STOP Spillover

Sierra Leone Spillover Ecosystem Report

March 2023

Photo Image: BBC (https://www.bbc.com/news/world-africa-31985826)

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ACRONYMS

AFENET	African Field Epidemiology Network
BOMV	Bombali Virus
BPEHS	Basic Package for Essential Health Services
BSL	Biosafety Level
CAHW	Community Animal Health Worker
CBO	Community-Based Organization
CDC	Centers for Disease Control and Prevention
CHW	Community Health Worker
CoV	Coronavirus
COVID-19	Coronavirus Disease 2019
DHIS2	District Health Information Software 2
DHMT	District Health Management Team
DHSE	Directorate for Health Security and Emergencies
DNA	Deoxyribonucleic Acid
DRC	Democratic Republic of the Congo
EBOV	Zaire Ebolavirus
eIDSR	Electronic Integrated Disease Surveillance and Response
ENADIS	National Epidemiological-Surveillance System (Sierra Leone)
EOC	Emergency Operations Center
EVD	Ebolavirus Disease
FAO	United Nations Food and Agriculture Organization
GDP	Gross Domestic Product
GHSA	Global Health Security Agenda
GoSL	Government of Sierra Leone
HCOV	Human Coronavirus
HIS	Health Information System
HPAI	Highly Pathogenic Avian Influenza
IAV	Influenza A Viruses
IADSR	Integrated Animal Disease Surveillance and Reporting System
IDSR	Integrated Disease Surveillance and Response
IFRC	International Federation of the Red Cross
IHR	International Health Regulation
IPC	Infection Prevention and Control
JEE	Joint External Evaluation

LPAI	Low Pathogenic Avian Influenza
LVS	Livestock and Veterinary Services
MAF	Ministry of Forestry and Agriculture
MARV	Marburg Virus
MERS-CoV	Middle East Respiratory Syndrome Coronavirus
MoHS	Ministry of Health and Sanitation
NAP	National Adaptation Program
NAPHS	National Action Plan for Health Security
NGO	Nongovernmental Organization
NIPCU	National Infection Prevention and Control Unit
OIE	World Organization for Animal Health
PHU	Primary Health Unit
PoE	Point of Entry
PREDICT	USAID Project within the Emerging Pandemic Threats Program
RAVV	Ravn Virus
REDISSE	Regional Disease Surveillance Systems Enhancement Project (World Bank)
RNA	Ribonucleic Acid
RRT	Rapid Response Team
SARA	Service Availability and Readiness Assessment
SARS	Severe Acute Respiratory Syndrome
SARS-CoV	Severe Acute Respiratory Syndrome Coronavirus
SBC	Social Behavior Change
STOP Spillover	Strategies to Prevent Spillover (STOP) Spillover Project
SUDV	Sudan Zoonotic Ebolavirus
UN	United Nations
WASH	Water, Sanitation, and Hygiene
USAID	United States Agency for International Development
WHO	World Health Organization

STOP Spillover

Strategies to Prevent Spillover (or STOP Spillover) is a USAID-funded project implemented by a consortium of partners led by Tufts University. The purpose of the project is to enhance country capacity to prevent and/or mitigate spillover, and to reduce the amplification and spread of known priority target viruses once they have spilled over to humans. Priority viruses include filoviruses (Ebola and Marburg), Lassa Fever, Highly Pathogenic Avian Influenza, Nipah virus and viruses in the MERS, severe acute respiratory syndrome (SARS)-CoV2 family. The project will be implemented in up to 10 countries in Africa and Asia, including Uganda, Liberia, Sierra Leone and Cote d'Ivoire in Africa, and Bangladesh, Cambodia, and Vietnam in Asia, from October 2020 to September 2025. STOP Spillover provides a critical opportunity to enhance global understanding of the complex drivers of viral spillover and augment national capacities in risk analysis and mitigation, spillover intervention, and social and behavior change.

Recommended Citation

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EXECUTIVE SUMMARY

Sierra Leone has been seriously impacted by civil war (1991 – 2002), two global food price emergencies (of 2007/08 and 20011/12), a cholera outbreak in 2012/13, and the Ebolavirus Disease (EVD) crisis of 2014/15, as well as the global coronavirus pandemic (CDC 2020a; 2020b). Malaria affects almost one quarter of the population each year. Almost one-half of the population is food insecure, and one-eighth suffers from severe food insecurity. Forty-three percent of the population lives on less than 2 US$/day. Maternal mortality is high (700 women per 100,000 live births), and life expectancy is low (54.7 years) (UNDP 2020).

These social, political, economic, and health-related challenges leave government departments depleted of fiscal and human resources, while increasing poverty particularly in rural areas pushes people to exploit all available natural resources. Habitats where zoonotic diseases and their hosts hide are increasingly disrupted, putting rural communities in danger of exposure. Drivers of deforestation including cash cropping, urbanization, climate change, and illegal mining bring more people into contact with potential zoonotic hosts and reservoirs.

As the STOP Spillover project begins activity implementation, it will be critical to consider the limited service delivery infrastructure, insufficient number of human and animal health workers, minimal private sector regulation and coordination, and partner-dependent development programming. However, Sierra Leone's experience with the EVD and COVID-19 epidemics sensitized leaders and much of the population to the risk of (re)emerging threats. STOP Spillover must capitalize on this political will.

Hunting and wildlife consumption are widespread in Sierra Leone. Bats, rats and wild animals are hunted by young men and boys, butchered and cooked by women, and consumed by rural households. These practices exacerbate zoonotic spillover risks. Biosecurity practices are minimal. However, people are aware of the potential to contract diseases by handling, butchering, or eating bats and wild animals, because of previous Ebola risk reduction efforts.

In Sierra Leone the highest priority zoonotic viruses within the remit of the STOP Spillover project include i) Lassa Fever ii) filoviruses (Ebola and Marburg), (iii) zoonotic influenza A viruses (IAV), and iv) zoonotic coronaviruses. The main risks for spillover are found at specific interfaces, including the wildlife-human interface in rural forest communities.

The basic features of Lassa and IAV are well researched, and key reservoir and bridging hosts have been identified. Nonetheless, significant challenges remain to designing and implementing effective and culturally relevant interventions that meaningfully reduce the risk of viral spillover, amplification, and spread. There is much less known about zoonotic coronaviruses. There appears to be a deep reservoir of undescribed and potentially zoonotic severe acute respiratory syndrome (SARS)-like coronaviruses, primarily in bat reservoir hosts. While further research is needed, it is possible to address spillover risk of zoonotic coronaviruses by targeting high-risk bat-human interfaces, such as bat hunting and consumption. Interventions that reduce spillover risk for Lassa Fever, IAV, or zoonotic coronaviruses may reduce spillover risk for multiple pathogens, both known and unknown. Strengthening health information systems, local disease surveillance, and the integrative functions of the One Health platform will be critical to mitigating the risk of amplification and spread of numerous zoonotic viruses. Coordinated actions at multiple scales are needed to mitigate the risk of zoonotic spillover, amplification, and spread in Sierra Leone.

There are opportunities for STOP Spillover to support government and private sector efforts to protect against future spillover risks. Through its own activities and with support from the USAID Emerging Pandemic Threats and PREDICT programs, Global Health Security Agenda (GHSA) actors, and the work of intergovernmental bodies such as the World Health Organization (WHO), United Nations Food and Agriculture Organization (FAO), and World Organization for Animal Health (OIE), the Government of Sierra Leone (GOSL) has embraced a One Health approach to combating risks posed by emerging viral zoonoses. Sierra Leone has established a One Health secretariat and a strategic framework for implementation, but struggles to share animal, environmental, and human health information across ministries and stakeholders to ensure efficient and effective performance and interoperability across sectors.

Additional opportunities to leverage in Sierra Leone include:

- A cadre of 13,000 community health workers and Community Animal Health Workers.
- An existing integrated disease surveillance and response (IDSR) system that tracks 28 priority diseases through routine weekly public health reporting from health facilities.
- A field epidemiology training program, recognized by WHO's Joint External Evaluation (JEE) as a sign of Sierra Leone's capacity for isolating, transporting, and referring highly infectious patients (WHO 2017 and WHO 2020a).
- A 117 Call Center, set up in 2012 as part of a support system to improve maternal and child health, expanded during the EVD outbreak, and transitioned into a national events-based surveillance system in support of the One Health Initiative (eHealth Africa 2020).
- Current human and animal health and environmental conservation work by implementing partners including Breakthrough Action, the BROAD Institute, the University of California at Davis, Tulane University, the World Bank, Johns Hopkins University, and nongovernmental organizations such as World Vision, Plan International, and Catholic Relief Services. John Snow International and Tetra Tech implement USAID-funded global health and biodiversity/wildlife conservation projects in Sierra Leone that can be leveraged to support STOP Spillover.

SECTION 1: GENERAL INTRODUCTION TO BIOPHYSICAL ENVIRONMENT AND RELATED FACTORS IN SIERRA LEONE

1.1 Geography

Located on the coast of West Africa, Sierra Leone is a tropical country bordered by Guinea and Liberia. Land area is roughly divided into four distinct topographical and agroecological zones: a coastal mangrove zone along the Atlantic Ocean, a zone of hills, an upland plateau, and a range of mountains in the east, the highest of which rises to 6,400 feet above sea level.

Sierra Leone is divided into five major regions (Northern, Northwestern, Southern, Eastern Provinces, and Western Area [where Freetown is located]). Regions are divided into 16 districts, which are in turn divided into 190 chiefdoms and sections, governed by Paramount Chiefs and Section Chiefs, respectively (Figure 1). Politically, Sierra Leone is divided into 21 local councils that are further divided into wards. An elected councilor heads each ward.

The country has eight main river systems: the Great Scarcies, Little Scarcies, Rokel, Jong, Sewa, Wanjei, Moa, and Mano. Rivers flow from northeast to southwest toward the Atlantic Ocean.

1.2 Climate

Sierra Leone's climate is dominated by a tropical monsoon pattern characterized by a long dry season (November to May) and a season of heavy rains, high heat, and humidity (June to October). In March and April, the mean daily temperature exceeds 35°C with 50% humidity.

1.3 Agriculture

Roughly one quarter of the country's land is classified as arable, with another 30% used for pasturing livestock. The agriculture sector is a major contributor to the nation's economy, accounting for approximately 60% of Gross Domestic Product (GDP), up from 30% in 1980 (US Department of Commerce International Trade Association 2021 and World Bank 2021a). Major staple crops include rice (the country's principal food), cassava, maize, millet, cashews, ginger, and a range of fruits. Despite good farming conditions in many areas, only 55% of arable land was under cultivation in 2018, largely due to low returns to labor in agriculture (underpinned by poor market access, lack of mechanization, limited irrigation infrastructure, and constrained access to rural finance) and migration to cities (Kiendrebeogo et al. 2021). Growth in this sector's economic activity relates mainly to cash crop production, including rubber, sugarcane, cocoa, coffee, and palm oil. Recent policy reforms aimed at increasing total factor productivity in agriculture through enhanced private sector participation are expected to reap dividends. However, the impact of Coronavirus Disease 2019 (COVID-19) restrictions on a sector that is contact intensive have been and will continue to be severe in the short term. Agriculture's contribution to the rate of GDP growth is expected to fall from 2.2% of the total in 2017 to 1.9% in 2023 (Kiendrebeogo et al. 2021).

1.4 Deforestation and Forest Fragmentation

Forested areas accounted for 43% of the country's land area in 1990; by 2020 this had fallen to 35% (World Bank 2021b). The largest rate of loss has been reported for the southern zone, where most economic and human activity is concentrated (Mongabay 2022). Some of the main reasons for forest contraction include expansion of land dedicated to cash cropping (particularly oil palm and biofuel production) but also illegal logging, drought, forest fires, and urban encroachment (Fayiah 2021). There are 50 protected forest areas covering 9% of the land, but protecting these areas is a challenge in the face of illegal mining activities, wildlife hunting, and a poorly resourced forestry department (Parks.it 2023). In July 2020, the Government of Sierra Leone (GoSL) passed a supplemental budget of US$138 million (3.3% of GDP) as a response to the COVID-19 pandemic, yet the bulk of these funds went directly to the health sector or to support labor-intensive employment programs, such as building roads and digging for water pipe infrastructure. The share allocated to tree-planting and reforestation was small and only exceeded that for food aid, cash transfers, and small micro-credit schemes (Kiendrebeogo et al. 2021).

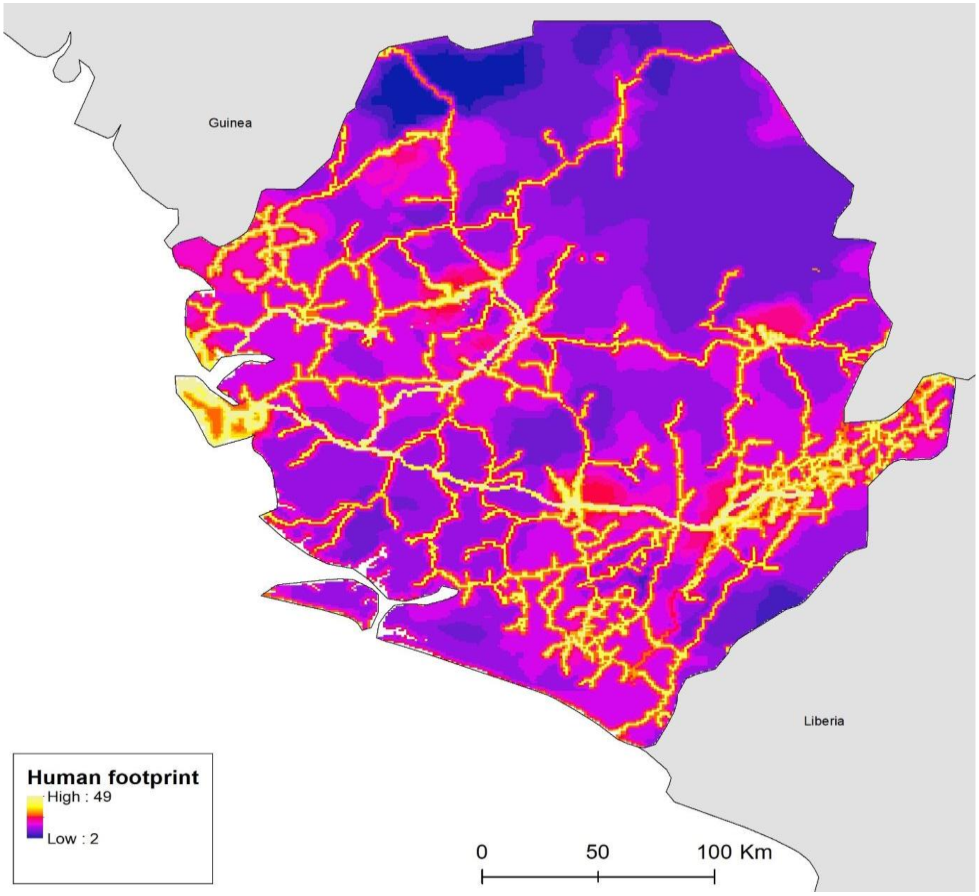

Figure 1: Estimated cumulative human pressure on the environment in 2009 in Sierra Leone. The human pressure is measured using eight variables including built-up environments, population density, electric power infrastructure, crop lands, pasture lands, roads, railways, and navigable waterways. (Venter et al. 2018).

SECTION 2: SOCIOECONOMIC FACTORS

2.1 Demographics

Sierra Leone's population exceeded 8 million as of 2020, although average life expectancy for men and women is less than 56 years (African Studies Centre Leiden, 2021). Sierra Leone has a young population—almost 41% of the population is under 15 years of age, and 3.5% are over 65 years of age. Literacy averages 42.8%. Men are less likely than women to have no education (29% versus 46%) and more likely to be educated beyond the secondary level (8% versus 4%). Most of the population is Muslim (77%); 21.9% is Christian (Statistics Sierra Leone and ICF 2019).

Fertility rates have fallen over recent decades, from 6.5 in 2000 to roughly 4.3 in 2020 (ASCL 2021). Ethnically, an estimated 70% of the population align themselves with the Mende or Temne groups, which tend to be more rural and poorer than other ethnicities. In 2013, some of the highest rates of child mortality were among the Koranko and Sherbro groups. There are 15 distinct ethic groups in the country, reflecting a rich cultural diversity (GoSL 2015a).

2.2 Urbanization and Population Trends

Most Sierra Leoneans still live in rural settings, but urbanization is rising fast at 2.9% per annum, compared with overall population growth of 2.1% per annum (World Population Review 2022). The nation's capital, Freetown, has an official population of over 800,000, but that is likely to be an underestimate. Other major urban centers Bo and Kenema both have populations exceeding 200,000. Fifty-eight percent of the population lives in rural areas. Approximately 42% of Sierra Leone's population lives in cities and urban areas; an increase of 4% from 2009 (World Population Review 2022).

2.3 Economic Trends

The country saw steady economic growth from 2000 until 2014, rising from US$139 to US$715 per capita over that period. In 2014 the Ebolavirus Disease (EVD) crisis significantly curtailed all activity (Macrotrends 2022). The economy contracted as the outbreak was addressed, bottoming out at US$499 per capita in 2017. The slow process of rebuilding the economy was initiated with some success, climbing from an annual growth rate of *minus* 20.6% in 2015 to *plus* 5.6% in 2019. At that point, the COVID-19 global pandemic hit, resulting in a new economic contraction in 2021 of around 2.16%—a 6.23% decline over 2019 (Macrotrends 2022).

Although the economy is still predominantly driven by agriculture, the share of GDP attributed to agriculture has been declining due to increased focus on mining and services. Iron ore is mined in northern Sierra Leone. Coffee, cacao, and fish are major agricultural exports.

2.4 Gender and Cultural Issues

While girls and boys suffer roughly the same levels of acute malnutrition in Sierra Leone, girls are more likely to drop out of school before reaching secondary education. Households headed by women (roughly 20% of the total) have slightly worse levels of food consumption than those headed by men (WFP 2021). Anemia among women of reproductive age (which carries serious risks in pregnancy as well as mental and physical productivity potential) averages roughly 45% in Sierra Leone. Despite playing significant roles in most household livelihood activities, women are still underrepresented as participants in, let alone designers of, relevant development programs at community and national levels (Larkoh et al. 2021). For example, as found in many other parts of the world, the promotion of cash crop production may increase net household incomes, but without dedicated program components focused on women's needs, including nutrition and health education, there are limited impacts in terms of maternal and child dietary diversity and quality (Bonuedi, Gerber, and Jornher 2021).

2.5 Food Insecurity

As of late 2020, an estimated 4.7 million people (57% of the population) were food insecure, of whom almost 1 million were in the "severely food insecure" category (WFP 2021). An estimated 3.3 million of the total population reside in rural areas of the country; the districts with the highest number of food insecure individuals are Kenema, Kailahun, Pujehun, and Tonkolili—accounting for 400,000 or more people each. Roughly 85% of children aged 24 to 59 months across Sierra Leone do not eat daily meals that meet minimum thresholds for dietary diversity. Rates of severe acute malnutrition have risen by over 600% since 2017. The districts presenting the highest rates of moderate plus severe malnutrition in 2020 were Moyamba, Falaba, and Kenema (WFP 2021).

2.6 Political-Economic Approaches

The political-economic responses of the GoSL to pandemic threats are of critical importance as they cause great loss of life and immense financial cost. For instance, the economy contracted by 2% as the COVID-19 pandemic led to slowdown in all sectors following lockdown measures and global supply chain disruptions. GDP per capital fell by 4%, reversing some of the recent gains in poverty reduction. In response, the government has revitalized integrated disease surveillance and response systems for both animal and human health and are working with the FAO to build similar systems for ecosystems surveillance. Socioeconomic interventions at the community level have also been augmented with highly effective emergency operation centers (EOCs) with functioning multisectoral and multidisciplinary rapid response teams (RRTs). However, more investment needs to be made in building institutional capacity in the animal and environmental health sectors and strengthening cross-institutional and cross-border collaboration and communication.

2.7 *Climate Vulnerability Assessments and Existing Behavioral Risk Assessments*

The United Nations (UN) has identified Sierra Leone as one of the 50 least developed countries. In 2018, the Notre Dame Global Adaptation Index ranked Sierra Leone 151 out of 181 countries in terms of vulnerability to climate change with high vulnerability and low readiness (ND-GAIN 2018). A World Bank study also found that the mortality from multiple, climate-induced hazards is high and getting worse as exposure continues to increase (World Bank 2017). The coast is particularly vulnerable to climate change because of the extent of mangrove forest loss, exposure of people to the effects of sea level rise and winds, and high poverty levels (WA BiCC 2019).

With one of the highest malnutrition and child mortality rates in the world, the population is extremely vulnerable to climate shocks, especially as incidents of high temperature morbidity and mortality are projected to increase. Increased temperatures are also associated with increased episodes of diarrheal diseases, seafood poisoning, and elevated pollutants. As temperatures increase above 25°C, malaria infection is expected to rise. Malaria is the most common cause of illness and death in the country. Malaria-related illnesses contribute to 38% and 25% of child and all ages mortality rates, respectively. The most vulnerable groups include children aged under five years and pregnant women (GoSL 2015b).

