators can help reduce the volume and density of rodent populations, potentially reducing the risk of zoonotic transmission (Ostfeld & Holt, 2004).

Finally, some interventions focus on controlling the interface between domesticated and wild animals. For example, blocking horses' nighttime access to pastures has been proposed to prevent the spread of Hendra virus, as the grasses may contain fresh and potentially contaminated bat secretions (Martin et al., 2015). Likewise, there are ways to move wildlife away from human settlements naturally. Mandating that planting fruit trees, the primary food resource for fruit bats, be done away from pigsties appears to have prevented the introduction of Nipah virus into Malaysian pig populations since 1999 (Pulliam et al., 2012).

[11] Conventional solutions such as culling or chemical control can adversely affect the environment and generate resistance. In addition, they are challenging to implement and sustain logistically, so they involve high costs, and their benefits diminish over time (Sokolow et al., 2019).

- **Avoiding the overuse of antibiotics in the animal industry**

In 2001 the World Health Organization published a *WHO Global Strategy to Contain Antimicrobial Resistance.* One of the points addressed in the document is the administration of antimicrobials to food-producing animals. Among other issues, it recommends a mandatory prescription of all antimicrobials and guidelines for veterinarians to reduce over- and under-administration.

The European Union is one of the jurisdictions that has made the most progress on these recommendations. Regulation (EC) No. 1831/2003 prohibits using antibiotics as growth promoters, while Regulation (EU) 2019/6 prohibits antibiotics from being used routinely or to compensate for lack of hygiene or care. In Guatemala, Ministerial Agreement No. 181-2019 already obliges establishments to dispense antibiotics only with a doctor's prescription. However, the animal industry has no specific regulation on using antimicrobials. According to the 2022 Tracking AMR Country Self Assessment Survey, the use of antibiotics in terrestrial and aquatic animals in the country is generally inadequate and suboptimal.

In this context, we recommend approving stricter regulation of non-therapeutic antibiotics in the animal industry. More specifically, we propose a **gradual restriction of the use of antibiotics**, with particular emphasis on those of paramount importance in human medicine. The new legislation could feed into OIRSA's Action Plan on Antimicrobial Resistance, which is already working on promoting the good use of veterinary medicines and developing regulatory proposals. It is also crucial that alternatives to banned antibiotics are sought. Probiotics, prebiotics, antimicrobial peptides, in-feed enzymes, organic acids, and phytochemicals can be used for growth promotion. For disease prevention, vaccines, immune modulators, and bacteriophages may be used (The Pew Charitable Trusts, 2017).

We recommend that this transition be gradual so that production costs do not suddenly increase. Adopting substitutes with more scientifically proven efficacy, such as probiotics, might be a good first step.

We also propose that this new legislation include a central veterinary prescription registry, which would centralize all antibiotic prescriptions and link each prescription to a licensed veterinarian. In addition, the legislation could require electronic authorization of each antibiotic prescription by a registered veterinarian, ensuring that only licensed professionals issue prescriptions and allowing for effective tracking.

Regarding monitoring policies, we recommend that the Official Meat Inspection System periodically examine the levels of antimicrobial resistance in meat products destined for human consumption. More proactively, we propose that the Department of Registration of Inputs for Animal Use adapt the antibiotic use standards to international recommendations and conduct inspections in production plants accordingly. In this regard, it is imperative to ensure that prohibited or non-prescribed antibiotics are not used and that optimal and proportional amounts are administered.

Finally, we recommend developing awareness and training programs for the veterinary sector. In this context, we suggest promoting the work of the National Network for Surveillance and Control of Antimicrobial Resistance (RED RAM in Spanish), a multidisciplinary group of professionals who promote the appropriate use of antimicrobials in human and animal health and which has already been supported by MSPAS and MAGA among others.

We also recommend integrating measures to prevent antifungal resistance into RAM efforts. In this regard, it is crucial to include fungal infections in existing surveillance programs progressively (Fisher et al., 2022), as well as to replace fungicides in agriculture with alternatives such as endophytic fungi, which are effective agents for disease and pest control (Brauer et al., 2019).

Detection

- **Comprehensive epidemiological surveillance systems**

In this section, we propose to expand epidemiological surveillance systems horizontally and vertically. That is, these systems should integrate various sectors and various segments of the population through the following actions:

Coordinate the human and animal health sectors.

The *Tripartite Guide to Addressing Zoonotic Diseases in Countries*, developed by the World Health Organization, the World Organization for Animal Health, and the Food and Agriculture Organization of the United Nations, provides guidance and operational tools for the implementation of the "One Health" multisectoral approach to the control of zoonotic diseases. In this context, the need to deepen the coordination between animal and human health has become evident, as veterinary research is currently carried out in isolation, without an effective connection with the health system (Appendix 1. Interview with Ediner Fuentes).

In Guatemala, collaboration between public health departments and health centers depends on each municipal office or departmental coordination, and there are difficulties in reaching agreements and working jointly between public health and veterinary health (See Appendix 1. Interview with Juan Carlos Moreira). This lack of coordination hinders the effective implementation of integrated biosurveillance. For this reason, we propose **greater coordination between the Ministry of Public Health and Social Assistance (MSPAS) and the Ministry of Agriculture, Livestock and Food (MAGA) to improve the articulation of human and animal epidemiological surveillance systems**.

To this end, we suggest i) creating an intersectoral committee composed of representatives from the Ministries of Health and Agriculture responsible for coordinating and promoting collaboration between the two sectors; ii) organizing joint training programs for human and veterinary health professionals to increase understanding and cooperation between the two disciplines; iii) establish transparent and efficient communication channels between public health departments and health centers, as well as between animal and human health agencies; and iv) implement integrated surveillance systems (human and animal health) that allow for early detection, continuous monitoring and rapid response to possible outbreaks of zoonotic diseases.

