Ebola virus disease and forest fragmentation in Africa

A report by the ERM Foundation and the Environmental Foundation for Africa_DRAFT

July 2015

EBOLA VIRUS DISEASE AND FOREST FRAGMENTATION IN AFRICA

This report was prepared by the ERM Foundation with technical advice from the Environmental Foundation for Africa (EFA).

1 EXECUTIVE SUMMARY

- This report summarises research conducted on the possible effects of forest fragmentation in increasing the risk of an outbreak of Ebola virus disease (EVD) in humans, and assesses it in relation to existing knowledge about epidemiology, bat ecology, recent development priorities in three countries most affected by EVD – Guinea, Liberia and Sierra Leone – and post-EVD crisis economic recovery plans. It is written for a non-technical, generalist audience, in particular policy makers planning post-EVD recovery as their decisions may be influenced by this study's findings.

- In attempting to gain a clearer understanding of the countries and populations at risk from future EVD outbreaks, Pigott *et al* (2014) re-evaluated the zoonotic niche for EVD in Africa and have found that an 22 million people in 22 countries across West and Central Africa could be at risk, both in countries that have had confirmed index cases and those for which strong environmental suitability for outbreaks is predicted.

- The current outbreak of EVD in West Africa had as of early July 2015 killed more than eleven thousand people, which is six times more than the combined total of all recorded outbreaks since 1976. The current outbreak is also the first recorded in West Africa, which is beyond the previously known range of the Ebola virus (Pigott *et al*, 2014). The World Bank predicts that the economies of Guinea, Liberia and Sierra Leone will lose an estimated US$1.6 billion in economic activity during 2015. The cost of the global response to the crisis has already run into tens of billions of dollars. The wider socio-economic impacts of this crisis will no doubt be felt for many years to come in the three worst affected countries.

- The global community is preparing to respond more effectively to future outbreaks of EVD *after* they occur, but there has been little discussion about finding ways to reduce the risk of future outbreaks *before* they occur. However, with increased comprehension of the factors that increase the risk of animal-to-human transmission of the Ebola virus, it may be possible to reduce the likelihood of re-occurrence.

- This report investigates the impact of forest fragmentation on the foraging and roosting habits of bats, that may expand the interface between bats and humans and thereby bring humans into closer and more frequent contact with the Ebola virus, which bats are believed to host.

- Central to proving this hypothesis is a satellite-imagery modelling exercise that has mapped and analysed trends in forest fragmentation at several index-case locations including the current outbreak of EVD in West Africa and six historical outbreaks across Central Africa. Initial results from the modelling suggest that a specific configuration of forest-fragmentation parameters generally correlates with EVD outbreaks in humans. Specifically, in six out of seven case studies, EVD outbreaks in humans occurred in locations with high Shannon Diversity Index values but low connectance values in terms of total values as well as relative to the surrounding landscape. This suggests that as the proportion of forested versus non-forested land equalises in a given location within a tropical African landscape, forest patches become more isolated from one another and the risk of EVD outbreaks increases there.

- Studies have shown that moderate forest fragmentation is associated with an increase in the abundance and diversity of certain bat species that can successfully exploit the variable resources and roosting sites available in fragmented and human-influenced landscapes. Some anthropogenic, agricultural landscapes promote contact between humans and bats. Further, as forest interior-dependent bat species lose habitat, they add to already prevalent bat populations in the human-modified landscape as they search for new habitats and food. Forest fragmentation concentrates potential hosts of the Ebola virus in remaining forest patches, where the risk of disease transmission between bats, other wildlife and humans entering these patches increases dramatically.

- Apart from a distinct emphasis on strengthening health-care systems, the post-EVD recovery plans for Guinea, Liberia and Sierra Leone take a ‘business-as-usual’ approach to rebuilding their economies, adopting a classic economic model that attributes significant value to natural resources and capital only when they can be transformed into measurable assets. Little reference or funds are devoted in the various recovery plans to improving forest management or wider environmental issues. Considering the estimated combined cost of the three recovery plans is US$5.86billion in the period 2015 – 2017 (see section 7), this could undermine the core objectives of such economic recovery. The amount dedicated to forest and environmental management within the three plans is just US$1.85million[1], which represents 0.03 percent of the total financing requirements.

- In recent decades, funding and policy initiatives in Guinea, Sierra Leone and Liberia have not prioritised environmental protection or sustainable forest management. Rather, it was estimated that a decade ago Guinea alone was losing 35,000 hectares of forest annually (USAID, 2007), and Sierra Leone has already lost almost 70 percent of its forest cover. In the wake of the EVD crisis, without more attention to forest management, continued pressures on forests through agricultural development, expansion of roads and other ‘economic recovery’ could actually increase the prospect of future outbreaks of EVD and undermine recovery efforts.

- Post-EVD recovery planning is an opportune moment to re-evaluate approaches to the management of natural resources in moist, tropical Africa, especially forests. Specifically, EFA and the ERM Foundation recommend convening an interdisciplinary focus group consisting of development

[1] Only the post-Ebola recovery plan for Guinea makes explicit reference wihin its financing plan to environmental protection.

planners, tropical forest management professionals, satellite imagery/GIS specialists, zoologists (especially bat specialists), and medical doctors and epidemiologists to review existing knowledge about how land uses and forest fragmentation influence zoonoses. The group would make two sorts of recommendations: (i) how current recovery plans should be adjusted to reduce the risk of future outbreaks, and (ii) avenues for further study to understand what promotes or inhibits outbreaks of EVD in humans.

"An ounce of prevention is worth a pound of cure"

The ERM Foundation

The ERM Foundation is the charitable entity of the global environmental and sustainability consulting firm, Environmental Resources Management (ERM). The ERM Foundation was established in 1995 with a remit to provide fundraising and pro bono technical support for NGOs and social enterprises that work in the fields of conservation and biodiversity, clean water and sanitation, low-carbon development, environmental education, and empowering women and girls. The ERM Foundation is a registered charity in England & Wales, the USA and Australia.

The Environmental Foundation for Africa

The Environmental Foundation for Africa (EFA) is a Sierra Leone-based NGO, established in 1992. EFA is working to facilitate the establishment of community-led programmes for sustainable environmental management as a basis for poverty alleviation in Africa. It seeks to achieve this through environmental awareness and education programmes as well as undertaking practical activities in partnership with communities and other entities, to conserve and protect the integrity of nature and natural resources. EFA is also a registered charity in the UK and Ireland.

---

2 INTRODUCTION

The global response to the current outbreak of EVD in West Africa has focussed overwhelmingly, and quite justifiably, on addressing the immediate medical emergency and bringing the number of new cases down to zero. As the rate of new cases has declined, there has been much discussion and reflection on how to respond more effectively to the next outbreak, which is viewed widely as inevitable. Largely absent from this debate has been a discussion on finding ways to prevent or reduce the risk of future outbreaks of EVD before the virus has been transmitted to the human population.

Apart from the emphasis on strengthening health-care systems, the majority of attention surrounding EVD recovery planning has focussed on rebuilding the affected economies according to classic economic models that do not place significant value on natural capital unless it is transformed into measurable assets. In fact, one could argue that post-Ebola crisis recovery programmes are being used as a vehicle to promote pre-existing agendas (see section 7). It is in response to this 'business as usual' approach that this report has been prepared.

The focus of this report

This report investigates concerns that human encroachment into forests, and the resulting transformation, especially fragmentation, of forested landscapes, may create conditions favourable to the transmission of the Ebola virus from its reservoir host into the human population. The research focusses on the current outbreak in West Africa (Meliandou, Guinea) and historical cases in Uganda, the Democratic Republic of Congo (DRC), the Republic of Congo (ROC), South Sudan and Gabon. For each country, land-use and vegetation-cover trends have been mapped surrounding the index case location to see if any common patterns or trends emerge. These could indicate the interface required for transmission of the Ebola virus to humans from wildlife and from bats in particular, which are believed to be the reservoir host of the Ebola virus. In the case of Guinea, donor funding and government policy priorities have also been analysed during the years leading up to the outbreak to build up a picture of the conditions that may have contributed to the 'spillover' of the virus from its animal host into the human population.