Waterborne diseases are also expected to increase with more frequent and intense flooding. Currently, the heavy rains have increased the likelihood of the outbreak of communicable diseases. More intense dry seasons (with increased temperatures) in the north and west have been linked to reduced water quality and disease outbreaks. The last major cholera epidemic outbreak in 2012 caused 300 deaths and affected more than 20,000 people. Warmer seas contribute to toxic algae bloom and increased cases of food poisoning from consumption of shellfish and reef fish, as seen in Freetown in July–August 2011 and August 2012. The Ebola outbreak revealed a deficient health system, including understaffed, unavailable, or unaffordable health care that will be further stressed by climate change impacts (USAID 2016).

No comprehensive national vulnerability assessment has been conducted in Sierra Leone. Existing data focuses on a sector or a small area of the country. Many have been produced through donor-financed programs such as the USAID West Africa Biodiversity and Climate Change Program that conducted a climate change vulnerability assessment on coastal areas. These small-scale assessments, however, have not been collected in one place or reproduced nationally. No comprehensive assessments have considered social and ecological interactions, urban and rural issues, and the interactions between climate and non-climate risks. Additionally, there has not been gender-sensitive analysis of vulnerabilities and risks. A comprehensive series of vulnerability assessments are a top priority for implementing the National Adaptation Program (NAP).

2.8 Implications for the STOP Spillover Project

The government has faced many challenges responding to successive crises that slowed economic progress in moments of relative stability. It has had to increase spending at a time when economic activity has collapsed, and more people found it increasingly difficult to meet their food and other needs. This accumulation of economic insults has left government departments depleted of fiscal and human resources, while increasing poverty has pushed people to exploit the human and natural resource options available. The danger posed by this juxtaposition of rising human need and falling capacity to protect public resources is that habitats where zoonotic diseases and their hosts hide and reside are increasingly disrupted, putting more rural people in danger of exposure. Despite these challenges, there are also opportunities for STOP Spillover to support government and private sector efforts to reduce future spillover risks.

SECTION 3: GENERAL OVEREVIEW OF THE HUMAN HEALTH SYSTEM

3.1 Background

In the immediate aftermath of the civil war, Sierra Leone's health priorities focused on re-establishing basic health sector systems, including facilities, healthcare workers, supply chain, reporting systems, and policies, among numerous other needs. Post-war, Sierra Leone has experienced multiple, severe infectious disease outbreaks. From 2012 to 2013, Sierra Leone experienced a severe cholera outbreak affecting 12 districts and over 23,000 people with 301 documented deaths. In 2014, Sierra Leone experienced a devastating EVD outbreak. An estimated 14,000 cases occurred resulting in 4,000 deaths, including approximately 300 deaths among health workers (CDC 2020a). There are an estimated 3,400 EVD survivors in Sierra Leone; in addition to facing stigma from fellow community members and socio-economic vulnerability due to lost livelihoods and family members, EVD survivors face myriad long-term health sequalae, including vision and hearing challenges, musculoskeletal and neurological symptoms, and mental and sexual health concerns (GoSL 2015c).

With the backdrop of long-standing development challenges, a protracted civil war, and the EVD epidemic, Sierra Leone remains one of the poorest countries in the world. Ranking 182 out of 189 countries in the Human Development Index, an estimated 43% of Sierra Leoneans live on less than $2 per day, and 61.7% live in multidimensional poverty (UNDP 2020). While economic indicators have improved in the last decade, COVID-19 lockdowns have negatively affected livelihoods, and poverty is projected to rise in the near term. More than a third of the population lacks access to limited-standard drinking water; 87.2% and 68.7% of the population lack access to sanitation and electricity, respectively (World Bank 2020).

Sierra Leone continues to have some of the highest rates of preventable morbidity and mortality in the world. Life expectancy at birth is one of the lowest in the world at just 54.7 years (UNDP 2020). One in 31 women die due to maternal causes, while one in eight children may die before age five (Statistics Sierra Leone and ICF 2020). Only 56% of children aged 12–23 months have received all basic vaccinations: a single dose of the Bacillus Calmette-Guérin vaccine, three doses each of diphtheria-pertussis-tetanus and polio vaccines, and one dose of the measles vaccine (Statistics Sierra Leone and ICF 2020). Malaria is endemic throughout the country, with 2.6 million cases and more than 6,800 deaths in 2019 (WHO 2020b).

As the STOP Spillover project begins activity implementation, it will be critical to consider the limited service delivery infrastructure, insufficient number of health workers, minimal private sector regulation/coordination, and partner-dependent community health programs.

3.2 Health Service Delivery

- Total health facilities: 1,200 (estimated)
- Hospitals: 24
- Primary Health Units (PHUs): 1,160 (estimated), including:
  - 227 Community Health Centers (CHCs)
    - Larger facilities with higher-skilled workers
    - Epidemiology and environmental health services
    - Basic emergency obstetric and newborn care centers
  - 320 Community Health Posts
    - Medium-sized facilities with lower-skilled workers
  - 616 Maternal and Child Health Posts (GoSL 2017a)
    - Staffed by maternal and child health aids
    - First point of contact with facility-based healthcare system employees (GoSL 2017a)

Sierra Leone's health delivery system includes tertiary, secondary, and primary health care facilities. Nine of Sierra Leone's twenty-four hospitals are in the Western area, including the three primary tertiary hospitals: Connaught, Princess Christian Maternity Hospital, and Ola During Children's Hospital. The remaining hospitals provide secondary referral care.

In addition to these facilities, community health workers (CHWs) operate at the village level. While CHWs have long played a critical role in supporting health at the community level, there have been many variations in scope, supply, and supervision. Launched in 2017, the National CHW Policy attempted to harmonize CHWs' scope with a focus on the following health areas: reproductive, maternal, newborn, and child health; integrated community case management (iCCM 'Plus'); disease prevention and control; and community sensitization to HIV and tuberculosis (GoSL 2016). The policy sought to further integrate and support CHWs in their role within the health system, as well as to harmonize approaches to supervision, incentives, and training.

The private sector is thought to play an important role in health care service provision. However, there is minimal visibility into the total number or private sector facilities, including hospitals, clinics, laboratories, pharmacies, and unregistered drug sellers. The current National Health Sector Strategic Plan identified this information gap and indicated a planned landscape analysis and strategy development (GoSL 2021).

3.3 Health Workforce

- Health professionals providing patient services: 7,107
- Doctors per 1,000 people: 0.074
- Nurses/midwives per 1,000 people: 0.753
- CHWs per 1,000 people: 0.023
- Percentage of women in the health workforce: 62% (GoSL 2017b)

Given the drastic state of the health sector during and after both the war and the recent EVD epidemic, Sierra Leone has struggled to recruit, train, and retain a skilled health workforce. The EVD epidemic caused many health workers to exit the workforce. The health workforce per population is far below recommended ratios for basic health service provision, and there are insufficient staff in every cadre to implement the full Basic Package for Essential Health Services (BPEHS)(GoSL 2017b).

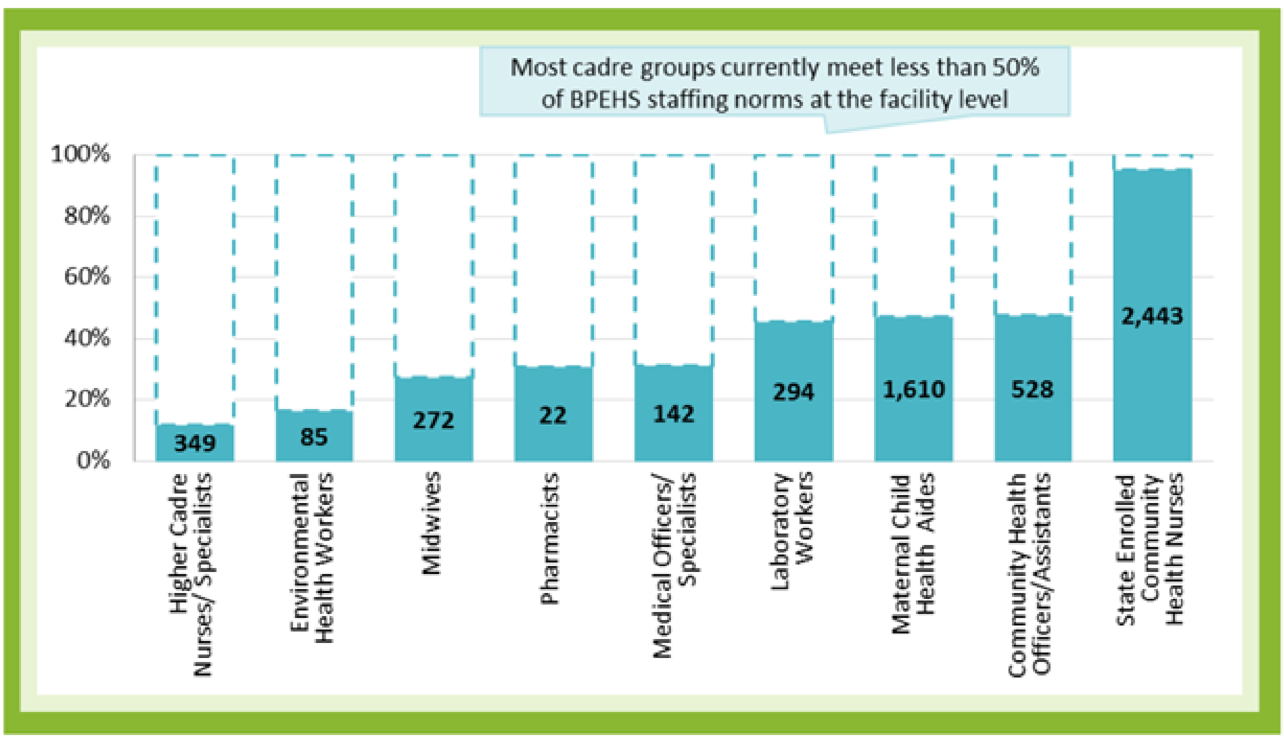

Figure 2: Availability of staff cadres across the health sector (GoSL 2017b)

While nearly two-thirds of the health workforce is female, there is a dearth of women in management and leadership positions. Doctors occupy most of the senior level Ministry of Health and Sanitation (MoHS) positions, and there are few female physicians.

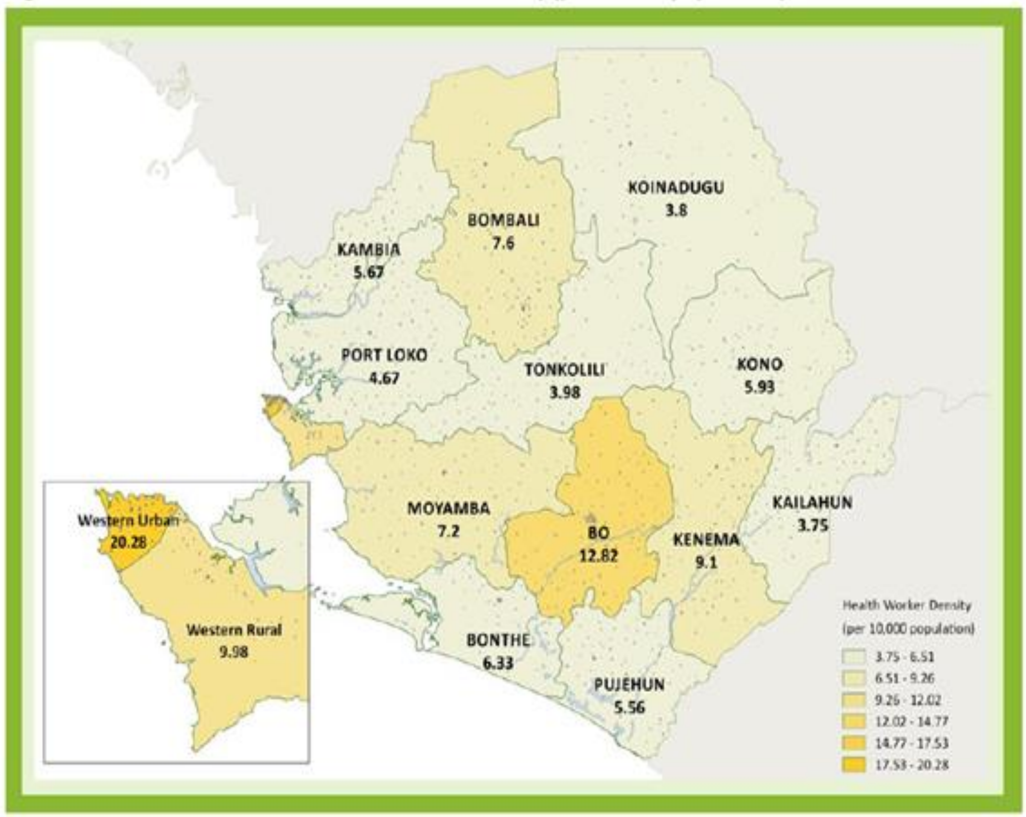

Figure 3: Sierra Leone clinical health workforce density per 10,000 population (GoSL 2017b).

Sierra Leone's health workforce distribution presents another challenge, as it is skewed toward urban areas. The highest ratio of health worker per population is found in the Western Urban district (20.28 health workers per 10,000 residents, see map inset in Fig. 3), and higher ratios are evident in Western Rural, Bo and Kenema districts (districts with major urban centers), while rural and remote districts like Koinadugu and Kailahun continue to struggle to provide sufficient providers for their populations (GoSL 2017b).

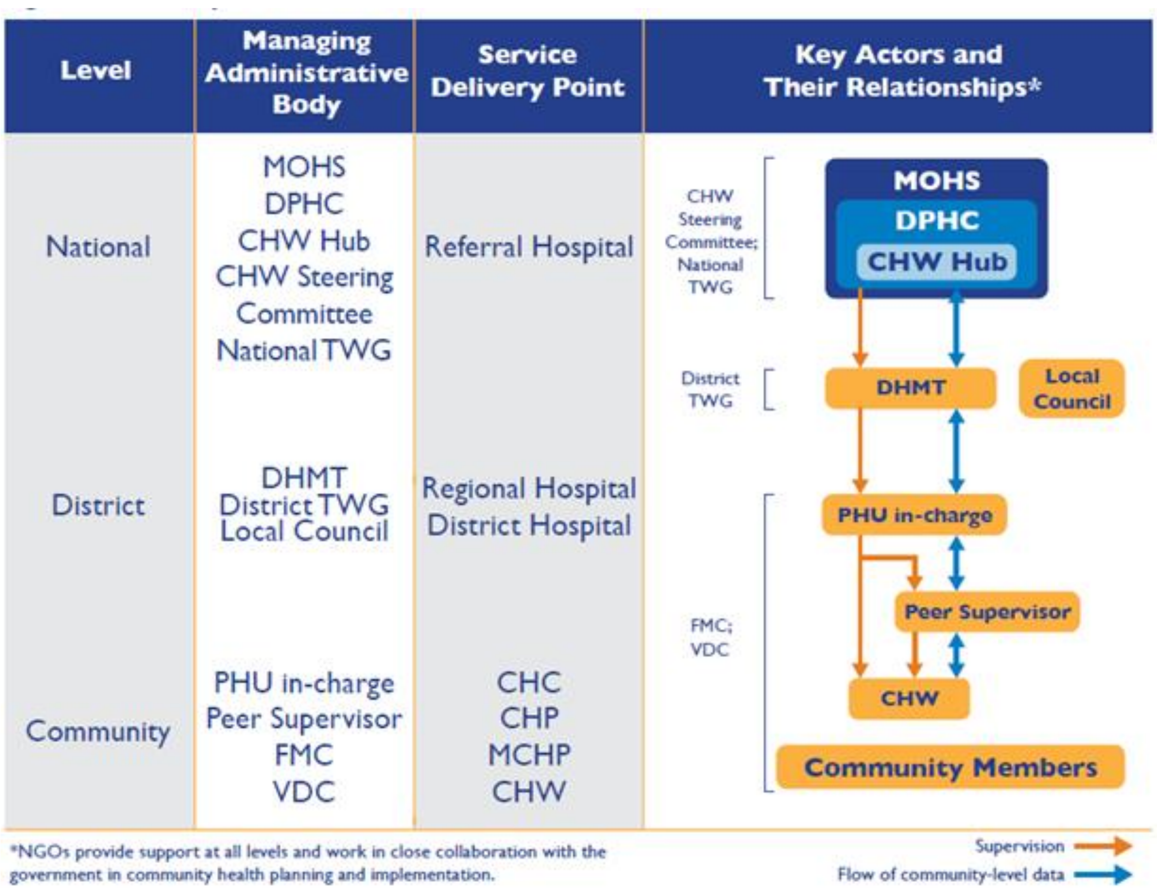

Figure 4: Sierra Leone Community Health System Structure. Actors include the Ministry of Health Services (MOHS), Directorate of Primary Health Care (DPHC), Community Health Workers (CHW), national and district technical working groups (TWG), district health management team (DHMT), peripheral health units (PHU), facility management committee (FMC), village development committee (VDC), community health center (CHC), community health post (CHP), maternal and child health post (MCHP) (Devlin, Farnham Egan, and Pandi-Rajani 2017).

3.4 Community Health Workers

There are an estimated 13,000 CHWs in the country covering a variety of health areas who are largely depending on implementing partner presence and funder support (Devlin, Farnham Egan, and Pandi-Rajani 2017). While the CHW is enshrined in policy, the MoHS has yet to take on this population as a formal cadre, and many CHWs rely on nongovernmental organizations (NGOs) for supervision, supplies, and report submission. As a result, the day-to-day availability, capacity, and activity of CHWs is highly variable across the country. While the CHW policy stipulates that women should be prioritized for recruitment, cultural values and prevailing norms around paid work are such that the majority of CHWs are men (Raven et al. 2020).

Nongovernmental, faith-based, and private sector partners play a substantial role in supplementing basic health care services in Sierra Leone, both at health facility level and through CHWs. While this support helps address the immediate challenges, it also presents a substantial coordinating, reporting, and planning burden for the MoHS and district health management teams (DHMTs). This arrangement makes it challenging to predict resource flows and has been credited with contributing to Sierra Leone's fractured health system (Barr et al. 2019).

3.5 Health Information Systems

The national health information system (HIS) in Sierra Leone is evolving from paper-based systems to electronic information systems for the management of health data. The HIS consists of the following subsystems:

- Integrated disease surveillance and response (IDSR)
- Data generated through household surveys
- Data collection based on patient and service records and reporting from CHWs, health workers, and health facilities
- Program-specific monitoring and evaluation (e.g., for tuberculosis, HIV/AIDS, malaria, reproductive health/family planning, nutrition, and expanded immunization)
- Living standards measurement survey
- Administration and resource management (including budget, personnel, and supplies)

The Directorate of Policy, Planning, and Information manages routine health information while the Directorate of Health Security and Emergency is responsible for collecting data on epidemic-prone diseases for immediate action using the IDSR system. Other directorates and programs are responsible for managing specific subsystems of the HIS.

District Health Information Software 2 (DHIS2) is used for reporting all routine health information, including IDSR. Health data and information typically flow from the community and health facilities to districts and from districts to the national level (see Figure 5).

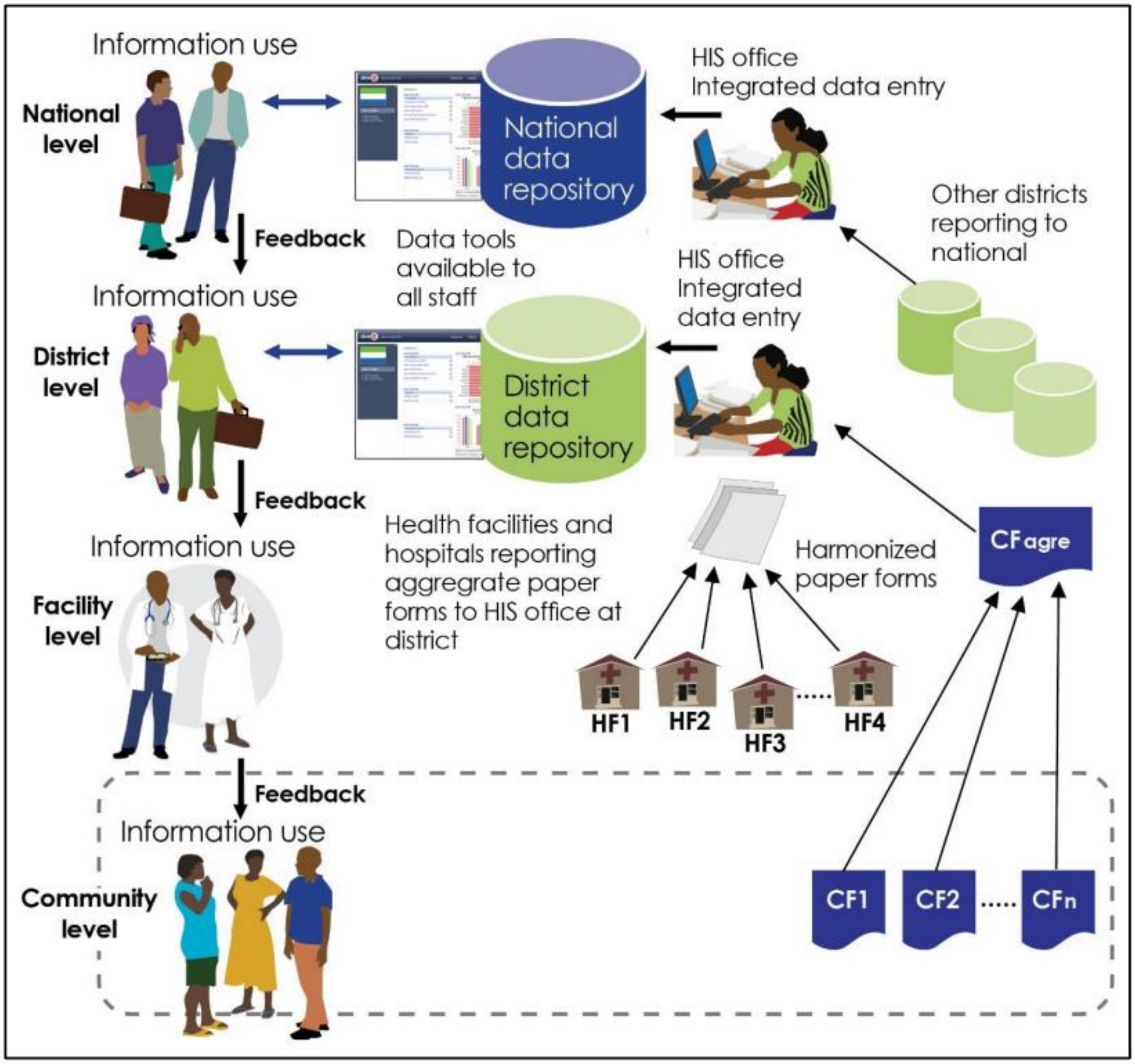

Figure 5: Pictorial representation of the health data and information flow (MEASURE Evaluation 2020)

Along with strengthening routine health information data, significant investments have been made to revitalize and convert the IDSR system from being paper based to a fully electronic system using an electronic integrated disease surveillance and response (eIDSR) mobile app integrated into DHIS2 (Martin et al. 2020).