Involving local communities for participatory monitoring

Obtaining first-hand and real-time information from segments of the population in contact with animals is critical to an effective biosurveillance system. However, the coordination levels necessary to ensure this information's transmission are not always sufficient. In this section, we recommend **strengthening the role of communities in participatory surveillance through low-cost technological solutions, educational programs, and greater logistical efficiency.**

Mobile technologies are an excellent tool for facilitating real-time reporting. In Thailand, through Participatory One Health Disease Detection (PODD), hundreds of volunteers report, with text or images, abnormal events in the community, especially in animals, such as sudden deaths and visible symtomps. All reports are automatically analyzed and, if they match the definition of a relevant case, are sent to the epicenter of the system, which determines whether there is any consistent pattern in the data and, if so, labels the events in question as "suspected outbreak" to initiate a further investigation (Yano et al., 2018). In Tanzania, the AfyaData application is powered by information submitted in real time by community reporters, health officials, and animal owners, enabling early detection of clinical cases (Karimuribo et al., 2017).

Mobile applications have been used successfully in Guatemala in at least two participatory biosurveillance pilots. In one case, participants reported influenza syndromes based on weekly reminders and rewards in the form of phone credits (Prieto et al., 2017). In the other, inhabitants of a rural area reported weekly symptoms of acute fever and gastroenteritis, potential indicators of dengue and norovirus (Olson et al., 2017). Both projects were considered a good complement to more traditional epidemiological surveillance mechanisms. We propose that apps be implemented more systematically and extended to animal surveillance.

On the other hand, it is also essential to promote training projects. Knowledge and language gaps between local communities and health authorities have been identified as a significant obstacle to developing community biosurveillance systems (Cerón et al., 2016). In this context, developing training programs to bridge the gap between the two groups is important. For example, the Thai PODD initiative included an educational program on disease prevention and control in poultry, through which the main diseases and their corresponding symptoms were defined (Yano et al., 2018).

At the logistical level, it is essential to establish nodes for the reception and processing of samples, which would allow more effective follow-up of epidemiological situations. These nodes could play a significant role in sample management and the inclusion of local communities in sample collection, strengthening the social connection with disease monitoring. Since there are limitations regarding the capacity to send technicians to collect samples in all required locations, smaller and more remote health centers could function as these nodes, establishing a connection to the main center and acting as repositories where samples can be stored and sent. This strategy would take advantage of the increased storage capacity during the pandemic and facilitate the collection and processing of essential samples (Appendix 1. Ediner Fuentes interview).

- **Proactive approach to pathogen detection**

Proactive pathogen detection is a strategy that seeks to identify and monitor the presence of infectious agents in various environments. Unlike the traditional approach, which waits for symptoms to manifest or for patients to seek medical attention, this initiative is based on the early detection of pathogens before clinical signs are present. The proactive approach is based on implementing surveillance and continuous monitoring techniques through the systematic collection and analysis of samples to detect the presence of pathogens in wildlife populations or human populations located in areas of high risk for the spread of infectious diseases. We have identified two main aspects for the implementation of this approach:

Monitoring pathogens present in wildlife

It is crucial to strengthen laboratory capacity and establish integrated surveillance systems to comprehensively track pathogens at the interface of humans, domestic animals, and wildlife (Vora et al., 2023). Some proposals that can improve existing wildlife pathogen monitoring programs (Ellison et al., 2014) involve strengthening laboratory capacity; equipping labs with appropriate technology for diagnosing infectious diseases in wild animals; and training personnel specialized in sample handling, pathogen detection, and analysis techniques.

Implementing **an active surveillance system in strategic areas that harbor high-risk animals**, such as nature reserves, national parks, and areas of human-animal interaction, will be necessary. In addition, a regular mechanism should be established for collecting samples from wild animals, followed by their analysis in specialized laboratories. We consider it essential to promptly notify civil society of the relevant results of these analyses, especially to local communities residing in areas close to wildlife habitats, to keep them informed and promote their participation.

We also suggest systematizing the results of epidemiological studies in wildlife populations to better understand the prevalence, distribution, and risk factors associated with specific pathogens, including collecting demographic data, seroprevalence analysis, and identifying host species. To complement this systematization, it is possible to use tools such as SpillOver, which classifies the potential for spreading viruses present in wildlife, including those that could cause emerging infectious diseases (EID) if transmitted to humans. The information provided by such tools is vital to inform the decision-makers and health professionals who design prevention and control measures (Grange et al., 2021).

However, when implementing any intervention, it is important to take into account the risks associated with them. For example, the United States government has canceled virus-hunting programs due to the possible adverse consequences of the activity in terms of biosecurity. More specifically, the genomic characterization of viruses is information that can be used by malicious actors to design these pathogens (Willman, 2023). For this reason, we recommend that monitoring focus on pathogens whose consequences and potential for spread are already known.

Frequent testing of high-risk population

Frequent testing of high-risk populations is a strategy for early detection of zoonotic diseases. By focusing monitoring on people with high exposure to wildlife, such as hunters, wildlife veterinarians, and zoo and wildlife market workers, it is possible to identify and track animal-borne viral infections, contributing to the early warning system and archiving of pathogens that infect both humans and animals (Wolfe et al., 2007). Implementing sentinel surveillance in high-risk populations allows rapid testing to rule out known disease causes. Monitoring through rapid tests using technologies such as PCR can be helpful (See Appendix 1, Interview with Alex Demarsh).