The report also looks at how international donors and the governments of Guinea, Sierra Leone and Liberia are currently prioritising interventions in the post-EVD recovery effort to see if these make adequate provision for measures that could mitigate the risk of future EVD outbreaks.

It should be noted that the focus of this study is *not* to suggest ways to reduce the human-to-human transmission of this disease, which is largely dependent on social factors. This is a very important issue and one that is being looked at by a number of other organizations.

Figure 1: *Cases of Ebola Virus Disease in Africa, 1976 - 2014*

Country	Town	Cases	Deaths	Species	Year
Dem. Rep. of Congo	Multiple	66	49	*Zaire ebolavirus*	2014
Multiple countries, primarily Guinea, Liberia and Sierra Leone	Multiple	27076	11155	*Zaire ebolavirus*	2014
Uganda	Luwero District	6	3	*Sudan ebolavirus*	2012
Dem. Rep. of Congo	Isiro Health Zone	36	13	*Bundibugyo ebolavirus*	2012
Uganda	Kibaale District	11	4	*Sudan ebolavirus*	2012
Uganda	Luwero District	1	1	*Sudan ebolavirus*	2011
Dem. Rep. of Congo	Luebo	32	15	*Zaire ebolavirus*	2008
Uganda	Bundibugyo	149	37	*Bundibugyo ebolavirus*	2007
Dem. Rep. of Congo	Luebo	264	187	*Zaire ebolavirus*	2007
South Sudan	Yambio	17	7	*Zaire ebolavirus*	2004
Republic of Congo	Mbomo	35	29	*Zaire ebolavirus*	2003
Republic of Congo	Mbomo	143	128	*Zaire ebolavirus*	2002
Republic of Congo	Not specified	57	43	*Zaire ebolavirus*	2001
Gabon	Libreville	65	53	*Zaire ebolavirus*	2001
Uganda	Gulu	425	224	*Sudan ebolavirus*	2000
South Africa	Johannesburg	2	1	*Zaire ebolavirus*	1996
Gabon	Booue	60	45	*Zaire ebolavirus*	1996
Gabon	Mayibout	37	21	*Zaire ebolavirus*	1996
Dem. Rep. of Congo	Kikwit	315	250	*Zaire ebolavirus*	1995
Côte d'Ivoire	Tai Forest	1	0	*Taï Forest ebolavirus*	1994
Gabon	Mekouka	52	31	*Zaire ebolavirus*	1994
South Sudan	Nzara	34	22	*Sudan ebolavirus*	1979
Dem. Rep. of Congo	Tandala	1	1	*Zaire ebolavirus*	1977
South Sudan	Nzara	284	151	*Sudan ebolavirus*	1976
Dem. Rep. of Congo	Yambuku	318	280	*Zaire ebolavirus*	1976

Source: Centers for Disease Control & Prevention (CDC). Figures accurate to May 2015

3 ZOONOTIC PATHWAYS AND MECHANISMS

Introduction

Zoonoses are diseases or infections that are naturally transmissible from vertebrate animals to humans and vice-versa. A zoonosis requires interaction between at least three species: one pathogen and two host species including humans and another animal species as the reservoir. Zoonoses have been recognized for many centuries, and over 200 have been identified, including Ebola virus disease, SARS, and HIV.

Zoonoses are caused by all types of pathogenic agents, including bacteria, parasites, fungi, and viruses.[1] Viruses are the most problematic because they evolve quickly, are unaffected by antibiotics and can be elusive, versatile and inflict extremely high rates of fatality (Quammen, 2012). More than 60 percent of Emerging Infectious Diseases (EIDs) are zoonoses, which represents a significant threat to public health and to the global economy (Jones *et al*, 2008).

Suspected pathways of zoonotic transmission

The emergence of zoonotic pathogens originating from wildlife has dominated the pandemics of the past century (Morse *et al*, 2012). Understanding how these enter into the human population is a major area of study within emerging infectious diseases. The transmission of pathogens into human populations from other species can be considered a logical sequence of pathogens' ecology and evolution, as microbes exploit new niches and adapt to new hosts. The underlying causes that create or provide access to these new niches seem to be mediated by human actions in most cases, and include changes in land use, modern transportation and animal production systems. Although the underlying ecological principles that shape how these pathogens survive and change have remained similar, people have changed the environment in which these principles operate (Karesh *et al*, 2012).

In their 2000 paper, Wolf *et al* explore the links between deforestation, hunting and microbial emergence in Central Africa. Here we set out a summary. Human activities that occur in moist tropical forests, such as logging, eco-tourism and hunting, provide a rich environment for microbial emergence due to their combination of high vertebrate and microbial diversity. Logging in Central Africa tends to focus on high-value timber species and so timber extraction is selective rather than a process of intensive cutting across large areas. This kind of selective extraction requires the construction of roads into relatively undisturbed forests.

Hunting is widespread in African forests in subsistence as well as industrial contexts. It radiates in a circular fashion around a village, but the construction of roads increases dramatically the number of points at which hunting activities can commence and the area in which hunting can be conducted. In essence, forested landscapes that are fragmented by roads serve to increase the interface between humans and vertebrate diversity in forested regions, which is likely to increase the frequency of microbial contact. The act of hunting and butchering prey facilitates the initial contact with a range of microbial organisms and increases the probability that hunters will be infected by novel microbes.

The Ebola virus

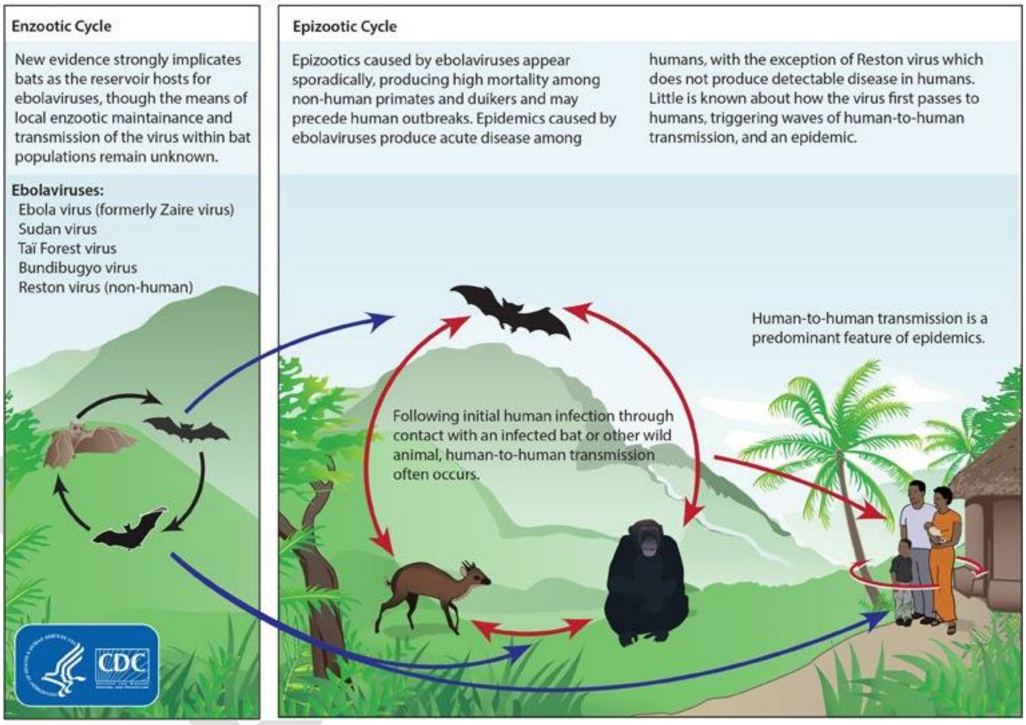
EVD is a complex zoonosis that is highly virulent in humans. The first recorded outbreak of EVD was in Zaire (now the Democratic Republic of Congo (DRC)) in 1976. During the past 39 years there have been numerous outbreaks with fatality rates ranging from 50 percent to 90 percent (see figure 1). The current outbreak of EVD in West Africa is unprecedented in terms of its size and scale, with six times more deaths than all previous outbreaks combined.