In addition, the 117 Call Center, originally set up in 2012 as part of a wider support system to improve maternal and child health and then expanded significantly during the EVD outbreak, has transitioned into a national events-based surveillance system in support of the government's One Health Initiative (eHealth Africa 2020).

3.6 Access to Essential Medicines

- Mean availability of essential medicine tracer items: 31%
- Mean availability of diagnostic tracer items: 33% (GoSL 2017a)
- Mean availability of essential medicines: 24%–37% (depending on the district)

According to the 2017 Service Availability and Readiness Assessment (SARA) survey, only six of the twenty essential medicine tracer items monitored were available at health facilities, indicating that facilities lack many critical commodities to treat the most common health conditions. Availability of diagnostics was also among the lowest scoring domains (Figure 6), with only 2% of health facilities able to offer hemoglobin or blood glucose testing; urine dipsticks for protein or glucose; HIV, malaria, or syphilis diagnostic tests; or urine pregnancy testing (GoSL 2017a).

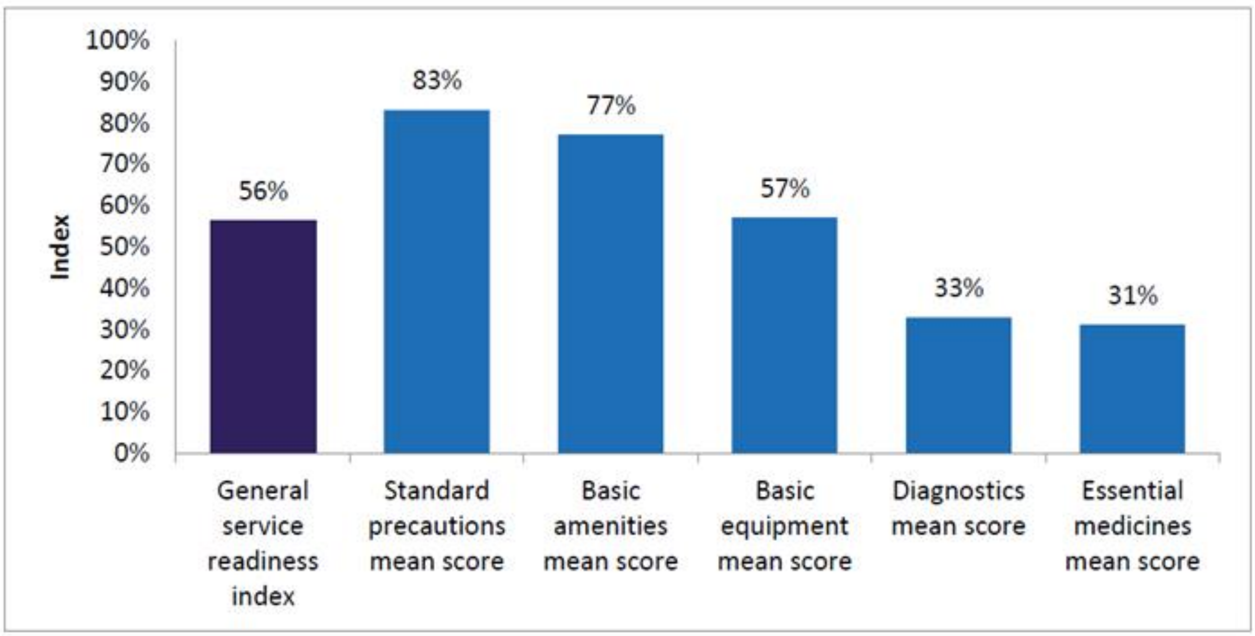

Figure 6: Sierra Leone Community Health System Structure (APC, 2017)

From a health security perspective, the limited availability of essential medicines and basic diagnostics is of great concern. On the positive side, however, most health facilities met the recommended level of infection prevention.

According to the BPEHS, key commodities should be available at the community level (via the PHU and through CHWs) for family planning, maternal health, newborn and child health, HIV and tuberculosis, diarrhea, malaria, and nutrition. National supply chain stockouts are frequent, and NGOs have long had to step in to support last mile logistics through district medical stores, frequently procuring and distributing buffer supplies to PHUs and CHWs (Raven et al. 2020).

3.7 Health Financing

- Health spending per capita (US$): $46 (2019)
- Government health spending (% of health expenditures funded by the government of Sierra Leone): 14.0 % (2019)
- Out-of-pocket spending as % of health spending: 55.2 % (2019)
- GDP per capita (US$): $515 (2019) (World Health Organization 2023)

Sierra Leone's BPEHS, created as part of its Free Healthcare Initiative of 2010, shows a commitment to universal health coverage, particularly for children under five, pregnant and lactating women, and other vulnerable populations. The government reaffirmed its priority for universal health care in the Sierra Leone Medium-Term National Development Plan (2019–2023), with a strong commitment to investing in human capital. Nevertheless, insufficient public funds have been available to fully resource this initiative, and deficits in health workforce, supply chain, and infrastructure are such that this vision remains largely aspirational. At 55.2% of total health expenditure, out-of-pocket payments for health care services significantly exceed the WHO's 15–20% threshold for highly regressive out-of-pocket payments for health (World Health Organization 2023).

3.8 Global Health Security

After endorsing the Global Health Security Agenda (GHSA) in 2016, the MoHS, Ministry of Agriculture and Forestry (MAF), Office of National Security, and civil society partners developed a five-year roadmap for the agenda. The GoSL then participated in a Voluntary Joint External Evaluation (JEE) in October 2016 that identified several positive developments, including strong political and technical leadership, which were instrumental in the EVD outbreak recovery. The JEE identified several areas for improvement, including the need to finalize several legislative priorities. The assessment recommended resourcing the units and staff responsible for One Health (OH) activities to render them fully functional. It suggested that the GoSL form a multi-hazard National Public Health Emergency Preparedness and Response Plan as well as a tri-hazard assessment (radiation, chemical, and infection risks), among other recommendations.

Based on the JEE results, the GoSL convened stakeholders from multiple sectors to develop the National Action Plan for Health Security (2018–2022). The GoSL identified 47 priority diseases, including non-communicable diseases and (re)emerging diseases. The group highlighted cholera, Ebola, Lassa fever, yellow fever, and measles, given the high risk of outbreaks.

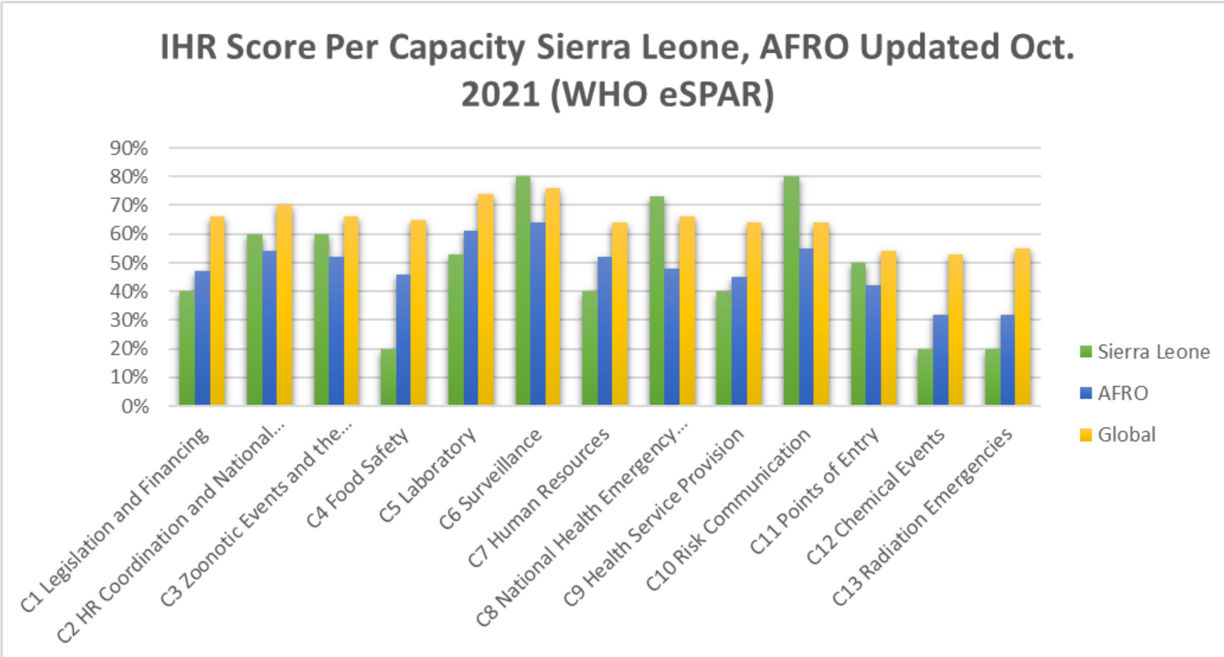

Figure 7. Sierra Leone Self-Reported Performance on International Health Regulation (IHR) Capacities (WHO 2021a)

As part of the GHSA, development partners have supported workforce development, laboratory systems, surveillance, emergency management, immunization, and antimicrobial resistance, as well as the establishment of a National Public Health Institute. Sierra Leone's Public Health Emergency Operations Center is active, working with the Directorate of Drugs and Medical Supplies and National Medical Supplies Agency to convene partners to respond to emergencies, such as COVID-19 and Ebola.

SECTION 4: GENERAL OVEREVIEW OF THE ANIMAL HEALTH SYSTEM

4.1 Animal Health Services and Infrastructure

The animal health service is the responsibility of the Livestock and Veterinary Services (LVS) Directorate, which falls under the MAF. The LVS Directorate oversees both livestock and animal health activities. At the central level, responsibilities are shared between the Deputy Director, Animal Health, and Deputy Director, Animal Production. However, at local levels (districts, posts), the same personnel carry out the tasks differently. A veterinarian and veterinary paraprofessionals working at district level will also oversee livestock activities. At the district level, the District Agriculture Officer supervises all the divisions under the MAF, including the LVS Division. This division should be headed by a Veterinary Officer but in practice (since there is limited number of veterinarians), a District Livestock Officer leads it and supervises the work of field staff.

According to the Performance Veterinary Services Gap Analyses Report (Diop et al. 2012), the national epidemiological surveillance system (ENADIS) was introduced in July 2009 to provide the LVS Division with accurate information on the occurrence of animal diseases in the country and facilitate the collection and submission of samples for laboratory diagnosis of suspect cases using different ENADIS forms. This system only started full operation in 2019 when the MAF established an Integrated Animal Disease Surveillance and Reporting System (IADSR) with support from FAO. Using this system, District Livestock Officers successfully collect reports from Community Animal Health Workers (CAHWs) on the occurrence of priority animal diseases and zoonoses. In 2021, the MAF, with support from FAO, established the Event Mobile Application (EMA-i) used by frontline animal health officers for real-time surveillance and early warning with geo-referenced information on animal diseases using smartphones and tablets.

4.2 Challenges

Despite significant progress in developing human resources for animal health, human resources in the LVS Directorate are still limited. Studies have shown that the directorate has a limited number of veterinarians and other relevant cadres to adequately carry out animal health services. Also, the number of CAHWs is limited, and they are not present in all the chiefdoms (Leno et al. 2021). Lack of uniformity in terminology creates concern over the data quality of animal disease reporting (Bangura et al. 2022). Most CAHW diagnoses of animal diseases are based on signs and symptoms and are not confirmed in the laboratory due to constraints in access to laboratory services; therefore, diagnoses are subject to misclassification.

SECTION 5: CAPACITY FOR HUMAN AND ANIMAL DISEASE SURVEILLANCE AND OUTBREAK RESPONSE

5.1 Zoonotic Disease Capacity

Despite zoonotic diseases being identified as one of the greatest public health threats, Sierra Leone scored very low on the three major indicators in the 2016 JEE on International Health Regulation Core Capacities (Table 1)(WHO 2017). The low scores were a result of major disparities between human and animal health surveillance systems, the limited and diminishing capacity in veterinary and animal health workforce, and no established systems for coordinated response to zoonotic disease outbreaks by the human, agriculture, and wildlife sectors. Updates in 2019 and 2022 indicate that these challenges continue, although scores have improved and indicators have changed (GoSL 2018).

Table 1: Sierra Leone JEE (2016) International Health Regulation Core Capacities Related to Zoonotic Disease Preparedness Scores*

Capacities	Indicators	Score
Zoonotic diseases	P.4.1 Surveillance systems in place for priority zoonotic diseases and pathogens	1
	P.4.2 Veterinary or animal health workforce	1
	P.4.3 Mechanisms for responding to zoonoses and potential zoonoses are established and functional	1

* In the JEE system, 1 is the lowest possible score and 5 is the highest.

The animal health surveillance system is weaker and less integrated than human health, due to the need to develop capacity and the veterinary public health sector. Information sharing and networking between animal and human health laboratories need to be improved, especially during outbreaks (WHO 2017).

Despite these challenges, some practices in Sierra Leone can be leveraged for continued strengthening. These include training programs for controlling zoonotic disease in animal populations, specifically at Njala University, and the country's experience with managing rabies through joint task forces. Additional efforts have been made since the JEE, including a USAID initiative to support national and subnational veterinary diagnostic laboratories. In 2019, the FAO supported the refurbishment of the national veterinary laboratory and reinforced staffing capacity (FAO 2021a). There is also hope for major improvement in the realm of zoonotic diseases with the launch of Sierra Leone's national One Health platform in 2017 (USAID 2021).

5.2 *Biosafety and Biosecurity*

The ability to safely work with pathogens in a laboratory setting is critical to a competent One Health approach. The 2014/2015 Ebola outbreak in Sierra Leone resulted in significant attention to enhanced biosafety for health workers. However, Sierra Leone still scored low on biosafety and biosecurity indicators in the 2016 JEE (Table 2). As of 2016, there was no comprehensive national biosafety and biosecurity system in place. Though there have been training needs assessments conducted to identify gaps in training and practice, effective and sustained implementation of these biosafety and biosecurity practices has not occurred (WHO 2017). The low scores in biosafety and biosecurity capacity highlight the need to establish and implement regulations on biosafety and biosecurity, especially with laboratories.

Table 2: Sierra Leone JEE (2016) Biosafety and Biosecurity Scores *

Capacities	Indicators	Score
Biosafety and biosecurity	P.6.1 Whole-of-government biosafety and biosecurity system is in place for human, animal and agricultural facilities	1
	P.6.2 Biosafety and biosecurity training and practices	2

* In the JEE system, 1 is the lowest possible score and 5 is the highest.

The human health sector is far ahead of the animal health sector in terms of formally addressing biosafety and biosecurity through systems and laboratory guidelines. Regional laboratories are at a particular disadvantage since they do not have access to biosafety and biosecurity control measures (WHO 2017). Despite training needs assessments conducted and some training programs in place, there also seems to be a disparity between biosafety- and biosecurity-specific training, with biosafety more commonly emphasized in training programs and a lack of awareness around biosecurity.

A 2017 assessment of SARA found that 83% of health facilities had items for standard precautions for infection prevention such as disposable syringes, disinfectant, sharps waste disposal, latex gloves, soap and water or alcohol-based hand sanitizer, and appropriate storage and guidelines for their use (GoSL 2017).

5.3 *Real-Time Surveillance Capacity*

Overall, Sierra Leone scored high on indicators related to real-time surveillance in the 2016 JEE (Table 3). The MoHS manages the surveillance program for Sierra Leone (WHO 2017), and there is a Veterinary Epidemiology Unit in the Ministry of Agriculture, Forestry, and Food

Security (MAFFS) (WHO 2019). Four types of surveillance are in place: event-based, community-based, indicator-based, and syndromic surveillance. Event-based surveillance (EBS) is in place for formal and informal reporting in all districts through the 117 national telephone hotline. Community-based surveillance has been rolled out in three of fourteen districts, as of 2016. Community health workers report through their supervisors to health facilities that respond and investigate these reports. Indicator-based surveillance is conducted for priority diseases in the human health sector. Reports are generated from health facilities and sent to District Health Teams, who then submit them to the WHO system weekly. Syndromic surveillance is conducted in the human and animal health sectors and focuses on diseases such as severe acute respiratory infection, influenza, and acute viral hemorrhagic fever (WHO 2017). The Sierra Leone MoHS, Centers for Disease Control and Prevention (CDC), and WHO set up the Sierra Leone Viral Hemorrhagic Fever (VHF) database following the 2014/2015 Ebolavirus outbreak. The surveillance system includes laboratory and suspected case data (Dietz et al. 2015). The Sierra Leone-China Friendship Biological Safety Laboratory opened in 2015 with support by the Chinese government; the biosafety lab (BSL) is a BSL-3 lab in Freetown (Wang et al. 2016).

Table 3: Sierra Leone JEE (2016) Surveillance Scores*

Capacities	Indicators	Score
Real-time surveillance	D.2.1 Indicator and event-based surveillance systems	4
	D.2.2 Interoperable, interconnected electronic real-time reporting system	2
	D.2.3 Analysis of surveillance data	4
	D.2.4 Syndromic surveillance systems	4

* In the JEE system, 1 is the lowest possible score and 5 is the highest.

In 2015, the country revised its IDSR strategy and at least one health worker at each health facility is trained in the system. The MoHS has developed an interoperable, interconnected real-time surveillance reporting system, utilizing animal surveillance reporting tools to submit data to the African Union and OIE. In fact, reporting timeliness and completeness frequency is above 90% for the public sector; however, the private sector does not report (WHO 2017). Recently, an eIDSR has been rolled out in at least 12 of 14 districts, with >85% coverage of all government health facilities (WHO 2019). In fact, Sierra Leone was the first country in the WHO Africa region to fully transform from a paper-based national disease surveillance system to one that is web based.

Despite major improvements in surveillance databases and capacity, there are no structured data quality assurance and validation systems for animal health surveillance, and the reporting system overall is not interoperable with other systems (WHO 2017). FAO recently conducted targeted workshops on an Event Mobile Application to improve animal disease reporting, early warning, and surveillance from the field to the national level. The Event Mobile Application allows animal health workers to collect and transmit real-time, geo-referenced data on animal diseases from the field using smartphones or tablets (FAO 2021b). However, there are no formal arrangements for routine data sharing between ministries or sectors (WHO 2017).

In 2016, the USAID/MEASURE Evaluation project's review of the national HIS found that most disease systems existed but were insufficient. Challenges included:

- Among health workers who make primary diagnoses, fewer than 25% could correctly cite the case definitions of the majority of notifiable diseases.
- Fewer than 25% of health facilities submit on-time weekly or monthly surveillance reports at the district level.
- Essential patient information is usually not recorded, and most patient records often cannot be retrieved.
- During the past year, no bulletin on surveillance data for epidemic-prone diseases had been produced.
- Health workers and managers face a heavy burden for reporting on disease surveillance and other focused public health programs (e.g., maternal care).

5.4 Outbreak Preparedness and Emergency Response Operations Capacity

Preparedness and emergency response operations are key components for outbreak response capacity. Though Sierra Leone scored poorly on preparedness capacity indicators, the country scored well on emergency response operations capacity indicators (Table 4).