We suggest **establishing mobile testing clinics that travel to communities where the high-risk population is concentrated**, which could offer rapid and accessible tests, such as antigen-specific tests or serological tests with on-site results and rapid response in case of positive detection. In addition, as a complement to these tests, we recommend performing broad-spectrum testing (Poggi M et al., 2009) and conducting a systematic collection of samples that would be safely transported to a specialized laboratory for analysis (Sanchez-Romero et al., 2019). Combining broad-spectrum testing and systematic sample collection will increase the ability to detect potential emerging pathogens.

Concerning the operation of these mobile clinics, we propose establishing a periodic testing program specifically for the high-risk population, where testing frequency would be determined according to the level of exposure and risk associated with each group. As an illustration, pilot testing every three months could be considered for communities in permanent contact with wild animals or access to caves. In contrast, wildlife veterinarians and zoo workers could be tested monthly.

Finally, we believe it is necessary to ensure that there are sufficient test kits, laboratory equipment, and trained staff to perform frequent testing effectively. This is also crucial for implementing follow-up and notification strategies for test results from the high-risk population in order to effectively monitor positive cases, identify close contacts, and follow through with appropriate control and prevention measures, such as isolation and quarantine.

- **Data accessibility and transparency**

Accessibility and transparency of biohazard data is a crucial aspect of strengthening the health system in Guatemala. In the GHS index, the country scores 10 points out of 100 for data accessibility and transparency, below the global average of 34.7 (NTI, 2021). This translates into poor availability of electronic health records, data exchange, and a lack of public accessibility to information, which hinders public health research and coordination during potential emergencies.

Improving the digital infrastructure to collect and process data effectively enables timely availability of information at the correct times and places, which is vital for effective response (Toner et al., 2011b). Some capabilities that a transparent real-time biosurveillance system should have are (NTI, 2020):

- ➢ Bioinformatics systems networks and information-sharing platforms.
- ➢ Standards for transparent reporting of health emergencies.

- ➢ Analysis of diagnostic and laboratory data for early detection.

To address this issue, it is important to establish transparency measures with the collaboration of different sectors, and to promote public reporting and scientific exchange, among other actions (NTI, 2020). To this end, we have focused on two initiatives: i) interdepartmental data-sharing networks and ii) effective communication with the international community.

Interdepartmental data-sharing networks

Effective biological risk management requires close collaboration and efficient coordination between the departments and entities involved in human health, animal health, and the environment. An integrated approach is needed to generate synergies between different institutions to identify gaps, develop mitigation strategies, and improve the response capacity of the health system (See Appendix 1. Interview with Luis Alberto Ochoa). To achieve this integration, we propose implementing a data exchange system between the relevant departments.

This proposal involves establishing clear protocols and data exchange standards to ensure the consistency and quality of shared information, including standardized data formats, data update procedures, and information security policies. We suggest establishing **a centralized platform to enable data sharing between departments involved in biohazard management**. This platform should be accessible and easy to use, protecting data privacy and confidentiality. Developing monitoring indicators and dashboards that allow precise and understandable visualization of the shared data will be necessary. They should include management tools to assess the situation, identify trends, and support data-driven decision-making. The effective implementation of this platform will require:

- ➢ Generating standardized data reporting protocols to guarantee the consistency and quality of the information collected, facilitating the comparison and analysis of data at the local, regional, and national levels.
- ➢ Providing training in data management and bioinformatics to health professionals and other actors involved in collecting and analyzing data from the platform. This is to strengthen their technical skills to manage and use the information generated efficiently, increasing institutional capacity to interpret and efficiently use the data.

In turn, we suggest implementing feedback mechanisms and conducting a periodic evaluation of the data exchange system to identify areas for improvement and ensure its effectiveness. This involves reviewing the exchange processes for user feedback and introducing improvements. Finally, it is helpful to have the advice of entities specialized in digital health, such as RECAINSA, to ensure the interoperability of the new platform with existing systems.

Effective communication with the international community

International cooperation facilitates identification of transmission patterns and understanding of pathogen ecology. Furthermore, it allows for more effective coordination in detecting and responding to cross-border outbreaks and exchanging best practices at the regional level. To this end, Guatemala must promote a culture of transparency in which all states commit to providing clear, timely, and accurate information on outbreaks or epidemiological situations that may pose a risk to public health. If, at some point, there is a limitation to generating reliable information immediately, we suggest making data from clinical centers available for direct analysis by international organizations in order to have an impartial and expert evaluation of the situation.

In turn, we suggest that Guatemala strengthen its links with international organizations such as the International Agency for Plant and Animal Health (OIRSA), the World Health Organization (WHO), the Pan American Health Organization (PAHO), and the Central American Integration System (SICA). Guatemala is also encouraged to **join international networks and platforms dedicated to communication and cooperation in the field of** emerging infectious diseases, such as the Global Outbreak Alert and Response Network (GOARN), the World Health Organization (WHO) Laboratory Network, or the GISAID Global Genomic Data Platform. To this end, Guatemala needs to improve its epidemiological reporting system, ensuring the prompt communication of relevant data on outbreaks, transmission, and control of diseases.

As a complement, Guatemala can establish research partnerships with international institutions, universities, and experts. By participating in joint research projects, Guatemala could contribute its local resources and experiences and benefit from the expertise and funding of international institutions, multilaterally strengthening capacities for early detection and epidemiological surveillance.