[1] World Health Organization. http://www.who.int/zoonoses/en/

The Ebola virus has not yet been isolated but bats are believed to be the reservoir host for the virus. Several species of fruit bat are thought to be likely candidates, including the Little Collared fruit bat (*Myonycteris torquata*), the Hammer Headed fruit bat (*Hypsignathus monstrosus*) and the Franquet's epauletted fruit bat (*Epomops franqueti*) (Leroy *et al,* 2015). Transmission of the virus to humans is believed to occur either from direct contact with the reservoir host, or with another animal that has been infected by the reservoir host (see figure 2). The latter is thought to occur through coming into contact with the blood of another mammal by handling (hunting, butchering, cooking) the animal carcass. (Pigott *et al*, 2014).

In attempting to gain a clearer understanding of the countries and populations at risk from future EVD outbreaks, Pigott *et al* (2014) re-evaluated the zoonotic niche for EVD in Africa and found that 22 million people in 22 countries across West and Central Africa could be at risk, both in countries that have had confirmed index cases and those for which they predict strong environmental suitability for outbreaks.

***Figure 2**: Ebolavirus ecology*



Source: Centers for Disease Control & Prevention (CDC)

The 2013/14 outbreak of Ebola virus disease in West Africa

Research undertaken at the location of the 2013/14 outbreak in Meliandou, Guinea suggests that the reservoir host may *not* have been a fruit bat but instead an insectivorous free-tailed bat (*Mops condylurus*) (Saéz *et al*, 2015). The index case is believed to have been a 2-year-old boy from Meliandou who is thought to have come into contact with an infected bat while playing in a hollow tree in which bats were roosting on the outskirts of the village. Fruit bats were considered an unlikely reservoir host in this case because although hunting fruit bats is common in the area, no hunters were members of the index-case household and food-borne transmission would likely have affected adults first or concurrently. Hunting bushmeat was also considered an unlikely source of the disease as local women, hunters and the regional authorities stated that, in contrast to Central Africa, primates are rare in south-eastern Guinea and so most game consumed in the region is imported pre-smoked from Liberia or other parts of Guinea. Saéz *et al* go on to say that children from the local village played regularly in the hollow tree, which was later found to contain many roosting insectivorous free-tailed bats.

Bausch *et al* (2014) examine the question of why the current outbreak in West Africa occurred in this location (Guéckédou, Guinée Forestière region), at a time when no previous cases of EVD had been recorded in West Africa. They note that the Guinée Forestière region, and the needs of its people, have been neglected for many years and its forests plundered to the extent that little forest remains. Local residents in Meliandou reported an unusually long and arid dry season in 2013. More research is required to understand if these drier ecologic conditions may have influenced the number of Ebola virus-infected bats, the frequency with which they are likely to come into contact with humans, and / or bats' or humans' susceptibility to infection.

Figure 3: *The area known as the Guinée Forestière (Forested Guinea) Region, now largely deforested because of logging, and clearing and burning of the land for agriculture.*

Photo credit: Daniel Bausch. doi:10.1371/journal.pntd.0003056.g003 PLOS Neglected Tropical Diseases www.plosntds.org

4 MODELLING TRENDS IN FOREST FRAGMENTATION

This research sets out to identify forest conditions that are hypothesized to play a role in increasing the likelihood of the Ebola virus jumping from its wildlife reservoir into the human population. A satellite-imagery modelling exercise investigated trends and thresholds in local forest fragmentation at outbreak locations of EVD in humans. The central hypothesis is that observable changes in forest fragmentation correlate with EVD outbreaks in humans, and that common ranges exist for specific forest-fragmentation parameters within which the risk of Ebola-virus transmission to humans increases. The modelling exercise did not investigate the reasons for subsequent transmission of the Ebola virus between humans.

The hypothesis of a correlation between changes in particular forest-fragmentation parameters and EVD outbreaks in humans would represent only one of several factors that increase the risk of outbreaks in humans. Other potential, contributing factors not investigated in this modelling exercise are population density and dynamics, cultural practices, subsistence activities, weather/climate and distributions of purported disease-carrying species like bats, primates and ungulates.

Figure 4: *Map Showing All Recorded Ebola Index (i.e. Outbreak) Events in Africa, and those Selected for Analysis in this Study*

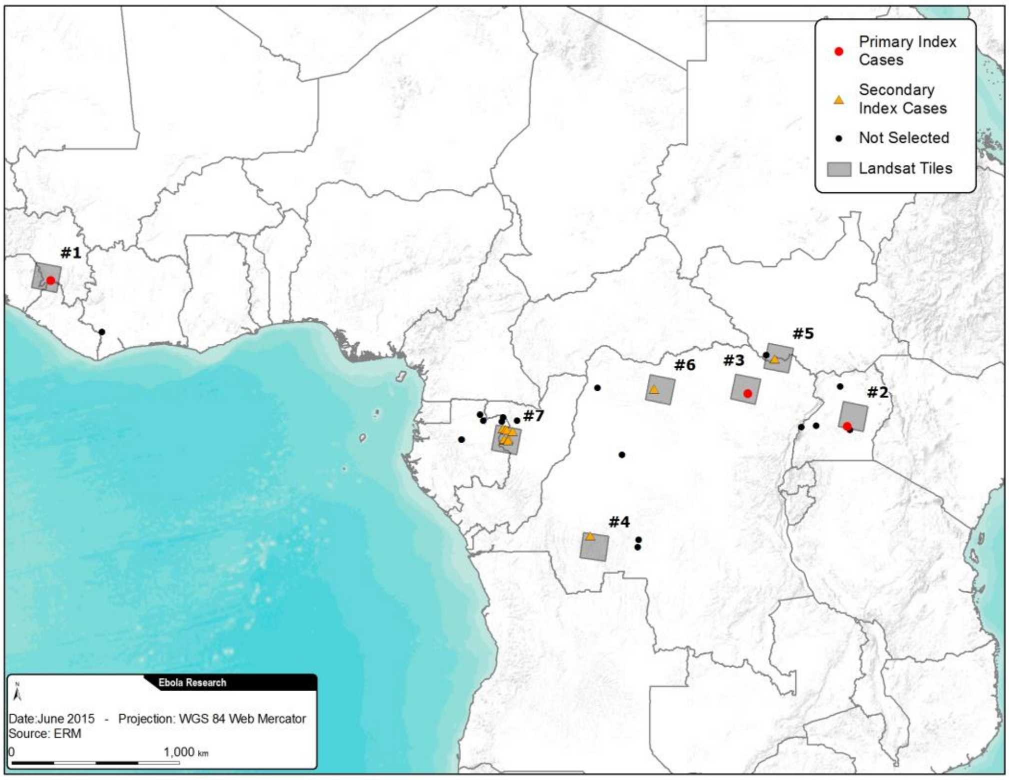


Figure 5: List of Primary and Secondary Index Case Studies Targeted for Analysis

Case #	Case study Level	Case Study	Outbreak Years(s)	Ebola Virus Stain	Local Population Density	# of Cases	# of Deaths
1	Time-series	Meliandou Village (Gueckedou Dist.), Guinea	2014	Zaire	Medium	27,505	11,220 [1]
2	Time-series	Luwero district, Uganda	2012	Sudan	High	6	3
3	Time-series	Isiro health zone, DRC	2012	Bundibugyo	Low	36	13
4	Outbreak year	Mwembe, DRC	1995	Zaire	High	315	250
5	Outbreak year	Yambio, South Sudan	2004	Sudan	Medium	355	180
6	Outbreak year	Yambuku, DRC	1976	Zaire	Low	318	280
7	Outbreak year	Several Locations, Congo and Gabon	2001; 2002; 2003	Zaire	Low	136	107

METHODS

Data sources and materials

Data concerning EVD outbreaks in humans come primarily from a comprehensive geospatial database of past Ebola-virus zoonotic events (Mylne, *et al*. 2014), supplemented with information provided on the CDC website. Figure 4 presents a map of all recorded historic, African EVD index cases in humans, and indicates which were analysed in the 30 or so years up to the outbreak ("time-series cases") versus only in the year of the outbreak ("outbreak-year cases"). Figure 5 is a table that lists and provides additional information on each of the selected case studies.