Table 4: Sierra Leone JEE (2016) Preparedness and Emergency Response Scores*

Capacities	Indicators	Score
Preparedness	R.1.1 Multi-hazard NPHEPR plan is developed and implemented	1
	R.1.2 Priority public health risks and resources are mapped and utilized	1
Emergency response operations	R.2.1 Capacity to activate emergency operations	4
	R.2.2 EOC operating procedures and plans	3
	R.2.3 Emergency operations programme	4
	R.2.4 Case management procedures are implemented for IHR relevant hazards	2

* In the JEE system, 1 is the lowest possible score and 5 is the highest.

Though preparedness plans exist, such as the National Multi-Hazard Contingency Plan (2007), they are not oriented to health (WHO 2021b). Other plans focus specifically on one disease or hazard and are not integrated into a comprehensive public health emergency preparedness and response plan (WHO 2017). Multisectoral risk profiling for biological hazards has been conducted at the national level but has yet to be done at the district level. In addition, resource mapping has not been conducted at the district level (WHO 2017).

Public health emergency operation centers were critical to fighting the Ebola outbreak of 2014–2015, and as a result, Sierra Leone constructed 13 district emergency operation structures and one national EOC. To operationalize the EOC, there is an incident management system, emergency operations plan and standard operations procedures, and surge capacity and supplies (e.g., vehicles, ambulances, biomedical supplies) for rapid response teams. All of this highlights the substantial public health emergency operations system in place in Sierra Leone. In fact, the EOC has demonstrated an ability to activate a response within two hours of the identification of a public health emergency. However, there is a need for increased training programs and simulations to maintain this capacity (WHO 2017).

5.5 Summary for STOP Spillover

The STOP Spillover project could focus on recommended priority actions identified in Sierra Leone's JEE. Major focal areas for improvement have been identified in the list below:

- Accelerate One Health approaches across all sectors, with special emphasis on the animal health sector.
- Address gaps in veterinary and animal health capacity.
- Improve coordination and collaboration between human and animal health laboratory systems.
- Establish all elements of a comprehensive national biosafety and biosecurity system for both human and animal health sectors.
- Formulate integrated emergency response plans for biological hazards that incorporate points of entry (PoEs) contingency plans.
- Conduct capacity assessments at all designated PoEs to guide the development of contingency plans.
- Conduct risk and resources mapping of all priority public health risks to improve outbreak preparedness and response (WHO 2017).

To address these areas of improvement listed above, the STOP Spillover project can leverage key strengths identified in the JEE that are already present in the country. These current strengths and best practices are listed below:

- Strong political and technical leadership that have facilitated significant progress in recovery from the disruptions caused by the Ebola outbreak.

- Strong collaboration and synergy between in-country partners and stakeholders in the human health sector.
- Robust revitalized IDSR system with countrywide coverage in human health, including indicators and event-based and syndromic surveillance systems, in place.
- Regular analysis of data and feedback at national and subnational level.
- Formal government arrangements and systems in place for risk communication with multisectoral and multi-stakeholder involvement.
- An excellent national laboratory network system (a best practice in the human health sector but not in the animal health sector).
- Highly effective EOCs with a functioning multisectoral and multidisciplinary incident management system and multisectoral and multidisciplinary rapid response teams.
- Established links between public health and security authorities (WHO 2017).

SECTION 6: LEGISLATIVE FRAMEWORKS AND GOVERNMENT POLICIES

6.1 JEE Review of Legislation and Frameworks Relevant to One Health

Ministries most involved in One Health include MoHS, Ministry of Environment, MAF, and Office of National Security. The 2022 JEE self-assessment used the National Action Plan for Health Security (NAPHS) developed by the GoSL after the 2016 JEE. The NAPHS is a multisectoral plan that is drawn from 19 technical areas, cutting across various ministries, departments, and agencies. To address the gaps in IHR capacity, the country developed the 2022 NAPHS Annual Operational Plan. If most of the 74 priority activities and 220 sub-activities are implemented, the score is expected to improve.

Best Practices Observed:

1. Cross-sectoral engagement using the One Health approach and collaboration with partner organizations, civil society, and the private sector have resulted in improvements in planning, implementation, and emergency preparedness. This is well demonstrated by the successes in risk communications. Formal coordination mechanisms and service level agreements have resulted in strong partnerships between government sectors and development partners for IHR implementation.
2. A comprehensive NAPHS was developed with multi-sector participation. The NAPHS (total cost: US$291M) was prioritized to identify priority activities (cost: ~US$50M). This reduces the workload for implementation and makes resource needs clearer.
3. Resource mapping was done in 2018. This activity identified resources for IHR implementation and areas for collaboration.

Progress Areas:

1. Creating an enabling environment for implementation of the International Health Regulations (2005): Restructuring within the MoHS created a new Directorate for Health Security and Emergencies (DHSE), which hosts the IHR National Focal Point. The DHSE now has the capacity and mandate to coordinate IHR implementation, including oversight of the NAPHS and the World Bank's Regional Disease Surveillance Systems Enhancement (REDISSE) project.
2. Revision of Public Health Ordinance (1960): A revised Public Health Bill (2019) has been finalized and is anticipated to be enacted by Parliament.
3. Advancements in One Health: One Health committees have been established at the national and district levels. Strong coordination has been demonstrated by the agreement

of ministries on a priority zoonotic disease list. A zoonotic surveillance unit has been created in the DHSE.

4. Surveillance Systems Enhancement: The IDSR has excellent (>95%) timeliness and completeness of reporting. A new eIDSR has been rolled out in 12 of 14 districts and now has >85% coverage of all government health facilities. RRTs have been able to respond to 95% of verified signals within 24 hours.
5. Laboratory testing for viral hemorrhagic fever has been established at the national and subnational levels.

6.2 Additional Relevant Legislation and Frameworks

Based on the gaps identified during the 2016 JEE, multisectoral and multidisciplinary teams established many structures and developed multiple documents. These include:

- Establishment of DHSE, which is responsible for all global health security agenda activities.
- Development and implementation of the NAPHS (2018–2022).
- Development of the National One Health Strategic Plan (2019–2023) and National One Health Governance Manual (2018), which guide the introduction and expansion of One Health approach in Sierra Leone.
- Development of the One Health Communications Strategic Plan (2019)
- Development of the Sierra Leone Public Health Surveillance Strategic Plan (2019–2023)
- Development of the Sierra Leone Bio Risk Policy and Guideline
- Development of the Public Health Final Bill
- Development of the final Animal Health Bill (2021) and Animal Welfare and Protection Bill (2020)
- Development of the National Livestock Policy and Implementation Plan
- Development of the Environment Protection Agency Act (2008)
- Development of the Environmental Quality Standards (2014)
- Development of the Food and Feed Safety Act (2017)
- Development of the National Food Safety and Quality Control Guidelines
- Development of the National Disaster Management Act (2020)

6.3 Gaps and Challenges

- *Workforce:* The existing civil service does not include career categories or pathways for public health personnel including epidemiologists, biostatisticians, laboratory workers, and animal health workers; there are major human resources gaps for animal health at the district and national levels. Also, the One Health platform operates at the national level with some technical working groups not effectively coordinating and collaborating to act beyond the national level. This presents an opportunity for STOP Spillover One Health Design, Research and Mentoring (OH-DReaM) Working Groups to build a multi-stakeholder network around One Health issues while facilitating dialogue across prioritized interfaces.

- *REDISSE Implementation:* Challenges in obtaining timely approvals from the World Bank for the REDISSE annual work plan and delays by the fiscal agent have delayed implementation of activities.
- *Sustainable Domestic Financing:* Efforts are in place for Sierra Leone to meet its Abuja Declaration commitment of 15% expenditure on the health sector; currently 11% is allocated.
- *Infrastructure:* Lack of consistent provision of electricity and running water at laboratories and health facilities creates challenges for specimen storage, cold chain functioning, biosafety, infection prevention and control (IPC), and water, sanitation, and hygiene (WASH) compliance.
- *Laboratory Systems:* Animal health laboratory capacity lags behind what is available for human health. There is limited testing capacity for antimicrobial resistance. An integrated specimen transportation and referral system has not been operationalized, delaying clinical diagnosis and detection.
- *Political:* The enactment of the bills and acts for both animal and human health sector has been delayed by Parliament, which has delayed some interventions including the establishment of the National Public Health Agency (NPHA).
- *Gender:* There have not been any systematic gender analyses targeting the main One Health sectors, so there is no gender policy for implementation of One Health activities.

SECTION 7: PRIORITY VIRAL PATHOGENS FOR SIERRA LEONE

The identification of the political, economic, and cultural drivers of zoonotic spillover requires nuanced investigation of viruses of interest, modes of transmission, and habitat disruption (by human activity, climate change, or natural disasters) that can change the normal geography and ecology of vector transmission, human demand systems (wildlife for trade, food, medicinal remedies, sport), and gaps in institutional capacities to manage risks (gaps and loopholes in policies, lack of enforcement of legislated norms, trade-offs among vested interests, and limited awareness of the extent and danger of viral transmissions). This review focuses on the complex interfaces between animal and human hosts, society, economy, environment, climate, and priority STOP Spillover pathogens/pathogen families: Lassa virus, Filoviruses, animal coronaviruses, and highly pathogenic avian influenza virus.

7.1 Lassa Fever

7.1.1 Lassa Virology

Lassa virus (*Lassa mammarenavirus*) is a member of the *Arenaviridae* family and infects humans and rodents. Lassa fever is an endemic zoonotic disease in most regions of Sierra Leone and a top priority for the country and government. The eastern province of Sierra Leone is considered to have the highest incidence of Lassa fever in all West Africa (McCormick et al. 1987). While cases also occur in the Northern Province, these are not as frequent (Shaffer et al. 2014). This could be a consequence of surveillance efforts being focused in the Eastern Province or a function of migration and climate-driven disease evolution.

7.1.2 History of Lassa Spillover Events

Lassa fever is endemic in Sierra Leone (Figure 8), and cases are reported nearly every year in the country (see Figure 9). However, an *outbreak* is defined as a sudden increase in the number of cases of disease than what is normally expected and is generally specific to a geographic region (CDC 2012).

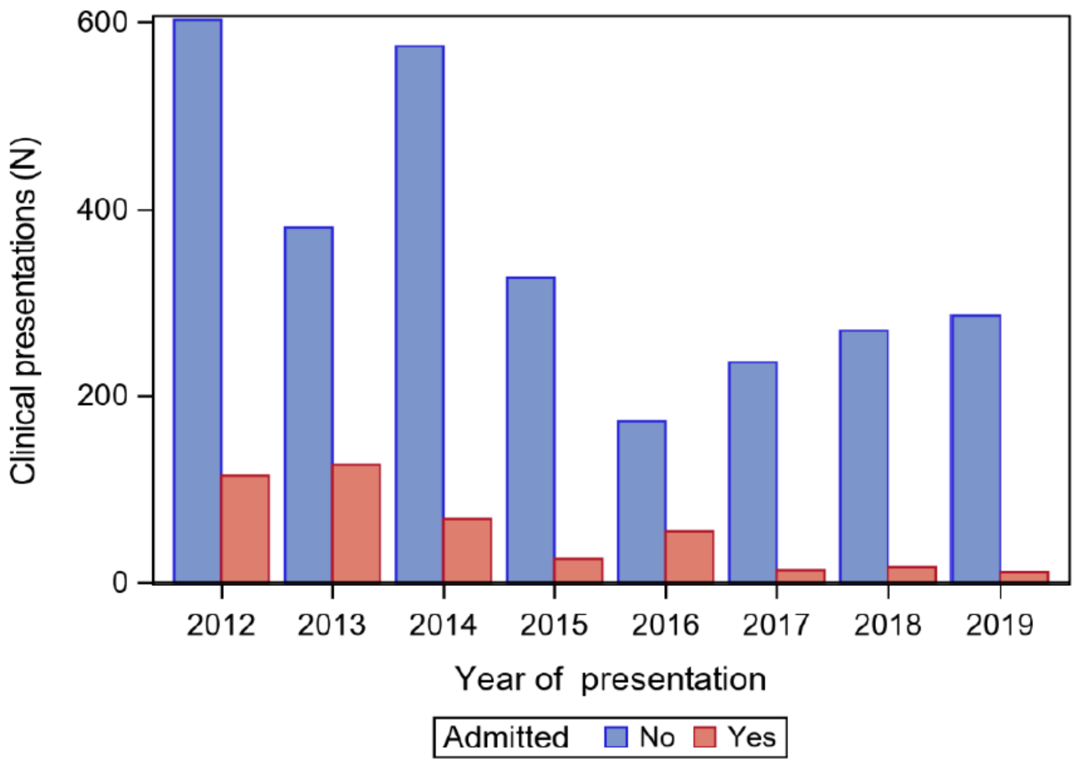

Figure 8: Lassa fever cases at Kenema Government Hospital in Sierra Leone from 2012 to 2019 (Source: Shaffer 2021)

7.1.3 Associated LV Interfaces

The main host of Lassa virus, the multimammate rat, has been observed in multiple environments, including houses, fields, grasses, and brush and moving back and forth between them (Mariën et al. 2018). Their generalist diet allows them to adapt to different environments and conditions (Leirs, Verhagen, and Verheyen 1994). The tendency of Mastomys to live inside houses might facilitate transmission of Lassa virus. Transmission is thought to occur through contaminated food or water or by direct contact with blood, feces, or rodent saliva. Human-to-human transmission is common, and the hospital setting offers an environment for nosocomial transmission. The virus has been isolated from blood, feces, urine, throat swabs, vomit, semen, and saliva of infected persons. Activities like hunting, cooking, and eating rats could facilitate transmission of Lassa virus through direct contact with the host and their blood (Bonwitt et al. 2016). Individuals in rural homes and those working in agricultural areas are at higher risk than those in urban and forested areas, as well as those in more poorly constructed housing and homes with high human density (Bonwitt, Kandeh, et al. 2017; Bonwitt, Sáez, et al. 2017; Gibb et al. 2017).

Incidence of Lassa fever fluctuates seasonally, with peaks reported during high rodent breeding times during the dry season in February and May and the rainy season in June and July (Leach et al. 2017). Attempts to eradicate the reservoir have proven to be ineffective, as rodent populations bounce back after six months of treatment (Eisen et al. 2013; Mari Saez et al. 2018).

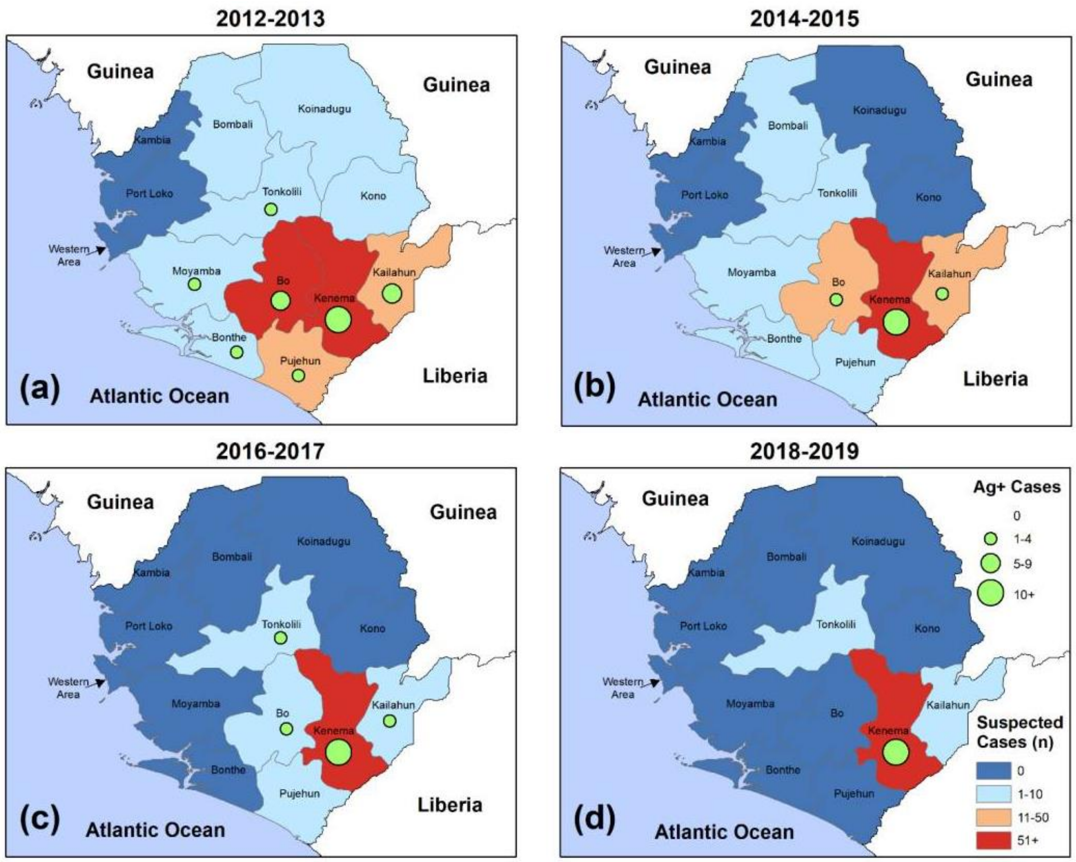

Figure 9: Geographic distribution of Lassa Fever suspected and confirmed cases in Sierra Leone by District, 2012–2019 (Shaffer et al. 2021)

CLIMATE AND ENVIRONMENTAL DRIVERS

Although Lassa fever cases fluctuate seasonally, peaking during the dry season, Lassa virus prevalence in the rodent host is higher during the rainy season (Fichet-Calvet et al. 2007). This peak in cases coincides with an increase in *Mastomys natalensis* population. Both Lassa fever cases and Mastomys population have been observed to increase 60–120 days after the first rains (Leirs, Verhagen and Verheyen 1994; Redding et al. 2021). The increase in the host population could be increasing the risk of transmission to humans. Additionally, the fact that the harvest coincides with the beginning of the dry season has many researchers considering that the rodents will migrate from the fields to the houses, increasing the risk of spillover. As global temperatures increase and land use changes, we expect to see an expansion of the Lassa virus geographic range.

HUMAN-RODENT

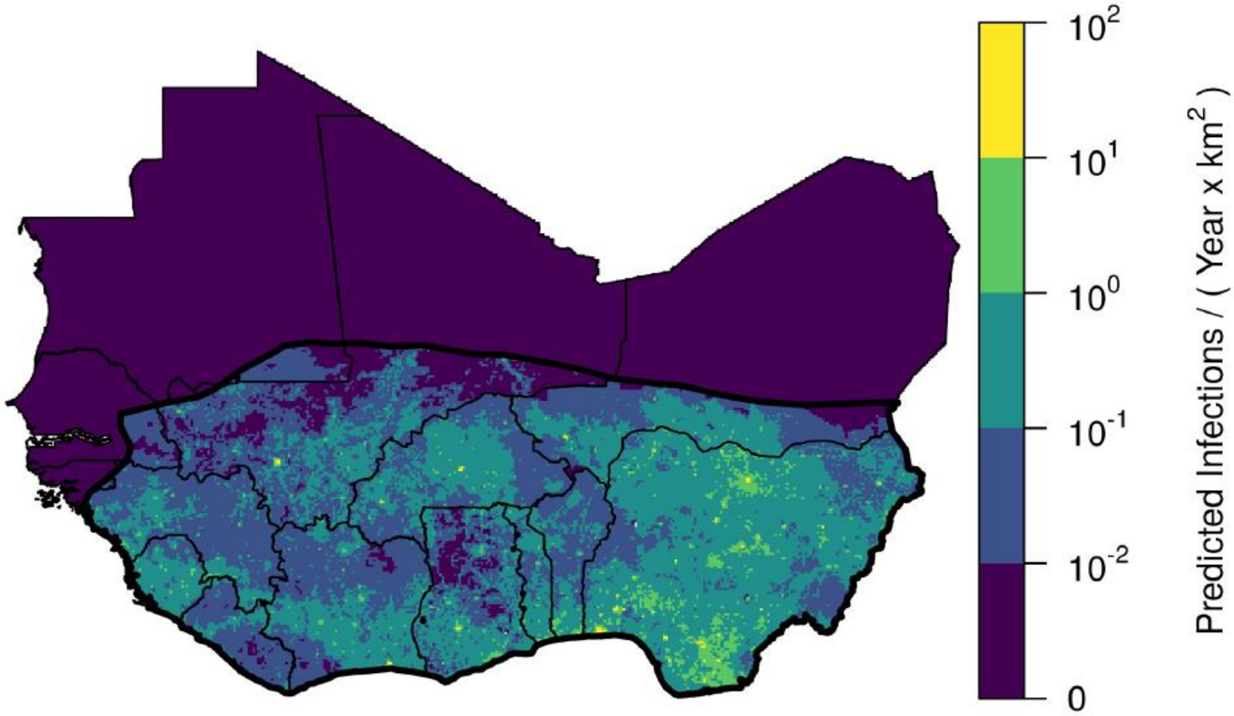

Fig 6. Predicted spatial density of Lassa virus infections in humans. Map shows the predicted infections per km^2. Yellow colors, representing a high number of infections, tend to occur in areas with high human population density and a high predicted seroprevalence.

https://doi.org/10.1371/journal.pcbi.1008811.g006

Figure 10. Predicted Lassa virus infections in West Africa (Basinski et al. 2021).