- **Implement technological solutions**

Traditional epidemiological surveillance and public health activities alone are insufficient to adequately and comprehensively address the problem of infectious diseases (Morens et al., 2004). Implementing high-tech solutions can contribute to the solution, as they provide more accurate and rapid detection of pathogens, improving real-time epidemiological surveillance. Tools such as **genomic sequencing and natural language processing systems designed for epidemiological**

surveillance are valuable ways to strengthen the State's capacity to detect, respond to, and control epidemic outbreaks.

Sequencing technologies, such as those offered by Oxford Nanopore, have proven helpful in detecting genetic variants, identifying pathogens, and understanding disease evolution (Xu et al., 2021). These technologies allow pathogens to be identified quickly and easily without a highly equipped laboratory. Although the initial investment may be high, the long-term benefits are considerable, as they improve the ability to respond to epidemic outbreaks and facilitate early detection of genetic variants and pathogen evolution. One of the key advantages is their ability to sequence long DNA or RNA molecules in real-time, enabling rapid and direct detection of genetic sequences. This is especially useful in the epidemiological surveillance of infectious diseases, where accurate and rapid identification of pathogens is essential.

It is also possible to analyze large volumes of data through artificial intelligence, allowing for more effective and detailed epidemiological surveillance and the identification of patterns, trends, and risk areas. In turn, these are helpful tools to facilitate clinical guidelines during care and provide advice on possible diagnoses or treatment plans (WHO, 2022). Several organizations have developed tools to track information, allowing public health professionals to identify what information exists and is shared in a community, how that information is discussed, and what gaps exist in that information. Most of these tools are social listening and use natural language processing to track trends in popular social networks, such as WHO's EARS platform (Johns Hopkins Center for Health Security, 2023).

Adopting these and other new technological solutions (WHO, 2021) will be essential to strengthen surveillance capacity and make more informed decisions in the face of epidemic outbreaks, making it possible to protect the health of the Guatemalan population more effectively.

5. Conclusions

Emerging infectious diseases represent a significant challenge worldwide. These diseases have experienced an increase in incidence in recent decades due to multiple factors, including accelerated urbanization, deforestation, advancing agricultural and livestock frontiers, contact with wild animals, environmental changes, human mobility, and global trade patterns. Lack of preparedness and lack of corresponding treatments make these diseases especially dangerous. The Central American region, including Guatemala, faces challenges in managing zoonotic diseases due to socioeconomic, environmental, and health factors related to a lack of sanitary infrastructure, rapid urbanization, unsustainable agricultural expansion, lack of coordination, and insufficient resources.

In this report, we made recommendations to strengthen the prevention and detection of emerging infectious diseases in Guatemala, including halting deforestation, combating illegal wildlife trafficking, preventing the abuse of antibiotics in the animal industry, and carrying out interventions at the local level. In addition, we suggested designing comprehensive epidemiological surveillance systems, adopting a proactive approach to pathogen detection, ensuring transparency and accessibility of data, and implementing technological solutions. Adopting these recommendations will require the collaboration of different actors, including governmental institutions, international organizations, research laboratories, and local communities.

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Claudette	Salinas Leyva	Riesgos Catastróficos Globales
Jaime	Sevilla Molina	Riesgos Catastróficos Globales, Epoch, Centre for the Study of Existential Risk (Cambridge University)
Michelle	Bruno	Omica.bio, IFBA
Alonso	Flores	iGEM
Paulina	Paiz	Genentech

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6. Appendix

Appendix 1 Interviews

Luis Alberto Ochoa

High Containment Lab/Pandemic Safety Manager, Michigan State University

The current health system, with significant shortcomings evidenced during the COVID-19 pandemic, needs revitalization in emergency planning and response and recovery. Many laboratories, which had to adapt and gain valuable experience during the crisis, should continue their training for future pandemics and strengthen investment activities and efficient use of resources.

The availability of information in the right places at the correct times is vital. Rather than addressing these components separately, an integrated approach that generates synergies among various institutions to identify gaps, develop mitigation strategies, and improve the health system's response capacity can be more effective and beneficial in the short, medium, and long term.

Currently, many potential candidates are references in the Americas region (e.g., Argentina, Brazil, and Mexico). These countries have proven to have good experience in responding to different events and are countries with installed capacity and active representation at relevant meetings.

However, further work is needed in the region to raise the level of response and subsequently to work jointly with various countries to assess the current status and potential application of strategies for common problems.

Ediner Fuentes

Consultant for the Inter-American Institute for Cooperation on Agriculture (IICA) and Founder and Executive Director of The Bridge Biofoundry.

Ediner Fuentes points out that the research focus should be directed towards regional "hotspots" in Latin America rather than being limited to a national focus per country. Many research centers are located in metropolitan areas, but we lack receiving centers in key locations for sample processing. Establishing "nodes" for sample receipt and processing is essential, which would allow more effective monitoring of epidemiological situations. These nodes could play a significant role in sample management and the inclusion of local communities in sample collection, strengthening the social connection to disease monitoring.

However, there are limitations to the ability to send technicians to collect samples at all required locations. Therefore, more minor, remote health centers could function as these nodes, establishing a connection to the main center and acting as repositories where samples can be stored and sent. This would imply a crucial change in how samples are obtained, allowing them to be stored until there is a budget to analyze and process them. This strategy would take advantage of the increased storage capacity during the pandemic and facilitate the collection and processing of essential samples.

Another challenge is communication between veterinary entities and ministries of health in many countries, compounded by bureaucratic problems. However, with the initiative of a "One Health" approach, this connection can be improved, enabling better collaboration between these sectors. It is crucial to deepen the relationship between animal and human health, given that most new diseases originate from animals. Currently, veterinary research is mainly carried out in ministries of agricultural development and national security secretariats, but it happens in isolation from the health system. To adequately prepare for future pandemics, it is essential to integrate these fields and recognize the importance of animals as potential sources of new diseases.