Imagery from the Landsat satellite program was used. The range of Landsat satellites used in this analysis were Landsat 1-5 MSS, Landsat4-5 TM, Landsat 7 ETM+, and Landsat 8. The geospatial software platform Idrisi was used for classifying forest and non-forest land cover from the satellite imagery. The statistical platform FRAGSTATS was used to quantify different aspects of forest fragmentation.

Case study selection

The modelling exercise included two levels of analysis: time-series case studies and case studies where only the year of outbreak was analysed. The principal distinction between the two is that the former aimed to investigate changes in forest fragmentation over two 15-year time intervals – 30 years before outbreak, 15 years before and the year of outbreak – whereas the latter investigated only the year of outbreak.

[1] Case and death counts for the current outbreak in West Africa (Guinea, Sierra Leone, Liberia) obtained from the CDC website on 30, June, 2015 (CDC 2015)

The selection of time-series case studies relied on two elimination criteria related to unique limitations of historic satellite imagery analysis: (1) eliminating EVD index cases in humans prior to the year 2000, since historic Landsat imagery is not available before 1970, and (2) eliminating EVD index cases in humans due to excessive cloud cover in available Landsat imagery.

After applying the elimination criteria, only three outbreak locations remained that could be investigated over the two 15-year intervals:

1) the 2014 outbreak in Meliandou, Guinea,
2) the 2012 outbreak in Luwero District, Uganda, and
3) the 2012 outbreak in Isiro, DRC.

The goal of the time-series case studies was to identify trends in forest structure leading up to the year of outbreak to detect observable changes between the year of outbreak and earlier periods. On one hand, for example, if no consistent, observable changes were found in forest structure between the year of outbreak and earlier years, then the likelihood of forest structure playing a role in EVD outbreaks in humans would decrease. On the other hand, if a consistent, observable change was found in forest structure between the year of outbreak and earlier years, then the hypothesis that recent changes in forest structure may increase the likelihood of EVD outbreaks in humans is supported and worthy of additional analysis.

Based on outbreak year and heavy cloud cover, time-series analysis could not be conducted for all recorded human EVD outbreak locations. Accordingly, outbreak-year case studies were selected based on satellite image quality and included:

1) a cluster of four outbreak events between 2001 and 2003 on the border of Gabon and Congo,
2) the 1996 outbreak in Mwembe, DRC,
3) the 1976 outbreak in Yambuku, DRC, and
4) the 2004 outbreak in Yambio, South Sudan.

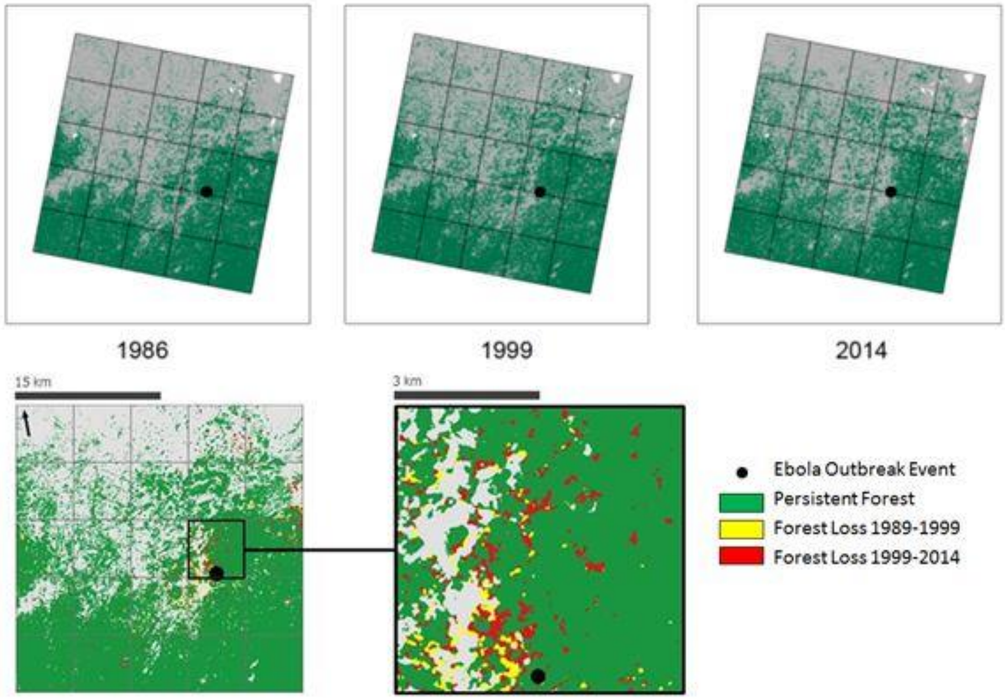
These case studies were then classified into forest and non-forest images using the same methods as the time-series case studies. Several other case studies could be analysed in a similar manner at a later phase of research, but due to time constraints only four were conducted.

The goal of the outbreak-year case studies was to increase the number of samples beyond the three initial ones. By modelling the type of forest fragmentation at the year of outbreak, the latter case studies could be compared to the year-of-outbreak models from the time-series case studies. Thus the analysis sought to identify common ranges of forest-fragmentation parameters correlated with EVD outbreaks in humans.

Classification of forest vs. non-forest

Classification of forest versus non-forest used the software platform Idrisi on the Landsat satellite imagery. Each case study was separated into 25, 1:30,000-scale grids for comparison (see Figure 6).

Figure 6: *Example of Forest Classification from Primary Case Study #1 (2014 - Meliandou Village, Guinea)*



With the classification of forests at 15-year intervals, it is possible to analyse forest-cover changes over time. Figure 6 shows forest loss from 1989 to 2014 at the location of the Meliandou outbreak in Guinea in 2014. The overall study area shows a dynamic mixture of forest and non-forested areas with denser forests located in the south, mixed forest and non-forest in the centre, and less forested areas in the north east. The exact 6km X 6km grid cell where the Meliandou outbreak occurred witnessed the highest amount of deforestation and among the highest increase in forest fragmentation anywhere within the 30km X 30k Landsat tile, as described in the section below. This process was repeated for the other two time-series case studies. The outbreak-year case studies were analysed for forest cover and fragmentation in the same way, but not for changes across time.

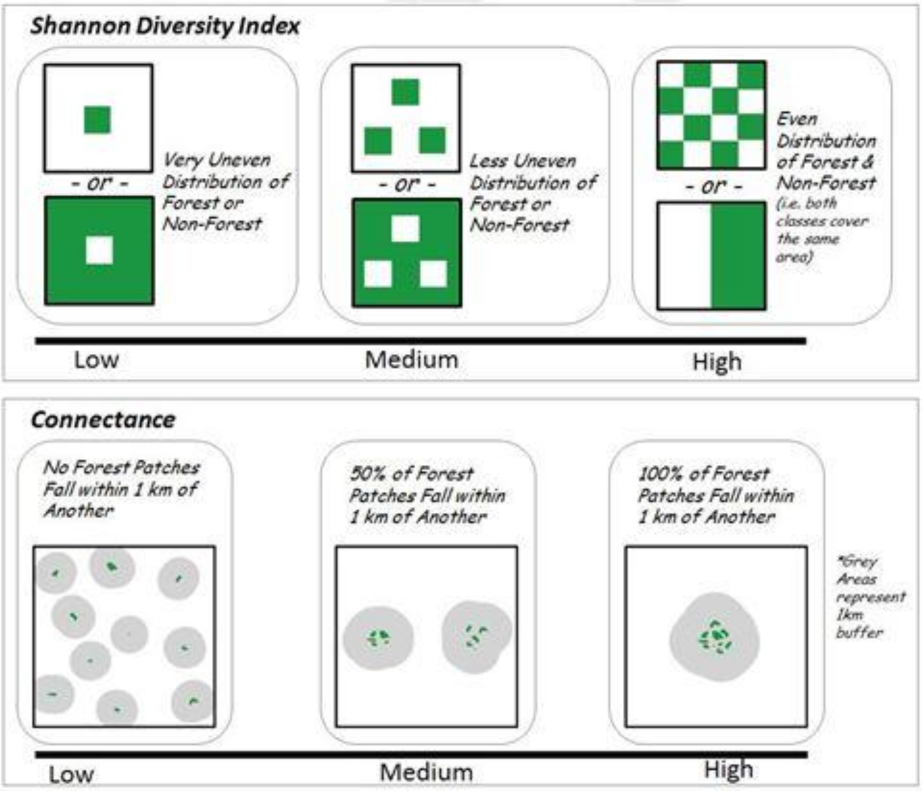
Forest fragmentation analysis

Forest fragmentation metrics were calculated using the program FRAGSTATS. Two of the calculated metrics were Shannon's Diversity Index and 'connectance' (see Figure 7). Both of these metrics measure types of forest fragmentation.