Rodent control measures have been tested as a method to reduce risk of Lassa transmission with limited results. Rodent exclusion is not practical in African rural environments (e.g., wattle and daub housing). Limiting access to food resources might be an alternative to reduce rodent abundance inside houses. Natural control of rodent populations in fields might have some effect on spillover risk. Poor living conditions facilitate contact with rodents and exacerbate the risk of disease emergence and spread. Hunting and eating rats have been described in Sierra Leone, and it is considered a potential route of infection. The CDC (2019) identifies development of rapid diagnostic tests and prevention of high-risk contact with the rodent reservoir host as the most effective approaches to address transmission of Lassa fever disease in humans.

BORDER CROSSINGS

There is flourishing informal cross border trade among Mano River Union countries, especially Guinea, Liberia, and Sierra Leone. Informal border crossings are unregulated international border areas where humans, animals, and goods move daily between countries. Border porosity allowed

EVD-infected individuals to enter the country in 2014. Although the IHRs mandate that specific capacities be installed at PoEs to prevent the spread of pathogens across borders, especially with the level of unofficial traffic that occurs, cases of transboundary pathogen transmission continue. Because women make up most of the marketers, small-scale farmers, and cross-border traders in Sierra Leone, quarantines and bans on cross-border trade had a particular impact on female-headed households (Ravi and Gauldin 2014; Pailey 2016).

Similarly, Lassa virus has also been shown to cross borders (Figure 10). A woman who had been experiencing symptoms for roughly one week and who had been treated for typhoid and malaria in Guinea was hospitalized in Ganta (Nimba County, Liberia) and diagnosed with Lassa fever on January 9, 2018. During her illness, this individual met several other people (family members and health care personnel) in both Liberia and Guinea, during which further transmission of Lassa could have occurred (WHO 2018).

A final example of cross-border pathogen transmission comes from domestic livestock: The Livestock Services Division of the Ministry of Agriculture and Forestry of Sierra Leone reported two outbreaks of foot-and-mouth disease in two provinces of Sierra Leone. The source of the outbreak could not be confirmed but was associated with porous borders and uncontrolled movement of animals (Bangura et al., 2022).

7.1.4 Relevant Socioeconomic, Political, and Institutional Drivers of LV

RELEVANT CULTURAL/SOCIETAL NORMS

Lassa fever is endemic in parts of Kenema District in eastern Sierra Leone, an agricultural and mining cosmopolitan settlement. The majority of the population in this area relies on natural resources for their primary source of income and food consumption. The consumption of rodents, including the Mastomys species, is widespread. The reasons for rodent consumption are multifactorial, including taste preferences, food insecurity, and traditional and opportunistic behavior. Hunting rats does not align with specific generational, ethnic, or religious attributes; rather it is a highly opportunistic and domestic practice in which the vast majority of people engage. Women are more exposed and vulnerable to the risk of transmission because of the roles they play, including caring for children and the sick; travelling to *luma* markets to trade in usually open fields with poor hygiene and sanitation; processing meat and preparing food in the home; participating in traditional healing, midwifery, secret society leadership, and bushmeat trading; and working in health care. Gendered risk factors affect mortality rates by Lassa virus for certain groups. Pregnancy is associated with increased Lassa fever mortality; there is a threefold increase in the risk of mortality for pregnant women (Kayem et al. 2020). Pregnancy outcomes from the virus also result in high instances of fetal death, miscarriage, stillbirth, and concomitant death of the mother and fetus (Duvignaud et al. 2021). In addition, evidence from Ebola outbreaks in 2014 showed that time from symptom onset to hospitalization was shorter for females than for males, suggesting a systematic, gendered assessment of hospitalization rates and time to hospitalization of Lassa patients in Sierra Leone might be needed (Nkangu, Olatunde, and Yaya 2017).

GOVERNMENT PRIORITIES, INSTITUTIONAL CAPABILITIES, AND POLICIES IN PLACE

Lassa response, especially in the hotspot district of Kenema in eastern Sierra Leone, is now well coordinated and quite successful because of many years of research and community engagement. The government has prioritized diagnostics over time, working with various local and international partners to study the disease ecosystem and produce guidelines for testing for and responding to cases. Tulane University is a long-time partner while the University of California-Davis, and Broad Institute recently supported community-based surveillance and policy planning activities. PREEMPT and PREDICT also supported risk awareness, identification, analysis, and management trainings in the past and have conducted research to further shape current knowledge of the disease. The true incidence and prevalence of the disease across known hotspots and emerging areas are still poorly understood.

7.2 Filoviruses

7.2.1 Filovirus Virology

The family Filoviridae contains two genera of public health importance: *Ebolavirus* and *Marburgvirus*. Within these genera, there are two Marburg viruses (Marburg virus [MARV] and Ravn virus [RAVV]) and four Ebolaviruses (Bundibugyo ebolavirus [BDBV], Sudan zoonotic ebolavirus [SUDV], Tai Forest ebolavirus [TAFV], and Zaire ebolavirus [EBOV]) that cause disease in humans. Together, these six viruses have caused over 40 outbreaks in humans, with case fatality ratios as high as 90% (Feldmann, Sprecher, and Geisbert 2020). Transmission is via contact (mucous membrane, abraded skin) with infectious viral particles in blood or secretions (e.g., milk, semen, urine, sweat, feces, vomit, saliva, amniotic fluid). Transmission through indirect contact is less common and includes contact with objects (e.g., bedding, clothing) that have been contaminated with bodily fluids (WHO 2021; 2021c; Brainard et al. 2016). Disease is due to direct effects of viral replication as well as the host response to infection. Incubation is 2–21 days (typically 6–10), and patients can present with a wide range of symptoms.

Recently a novel Ebola virus, Bombali virus [BOMV] was discovered in Sierra Leone in little free-tailed (*Chaerophon pumilus*) and Angolan free-tailed (*Mops condylurus*) bats found roosting inside houses. Bat reservoir proximity to humans and experimental evidence of viral entry to human cells suggest that BOMV could pose a zoonotic risk to humans, however the zoonotic and pathogenic potential is currently unknown (Goldstein et al. 2018). Additional filoviruses of unknown zoonotic potential and pathogenic potential include Reston virus, which has been detected in pigs in the Philippines and China; Lloviu virus, which was sequenced in bats (*Miniopterus schreibersii*) from Spain and Hungary; and Měnglà virus, which was detected (sequenced) in Chinese rousettus species (Feldmann, Sprecher, and Geisbert 2020).

7.2.2 Filovirus Pathology and Epidemiology

Historically, all Marburgvirus and Ebolavirus outbreaks were thought to have originated from one or multiple wildlife-to-human spillover events and had resulted in relatively limited human-to-human transmission occurring, especially in the case of MARV. Thus, the number of human cases and fatalities were relatively few. However, the source of the most recent EBOV outbreaks in the Democratic Republic of the Congo (DRC) and Guinea in 2021 and in DRC in 2020 was attributed to persistent EBOV infection in survivors. Substantial sustained human-to-human transmission occurred during the 2014–2016 EBOV outbreak that began in Guinea and spread to Liberia and Sierra Leone, resulting in an unprecedented number of cases (28,610) and fatalities (11,308) (CDC 2021a; 2021b; 2020; Feldmann, Sprecher, and Geisbert 2020; Park et al. 2015; Gire et al. 2014).

When infected, patients initially present with fever, malaise, fatigue, and myalgia and gastrointestinal symptoms of anorexia, nausea, vomiting, and diarrhea with the potential for substantial fluid loss. Other possible clinical signs/symptoms include dysphagia, headache, conjunctival injection, abdominal pain, arthralgia, and a maculopapular rash. Bleeding abnormalities are less common and present as bleeding from gums, petechia, oozing from venipuncture sites, subconjunctival hemorrhage, and blood in vomitus and stool. Because bleeding abnormalities are not consistently seen, the disease is now referred to as Ebola virus or Marburg disease, not hemorrhagic fever (Feldmann, Sprecher, and Geisbert 2020). Misdiagnosis can result due to the wide range of non-specific potential clinical presentations and their similarity with other more common diseases.

In some cases, post-Ebola syndrome can occur in survivors and presents as musculoskeletal pain, headache, encephalitis, and ocular problems (Scott et al. 2016). Occasionally, the virus has been detected in multiple body fluids of survivors, and these individuals can pose a transmission risk to others. Greater duration of viral persistence in semen has been associated with individuals with more severe disease (Thorson et al. 2021) and HIV-positive status (Purpura et al. 2017). Recently, several outbreaks have been attributed entirely or in part to persistent infection in survivors from prior outbreaks, such as the 2021 EBOV outbreaks in Guinea and the DRC.

7.2.3 History of Filovirus Spillover Events in Sierra Leone

The history of spillover events in Sierra Leone is as follows:

- *2021 (Guinea):* MARV. 1 case, 1 fatal. Guéckédou Prefecture, Nzérékoré Region. Affected village was in a remote forest area at the border of Sierra Leone.

- *2021 (Guinea):* EBOV. Total of 23 cases, 12 deaths. Nzérékoré Prefecture (borders Sierra Leone). Sequences like those of 2014–2016 West Africa outbreak. Suspected source is persistent infection in a survivor (CDC 2021c; 2021b; Keita et al. 2021).
- *2014 (DRC):* EBOV. 69 cases, 49 deaths. Equateur Province. The EBOV variant was similar to that from the 1995 outbreak in Kikwit so this outbreak was not linked to the large outbreak occurring in West Africa (Guinea, Liberia, Sierra Leone) (CDC 2021a).
- *2014–2016 (Guinea, Liberia, Sierra Leone):* EBOV. Total of 28,610 cases, 11,308 deaths. Largest EBOV outbreak in history. The original source of spillover is unknown, but an association exists between the proposed index case in Guinea and a colony of insectivorous bats (Kock et al. 2019). Epidemiological and genomic analyses suggest a single zoonotic transmission event in Guinea was followed by subsequent sustained human-to-human transmission (human cross-border issue) in Liberia and Sierra Leone (Dudas et al. 2017; Gire et al. 2014). Sierra Leone had 14,124 cases, 3,956 fatal (CDC 2021a).

***NB*:** Although no human MARV outbreaks have been detected in Sierra Leone, the geographic range of the putative MARV reservoir host (*R. aegyptiacus*) includes parts of Sierra Leone (Pigott et al. 2015), MARV isolates have been collected from *R. aegyptiacus* in Sierra Leone (Amman et al. 2020; PREDICT Consortium 2021), evidence of exposure (antibodies) in humans from Sierra Leone has been detected serologically, and a case of MARV occurred in neighboring Guinea in 2021 (O'Hearn et al. 2016; Pigott et al. 2015; Amman et al. 2020; WHO 2021c).

7.2.4 Filovirus Interfaces and Viral Ecology

ANIMAL RESERVOIR(S)

Ebolaviruses

The reservoir for viruses within the genus *Ebolavirus* has yet to be identified. The current leading hypothesis is that the reservoir is one or more bat species and that other hosts that encounter bats may transmit the virus to humans. Antibodies to EBOV have been detected in nine bat species, and EBOV ribonucleic acid (RNA) has been detected in three fruit bat species (Caron et al. 2018) and in an insectivorous bat (*Miniopterus inflatus*) (Kupferschmidt 2019). However, despite sampling of thousands of bats, there has never been isolation of Ebolaviruses from any bat species (Caron et al. 2018; Feldmann, Sprecher, and Geisbert 2020). Asymptomatic infection has been detected in at least three species of fruit bats, suggesting that bats are the most likely reservoir (Leroy et al. 2004; 2005; Walsh et al. 2003; Kock et al. 2019). In addition, Leroy et al. (2009) found epidemiological links between exposure to fruit bats and the 2007 EBOV outbreak in the DRC, further supporting the theory of bats as the reservoir. Others argue that only two EBOV disease outbreaks have clear epidemiological linkages to bat exposure, and these links are tenuous (Amman et al. 2017; Leroy et al. 2009; Marí Saéz et al. 2015). EBOV infection (viral RNA) or evidence of exposure (antibodies) has been detected in non-human primates, duikers (*Cephalophus* spp), and multiple bat species (Kock et al. 2019), and some human infections can be traced to contact with primate and duiker carcasses. High mortality in primates and duikers suggests that these species are dead-end hosts that may simply act as a bridge between the true reservoir and people. Domestic dogs and pigs have tested positive for Ebolavirus reactive antibodies, and experimentally infected pigs can shed high levels of virus (Amman et al. 2017; Kock et al. 2019); these species should also be considered as possible amplifiers or bridge hosts.

Marburg viruses

Field (Towner et al. 2009; Amman et al. 2012; 2017; Kuzmin et al. 2010) and experimental data (Jones et al. 2015) provide strong evidence that *Rousettus aegyptiacus*, the Egyptian fruit bat, is the reservoir for MARV and RAVV. Anti-MARV antibodies, MARV RNA, and MARV isolates have been detected from *R. aegyptiacus* during field surveys, and experimental infection has resulted in incubation periods that may be greater than 21 days, viral shedding in saliva and feces—supporting these as potential transmission routes—and generation of protective antibodies. Seasonal peaks of MARV infection in juvenile *R. aegyptiacus* correlate with birthing months (mid-June to mid-September and mid-December through mid-March), waning of maternal antibodies in juveniles, and outbreaks in humans (Towner et al. 2009; Amman et al. 2012; 2017). Therefore, reservoir host reproduction and demography and their environmental drivers must be considered when evaluating risk of spillover to humans and developing appropriate interventions.

For more details, see Section 7.4 'Bats as Reservoirs'.

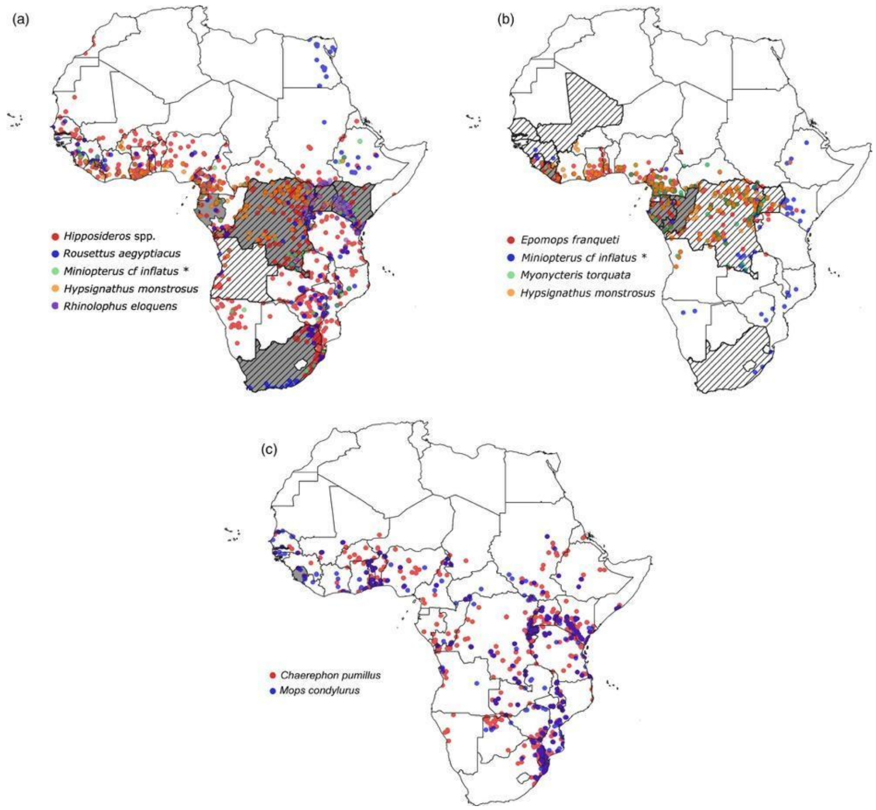

Figure 11: Distribution of bat species associated with filovirus species in Africa. "Distribution of bat species associated with filovirus species in Africa (ACR). (a) Marburg virus; (b) Ebolavirus; and (c) Bombali virus. Colored dots represent the geographical distribution of bat species in which a filovirus RNA was detected. Countries where viral RNA was detected in bats are indicated in grey, and where human cases were identified, countries are indicated by diagonal lines. *Evidence exists that *Miniopterus inflatus* is not one species throughout its distribution, and this distribution map will change with more scientific evidence published (QGIS 3. 6. 3-Noosa)." (Markotter et al. 2020)

HUMAN-TO-HUMAN TRANSMISSION AND FILOVIRUS RISK FACTORS

Filoviruses are transmitted from human to human through direct or indirect contact with bodily fluids of people that are infected or have died from the infection (WHO 2007). Such contact can occur while caring for the sick or preparing the dead for burial, and such tasks can have a gendered dimension to them. For example, in many African countries women are more likely to be nurses and to care for the sick in healthcare settings or in the home, and this may explain why in many of the EBOV outbreaks, the number of cases seen in women has exceeded those seen in men (WHO 2007). Evidence from some EBOV outbreaks suggests that gender can impact both the number of cases and case fatality rates, with higher numbers and case fatality rates seen in women (Nkangu, Olatunde, and Yaya 2017). However, these findings are not consistent for all EBOV outbreaks.

During the 2001–2002 EBOV outbreak in Gabon and Congo, more cases were seen in men during the early stages of the outbreak and more women were seen in the later stages (WHO 2007).

Interestingly, while there are known risk factors associated with confirmed EBOV cases during the 2014–2015 outbreak (e.g., physical contact with suspected EBOV cases or those who died from EBOV), about 50% of confirmed cases in Sierra Leone reported during this time had no known exposure (Dietz et al. 2015). Stigma associated with EBOV infection and inexperience conducting case investigations may factor into why half of the positive cases were not attributed to known exposures. However, evidence also suggests asymptomatic human-to-human transmission occurs (Keita et al. 2021) and may explain the lack of known exposure in some cases.

WILDLIFE-TO-HUMAN TRANSMISSION AND RISK FACTORS

There is strong evidence of wildlife-to-human MARV transmission after exposure to Egyptian fruit bat (*R. aegyptiacus*) colonies in caves or mines and of EBOV transmission associated with contact with infected wildlife carcasses (e.g., duikers and non-human primates). Although no definitive evidence currently exists, fruit or insectivorous bats are suspected to be the reservoir of EBOV (Feldmann, Sprecher, and Geisbert 2020; Leroy et al. 2009; 2005; Amman et al. 2017; Gire et al. 2014). Less is known about the reservoir of SUDV; however, hunting primates and touching and/or eating cane rats has been associated with increased risk of SUDV seropositivity in humans. Cane rats are peri domestic, are occasionally raised as a source of meat, and are commonly eaten in certain regions of sub-Saharan Africa (Smiley Evans et al. 2018)

Given these proposed reservoir and bridge hosts, likely spillover interfaces include caves and mines with roosting, cave-dwelling bats, especially *R. aegyptiacus;* contact with bats and cane rats in and around human dwellings (including tree-dwelling insectivorous bats); and contact with wildlife (including bats) through sharing the peri domestic environment, hunting, processing, and consumption (Kock et al. 2019; Smiley Evans et al. 2018; Gire et al. 2014).

For more details, see Section 7.4 'Bats as Reservoirs'.

7.2.5 Relevant Socioeconomic, Political, and Institutional Drivers of Filovirus spillover

RELEVANT CULTURAL/SOCIETAL NORMS

The relationship between men and women as demonstrated by their respective roles in power sharing, decision-making, and division of labor, both within the household and in the society at large, made women more vulnerable to EBOV than men in Sierra Leone (and resulted in more female deaths during the outbreak). In addition to caregiving and funeral preparation, females within the household are often assigned chores such as washing clothes and cleaning. Because Ebola is spread through contact with bodily fluids, and the disease itself manifests through severe vomiting, diarrhea, and bleeding, these socially rooted practices differentially exposed women and girls to the virus. Their roles in processing and selling bushmeat, providing herbal treatment to the sick, fetching water from often contaminated sources, playing as midwives and nurses, etc., make them more vulnerable.

Young girls were especially impacted by the 2014–2016 EBOV outbreak in Sierra Leone. Quarantines brought them into contact with strangers, often without family members around for protection, and this led to sexual violence and increase in teen pregnancies. In addition, these young girls were forbidden from attending school due to their pregnancies, furthering the negative impact experienced by these already traumatized teens (Jackson-Garrett 2016). These mental and tangible burdens of stigmatization exacerbate gendered inequalities in economic status, workload, and community support. Instances of husbands prohibiting their wives from attending their nursing jobs during the Sierra Leone EBOV outbreak also underscore the ways zoonotic crises may strain familial gender roles and impact women's income (Witter et al. 2017).