Regarding the selection of a country, he points out that it is important to focus the studies on countries with a good amount of existing information, such as Mexico, Argentina, and Brazil, which have a great capacity for research and monitoring. However, selecting a country that meets the bare minimum conditions is also essential, allowing us to understand and extrapolate data to other countries with similar administration and regulatory systems (Peru, Paraguay, Guatemala and Honduras could be a very good option). This would help to propose solutions and evaluate their feasibility and functionality in different contexts. Much can be learned by studying and characterizing successful cases in detail, which can generate valuable recommendations based on practical experiences. For example, an effective tool could be to map the process of importing and securing biological material in the region, learning from what has worked in one country and adapting it to another. Rather than simply doing a situational analysis, it would be more helpful to work on what has worked well in the region and take it to other countries to impact the governmental system functionally.

Merle Alejandra Fernández

Director of National and International Cooperation at the National Council of Protected Areas of Guatemala (CONAP).

Dr. Fernández explained the structure and functions of the National Council of Protected Areas (CONAP). She notes that Guatemala's Ministry of Environment and Natural Resources, the

Ministry of Agriculture, Livestock and Food, the Ministry of Culture and Sports, universities through conservation centers, and environmentally oriented NGOs participate. The Guatemalan Tourism Institute (INGUAT) and the Executive Secretariat of CONAP, an entity of the Presidency of the Republic, are also part of this body.

CONAP is responsible for managing Guatemala's protected areas and protecting the country's natural and cultural resources. In the north of the country, in Petén, there is a high concentration of protected areas that house essential tourist sites such as Tikal. In these areas, CONAP has authority or co-administration.

At the national level, CONAP has eleven offices. CONAP's Executive Secretariat is in charge of the Council's administration and is responsible for delegating functions and authorizations to its participants. CONAP monitors protected areas with the support of international cooperation. A significant problem in these areas is the change in land use, mainly caused by forest fires. According to regulations, these areas can only be inhabited by people who lived there before the protected area was declared. However, there are cases of migrants who illegally usurp land, which is prohibited.
She also mentioned ongoing research on zoonosis financed by German cooperation, carried out in the Petén region, which includes the participation of several entities such as the Ministry of Health, Ministry of Agriculture, and academia. She also mentioned a regional project in the Maya Forest involving Mexico, Guatemala, and Belize, which recently received more funds for its expansion.

The Council meets twice a month, and depending on the topics to be discussed, technical cooperation agreements are signed with other governmental and academic institutions, both public and private. CONAP also receives international cooperation from various institutions and countries, including Germany (GIZ and KfW), USAID from the United States, the Brazilian cooperation agency, the Canadian fund, and the European Union. In addition, she mentioned an upcoming project called "Ecological Transition of Petén," which also involves several Guatemalan institutions.

Juan Carlos Moreira Sáenz

Epidemiologist at the Department of Animal Health of the Ministry of Agriculture, Livestock, and Food

During the interview, Juan Carlos Moreira mentioned the existence of a departmental coordination of the Ministry of Agriculture, Livestock and Food (MAGA) in each department. He, for example, is in charge of the livestock area. He also highlighted the presence of agricultural extension offices in each municipality belonging to the Vice-Ministry of Rural Extension of MAGA. As for passive surveillance, there is a network of active informants who report animal diseases. Their participation is relied upon, and if no notifications are received, monitoring is carried out, and other agencies, authorities, or local committees are consulted to obtain information on possible outbreaks or diseases.

Regarding the Health Directorate, he mentioned the presence of epidemiologists and sanitary programs that are grouped by species, such as cattle, pigs, and poultry. A technical council has been formed for each species to coordinate the corresponding actions. In the context of wild areas, it was indicated that the National Council of Protected Areas (CONAP) is the authority in charge and that the Animal Health Directorate is not competent to evaluate these cases. However, veterinarians are requested to participate in the necessary sampling when specific outbreaks occur.

In terms of capacities and resources, he mentioned that there is no specific animal health program to strengthen capacities. Hence, the country depends mainly on international cooperation and training provided by organizations such as the Food and Agriculture Organization of the United Nations (FAO). He stressed the importance of having a livestock traceability system linked to the International Regional Organization for Animal and Plant Health (OIRSA) and an emergency fund to deal with situations such as classical swine fever.

Regarding collaboration and cooperation between human and animal health, concrete coordination actions depend on each municipal office or departmental coordination. Nevertheless, in general, coordination between public health and veterinary health sometimes presents difficulties in reaching agreements and working together.

Alex Demarsh
Senior Research Fellow, BlueDot

As for Global Catastrophic Biological Risks (GCBR), although COVID-19 did not represent a significant risk of civilizational collapse, its natural origin is not ruled out, and it could generate a scenario of this category. Likewise, the risky handling of pathogens in research can cause laboratory accidents at this level.

Public health and biological defense experts are more concerned about the natural origin of the risks, which Guatemala could have a relatively high ranking of natural pandemic risk due to its high biodiversity and other factors. In addition, sample collection could be extended to places like the Guatemalan rainforest. The question arises as to whether there are ongoing projects to discover pathogens in wildlife and where they are being conducted. It is also essential to assess the safety and reliability of transporting pathogens from Guatemala to other places, such as Argentina or Brazil, which could be obtained through public records, funding applications, or scientific publications.