The Shannon Diversity Index (SDI) measures the even distribution of forest and non-forest patches in a landscape. The SDI increases as the proportional distribution of forest and non-forest patches becomes more and more equitable. The SDI decreases as the distribution of forest and non-forest patches is increasingly unevenly distributed. For a given number of classes, the maximum value of the Shannon Diversity Index is reached when all classes have the same area.

Connectance is defined on the number of functional joinings between patches of the corresponding patch type, where each pair of patches is either connected or not based on a user-specified distance criterion. A standard threshold distance of 1000 meters was applied to define what constituted patches that were 'connected' versus 'not connected'. As connectance values decrease, fewer forest patches are located within 1000 meters of another forest patch. In other words, a decrease in connectance indicates that forest patches are becoming more isolated from one another.

Figure 7: Graphic representation of connectance and the Shannon Diversity Index

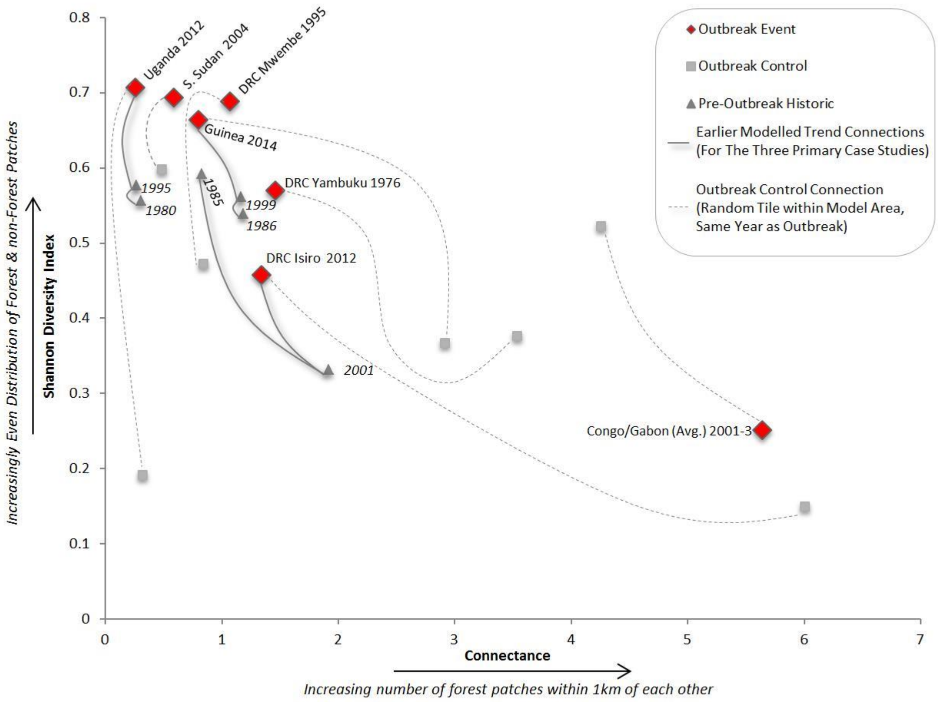


The goal of the FRAGSTATS analysis was to understand trends in these metrics in the 6km X 6km grid in which the index case occurred within the outbreak-location tile, i.e. the overall 30km X 30km tile. A random 6km X 6km grid cell that did not contain the index case was also selected from the larger tile and analysed, to act as a control to better understand if the index case occurred in an area with different degrees or dynamics of forest fragmentation when compared to nearby areas

RESULTS

Initial results from the modelling suggest that a specific range of forest-fragmentation values correlates with several EVD outbreaks in humans (see Figure 8). This is a potentially significant observation and may be a step towards isolating an indicator of where new EVD outbreaks are most likely to occur.

Figure 8: Scatterplot comparing Shannon Diversity Index vs. connectance



The patterns indicated in Figure 8 suggest that regions with high Shannon Diversity Index values but low connectance values may increase the risk of EVD outbreaks in humans. In other words as the proportion of forest versus non-forest becomes more equal and as forest patches become more isolated the risk of EVD outbreaks increases. There are significant outliers to this pattern, but this is not unexpected as there are likely several factors that influence where and when an EVD outbreak occurs in humans.

Figure 8 indicates some additional patterns. The grey triangles connected by solid lines to red diamonds (which represent EVD outbreaks from time-series case studies) represent historic forest-fragmentation levels calculated from these case studies' earlier imagery. Two of the time-series case studies (Uganda 2012 and Guinea 2014) show a clear increase in forest fragmentation compared to earlier years. This suggests that recent changes in forest fragmentation could have increased the risk of the EVD outbreaks. The DRC Isiro 2012 time series case study does not follow this pattern however, and more investigation is needed to understand why.

The grey squares connected by grey dotted lines in Figure 8 represent the forest-fragmentation metrics calculated for the randomly selected (control) grid cells from the year-of-outbreak case studies. The patterns observed in Figure 8 suggest that there is an observable difference between the forest-fragmentation levels in index case locations compared to the broader, surrounding landscape, which in turn potentially indicates that the risk of the Ebola virus infecting a human is fairly localised.

In summary, this analysis has not verified or rejected the central hypothesis that there is a combination of forest-fragmentation values that serve as a threshold within which the risk of Ebola-virus transmission from animal reservoir to humans increases significantly. Rather, the patterns observed from this analysis indicate the potential for a complex relationship between forest fragmentation and EVD outbreaks. Additional analysis could further isolate (or disprove) forest-fragmentation conditions as one of the factors promoting Ebola-virus transmission to humans.

Testing the hypothesized correlation between locations of EVD index cases and protected areas

A supplementary analysis was conducted to test the hypothesis that EVD outbreaks are more likely to occur in or near protected areas. To test this assumption a statistical comparison was conducted to observe differences between (1) the distances of EVD index-case sites from protected areas, and (2) the distance from randomly selected sites to protected areas. The objective of the analysis was to determine if the mean/median distance of EVD index-case locations to protected areas is significantly different from the distance of randomly selected locations to protected areas.

There were 33 EVD index-case locations used in this analysys with distances to protected areas ranging from 0 to 168.5 km. All randomly selected locations were selected with distances within this range. The locations of protected areas were obtained from the World Database of Protected Areas (www.protectedplenet.net).

Whereas the mean and median distances of EVD index-case locations to protected areas were less than those of the randomly selected sites' distances, there was no discernable distribution of the data for either of the two data sets, and therefore the non-parametric Mann-Whitney test was most appropriate for this analysis. This test showed a p-value of 0.238, which indicates that there was no significant difference between the medians of the data sets. Accordingly, it appears that EVD outbreaks are stastically not more likely to occur within or near protected areas than far from them, and the initial hypothesis appears to be false.

5 HOST BEHAVIOUR AND LAND COVER TRENDS

Behavioural response of bats to forest fragmentation

Section 3 explains how certain bat species are strongly considered to be a primary host reservoir for the Ebola virus. This section summarizes the results of a review of the scientific literature related to bats' response to forest fragmentation and forest loss to determine if there are predictable changes in bats' behavioural patterns, or their population or community dynamics, in response to forest fragmentation that could increase the risk of Ebola-virus transmission to humans.