ECONOMIC DRIVERS RELATING TO LIVELIHOODS AND DIETARY DEMAND

Poverty and population growth are the major drivers and threats to natural resources exploitation in Sierra Leone, which was widely considered a primary driver of risk during the EBOV outbreak (see Bausch and Schwarz 2014; Alexander et al. 2015). In Sierra Leone, about 5.1 million people lack sufficient nutritious food, and nearly 800,000 are severely food insecure. The demand for land for economic development and pressures from population growth are creating unprecedented land use changes. Households are resorting to more extreme livelihood coping strategies to survive, and this is evidenced in the diminishing forest cover because of charcoal production and fuel wood collection for the energy needs of both rural and urban populations, logging, and slash-and-burn techniques. Unsustainable farming practices and illegal mining activities have intensified pressures on natural resources and increased risks of adverse climate impacts and zoonotic diseases. A cross-sectional study in Kono District from November 2015 to September 2016 assessed the association of food insecurity with exposure to Ebolavirus using an adapted version of the Household Food Insecurity Access Scale (Kelly et al. 2018). Food insecurity was high (87%), and among EVD cases, those who were food insecure were 18.3 times more likely to die than those who were food secure ($p = 0.03$) (Kelly et al. 2018). Multiple pathways, such as nutritional status and mental health, may elucidate the relationship between food insecurity and poor outcomes related to Ebolavirus infection, and qualitative research is needed to improve the understanding of food distribution dynamics within groups during outbreaks (Kelly et al. 2018).

7.2.5 Ebolavirus – Risk Perception

During the 2014–2015 EVD outbreak in Sierra Leone, three cross-sectional, national surveys measured Ebola-related knowledge, attitudes, and practices and found that exposure to new media (e.g., the Internet) and community-level information sources (e.g., religious leaders) were positively associated with expressing risk perception (Winters et al. 2020). Two-way communication could be strengthened during health emergencies as community-level information sources may align the public's perceived risk with actual epidemiological risk (Winters et al. 2020).

Knowledge of EVD in March 2015 was assessed via interviews conducted in Jui, Grafton, and Kossoh Town communities in the Western Area Rural District. This was done following an intensified training for an EVD response project in January 2015, when village leaders, community leaders, religious leaders, and community volunteers from local and administrative villages had been trained to improve public awareness of EVD to change behaviors toward control (Jiang et al. 2016). The training increased the awareness of EVD control, prevention, and engagement. The radio was the preferred communication medium, and brochures were the least popular method for information dissemination since they are not easily available in remote villages (Jiang et al. 2016)

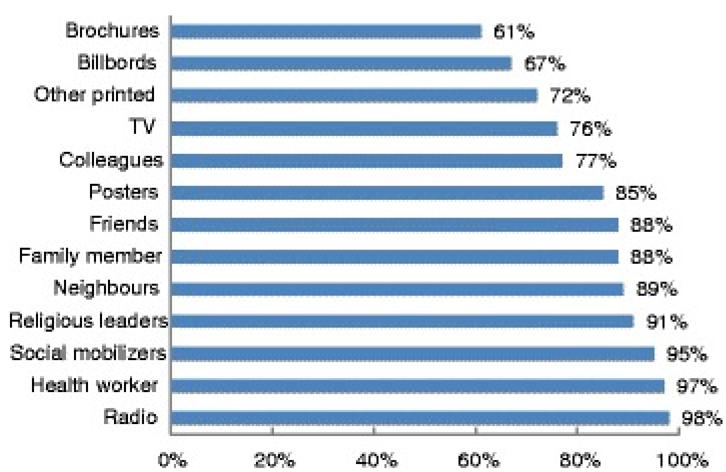

Figure 12: Preferred method of receiving EVD information (Jiang et al. 2016)

Communities in Port Loko continued to engage in high-risk practices and were unwilling to seek treatment during the 2014–2015 EVD outbreak in Sierra Leone. Interviews, focus groups, and questionnaires identified three primary barriers to seeking treatment: fear and limited information, concern about unknown outsiders, and distance/limited accessibility of treatment. Communities provided suggestions for addressing these barriers: providing information and better communication, including community members in decisions, providing closer treatment facilities with opportunities to learn how they operate, and using survivors to inspire hope for other sufferers (Carter et al. 2017).

A study part of the Ebola Host Project, an effort within PREDICT, took place at two sites in Bombali where human populations have had close contact with bats. More specifically, this study looked at contact with microchiropteran bats, which are associated with a new species (Bombali) of Ebolavirus, via household infestations and fruit bats by hunting practices (Euren et al. 2020).

The tables below are from Euren et al. (2020) and summarize the protective and risk factors reported from residents living with microchiropteran bats (Site 1) and fruit bat hunters (Site 2). The study noted that economic insecurity of hunters is a major barrier to behavior change (Euren et al. 2020).

Table 5. Household Bat Infestation Site 1 (Euren et al. 2020)

Protective knowledge/beliefs, skills, attitudes, and behaviors	
Avoiding exposed food and water	When evidence of bat contamination is found in water, many residents reported *no longer using the water for drinking or consumption*. Residents reported bats getting into uncovered food sources. Sometimes, the evidence of such contamination was obvious. In such cases, most residents said that they *threw out the partially eaten food*
Attempted bat exclusions	Several residents have *tried various bat exclusion techniques* to rid their houses of the bats, included rolled-up pieces of fabric stuffed into the roofline crevices and brambly branches. Residents reported that all exclusion attempts have been futile
Safe bat disposal	Residents disposed of dead bats in a variety of ways. Several residents described using plastic bags to pick up bats to *avoid touching them directly*, while others described using pliers or shovels to transport them. Once retrieved, *dead bats are removed from the human–environment*, variously buried, burned, tossed down the pit toilette, or thrown into the bush
Incentivized to act	Residents *considered bats to be invasive pests* and were desperate to have them removed or exterminated. This shared concern might facilitate community mobilization around bat interventions
Hold disease concerns	Residents knew that bats have been implicated in the Ebola outbreak. Several residents expressed *worry and concern about potential diseases that the bats may carry*, citing frequent direct contact with bats and contaminated food and water as primary exposures of concern

Risk-associated knowledge/beliefs, skills, attitudes, and behaviors	
Killing of bats	*Residents reported commonly killing bats*. When a bat gets indoors, residents described killing the bat with sticks. *Systematic extermination methods* included physically attacking the bats by entering the space between the roof and ceiling as well as use of insecticide. None of the described extermination attempts kept bats away for more than a few days
Children more exposed	In comparison to adults, *children* were reported to more frequently *remove the partially-consumed areas* of bat-contaminated food *to eat the rest*. Residents noted that children were often seen *handling bats with their bare hands*
Exposure to aerosols	Residents did not know or have the resources to protect themselves from *contact with aerosolized bat urine and excrement*. While residents should be discouraged from entering enclosed spaces with bats, appropriate PPE such as goggles and respiratory masks should be encouraged when needing to engage in such situations
Disdain for bats	A strong disdain for the infestation *may predispose residents to take violent actions against bats* if they believe the bats pose serious health risks to their community. Careful communication would be required to avoid community culling of bat populations, which could lead to unnecessary exposure or increased mobility and stress of bat populations making them more of a potential risk
Lack of knowledge	There appeared to be a *lack of knowledge about the kinds of diseases* bats can carry *and the mechanisms* by which those diseases can be *transmitted to humans*

Table 6. Fruit Bat Hunters Site 2 (Euren et al. 2020)

Protective knowledge/beliefs, skills, attitudes, and behaviors	
Washing and bathing	*Handwashing (with soap) and bathing was common* among the group after animal contact (including butchering and slaughtering) as well as bathing and washing clothes after hunting
Dedicated clothing	Several hunters described *wearing dedicated clothing for hunting and slaughtering*
Organized peer group	Several hunters also described their peer group as a major influence in starting to hunt bats. Since newer hunters were brought into the trade through social ties, the *hunters seem an excellent target for community-based interventions*
Avoid eating bats	A minority of hunters reported *no longer eating bats* after the Ebola outbreak
Knowledge of Ebola	*Many hunters were familiar with how Ebola is transmitted*, often citing public health messages that they had heard during the outbreak. Several knew that monkeys and bats were said to transmit Ebola and recounted that they were told to avoid hunting and/or eating them
Desire for other work	Many hunters described *bat hunting as an economic necessity*, given the limited opportunities within their community. Few hunters seem to enjoy hunting and said they would rather pursue other activities if they were available

Risk knowledge/beliefs, skills, attitudes, and behaviors	
Bat injuries	*Some hunters reported being bitten or scratched by bats*, but most insisted they were never injured by live bats. *Bats pose a risk of injury even after death*. During slaughtering, injuries occurred from both the knife and the bat's claws
Exposure to aerosols	Hunters described *constant exposure to bat urine and feces* at roosts
Open wounds	*No hunters described using any PPE for the slaughtering or butchering* of either bats or livestock. Injuries resulting in *open wounds were not treated* to prevent blood-to-blood exposure
Eating/hunting during and after ban	Many hunters recalled bans on the hunting and eating of bats, implemented during the Ebola outbreak. Several *hunters reported breaking these bans on bat hunting and consumption during the outbreak*. The rest either resumed or started hunting bats sometime after the outbreak ended. The *majority of hunters reported eating bats*, describing the flesh favorably
Bats kept as pets	*Two participants* reported having *kept bats as pets*. One kept a juvenile bat he caught as a pet for 6 months, until it got free
No use of PPE	Only a *few hunters described wearing any special protective equipment* while hunting
Demand-driven economy	The *bat meat value chain was largely demand-driven*. Since this community is known for its access to bats, buyers traveled there to commission the collection of bat meat from those eager for a quick job
Lack of concern	Though nearly all hunters knew that bats were thought to be associated with the Ebola outbreak, *many expressed little to no concern about continuing to hunt and/or eat bats*

A survey of bushmeat hunters and traders in Sierra Leone revealed that individuals involved in the preparation and trading of bushmeat were more likely to accidentally cut themselves, which puts them at greater risk of exposure to zoonotic pathogens (Subramanian 2012). Women are more likely than men to engage in bushmeat trading. The study also observed low awareness of potential zoonotic pathogens among all respondents (24%) (Subramanian 2012).

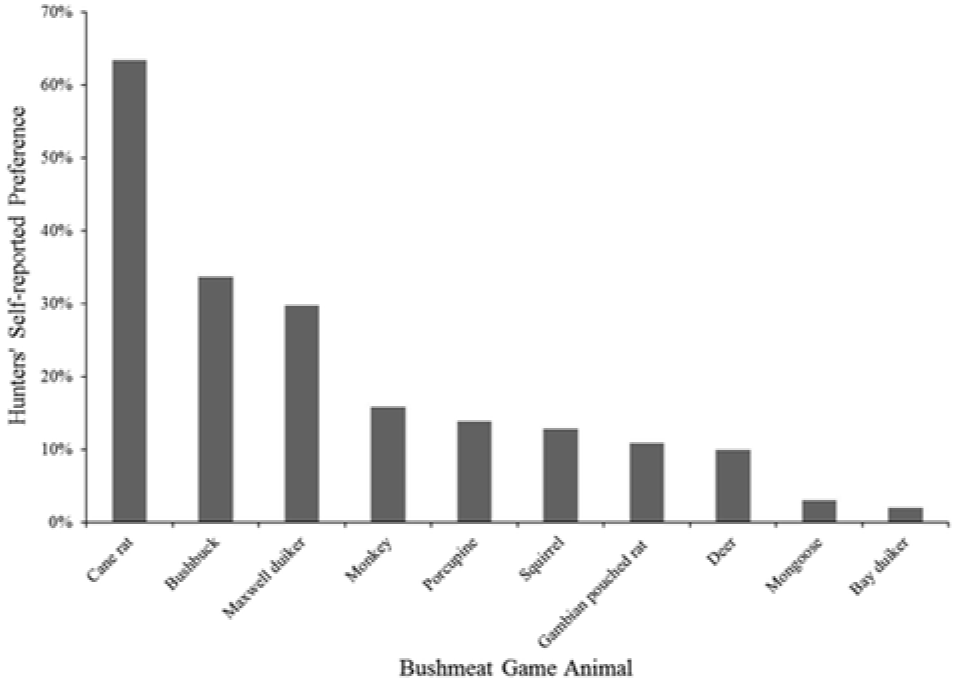

Figure 13. Top ten preferred bushmeat game animals among hunters (n = 101). Hunters were asked to list their three most preferred bushmeat game animals. The ten most frequently listed animals are represented. (Subramanian 2012)

7.2.6 Possible Intervention Points to Reduce Filovirus Spillover Risks

For MARV, where the reservoir host and animal-human interfaces are more clearly identified, interventions—particularly during identified periods of high shedding—are possible. For Ebolaviruses bat-human interfaces in frontline communities in and around protected areas such as parks and households in different parts of the country where previous filovirus outbreaks have occurred are plausible intervention points. Overall, the most important areas to target are those that have a high-risk wildlife-human interface coupled with high local human population density with limited access to healthcare. This combination could lead to a high probability of a major outbreak resulting from wildlife-human transmission and then rapid human-human transmission in a densely populated area. For Ebolaviruses, in addition to greater education about risky activities and times, and strengthened access to primary healthcare more generally, a focus on suppressing subsequent human-human amplification will generate high dividends. Risk reduction strategies relating to sexual transmission of Ebolavirus should consider the severity of disease and age. There is a substantial literature on Ebolavirus response practice in Sierra Leone (Gire et al 2014; McNamara et al. 2016; Tong et al. 2015; Widdowson 2016; Walker et al. 2015) that covers surveillance, rapid diagnostic procedures, rapid local response procedures, vaccines, and genomic diversity and evolutionary dynamics. Cross-border transmission may be the sole source of "spillover" for Sierra Leone and therefore Ebolavirus screening at borders and/or immediate border closures during Filovirus outbreaks may prevent movement of outbreaks into Sierra Leone or other countries (Prevent Epidemics 2020).

7.3 Coronaviruses

7.3.1 Coronavirus Virology

The *Coronaviridae* family of viruses (CoVs) are enveloped, non-segmented, single-stranded positive sense RNA viruses grouped into four classes: *alphacoronavirus, betacoronavirus, gammacoronavirus,* and *deltacoronavirus* (Hartenian et al. 2020). The *alphacoronaviruses* and *betacoronaviruses* infect mammals and cause mild to moderate respiratory infections in humans. The *gammacoronaviruses* and *deltacoronaviruses* infect birds, but some can infect mammals as well. The mutation rates of RNA viruses are higher than deoxyribonucleic acid (DNA) viruses, and CoVs exhibit high genome mutability (Hartenian et al. 2020). Due to this genetic volatility, there is high potential of evolution enabling CoVs to overcome species barriers and spillover into and establish onward transmission in novel host species (Hartenian et al. 2020). There are seven known human CoVs (HCoVs), most falling within the Beta-CoV genera: HCoV-229E, HCoV-NL63, HCoV-OC43, HCoV HKU1, severe acute respiratory syndrome coronavirus (SARS-CoV), Middle East respiratory syndrome coronavirus (MERS-CoV), and SARS-CoV-2 (also referred to as COVID-19). This review will focus mainly on SARS-CoV, MERS-CoV, and SARS-CoV-2 (i.e., the HCoVs that have recently emerged).

7.3.2 Pathology and Epidemiology of Coronaviruses

CoVs were not considered to be highly pathogenic to humans until the SARS-CoV outbreak in 2002 in Guangdong Province, China. This was the first HCoV known to cause severe disease in humans, and it had a case fatality rate of ~10% (Cui, Li, and Shi 2019; Gryseels et al. 2021). SARS-CoV cases initially present with fever, myalgia, headache, and chills, followed by a cough, dyspnea, and respiratory distress usually five to seven days later (Su et al. 2016). Human-to-human transmission is through respiratory secretions that are expelled from infected individuals to the mucus membranes of others (Song et al. 2019). This can occur directly when individuals are in proximity or indirectly through contact with contaminated surfaces (CDC 2004b). The SARS-CoV outbreak resolved by 2004 without any further cases reported since, indicating that neither sustained human-to-human transmission nor continued spillover from the reservoir occurred (CDC 2004a; Song et al. 2019).

The most recent, HCoV causing severe disease is SARS-CoV-2, which emerged at the end of 2019. In contrast with highly pathogenic SARS-CoV and MERS-CoV, which appear not to have adapted to humans well (i.e., outbreaks did not lead to substantial and sustained human-to-human transmission), SARS-CoV-2 transmits easily between humans, and as a result the world's population has been in a global pandemic since its emergence (McIntosh 2022; Ye et al. 2020). As of January 21, 2022, globally there have been over 340 million confirmed cases of COVID-19 (the disease caused by infection with SARS-CoV-2), and over 5.5 million deaths (WHO 2022). In Sierra Leone, there have been 7,562 cases and 125 deaths reported (WHO 2022). There have been five variants of concern (Alpha, Beta, Gamma, Delta, and Omicron) with subtle differences in pathogenicity, virulence, shedding amount and duration, transmission, clinical presentations, and case fatality rates (McIntosh 2022). Infections range from asymptomatic to severe, and cases can show a range of clinical signs including cough, fever, myalgia, headache, dyspnea, sore throat, diarrhea, nausea/vomiting, anosmia, ageusia, rhinorrhea and/or nasal congestion, chills, fatigue, confusion, and/or chest pain or pressure (McIntosh 2022). The primary means of transmission is direct, person-to-person respiratory transmission via droplets and aerosols; however, transmission through contact with contaminated surfaces may occasionally occur (Meyerowitz et al. 2021). Nosocomial transmission also occurs, and delays in diagnosis can lead to transmission to health care workers, family members, or other patients (Song et al. 2019), therefore, readily available, rapid diagnostic tests could substantially reduce forward transmission. Asymptomatic cases of COVID-19 have also led to wider spread because individuals are unaware that they are ill and do not seek diagnosis or treatment.

Interestingly, now that humans are a reservoir for SARS-CoV-2, examples of human-to-animal spillover, or spill-back, have been detected. SARS-CoV-2 has been isolated from domestic animals, livestock, captive wildlife, and free-ranging wildlife that were in close contact with human COVID-19 cases (Hedman et al. 2021; Palmer et al. 2021). Except for mink, it remains unclear if human to animal transmission could proceed to subsequent infections from animals to humans (Hedman et al. 2021). Human-driven environmental change, human behavior, and human-to-human transmission are some of the key drivers for the creation of bat-human interfaces, spillover, and epidemics of emergent viruses (Montecino-Latorre et al. 2020).

7.3.3 Coronavirus Interfaces and Virus Ecology

ANIMAL RESERVOIR(S) – CORONAVIRUSES IN GENERAL

According to current sequence databases, all HCoVs have animal origins: SARS-CoV, MERS-CoV, SARS-CoV-2, HCoV-NL63. and HCoV-229E are considered to have originated in bats, and HCoV-OC43 and HKU1 likely originated from rodents (Cui, Li, and Shi 2019; Goraichuk et al. 2021).

For more details, see Section 7.4 'Bats as Reservoirs'.

ANIMAL RESERVOIR(S) – KNOWN RECENT CORONAVIRUS SPILLOVER EVENTS

SARS-CoV: Although the reservoir of SARS-CoV is thought to be a *Rhinolophus* spp. bat, transmission to humans was likely through palm civet (*Paguma larvata*) and raccoon dog (*Nyctereutes procyonides*) as intermediate hosts (Gryseels et al. 2021).

SARS-CoV-2: Various studies and reviews indicate that *Rhinolophus* spp. bats were the ancestral reservoir of SARS-CoV-2, with transmission to humans having occurred through intermediate hosts; however, debate still surrounds its origins (Hedman et al. 2021; Holmes et al. 2021; Wacharapluesadee et al. 2021). Specific intermediate hosts are still unknown, put potential animals include not only those that were in the Huanan Seafood Wholesale Market (hedgehogs, badgers, snakes, and poultry) but also pangolins, felids, rodents, and others (Hedman et al. 2021). Since its emergence, natural or experimental SARS-CoV-2 exposure (antibodies) and infection (RNA or live isolates) have been detected in a wide range of animal hosts (Gryseels et al. 2021; Murphy and Ly 2021), with evidence that farmed and wild mink (Shriner et al. 2021), deer mice (*Peromyscus maniculatus*) (Fagre et al. 2021), and white-tailed deer (*Odocoileus virginianus*) (Palmer et al. 2021; Kuchipudi et al. 2022) can act as reservoirs. In addition, experimental work suggests that cats can be infected with and transmit SARS-CoV-2, while dogs can become infected and seroconvert, but do not appear to shed (i.e., transmit) the virus (Bosco-Lauth et al. 2020).

7.3.4 Relevant Socioeconomic, Political, and Institutional Drivers

RELEVANT CULTURAL/SOCIETAL SENSITIVITIES AND GENDER NORMS ASSOCIATED WITH EPIDEMIOLOGY

Policy responses to the outbreak, including closing health facilities and social distancing, had a more far-reaching impact on women because many make a living from activities that require close contact with people. Moreover, most frontline health workers (especially nurses, midwives, and childcare providers) are women, increasing their risk to work-life balance struggles because of the closure of schools, the stress of job and income loss, and the loneliness and isolation caused by social distancing, stigma, and discrimination. While the risk of exposure and the resulting impacts have not been comprehensively assessed, it is believed that women are at a higher risk of exposure to the spillover of coronavirus risks due to the current occupational gender segregation.

Data on COVID-19 in Sierra Leone has not been captured comprehensively. Nonetheless, existing data in late 2021 shows a trend of men having higher rates of hospitalization, deaths due to COVID-19, and vaccinations (Global Health 50/50 2021). Sierra Leone has seen a spike in domestic violence, rape, and sexual exploitation of women and girls during COVID-19 (Abwola and Michelis 2020). Building women's leadership is part of government efforts to promote gender equality in all areas of life. Supporting gender equality also means supporting the fight against COVID-19. "COVID-19 is an all-hands-on-deck situation," says UN Resident Coordinator Babatunde Ahonsi. "If women are prevented from taking leadership positions, then we're fighting the pandemic with one hand tied behind our back. When women are subjected to sexual violence, then there's that much less energy and resources to advance public health." (UN News 2021).