Well-established systems for counting and analyzing unknown infections are pretty rare worldwide. Some countries, such as the United States and the United Kingdom, have ongoing syndromic surveillance that analyzes syndromic clusters and performs secondary investigations to rule out known causes. However, it is not particularly robust anywhere in the world. Moreover, it is a slow process that requires accumulating enough cases for a significant fraction to reach hospitals for diagnostic analysis.

There is also sentinel surveillance in high-risk populations, such as wildlife market workers or veterinarians, who perform rapid tests to rule out known causes and seizure and testing of animal products seized in the illegal wildlife trade. These reduced-risk populations could have a significant impact with more intensive monitoring. In addition, event-based surveillance methods use non-traditional sources such as news and social media to detect potential public health events. Although there is no specific information on event-based surveillance in Guatemala, most countries have similar processes, and WHO monitors global systems.

He recommends that to be successful in Guatemala, it may be better to link proposed activities to economic productivity and population health rather than focusing on global health security and pandemic risk. Event-based monitoring is inexpensive but slow and less informative than sequencing-based methods. Metagenomic sequencing is complicated and expensive, so it would be more cost-efficient to identify high-risk populations and target more aggressively to reduce the number of samples and sequences. In addition, it is possible to obtain reasonably accurate information by combining careful population sampling with simpler technologies such as PCR or multiplex PCR test panels.

Tessa Alexanian

Ending Bioweapons Fellow, The Council on Strategic Risks

Tessa stresses the importance of understanding different countries' specific risks and challenges. She advocates using detailed country score justification summaries, which provide a complete picture of each country's unique circumstances. This approach allows for more nuanced and effective risk management strategies.

She points to Advanced Market Commitments (AMCs) in vaccine development. AMCs are agreements in which a government promises to purchase a specific quantity of a vaccine once it is produced. This provides an incentive for companies to invest in research and development. Tessa argues that this approach is particularly effective for prevention-focused drugs, as it secures a market for the product even before its development is complete.

Tessa emphasizes fostering a culture of responsibility in the life sciences. She argues that this is crucial to prevent adverse outcomes from biological research and applications. She suggests that governance should extend beyond regulation and policy, as policy formulation can be slow and complex. Instead, she advocates a broader approach that includes cultural and ethical considerations.

Finally, she discusses the risk of dual use in synthetic biology, which refers to the potential for research to be used for harmful purposes. She argues the need for multiple approaches to mitigate the risk of misuse. Rather than simply refraining from potentially risky research, she suggests that many strategies can be employed to ensure that the benefits of research are realized while the risks are effectively managed, such as developing countermeasures, such as gene drives that are naturally eliminated or require a specific concentration to function; responsible disclosure of research, limiting the publication of potentially harmful information; and balancing offense and defense, evaluating how research can aid in both the prevention of pandemics and their potential creation.

Paulina Paiz

Computational Biologist, GEM Fellow at Genentech

Paulina Paiz points out that vector-borne diseases such as Zika, Chikungunya, and dengue hemorrhagic fever are prevalent and pose a significant health threat in Guatemala. These diseases are not limited to remote areas but also occur in cities. In some cases, these diseases have resulted in the death of individuals, especially when adequate resources for treatment are not available.

In terms of disease detection, there have been significant improvements. A key player in this area has been FunSalud in Guatemala, not to be confused with the organization of the same name in Mexico. FunSalud in Guatemala was initiated by Dr. Edwin Asturias, who was part of the COVID-19 response team in the country. FunSalud uses Oxford Nanopore technology for disease detection.

The Universidad del Valle de Guatemala is also another important player to consider. This university is conducting joint research with Washington State University, where more than 1,000 people have been sampled (unconfirmed), a number more significant than the usual sample size of 200.

As for wastewater surveillance, this method has not yet been implemented in Guatemala (confirmation requested). However, it has the advantage that it is not sequenced per person, but somewhat larger samples are taken, which can provide a broader view of disease prevalence in a population. It is essential to clarify what percentage of Emerging Infectious Diseases (EID) come from clinical, zoonotic, or environmental sources. Although in Asia, the zoonotic source might be more relevant, in the case of Guatemala, more importance is given to vector-borne diseases.

Ian Peter Busuulwa

Project Officer, Biological Threat Reduction at the World Organisation for Animal Health (WOAH)

Ian Peter Busuulwa talks about the Biological Threat Reduction Strategy published by the World Organisation for Animal Health (WOAH), which covers five areas:

1. Policy, promotion, and communication
2. Maintain experience and establish standards, guidelines, and recommendations.
3. International Cooperation
4. Global disease intelligence
5. Capacity building and solidarity

The organization supports countries in updating their veterinary legislation to align with international frameworks for bio-risk reduction, assisting each country in developing national plans to control production diseases and supporting the implementation of these plans.

The organization is also responsible for setting standards in the animal health sector. They have four primary documents: the Terrestrial Animal Code, the Aquatic Animal Code, and manuals for both. These standards guide surveillance, trade, diagnostics, and disease definitions. They also guide how laboratory personnel should work and communicate on animal health issues. These guidelines are reviewed annually to ensure they keep up with scientific progress.

The organization has a network of experts divided into two groups: collaboration centers and reference laboratories. They have eight collaboration centers and six reference laboratories for various African diseases and topics. They also support countries in developing national plans to control diseases and support them in implementing these plans. They have a program called Performance of

Veterinary Services (PVS), which evaluates the performance of a country's animal sector and recommends how various aspects can be improved.

The organization contributes to bio-risk intelligence by obliging member countries to report WOAH-listed diseases, outbreaks of these diseases, and any other emerging diseases through a WAHIS platform. They also conduct risk scanning and active search activities to keep current on global health. They support building disease-specific networks to share knowledge and experiences among experts, countries, and institutions.