Bats are one of the most common taxa in fragmented landscapes due to their tolerance and adaptability to forest fragmentation. Many bat species are able to persist and even thrive in modified landscapes. Other forest taxa (other mammals, birds, herptiles, etc.) are often largely absent from highly fragmented landscapes. (Laurance *et al*, 2002; Law and Dickman, 1999; Turner, 1996).

The most successful species of bats in fragmented landscapes are generally those with wide dietary ranges, the capacity to forage and roost in a variety of habitats, and the ability to travel long distances to find high-quality food and roosts (Estrada, 2004; Faria, 2010). These traits are common in many frugivorous and nectarivorous bat species.

Many species of frugivorous bats prefer a heterogeneous landscape, reflecting a capacity for consumption of fruits in forest, secondary vegetation, and plantations or small farms. The ability of many frugivorous bat species to commute extensive distances during foraging may facilitate use of distant fragmented forests that provide high-value food resources during particular times of the year.

In one study the abundance of each of nine frugivorous species decreased with increasing forest cover (Gorresen and Willig). The abundance of frugivorous bats probably responded to landscape composition (e.g. percentage forest, mean patch density) because of an increase in early successional fruits and flowers in areas with reduced canopy cover. Further, generalized (non-specific) foliage roosting habits in most frugivorous bat species allow many to occupy almost the full range of fragmentation present in a given landscape.

Many studies of habitat fragmentation and its effects on bats have demonstrated that landscape composition (i.e. amount of forest habitat, patch size, and patch density) is a significant predictor of bat abundance, species richness, and community structure (Gorresen and Willig). These studies consistently find that, in general, species richness and diversity is highest in partially fragmented landscapes, whereas evenness (number of individuals in each species) is highest in forested (non-fragmented) habitats. These results are consistent with numerous studies concerning the response of bats to selective logging, which is a common practice in Africa (Clarke; Pio and Racey 2005; Restant and Racey, 2005; Peters, Malcolm, and Zimmerman, 2006).

In essence, less specific dietary requirements, higher mobility, and generalized roost preferences all facilitate lower sensitivity to the negative effects of forest fragmentation and increased likelihood of reaping benefits from the varied resources that fragmented landscapes can provide. The effects of each of these attributes on bats' responses to habitat fragmentation are discussed below.

Species-specific information on the hypothesized bat hosts

Annex 2 contains a summary of the available ecological information on the four species that have been hypothesized as hosts of EVD. The four species, hammer-headed fruit bat (*Hypsignathus monstrosus)*, little collared fruit bat (*Myonycteris torquata),* Franquet's epauletted bat (*Epomops franqueti)*, and Angolan free-tailed bat (*Mops condylurus)* are common throughout their range and regularly hunted for meat (or in the case of the Angolan fruit bat, a regular target of children). All but the Angolan fruit bat are generalist frugivores known to travel considerable distances among foraging and roost sites. The three fruit bat species are either solitary or small group roosters so they are most likely encountered by humans during foraging or at breeding concentrations, rather than at roost sites.

The Angolan fruit bat is an insectivorous species that forages in forests and along forest edges and has large communal roosts in wooded savannahs, tree hollows and, more recently, in buildings (under roofs or overhangs). A major avenue of potential contact between this species and people is at the roost site.

Linking the result of the landscape analysis, bats' behavioural response to fragmentation, and zoonosis theory

The landscape analysis suggests that as the distribution of forest versus non-forest becomes more equal and as isolation of forest patches becomes greater, the risk of EVD outbreaks can increase. Further, the results for 2 of the 3 case studies assessed (Uganda 2012 and Guinea 2014) indicate that recent changes in forest fragmentation around the index cases' locations enhanced the conditions associated with EVD outbreaks in humans in six out of seven case studies.

The scientific literature indicates that moderate forest fragmentation is regularly correlated with an increase in abundance and diversity of some bat species, particularly generalist frugivores that can both successfully exploit the highly variable forage resources and roost sites typically available in a moderately fragmented and human-influenced landscape, and disperse considerable distances among habitat patches.

Three of the four species hypothesized to be reservoirs for the Ebola virus are generalist fruit bats. Based on the expected responses of this type of bat to fragmentation, the number and diversity of potential bat hosts present in areas frequented by people should increase in fragmented landscapes, thus increasing the risk of bat-to-human Ebola virus transmission. Further, as forest interior-dependent bat species lose habitat through forest fragmentation, they add to the already prevalent bat populations in the human-influenced landscape as the former search for suitable habitats and food or while attempting exploit and adapt to the new environment. Because individuals in search of habitat are often physiologically stressed from habitat loss and potential food or roost shortage, they can be immunocompromised and potentially more susceptible to Ebola-virus transmission from other bats-*cum*-Ebola-virus-carriers during competitive interactions and shared roost sites. In turn, this could lead to a higher proportion of Ebola virus-infected bats in close proximity to humans (Leroy *et al,* 2005) and increase the risk of an EVD outbreak in humans.

Finally, with less natural habitat, potential hosts concentrate in remaining habitat patches which increases disease transmission among carriers and exposes people entering these patches to increased risk of contact with infected individuals.

All of these patterns indicate that there are potential and complex interactions among forest fragmentation, host behaviour, and EVD outbreaks. Further research and analysis into these interactions is warranted since understanding them is fundamental to recommending interventions to prevent new EVD outbreaks.

Additional information and recommendations for further research are set out in Annex 3.

6 POLICY AND DONOR PRIORITIES IN GUINEA

Agriculture and forest loss in Guinea

The majority of Guinea's population is rural, with more than 70 percent working in the agriculture, livestock, fishery, forestry and small-scale mining sectors. Agriculture is dominated by subsistence farming, particularly in Guinée Forestière where the Méliandou index case appeared. Population growth and low agricultural productivity have increased pressure on grazing and forestland as local communities struggle to meet needs for fuel, food and income. The forests of Guinea have been highly impacted by slash-and-burn agriculture as well as infrastructural development and human conflict. Unregulated commercial logging resulted in significant land degradation and forest loss from the 1980s to the 2000s. Rural people rely on forests for multiple products including firewood, roots, fruit and medicine. Increasing population pressures and lack of technological improvements in agriculture on traditional farmland have pushed rural people to encroach further into forests to meet their basic needs.

Natural resource legislation in Guinea is spread across multiple sectors – like agriculture, energy, water, livestock, forestry, wildlife management, urban development, mining – the provisions for which can be inconsistent, and their application depends on what ministry is most powerful. Guinea's Forestry Code (1999), which governs the country's forests, recognizes the customary rights of forest-edge communities to use land and forest products to meet domestic requirements and to graze livestock in classified forests. It also states that forest areas should be protected against any form of degradation or destruction and that local communities should not engage in commercial logging. Despite these intentions, forest policies and legislation have been implemented by continually changing and under-resourced governmental ministries that have struggled to implement this Code effectively (Deutsch 2009).