Efforts underway in Sierra Leone include a new law on sexual offenses, the launch of one-stop centers on sexual and gender-based violence, and President Julius Maada Bio's 2019 declaration of rape and sexual violence as a national emergency (Government of Sierra Leone 2019). Just as gender equality supports public health, public health can support gender equality—if proper attention is paid to it.

ECONOMIC DRIVERS RELATING TO LIVELIHOODS AND DIETARY DEMAND

The economic/livelihood activities increasing the risk of a coronavirus outbreak or the spread and amplification of the disease in Sierra Leone include farming, hunting, commercial transportation (taxis, motorbikes, tricycles), hotel and tourism, commercial sex work, trading of goods (import and export), and garbage collection and disposal. Native doctors, midwives, hairdressers, barbers, petty traders/hawkers, teachers, healthcare workers, and bankers are also exposed to the risk because of the nature of their jobs. Accordingly, the lockdowns and global supply chain disruptions had a huge impact on the country's economy and healthcare (see Buonsenso et al 2020, 2021), leading to changes in consumption patterns and shifts in dietary demand toward high-risk wildlife consumption and trading behaviors. The extent to which the current awareness of risks limits further spread and amplification of the disease or whether existing institutional capabilities and measures may prevent the spillover of coronavirus risks in the future is unknown.

GOVERNMENT PRIORITIES, INSTITUTIONAL CAPABILITIES, AND POLICIES IN PLACE

The COVID-19 pandemic has heightened interest in coronaviruses and necessitated its listing as a national priority zoonotic disease and an expansion in relevant diagnostic lab capacities. However, the status of animal coronaviruses and the true mechanism of incidence and prevalence in human environments are vaguely understood.

INSTITUTIONS AND PROJECTS FOCUSED ON SPILLOVER ECOSYSTEM CONCERNS IN-COUNTRY

The GoSL and its key development partners established the National COVID-19 Emergency Response Center to coordinate responses to the outbreak at the national level, as well as structures to perform a similar function at the district level. The roles included case detection, surveillance, reporting, and risk awareness raising. Nonetheless, risk analysis and communication still remain a challenge, although the establishment and operationalization of the EOC improved multi-sectoral and multi-level coordination, collaboration, and communication. Several studies are available on the institutional processes that have contributed to tackling the outbreak so far, including a recent survey of the perceptions of the effectiveness of the health sector's response (see Amara et al 2021).

7.3.5 SARS-CoV-2 – Risk Perception

A study comparing community perceptions to epidemic infection risk looked at two rural communities, one with substantial EVD and the one that had resisted infection (Kamara et al. 2020). The study assessed the understanding of infection risks via an experimental game that identified preference of one of two diseases—one resembling Ebola with lower risk of infection and the other resembling COVID-19 with lower risk of death. Over half (52%) preferred the disease model with lower risk of infection, 29% preferred the model with lower risk of death, and 21% saw the combined risk of infection and death as being equivalent (Kamara et al. 2020). The study concluded that rural people in Sierra Leone retain the lessons of experience from the 2014–2015 Ebola outbreak.

A national, cross-sectional knowledge, attitudes, and practices survey in Sierra Leone found that 70% of women were not aware that COVID-19 was survivable, compared with 61% of men. Sixty percent of men and fifty-four percent of women took actions to avoid infection with coronavirus, including handwashing with soap. Radio was the most used source for COVID-19 information, followed by social media. There is a knowledge gap differing by gender, regions, educational levels, and age, so messages should specifically target these audiences (Sengeh et al. 2020).

A qualitative study in two informal settlements in Freetown drew on actor-network theory to understand the role of community-based organizations (CBOs) in informing populations of health risks (Frimpong et al. 2021). Building on CBO capacity to create new channels for knowledge exchange can help strengthen networks in communities to address current and future health disasters.

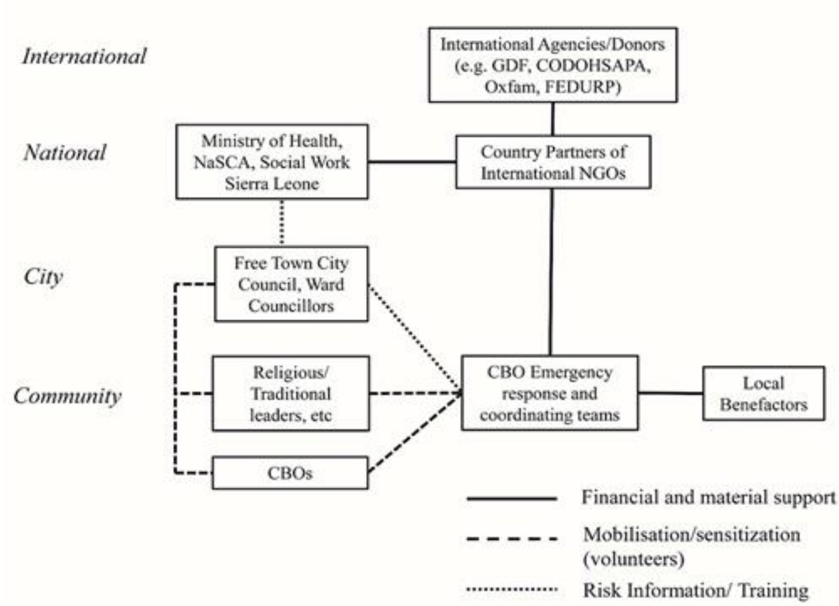

Figure 14. CBO Actor network and flows in COVID-19 response (Frimpong et al. 2021)

7.4 Bats as Reservoirs

7.4.1 Bats as the Reservoir for Filoviruses and Coronaviruses

Over 1,400 different species of bats have been recorded globally (Montecino-Latorre et al. 2020), over 220 species in sub-Saharan Africa (Monadjem et al. 2007), and an estimated 61 in Sierra Leone (Weber et al. 2019). Among this diversity are several species that are known or thought to act as reservoirs for filoviruses and coronaviruses (Ruiz-Aravena et al. 2021). For example, more than 100 bat species have been found to have a high genetic diversity of CoVs (Montecino-Latorre et al. 2020), it is estimated that hundreds to thousands of additional coronaviruses may reside in bats alone (Hartenian et al. 2020), and alphacoronaviruses and betacoronaviruses have been detected in 14 of the 21 bat families across six continents (Ruiz-Aravena et al. 2021). Evidence suggests that *Rousettus aegyptiacus*, the Egyptian fruit bat, is the MARV reservoir, and the leading theory for EBOV identifies bats as the most likely reservoir.

There are several characteristics of the bat host ecology that predispose them to be good viral reservoirs, and sources of spillover to humans:

- When infected, bats generally show no evidence of clinical disease (Chan et al. 2013; Markotter et al. 2020; Ruiz-Aravena et al. 2021).
- Annual or biannual reproduction results in the introduction of new susceptible hosts through these birth pulses, as well as periods of reproduction-related immunosuppression

of pregnant females. These can lead to cyclic viral dynamics with periods of high prevalence and viral shedding (Markotter et al. 2020).

- Bat roosting environments include those in close proximity to humans or in areas frequented by them (peridomestic, fruit trees, anthropogenic structures, caves used for ecotourism or guano harvesting, mines), providing opportunities for spillover to humans and livestock intermediate hosts through direct or indirect contact with infectious virus shed in saliva, urine, or feces (Chan et al. 2013; Markotter et al. 2020; Mbu'u et al. 2019; Mortlock et al. 2021; Ruiz-Aravena et al. 2021).
- Flight and seasonal, long-distance migration facilitate viral spread across large geographic ranges (Markotter et al. 2020; Mbu'u et al. 2019).
- Dense colonies and close social interaction facilitate within and between species transmission (Ye et al. 2020).

Very little information exists about the prevalence of bat meat in the Sierra Leone wild animal meat trade. One study found that communities in Sierra Leone meet fruit and insectivorous bats and their tissues through activities such as hunting, processing, and consuming and as children's play-things (Bonwitt et al. 2017). They also found that bat hunting may be more opportunistic for individuals living near bat caves and for children, given the specialized hunting methods required to catch them. Because bats are considered too small to sell, they are usually consumed at home or sold in the village (Bonwitt et al. 2017).

In Sierra Leone, the straw-colored fruit bat (*Eidolon helvum*) is of particular concern as a reservoir. These bats are one of the most abundant species of fruit bats in sub-Saharan Africa, have an extensive distribution, roost in large colonies of up to 1 million animals, frequently roost in the middle of cities, and can migrate up to 2500 kilometers a year. In addition, it is believed that this species is the most heavily harvested bat for meat in West and Central Africa (Cooper-Bohannon et al. 2020; Kamins et al 2011; Mickleburgh, Waylen, and Racey 2009; Weiss et al. 2012). These bats can harbor CoVs (Kumakamba et al. 2021; Leopardi et al. 2016; Nziza et al. 2019) and possibly Ebolavirus (Hayman et al. 2012), and previous studies on hunting, trade, and consumption likely underestimated the frequency and, thus, the risk for viral spillover associated with these activities.

7.4.2 Risk Factors for Bat-to-Human Spillover

1. Direct contact with infectious bat fluids (blood, saliva, urine, feces) or tissues, including inhalation of aerosolized fluids or tissues, and bat inflicted bite wounds.
    a. Montecino-Latorre et al. (2020) found that contact with bat feces is a main pathway for zoonotic CoV spillover, but shedding of these pathogens is not uniform over time, so mitigation strategies could be targeted at high-risk seasons.

2. Indirect contact with infectious bat excreta through consumption of contaminated food (including fruit that bats have fed on) or water or through contact with contaminated objects.
3. Direct or indirect contact (including inhalation) with infectious fluids or tissues materials of infected intermediate/amplifying hosts.
4. Contact with livestock that have a high risk of contact with bats and that may act as amplifying or intermediate hosts. This is especially true for livestock reared and managed under intensive conditions conducive to rapid spread within the livestock species.

7.4.3 Interfaces for Bat-to-Human Spillover

1. Hunting, trading, butchering, consuming. or otherwise handling bats (e.g., children will play with bats).
2. Wet markets and trade that involve housing multiple different wildlife species together over a period of time (e.g., can facilitate within and between species viral transmission).
3. Bat roosts, including:
   a. Mines and caves;
   b. Peri-domestic environments and anthropogenic structures in which bats roost; and
   c. Roosts in forests.
4. Wild or commercially grown and harvested fruit that bats feed on and may contaminate.
5. Livestock that are intermediate or amplifying hosts and:
   a. are free-ranging, and thus have greater opportunity for direct or indirect exposure to bat fluids or tissue; or
   b. are intensively managed at high densities, providing opportunity for rapid viral transmission once bat-livestock spillover occurs.

Regional specific drivers can also affect virus dynamics and spillover potential, for example Marburgvirus has been detected in *R. aegyptiacus* in South Africa, yet no human cases have been reported, possibly because of the absence of extrinsic factors driving outbreaks in other parts of Africa such as hunting for and consuming bats or entering of caves for guano mining (Mortlock et al. 2021).

7.4.4 Seasonal Drivers of Bat-Human Spillover

Trends in seasonal variations of viral shedding prevalence and intensity in bats are consistently detected for filoviruses (Amman et al. 2017, 2012; Towner et al. 2009), henipaviruses (Mortlock et al. 2021; Plowright et al. 2015), and coronaviruses (Geldenhuys et al. 2021), but patterns vary among studies (Ruiz-Aravena et al. 2021). The likely mechanisms driving these variations include reproduction, resource availability, and other aspects of host demography, physiology, and ecology, which will vary by location and bat host species (Mortlock et al. 2021). Associations between these drivers and shedding patterns have been detected, but the current understanding of the mechanisms is insufficient to accurately predict shedding pulses (Ruiz-Aravena et al. 2021). In addition, when shedding pulses are not occurring, many bat viruses are detected rarely or at low prevalence (Plowright et al. 2015). Therefore, more research is needed to fill this critical knowledge gap, enable accurate predictions of shedding patterns, and develop appropriate interventions to mitigate spillover to humans.

REPRODUCTION

Reproductive cycles can impact viral shedding prevalence and intensity through a number of different mechanisms:

- Pregnancy-related immunosuppression can increase shedding intensity and prevalence (e.g., HeV [Field and Kung, 2011]).
- Birth pulses can lead to an influx of susceptible hosts (once maternal immunity wanes) and a subsequent spike in new infections (Mortlock et al. 2021).
- Changes in behavior patterns, such as frequency and type of within and between species contact and aggregation due to changes in colony size, density and species composition (Ruiz-Aravena et al. 2021).

RESOURCE AVAILABILITY

Resource availability drives bat movements, including long-distance migrations, and can impact viral shedding prevalence and intensity, as well as the location of bats, and therefore the probability of contact with humans.

- Nutritional stress during periods of resource scarcity has been implicated in increased viral shedding by bats for HeV and other paramyxoviruses (Plowright et al. 2008; Ruiz-Aravena et al. 2021).
- Lack of preferred native food sources may drive bats to use anthropogenic food sources, bringing them in direct or indirect contact with humans or intermediate hosts (Plowright et al. 2008).

7.4.5 Land Use Change and Bat-Human Spillover

Fruit bats act as opportunistic generalists in that they exploit different food sources, feeding on nectar, pollen, or fruit depending on availability (Sudhakaran and Doss 2012). Deforestation and land use change (development, large-scale agriculture, deforestation) in Africa, Asia, and Australia may increase the potential for bat-to-human spillover due to changes in distribution, abundance, and density resulting from changes in resources availability (e.g., food, mates, roosting sites) (Kock et al. 2019; Markotter et al. 2020; Mbu'u et al. 2019; Plowright et al. 2021). Bat-human (and bat-livestock) contact may increase as bats migrate toward urban centers for food and roosts, and bat viral shedding may increase due to immunocompromise from nutritional or physiological stress experienced because of food scarcity and crowded roosts, thus increasing the risk of viral spillover to humans (Mbu'u et al. 2019; Plowright et al. 2021). For example, CoV shedding in horseshoe bats was higher in human-dominated landscapes than in natural landscapes (Anthony et al. 2017). Increased viral shedding by bats and cross-species transmission may increase with wildlife trade due to the combination of physiological stress, unsanitary conditions, and contact with high numbers and densities of other possible host species. (Ruiz-Aravena et al. 2021)

7.4.6 Climate and Bat-Human Spillover

The strong seasonal pattern of both human and wildlife EVD outbreaks (with many outbreaks occurring at the start of the dry season) suggests a link with climate and plant phenology (Kock et al. 2019; Leroy et al. 2005, 2004). This is supported by analyses that show that local plant phenology, particularly plants that constitute a seasonally varying food source, is a significant predictor of EVD outbreaks in people and wildlife (Wollenberg Valero et al. 2018). The fruiting plant-wildlife interface might therefore be an important component of the Ebolavirus spillover ecosystem to be considered.

7.4.7 Human Socio-Economic and Demographic Dimensions of Bat-Human Spillover

PERI-DOMESTIC AND URBAN SPILLOVER

Evidence from urban locations in Ghana demonstrate that direct and indirect contact with bats outside of hunting may be equally likely to occur in urban areas where individuals can be exposed to urine and droppings under urban bat roosts and trees in residential areas (Lawson et al. 2016).

HUNTING, TRADE, BUTCHERING, AND CONSUMPTION

A study conducted in the Southern and Eastern Provinces of Sierra Leone revealed that men, women, and children all participated in hunting and processing of wild game; however, children tended to target smaller animals, and males of all ages hunted more than females (Bonwitt et al. 2017). In addition, a study of communities from the Bombali District of Sierra Leone found bat hunting to be a social activity motivated by peer encouragement for young males, although primarily driven by the need to bring in income and a lack of other available work (Euren et al. 2020). Because the hunting method was through stoning via catapults due to gun restrictions in the area, hunters could be scratched or bitten by bats, and in many cases, they butchered animals without protective personal equipment. Wildlife species hunted in Sierra Leone include a range of species including cane rats, primates, and fruit bats (Bonwitt et al. 2017).

MINING

Zoonotic spillover of MARV in Uganda has been associated with mining (Nyakarahuka et al. 2020), which is primarily an activity conducted by young men, putting them at higher risk of initial wildlife-to-human spillover.

7.4.8 Interventions

A deeper understanding is needed of the reasons and motivations for bat hunting, the social factors involved, and bat hunters' risk perception (as well as any efforts being made to protect themselves) if one hopes to develop effective interventions that will reduce risk of spillover.

When considering spillover mitigation efforts, it must be kept in mind that while locations such as mines and caves containing *R. aegyptiacus* have been identified as potential spillover interfaces, interventions must be chosen carefully, as host species ecological dynamics in response to the intervention may result in unanticipated consequences. For example, MARV and RAVV were isolated from *R. aegyptiacus* in the Kitka mine in Uganda (Amman et al. 2012; Towner et al. 2009), and efforts to eradicate bats from this mine were followed by recolonization and a doubling in MARV infection prevalence (Amman et al. 2014). It is possible that this was due to the eradication efforts and a subsequent interaction between the host demographic response and pathogen dynamics.

Seasonality and host ecology should also be considered when devising interventions.

7.4.9 Conservation Concerns and Important Ecosystem Services of Bats

Bats play an important part in the ecosystem and to human society. Bats are relied upon for agricultural assistance, pollination of important plants, seed dispersal, and a source of protein and guano. Guano is the main energy source in cave ecosystems, and mining of this product is a major income source (Kamins et al. 2011; Montecino-Latorre et al. 2020). Therefore, protection of these animals is critical for a healthy ecosystem. However, recent negative attitudes toward bats because of their roles as viral reservoirs, as well as their use as a food source in many places in the world, place some species at a conservation risk. For example, *Eidolon helvum*, known to possibly harbor Ebolavirus (Hayman et al. 2012), is the most heavily harvested bat for meat in West and Central Africa, and the International Union for Conservation of Nature has categorized it as "near threatened," with the population trend declining (Cooper-Bohannon et al. 2020). However, in a study in Ghana, most vendors reported that bat meat made up very little of their income (Kamins et al. 2011)

Land use-induced spillover

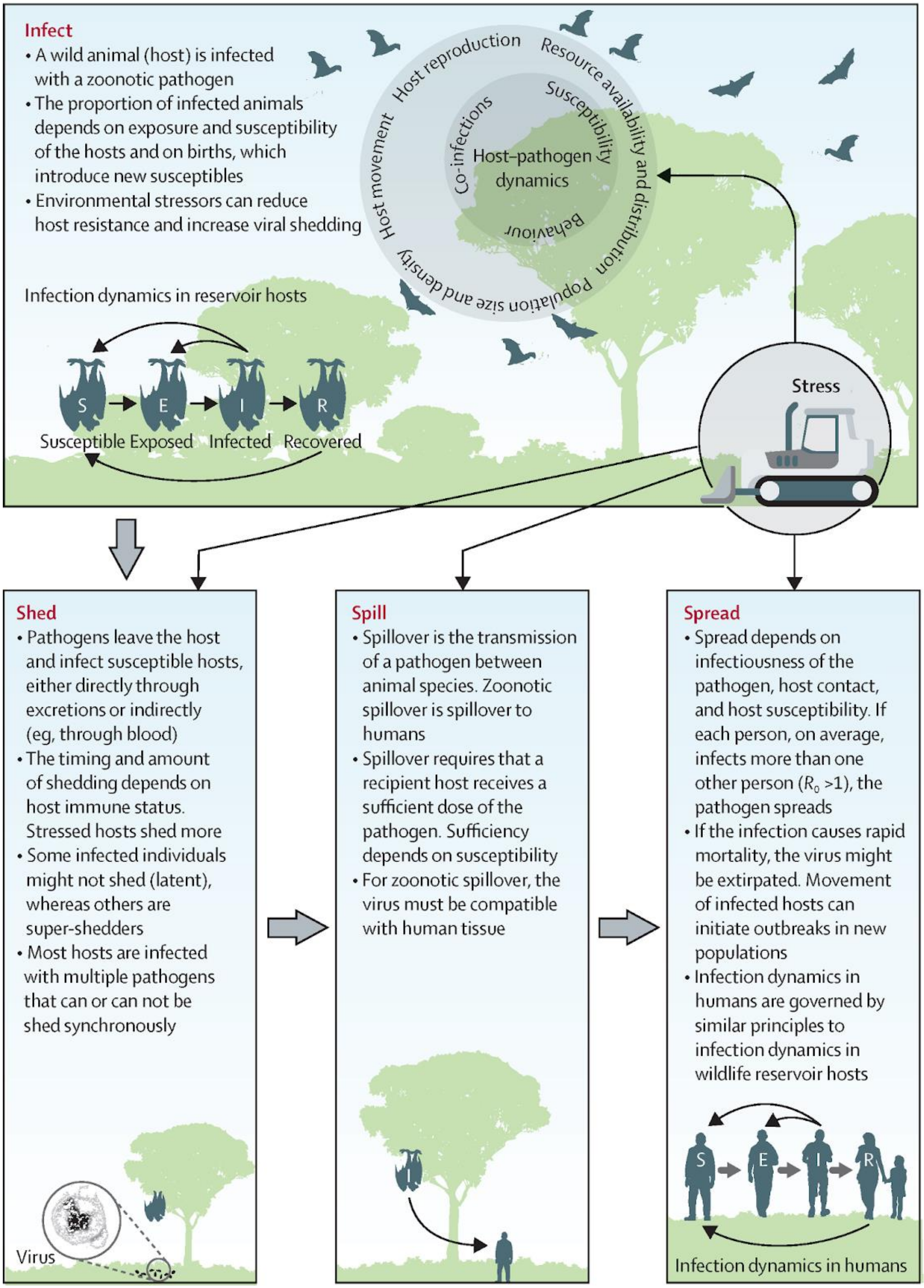

Figure 15: Land-use induced spillover (Plowright et al. 2021)

7.5 Highly Pathogenic Avian Influenza Viruses

H5Nx influenza viruses of clade 2.3.4.4 continue to cause outbreaks among poultry and wild birds worldwide. Historically unprecedented outbreaks have raised serious global concerns about the imminent arrival of other influenza pandemics. The WHO urges countries to develop and implement national pandemic preparedness plans to mitigate the health and social effects. As noted widely in the literature, effective and feasible strategies are needed to mitigate the impact of the next influenza pandemic in developing countries (Oshitani, Kamigaki, and Suzuki 2008).