Finally, the organization conducts training on topics relevant to bio-risk reduction, such as biosecurity, biosafety, intelligence, and surveillance. They also conduct emergency management training. They send out a pre-training survey to participants to determine their training needs and capabilities, which helps plan the training content. They also involve the countries in evaluating consultants to ensure that the training provided is what the countries need.

Daniela Ochaita

Social scientist at the Center for Health Studies (CES) of the Universidad del Valle de Guatemala

Daniela mentions that communication and language barriers were significant during the pandemic, especially in rural areas and among the indigenous population. In addition, there were problems with the distribution of vaccines, mainly done at the central level, with resources reaching primary care providers last. Some policies did not facilitate adequate coverage, such as the rule that a vaccine blister had to be opened only when ten people were already ready to be vaccinated. If fewer than ten people were sent home because health personnel opened the blister pack, they would have to pay for it, even though the vaccines had been donated.

Daniela suggests that the work axes proposed in the RCG report must be implemented differently. For example, cave practices, part of the indigenous cosmovision, are ancestral practices that will continue. However, there is also not much advocacy in education and promotion regarding how to carry out these practices safely. In addition, she mentions that it is necessary to disseminate information in local languages and that sometimes there are no translations from Spanish for technical concepts.

On the other hand, the Universidad del Valle de Guatemala is one of the country's leading actors in biosafety issues. It has strong links with institutions such as the CDC and has received cooperation from Switzerland and USAID. The university is recognized for its focus on technology, innovation, and science and has significantly influenced several government ministries, including the Ministry of Health. The university has recently upgraded its infrastructure and has innovative laboratories, including an aerospace laboratory and laboratories for physics, biology, mechanics, and food.

Juan Carlos Argueta

Head of Planning, International Regional Organization for Agricultural Health (OIRSA)

The International Regional Animal and Plant Health Organization (OIRSA) is an international intergovernmental entity composed of nine member states with functions comparable to those of the UN or the World Trade Organization. OIRSA is financed mainly through delegated services, such as quarantine treatments at ports, airports, and land borders, which generate approximately 90% of its resources. In addition, it manages projects with international cooperation. The fee for these services is used to prevent the entry of pests and diseases. In the case of Guatemala, this income amounts to approximately US$10 million, of which 80% is reinvested in local projects and 20% is allocated to headquarters for regional programs. An emergency fund is also maintained to act in case of phytosanitary emergencies.

Current health threats in the region include avian influenza, the giant African snail, and a fungus that affects bananas. However, the ministries of agriculture of the member countries establish priority projects and programs.

The importance of standards to ensure food safety and disease prevention in agriculture and livestock was emphasized. It was mentioned that the organization works to comply with international standards established by various organizations, such as the World Trade Organization, the International Plant Protection Convention, and the World Organization for Animal Health.

The need to improve the demonstration of countries' phytosanitary and zooanitary status was also emphasized, as this is a recurrent problem for exporting products, such as meat, to the United States from Guatemala. Lack of technical resources to carry out the necessary sampling and laboratory tests can be an obstacle. It was argued that agricultural health is interrelated with other elements, such as food safety, and it was suggested that some cooperation areas could be further exploited.

It was emphasized that climate change creates more favorable conditions for the proliferation of pests and diseases. Massively using agrochemicals without considering alternatives such as biological controls and organic products can contribute to pest resistance. He said it is crucial to improve the traceability of agricultural products and develop effective monitoring systems.

Finally, strengthening surveillance platforms was mentioned as a significant achievement, citing the example of avocado exports to the United States, which had faced phytosanitary problems for over a decade.

Paula Prist

Senior Research Scientist at EcoHealth Alliance

Land use change is one of the main drivers of zoonotic disease transmission, with landscape composition and configuration being key factors. In addition, each disease has a unique "landscape signature," showing different landscape characteristics. There are examples of how landscape composition and configuration can affect disease transmission: Hantavirus is affected by the presence and amount of forested areas (specifically deforestation), which affects the abundance of reservoir species, while yellow fever is highly dependent on landscape configuration (mainly the number of narrow forest edges).

Landscape ecology methodology involves understanding mechanisms and processes through the lens of land-use change. To do this, it is crucial to select landscapes by controlling for aspects that will not be measured (e.g., amounts of forest cover, spatial arrangement of forest areas, matrix type) and to sample rodent/baat/mosquito populations to see how communities change with different degrees of forest cover or aspects of configuration.

Strategies to make landscapes healthier include spatial planning of remaining forest areas through legal deforestation or forest restoration. However, deforestation is challenging to address because of the need to work directly with the environmental system and coordinate many actors. Disadvantages of restoration and deforestation include changes in wildlife communities, with some species unable to survive in degraded species and disease-carrying species more likely to adapt to anthropogenic (rural) and urban areas.

The importance of communication, especially with indigenous peoples, and the need to consider social scientists in disease prevention and control efforts are highlighted. The role of government in these efforts is discussed, with the suggestion that it is possible to build local prevention strategies without direct government involvement in the field, even if there is government support.

The strategy will vary in each country, and it is important to establish a collaborative network with local researchers and NGOs, proposing various strategies, such as ecological interventions, planning for landscape change when it will occur, and developing predictive models to be used by different stakeholders in support of landscape planning (predicting the risk of some zoonotic diseases if specific areas are to be deforested).