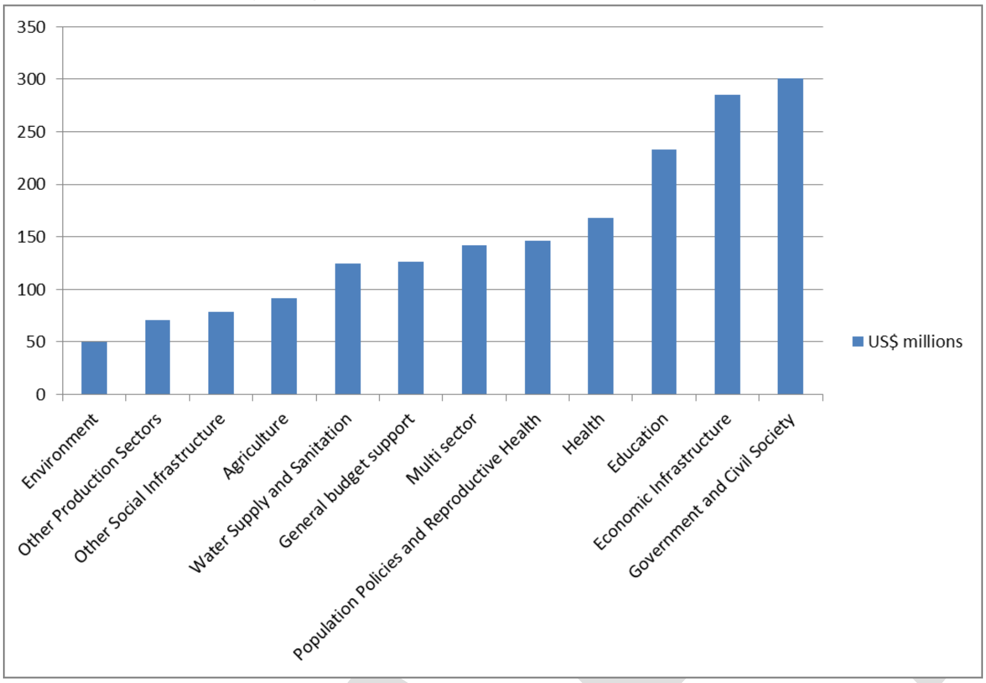
Deforestation in Guinea was occurring recently at an annual rate of 0.5 percent; it was estimated that 35,000 hectares of forest were lost each year at the turn of the millennium (USAID, 2007). This was in part an outcome of an unregulated approach to land use, energy production (firewoods and charcoal) and subsistence-agricultural production systems, themselves symptomatic of grinding poverty. Also prominent in this high rate of forest loss was poor to absent forest management practices and significant corruption in the forestry sector.

Donor funding priorities in Guinea

A number of donor organizations actively support natural resource management and conservation in Guinea. In recent years, the United States and France have been the largest bilateral donors to Guinea, followed by Japan. Guinea's top multilateral donors are the European Union (EU), the World Bank, and the United Nations agencies. The EU concentrates primarily on rural development, social and economic infrastructure, and macroeconomic support. The World Bank supports Guinea's rural and urban infrastructure programs, primarily, while the UN works across a wide range of sectors.

Funding for environmental protection and natural resource management has consistently ranked at or near the bottom of sectoral funding in Guinea (see figure 9).

Figure 9: *Total Country Programmable Aid[1] (CPA) to Guinea (2004 – 2012)*



Source: OECD/DAC

7 POST-EBOLA RECOVERY PLANNING

Global response

The overwhelming response to the current EVD outbreak in West Africa has focused on *mitigating* controls rather than *preventative* controls. However, effective risk management should focus mainly on preventing the likelihood and/or severity of a risk event occurring in the first place, since this is more cost-effective and avoids a range of negative outcomes. Pigott *et al* (2014) highlight the importance of mapping the risk of future outbreaks.

After eradicating the current EVD outbreak, post-EVD recovery is focused on improving health care systems to respond more effectively to the next "inevitable" outbreak, and on restoring economic growth according to previously defined development trajectories.[2,3,4] For example, the focus on preparedness for the United Nations Development Programme (UNDP) in Ebola-affected countries includes providing community-level training about EVD and the behaviours needed to reduce the risk of human-to-human transmission once an outbreak has started.[5]

Ebola recovery plans for the Governments of Guinea, Sierra Leona and Liberia have focused on addressing the adverse conditions that enabled a localized epidemic to escalate into national crises and to minimize the risk of future pandemics.[6]

[1] **Country programmable aid (CPA)** is the portion of aid that providers can programme for individual countries or regions, and over which partner countries could have a significant say. Developed in 2007, CPA is a closer proxy of aid that goes to partner countries than the concept of official development assistance (ODA)
[2] Hamilton, Charlie. "An Insurance Outbreak." The Africa Report. May 2015
[3] World Health Organization. "Ebola Response Roadmap." August 2014
[4] UN Mission for Ebola Emergency Response. EbolaResponse.UN.org
[5] Ebola Crisis in West Africa" United Nations Development Programme. UNDP.org
[6] Recovering from the Ebola Crisis: A summary Report. March 2015

Recommendations to the governments by the UN, World Bank, European Union and the African Development Bank include strengthening the provision of basic services, particularly strengthening primary health care, disease detection and quarantine systems, making sure that schools, health facilities and water resources are safe and more hygienic, rehabilitating social infrastructure such as rural roads, and socio-economic revitalization through restoring agriculture, mining and stimulating private investment to enhance human capital and livelihoods.

Although the Ebola recovery efforts include measures to mitigate the risk of another EVD pandemic characterised by uncontrolled viral transmission, almost no efforts focus on preventative controls for future EVD outbreaks. The reasons for this are unclear but it is certain that little to no information and no clear recommendations are available in forms that policy-makers can easily digest on the factors increasing the likelihood of EVD outbreaks and how to reduce this likelihood. The plan 'Recovering from the Ebola Crisis' (UN, World Bank, EU, AfDB, 2015) pays lip service to changing natural resources management and managing the landscape to reduce the likelihood of future outbreaks, but specifies no tangible measures and recommends no resources for it.

Mano River Union Sub-regional Programme for Post-Ebola Socio-economic Recovery

The Mano River Union (MRU) is an international association between Guinea, Sierra Leone and Liberia, established to foster economic cooperation between these three countries. The MRU's post-EVD recovery plan sets out strategic priorities for 2015 – 17. The financial requirements to implement the plan total US$4billion (see figure 10).

Within this plan, US$800million is assigned to agriculture, fisheries and food security, stating a need for the "intensification and diversification" of agricultural productivity in the three countries. The report also states that the Ebola crisis has had a negative effect on the artisanal and small-scale mining sector in the region, which provides employment opportunities for women, youth and start-up capital for low-income populations. However, small-scale mining of this type is known to have a negative impact on the environment and has a poor track record within the MRU member states regarding conditions for health, sanitation, education, human rights, civil stability, rule of law, crime and delinquency, *inter alia*. The plan states a need to "institute policies, actions and programmers to correct weaknesses at the sub regional level that have been revealed by the outbreak, essential for rebuilding a more resilient sub region", but no direct reference is made to finding ways to reduce the risk of future outbreaks of EVD or for any environmental protection measures that could support this.

Figure 10: *MRU Ebola recovery plan cost matrix*

MANO RIVER UNION POST EBOLA SOCIO-ECONOMIC RECOVERY COST MATRIX

SUMMARY SECTORAL COST MATRIX BY PRIORITY

SECTOR	Estimated Cost (US$ 000)	Yearly Allocations (US$ 000)		
		2015	2016	2017
PRIORITY LEVEL 1				
1 HEALTH, WATER, SANITATION AND HYGEINE	500,380	75,057	250,190	175,133
2 GOVERNANCE, PEACE AND SECURITY	139,850	20,978	69,925	48,948
3 AGRICULTURE, FISHERIES AND FOOD SECURITY	800,482	120,072	400,241	280,169
4 GENDER, YOUTH AND SOCIAL PROTECTION	231,000	34,650	115,500	80,850
5 PROGRAMME MANAGEMENT AND MONITORING	20,600	3,090	10,300	7,210
6 PRIVATE SECTOR SUPPORT PROGRAMME	65,150	9,773	32,575	22,803
Priority Level 1 Sub-Total	**1,757,462**	**263,619**	**878,731**	**615,112**
PRIORITY LEVEL 2				
7 ROADS PROGRAMME	574,638	86,196	287,319	201,123
8 ENERGY ACCESS PROGRAMME	1,321,262	198,189	660,631	462,442
9 INFORMATION & COMMUNICATIONS TECHNOLOGY(ICT)	346,640	51,996	173,320	121,324
Priority Level 2 Sub-Total	**2,242,540**	**336,381**	**1,121,270**	**784,889**
PROGRAMME TOTAL	**4,000,002**	**600,000**	**2,000,001**	**1,400,001**

Source: The Mano River Union Secretariat

Post-EVD recovery planning in Guinea

The Guinean Ebola Recovery Plan[1] is based on four fundamental pillars: (A) social sector support, (B) economic recovery, (C) infrastructure development, and (D) governance support. On the social sectors, the authorities envisage the strengthening of the health system (systems, human resources, and medicines) to meet the immediate needs of the population post-EVD. Also, there are plans to improve access to water and sanitation, accelerate literacy, promote gender equality, and ensure child protection.