7.5.1 Virology

Influenza A viruses (IAVs) are negative-sense single-stranded enveloped RNA viruses of the family *Orthomixoviridae*. IAVs can infect a broad range of hosts including wild and domestic birds and mammals, specifically humans, swine, horses, seals, dogs, cats, and bats. Although IAVs have been isolated from a multitude of aquatic avian species, the natural reservoir species of IAVs are *Anseriformes* (ducks, geese, swans) and *Charadriiformes* (gulls, shorebirds, terns, hawks), both of which are responsible for infecting domestic avian species and mammals, including humans, though often through intermediate hosts. Novel host and IAV interactions impact the accumulation of genetic adaptations in the virus that allow for either dead-end infections (where a limited number of new hosts are infected before the virus dies off) or enzootic circulation including efficient replication and transmission and the potential for a pandemic scenario (Long et al. 2019). In such a scenario, sustained transmission among humans via aerosolized respiratory droplets could result in the development of new variants due to antigenic drift, which could enable a seasonally circulating pandemic virus that is antigenically distinct from season to season (Taubenberger and Kash 2010). All human influenza pandemics throughout history (1918, 1957, 1968, 2009) have origins in wild avian species, often facilitated by interactions with intermediate hosts such as swine and poultry (Runstadler et al. 2013; Worobey, Han, and Rambaut 2014).

7.5.2 Comparative Pathology and Epidemiology

In birds, IAVs are classified as either low pathogenic avian influenza (LPAI) or HPAI. LPAI viruses do not produce signs of clinical disease in birds, whereas HPAI viruses can cause severe illness and mass die-offs. HPAI infection causes decreased energetics and egg production, periocular swelling, coughing, sneezing, and diarrhea; however, sudden mortality absent of any previous signs of disease has also been documented (USDA 2020).

7.5.3 Overview of Associated Interfaces

Key interfaces for inter-species transmission of IAVs include, but are not limited to:

- Wild bird-wild bird interfaces, which include breeding areas and staging locations where multiple species of wild birds interact, increasing transmission opportunities;
- Wild bird-domestic bird interfaces, including locations where domestic birds (ducks and geese) are raised in open ranges with access to wild waterfowl (Shortridge 1992); additionally, live poultry markets where high densities of domestic and wild birds are caged and sold provide optimal conditions for inter-species transmission (Donatelli et al. 2016); and
- Domestic bird-mammalian interfaces, including where domestic poultry and pigs are raised in direct contact with humans, including farms, live markets, and animal fairs (Donatelli et al. 2016).

AT-RISK POPULATIONS

Human populations most at risk for spillover of novel IAVs from animals include farmers, subsistence and backyard poultry keepers, animal fair workers, live market workers, and wild bird hunters. Women—who are disproportionately involved with small-scale backyard poultry production, marketing, and purchase/preparation of live poultry—may be at greater risk for novel IAV exposure and infection (Velasco et al. 2008).

POULTRY MARKETS AND VALUE CHAINS

Increased consumption of poultry products in Sierra Leone is occurring alongside rapid urbanization and growth in the industry. An average 37% of households in the country are involved in poultry keeping as a source of food and financial security (GoSL 2014). The demand for poultry meat increases at holiday times and during funerals and religious ceremonies. Most smallholders sell their output live at the farm gate or in local informal market (Schneider and Plotnick 2010). Despite the high demand, the industry faces high production costs, safety concerns due to lack of sanitary controls, and technical constraints in processing and marketing. As such, without adequate training and resources, small domestic producers may be unable to consistently supply high-quality products that can compete with the products supermarkets procure from imported sources.

VIRUS ECOLOGY

IAV ecology is dependent on multiple mechanisms related to viral persistence within avian populations and in the environment. First, IAVs circulate endemically in wild aquatic avian hosts. The maintenance of IAVs in wild bird populations is largely influenced by several important ecological factors. Wild bird movements across global regions enable IAVs to expand their spatial range (Ren et al. 2016). Following spring hatching in northern latitudes, juvenile immuno-naive birds interact at high densities with birds infected with IAV and proceed to migrate southward to disparate geographies, which perpetuates the spread of virus across continents.

Second, IAVs persist in water and soil. Environmental transmission through water bodies has been documented for ducks and other migratory aquatic birds (Markwell and Shortridge 1982) and is dependent on pH, salinity, and temperature (Brown et al. 2009).

7.5.4 Avian Influenza in Sierra Leone

Due to limited surveillance activities in the country, there are limited data on spillover events of IAV from wild birds to domesticated fowl or zoonotic transmission. However, in 2005, there was an HPAI outbreak (H5N1 subtype) that affected many countries, including Sierra Leone. Sierra Leone is positioned along the East Atlantic flyway for migratory aquatic birds that are potential reservoir hosts for IAVs, therefore, the country is a potentially high-risk geography for HPAI. To prevent future outbreaks, Sierra Leone created an emergency response plan in 2006, which has since been updated to incorporate the One Health approach (FAO 2022).

West Africa experienced H5N1 outbreaks among unspecified domestic birds confirmed in Senegal and Mauritania in 2020 and in Nigeria, Benin, Côte d'Ivoire, and Ghana in 2021 (FAO 2023). While Sierra Leone did not report an outbreak, it is still designated high risk, and influenza has been identified as one of the top six priority zoonotic diseases in the country (FAO 2022).

7.5.5 Relevant Socioeconomic, Political, and Institutional Drivers

RELEVANT CULTURAL/SOCIETAL SENSITIVITIES AND GENDER NORMS ASSOCIATED WITH EPIDEMIOLOGY

In Sierra Leone, dangerous poultry farming practices such as the killing, eating, and selling of sick birds; poor reporting of sick or dead poultry; and disposal of dead birds in public dumps increase the risk of transmission of HPAI from birds to humans. Women are typically considered the primary caregivers during illness, and women who are disproportionately involved with small-scale backyard poultry production, marketing, and purchase/preparation of live poultry are more at risk of contracting the virus. Gender norms, roles and relations, and inequality and inequity affect people's health, especially with regards to zoonosis. Farmers, backyard poultry keepers, animal fair workers, live market workers, and wild bird hunters are at risk of the infection.

ECONOMIC DRIVERS RELATING TO LIVELIHOODS AND DIETARY DEMAND

Per capita consumption of meat is low, particularly the consumption of poultry. Most poultry production comprises chickens and is conducted on a rural or a small scale, with more than 50% of households owning at least one chicken (Schneider and Plotnick 2010). In these rural and backyard sites, chickens range freely, which offers opportunity for exposure to wild birds that may be carrying IAV. Given ongoing outbreaks of HPAI clade 2.3.4.4 H5Nx viruses in western Europe in 2021–2022, increased surveillance along the Western coast of Africa is warranted.

GOVERNMENT PRIORITIES, INSTITUTIONAL CAPABILITIES, AND POLICIES IN PLACE

With significant economic constraints, limited health system infrastructure, and the lack of IAV surveillance, there is not a plethora of information on the impact of IAVs in Sierra Leone (Katz et al. 2012). A few organizations are attempting to address these limitations alongside the GoSL MoHS. For instance, the CDC/Naval Medical Research Unit No.3 team helped establish an influenza reference laboratory in Lakka. The WHO also supported this endeavor, helping the influenza surveillance system expand to eight sites (CDC 2013). The surveillance of influenza is also written into Sierra Leone's Basic Package of Essential Health Services (2015-2020).

7.5.6 Surveillance and Outbreak Response

With support from various national and international organizations, the GoSL has implemented several preparatory and surveillance activities to increase the country's capacity to respond to IAV outbreaks. Around 2010, Sierra Leone established an Influenza Reference Laboratory (CDC 2013) and implemented the Strengthening Influenza Sentinel Surveillance in Africa project (Kebede et al. 2013). In 2015, the MoHS created a National Infection Prevention and Control Unit (NIPCU) to manage IPC practices (WHO Africa 2022). In 2016, NIPCU began a three-year plan to oversee Sierra Leone's IPC capacity and assess its effectiveness. In 2021, the FAO provided support to execute simulation activities to determine Sierra Leone's capacity to prepare for and respond to future HPAI outbreaks. The simulation adopted a One Health approach and included representatives in public health, academia, research, animal health, and the Office of National Security (FAO 2022).

EXPLORATION OF ILLUSTRATIVE INTERVENTION OPTIONS

Biosecurity practices. The poultry market in Sierra Leone is limited by concerns about product safety. The current regulatory system does not adequately control the quality of inputs and poultry products (Schneider and Plotnick 2010). Lack of access to vaccines and qualified veterinary services is a consistent problem for all supply chain actors. Poor biosecurity along the entire supply chain creates an opportunity for the spillover and amplification of zoonotic risks, and the lack of training and widespread illiteracy among the workforce persist as crucial limitations to better safety and biosecurity practices (Schneider and Plotnick 2010).

7.5.7 HPAI – Risk Perception

There are limited data on the level of awareness that Sierra Leoneans have about the risk of contracting the virus. One study in Freetown found that only 46 of 706 respondents were vaccinated and had a lack of awareness about and the high cost of vaccinations to be the primary reasons (James et al. 2017).

SECTION 8: GAP ANALYSIS

8.1 Priority Knowledge Gaps

- Interface dynamics between deforestation, zoonotic transmission, and resource governance are not well understood. Case studies based on applied field research, like those conducted for virus transmission through bats, are needed. Conceptual frameworks mapping causality between the natural environment and human behavior and public health practices related to zoonotic transmission are limited.
- The potential and actual impacts of climate change on zoonotic transmission are not clearly understood. Complex chains of causality make it difficult to model how environmental shocks may trigger, amplify, or otherwise exacerbate the emergence of pathogens and transmission rates. These effects may be substantial as Sierra Leone is vulnerable to climate change impacts because of geographical location, urban and coastal population, and poverty.
- Little is known about the incentive structures needed to encourage risk avoidance behaviors (i.e., quarantines, lockdowns, social distancing, hand washing, etc.). Learning from experience with COVID-19 may help identify the types of public policies that worked and which ones did not for populations living and working in rural and urban landscapes.
- Zoonotic transmission occurs around particular value chains (wildlife meat markets, etc.).

8.2 Key in-Country Management Capacities and Constraints

- Exchange information among agencies working on different One Health interfaces;
- Update line agency and sector policies to facilitate One Health approach implementation;
- Budget allocation from different ministries for the One Health Secretariat;
- Sustained funding from both GOSL and development partners, and horizontal coordination and communication (as opposed to vertical structures of government); and
- Selected strategic priorities:
  - Institutional arrangements for data sharing among relevant departments,
  - Inclusion of One Health approach in government strategic plans/sector plans/policies,
  - Expansion of One Health engagement to additional departments.

8.3 In-Country Skills and Resources Gaps

- Lack of BSL-3 capable lab (this work is under way).
- Need for greater investment in influenza surveillance and biosecurity practices.

SECTION 9: OUTCOME MAPPING

About Outcome Mapping at STOP Spillover

A core component of STOP Spillover is a participatory planning process based on Outcome Mapping (OM). This project design process focuses on changes in targeted actors and in the spillover ecosystem as project outcomes to be influenced by STOP Spillover. Through participatory workshops, stakeholders identify and prioritize high-risk interfaces, describe current opportunities and limitations, and identify outcomes that will reduce related risks.

The goal of OM in Sierra Leone was to learn about the One Health (OH) zoonotic disease intervention landscape, understand the diversity and geographical distribution of organizations working in the space, and introduce STOP Spillover as a complementary, value-adding project seeking to learn and share best risk reduction practices related to specific viral pathogens and interfaces. The OM process in Sierra Leone included a combination of stakeholder meetings involving over 164 participants at the national, district and community levels between May 3 - 28, 2022. Participants represented a mix of sectors and interest groups, including the public service (local councils and field offices of the Ministries of Agriculture, Environment, and Health and Sanitation), community groups (e.g., bushmeat traders, traditional healers, etc.), women's groups, youth groups, and local Non-Governmental Organizations (NGOs). These meetings helped to corroborate findings from the country desktop review of zoonotic spillover risk gaps, barriers, capabilities, and opportunities from available literature. Participatory stakeholder discussions also helped to narrow down STOP Spillover priority pathogens to three (Ebola virus, Lassa virus, and HPAI) based on diseases previously prioritized by the Government of Sierra Leone (GoSL).

Spillover Interfaces, Opportunities and Barriers

The OM stakeholder engagement process helped the Sierra Leone Country Team to prioritize the pathogens of focus (Lassa and Ebola) and high-risk interface (forest-edge communities in the Gola Rainforest National Park (GRNP) in Eastern Sierra Leone) for STOP Spillover interventions. Barriers and gaps identified during OM included, among others

- limited awareness of zoonotic spillover risks by community members and traditional healers,
- low compliance with exposure restrictions,
- strongly held cultural and religious beliefs related to zoonosis,
- the absence of alternative livelihoods to reduce exposure risks, and
- poverty and poor living conditions.

Opportunities for managing these risks were mostly associated with the presence and roles of external organizations and institutions. These include the Government (Ministries of Health and Sanitation, Environment, Agriculture, Youth and VHF Task Forces) and global and national health programs [Breakthrough Action, PREEMPT (UC Davis), Doctors Without Borders, Welthungerhilfe (German Agro Action), Tulane (for Lassa fever control), the Gola Forest Program (on biodiversity conservation/ surveillance)]. It also includes civil society groups – Mano River Union Conservation Project, Women's Solidarity Community Action Group, Kenema Women's Governance Network, Clean Kenema (waste management), and Youth in Action for Development, among others.

Critical Partners, Target Outcomes and Supporting Interventions

Stakeholders identified actors whose roles or potential roles in increasing or reducing risks of Ebola and Lassa transmission and spillover at the community level would determine the project's target outcomes. This shortlist included: traditional healers; farmers; hunters/bushmeat traders; health workers; community leaders; and religious leaders. Stakeholders agreed on a range of target outcomes including increased knowledge and understanding of related risk behaviors, and improved capacity and resources to respond. For example, expected outcomes include:

- Community Health Workers (CHWs) have adequate knowledge & understanding of Lassa fever/Ebola risk behavior, improve their capacity to respond to related risk behaviours, and have the resources and skills to engage community leaders/community members.
- Traditional healers should establish a database of their practitioners and understand the referral pathway for suspected cases, and adhere to available guidelines for their operations.
- Hunters and bush-meat traders are aware of the risks involved in hunting and adopt risk reduction practices.
- Farmers increase their knowledge of target diseases, and minimize the use of farming practices that bring them into close contact with viral vectors and reservoirs.

To support these behavioral changes, a range of interventions was proposed. These included:

- training on the transmission/prevention/treatment of Lassa;
- designing by-laws for risk reduction and disease management' promoting hygiene and sanitation practices;
- supporting local artisans to fabricate rat-proof food storage systems; conducting Ebola virus sero-prevalence along the bush meat value chain; and
- support for surveillance early warning systems, among others.

Because proposed interventions were numerous and some went beyond STOP Spillover's mandate and scope, STOP Spillover synthesized information and selected the most appropriate interventions and studies using the following prioritization criteria:

- potential to reduce exposure to one or more hazards;
- potential to result in a health benefit;

- evidence of scientific coherence;
- feasibility in terms of cost and availability;
- acceptability to stakeholders; and
- potential to meet community needs and interests.

The selected list of interventions and research studies were reviewed by STOP Spillover technical experts and the Sierra Leone Country Team during an Intervention Study and Selection Process (ISSP) that generated work plan activities for Year 2 and Year 3. A more detailed description of the Outcome Mapping planning process and outputs can be found here: https://stopspillover.org/resources/sierra-leone-participatory-planning-using-outcome-mapping-summary-report.

Potential partners and stakeholder groups for STOP Spillover implementation include:

1. The Ministry of Agriculture and Forestry (MAF)
2. The Office of National Security
3. The Ministry of Health and Sanitation
4. Directorate of Livestock and Veterinary Services
5. One Health (OH) Secretariat
6. Ministry of Environment (MOE)
7. Universities (Njala University, University of Sierra Leone)
8. US Centers for Disease Control (US CDC)
9. United Nations Food and Agriculture Organization (FAO)
10. Journalists and media organizations
11. Local NGOs
12. Community leaders (Paramount Chiefs, youth leaders, town chief, imams/religious leaders, etc.)
13. Environment Protection Agency (EPA), Sierra Leone
14. Coalition for Epidemic Preparedness Innovations (CEPI)
15. University of California-Davis
16. The Viral Hemorrhagic Fever Consortium (Kenema Government Hospital, African Centre of Excellence for Genomics of Infectious Diseases, Center for Viral Systems Biology, Tulane University, Scripps Research, Harvard University, University of Texas Medical Branch, Zalgen Labs, La Jolla Institute for Allergy and Immunology, etc.)
17. Broad Institute (part of the Viral Hemorrhagic Fever Consortium)
18. USAID Breakthrough ACTION
19. GOAL Global (Ireland)
20. Sierra Leone Animal Welfare Society
21. German Agency for International Cooperation
22. African Field Epidemiology Network (AFENET)
23. International Federation of the Red Cross (IFRC)

Table of Potential STOP Spillover Partners and Stakeholders in Sierra Leone

Name of Organization	Geographic areas of intervention	Types of interventions	Contact information if available
USAID Breakthrough Action	National	Rabies research and social behavior change (SBC) activities around zoonotic diseases	James Fofana, Chief of Party, james@jhuccpsl.org
GOAL Sierra Leone	Western Area, Eastern Province, Northern Province	WASH, SBC	James Riak, Country Director, jriak@sl.goal.ie
Tulane University	Kenema District	Lassa research, surveillance, and technical assistance	
Ministry of Agriculture	National	Animal health surveillance and disease control	Mr. Mohamed Bah, Director, Livestock and Veterinary Services Division, medalphabah2014@gmail.com
Ministry of Health and Sanitation	National	Human health surveillance and disease control	Dr. Mohamed Vandi, Director, Health Security and Emergencies, mohamedavandi69@gmail.com

Name of Organization	Geographic areas of intervention	Types of interventions	Contact information if available
Ministry of Environment	National	Ecosystem health surveillance	Mr. Mo-Bash Idriss, Director, Environmental Health and Safety, Environment Protection Agency
UN Food and Agriculture Organization	Gola Rainforest National Park	HPAI, wildlife surveillance, community engagement and SBC	Dr. Noelina Nantima, Animal Health Advisor, noelina.nantima@fao.org
AFENET	National	Field epidemiology training programmer and technical support to lab networks in the MoHS	Dauda Sowa, Technical Adviser, dsowa@afenet.net
Njala University	Southern Province	CDC-funded Marburg research	Prof. Aiah Lebbie
IFRC	National	Coronavirus, Ebola relief and technical assistance	Mr. Swaray Lengor
GIZ	National	Ebola, Coronavirus research and surveillance	Amadou Traore, amadou.traore1@giz.de

Name of Organization	Geographic areas of intervention	Types of interventions	Contact information if available
University of Sierra Leone	National	Infectious disease research	Dr. Alhaji Njai, alhaji.njai@gmail.com
Gola Rainforest Company	Eastern and Southern Provinces (Gola Rainforest National Park)	Wildlife Surveillance	Francis Massaquoi, Project Manager
Metabiota		Research, surveillance of zoonotic diseases	James Bangura, Country Team Lead, jbangura@metabiota.com
Plan Verus	Outamba Kilimi National Park	Wildlife surveillance	Sarah Bell, bell_sarah@icloud.com
Tacugama Chimpanzee Sanctuary	Western Area and Gola Rainforest	Wildlife surveillance, community engagement	Bala Amarasekaran, tacugamasl@yahoo.com
National Protected Area Authority	National	Protection of forest ecosystems designated as parks and reserves	Bintu Kamara, Conservation Manager, bintusiaf29@gmail.com

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