Jon Arizti Sanz

Medical Engineering PhD student at the joint Harvard-MIT Health Sciences and Technology Department

Jon Arizti discussed different diagnostic technologies, including PCR, antigen testing, and CRISPR diagnostics (CRISPR-Dx). The latter is based on CRISPR proteins –mainly Cas12 and Cas13– and can be easily programmed to search for a specific genetic sequence (corresponding to a pathogen of interest). Although it is necessary to know precisely what is being looked for, the technology can be easily adapted to search for genome regions that are conserved within the same pathogen family.

He suggested that this technology could be helpful in regions such as Africa, where the main challenges lie in reagent procurement and distribution, especially in countries with poor access, such as Sierra Leone. Despite the obstacles, he argued that most of the necessary elements could be created in-country, although this would require significant investment. The key to sustainable use of the technology would be to build capacity within the country.

He stated that CRISPR-Dx is working very well at the research level and will soon break into the market, citing companies such as Mammoth Biosciences and Sherlock Biosciences as leaders in the field. Although most of the developments in this area are still in earlier stages, he sees great potential in the global application of the technology. He noted that nasal samples are suitable for this technology due to their lower complexity and that pathogens with high viral loads are easy to detect.

Implementing this technology presents challenges, such as securing distribution chains and validating the samples to be used. However, he argued that the cost of the tests, which is currently around US$8, primarily due to the reagents used, could be reduced through local production. He mentioned the case of Sherlock, which, although initially expensive, has established a non-profit sub-company intending to implement the technology in developing countries.

Finally, he stressed the importance of involving local communities in using and regulating the technology. He emphasized that these technologies are promising and easy to use outside conventional laboratories and that regulating them for the benefit of all could enhance the country's bioeconomy and reduce dependence on other countries. This technology democratization approach, together with investments and capacity building, could strengthen emerging economies' resilience in biosafety.

Edgar Bailey

Epidemiologist at Centers for Disease Control and Prevention (CDC)

Edgar Bailey details the methods of cooperation they use to deal with emerging and zoonotic diseases, especially in Guatemala. He discusses the research agreements with strategic partners such as the Council of Ministers of Public Health of Central America (COMISCA) and the Regional International Organization for Plant and Animal Health (OIRSA). Cooperation includes technical and administrative assistance to the ministries and early notification of possible disease outbreaks.

He explained how the disease response protocol and surveillance network works in Guatemala. The focus, for example, is on early detection and response to avian influenza, among other diseases, and coordinating actions from the agricultural sector. He highlighted the importance of early notification and mentioned a tool they had developed with OIRSA for this purpose, which is available to the public.

He also addressed the crucial role of communication in disease prevention. He spoke of an awareness campaign for the public to use the early notification tool and highlighted the need to overcome existing challenges in infectious disease prevention and control, such as the lack of risk communication and the absence of a culture of biosecurity and prevention.

In discussing the role in strengthening surveillance systems, he noted that CDC's work focuses on supporting measures implemented by international organizations and local ministries. Its work includes managing work plans, developing project frameworks, identifying needs, managing resources, and monitoring results.

He highlighted the significant efforts made during the COVID-19 vaccination campaign. He commented on the risk communication campaign they are designing to raise awareness about influenza and the need to implement basic biosecurity measures. He also spoke about the existence of CDC's migration division that works at country borders and in Central America to prevent the spread of disease from one country to another.

(The findings and conclusions of this report are those of its author(s) and do not necessarily represent the official position of the CDC.)

Abelardo De Gracia

Regional Director of Animal Health of the International Regional Organization for Agricultural Health (OIRSA)

The International Regional Organization for Agricultural Health (OIRSA) is an organization that is celebrating its 70th anniversary this year, specializing in the prevention, control, and eradication of diseases. Initially, it focused on the plague of the flying locust in Central America, creating a system for crews to cross borders and control the plague quickly. Later, the organization expanded to specialize in Agricultural Health, addressing threats like foot-and-mouth disease in South America.

Today, OIRSA has four main divisions: Animal Health, Plant Health, Quarantine, and Quarantine Treatment Services. They work on four principal axes: control and prevention of endemic diseases with zoonotic connotations, transboundary diseases, strengthening of diagnosis in animal health and veterinary medicines, and collaboration with other international organizations.

OIRSA is conducting research and projects to understand better the correlation between the misuse of medicines or antibiotics in animals and its impact on human antimicrobial resistance. This antimicrobial resistance can be multifactorial, and it can be caused both by the use of antibiotics in animals that then pass to humans and by malpractice in the use of antibiotics in general. OIRSA is working on education and awareness about the proper use of antibiotics, highlighting the importance of following the indicated doses and times and not using antibiotics unnecessarily.

He also mentions the "depletion period," during which an animal should not be slaughtered nor its milk used after administering an antibiotic. Finally, he points out that the presence of antibiotics in milk can affect cheese production, creating a public health problem and an industrial problem.

He points out that work is being done to improve notification in animal health surveillance. Although reports and complaints are received, there is underreporting, meaning that more animal health events are occurring than are known. To improve this, OIRSA is working on the digitization of notification systems. This would allow people, including veterinarians, to make a report through mobile devices such as smartphones or tablets. Central staff could receive this information in real-time, allowing for a quick analysis of the information and a faster response to possible animal health problems.

Likewise, work is being done in collaboration with other agencies and organizations to maximize resource use and avoid repeating actions. They are adding technical, financial, and logistical resources to achieve better results. Cooperation between different agencies and organizations has allowed for better management of animal health challenges in the region. This cooperation includes holding online seminars, discussions on common topics, and the sum of efforts to work together. This has allowed for better use of resources and greater effectiveness in managing animal health challenges.

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