The total estimated cost of this plan over the 2015-2017 period amounts to US$2.89 billion. The largest portion is devoted to health expenditure (US$1.24billion), which represents 48 percent of the total budget. Thirteen percent (US $343 million) is allocated to “Economic sectors”, of which “Agriculture” forms the largest portion (US $152 million), and “Environment” is the smallest at US$2.7million. Of the environmental allocation, US$860,000 is to fund latrines in schools and US$140,000 is earmarked for environmental awareness in Conakry. US$1.71million is for “Nature conservation and preventative fight against EVD”, which appears to focus primarily on contact with wildlife and wildlife management.There is no provision for forest management. Also absent from the report is mention of proposed measures to prevent or reduce the likelihood of future outbreaks of EVD. Rather, the report states a ‘need for vigilance’.

[1] Republique de Guinea Strategie de relance socio-economique post-Ebola (2015-2017), June 2015

Post-EVD recovery planning in Sierra Leone

The National Ebola Recovery Strategy for Sierra Leone[1] (March 2015) sets out the government's recovery strategy for implementation between 2015 – 2017.

The estimated cost of implementing the strategy between 2015 – 2017 is US$1.7 billion. The largest individual allocations are for achieving and maintain zero infections (US$424.9million), restoring access to basic healthcare (US$370.3million), getting children back to school (US$ 128.9 million) and improving access to water, hygiene and sanitation (US$ 59.9 million). Initiatives to restore economic growth and output include US $83 million for reactivating agricultural and rural livelihoods, US$30.8 million for restoring domestic revenue generation (including mining operations), US$14.6million for reactivating artisanal and industrial fishing activities and US$24million for re-starting all road and development programs. The strategy does state the need to apply "lessons learned" and identify "missed opportunities", but there is no reference made within the list of key deliverables to forest management, or the need for a more sustainable use of natural resources to reduce the risk of zoonotic disease outbreaks.

Post-EVD recovery planning in Liberia

The Overall Objective of the *Economic Stabilization and Recovery Plan* (ESRP) is to get the economy back on track toward the primary goals of the country's medium and long-term development plans. The plan focuses on three core objectives that are aligned to the objectives of the Liberia's Agenda for Transformation (AfT)[2] and Liberia Rising 2030. The three core objectives are to (A) revitalize growth to pre-crisis levels whilst ensuring that it is inclusive and that it creates more and better jobs, (B) provide support for the poor and other at-risk groups to strengthen resilience and reduce vulnerability, and (C) rebuild and strengthen the capacity to deliver core social services including education and health with better coverage particularly in the rural areas.

The financing requirements to implement the plan are estimated at US$1.27billion between 2015 – 2017. In light of the downturn in the mining sector, agriculture, including forestry, is seen as a key sector for expansion. There is emphasis also on road building and rehabilitation to enhance the country's profile for foreign investors. The plan refers to the problem of illegal logging, but goes on to state that the timber industry has the potential to generate "substantial environmental, social and economic benefits". However, paradoxically, in a bid to halt the destruction of Liberia's forests, the governments of Liberia and Norway have signed a US$150million partnership agreement aimed at "putting an end to the signing of new logging contracts, ensuring more scope for forest-dependent communities to manage their resources and increasing protected forest areas[3]".

Of the US$1.27billion budget, US$304.7million is assigned for recovering output and growth. This is broken down as follows: US$105.1million for the agricultural sector

[1] National Ebola Recovery Strategy for Sierra Leone. Government of Sierra Leone (March 2015). https://ebolaresponse.un.org/sites/default/files/sierra_leone_-_national_recovery_strategy_2015-2017.pdf
[2] Republic of Liberia Agenda for Transformation: Steps for Liberia Rising. 2013

[3] Paragraph 37 in the Economic Stabilization and Revovery Plan for the Republic of Liberia (april 2015)

including palm oil production, US$183.6million for infrastructure including roads, transport, ports and energy, and US$16million for private sector services including mining and manufacturing. Unlike the recovery plans for Sierra Leone and Guinea, the Liberian plan does make reference to the sustainable management of natural resources, but not in significant detail or in a way that deviates significantly from a 'business as usual' approach to forest management. How such traditional forestry is to be reconciled with the partnership with Norway is not addressed.

Next steps and recommendations

Post-EVD recovery planning is an opportune moment to re-evaluate approaches to the management of natural resources in moist, tropical Africa, especially forests. The causes of EVD outbreaks in humans are likely multiple; forest fragmentation is likely a significant factor, but not the only significant factor. EFA and the ERM Foundation alone cannot confidently recommend specific measures to assist post-EVD recovery to reduce the risk of future outbreaks. However they urge convening an interdisciplinary focus group consisting of development planners, tropical forest management professionals, satellite imagery/GIS specialists, zoologists (especially bat specialists), and medical doctors and epidemiologists to review existing knowledge about how land uses and forest fragmentation influence zoonoses. The group would make two sorts of recommendations: (i) how current recovery plans should be adjusted to reduce the risk of future outbreaks, and (ii) avenues for further study to understand what promotes or inhibits outbreaks of EVD in humans.

Annexes

In draft form, subject to further revision

Annex 1

OVERVIEW OF THE EVD RESPONSE LANDSCAPE

Médecins Sans Frontières (MSF) –Managing the large majority of the clinical treatment in Guinea, Liberia and Sierra Leone. MSF has provided high quality training and standards that IFRC has used in clinical treatment in Ebola treatment centers. MSF standards are guiding Red Cross volunteers in their implementation work. [1]

International Committee of the Red Cross (ICRC) - helping National Society volunteers and State workers by managing the remains of people who succumbed to Ebola fever to do so in a proper and dignified manner, training health staff to protect themselves and others from infection, upgrading water infrastructure and installing back-up power supply systems, helping State health centers in the country deliver quality preventive and curative care to patients not infected with Ebola, in particular by supporting the creation of disease-prevention teams and by coordinating the speedy referral of Ebola patients and people requiring emergency care with hospitals, drawing up a nutritional protocol for patients to contribute to their recovery, providing household essentials such as bed sheets, blankets, clothing, hygiene items, mosquito nets and tarpaulins for distribution by the Liberia National Red Cross to families of Ebola victims whose belongings were lost when disinfection procedures were carried out.2

American Red Cross – Working to strengthen the capacities of the affected local Red Cross societies including managing the outbreak, assisting with the epidemiological investigation and increasing public awareness about virus prevention.

Canadian Red Cross - Recruiting and deploying qualified and highly trained healthcare workers to support the Red Cross response. The response requires efforts on multiple fronts, including community outreach, contact tracing, surveillance, care for the deceased and case management.

Military – The British and American governments have deployed troops to Sierra Leone and Liberia and, together with German and French governments, have made bilateral commitments to the Governments of Sierra Leone, Liberia and Guinea respectively, and are providing large contingents of medical and logistics army personnel. [1]

African Union – Formation of the African Union's Center for Disease Control and Prevention (CDC) modeled after the U.S.'s CDC which will be charged with coordinating health program development and response to health crisis across the continent. [3] In addition, they are pioneering an Ebola insurance policy package to be added to the African Risk Capacity (ARC), a program that provides protection to states seeking cover against natural disasters, to provide fast-response financing and initial payment once an outbreak is confirmed, plus a contingency fund to provide additional financing to limit the spread of disease.[4]

---

[1] International Federation of Red Cross. "Ebola Strategic Framework." January, 2015.
[2] "Ebola: Stepping up the humanitarian response" International Federation of Red Cross. Setepmber 23, 2014.
[3] Ebola Innovation Summit. San Francisco, CA. April 21, 2015
[4] Hamilton, Charlie. "An Insurance Outbreak." The Africa Report. May 2015.

World Health Organization – Developed an Ebola Response Roadmap, in August of 2014, which had three objectives: 1) To achieve full geographic coverage with complementary Ebola response activities in countries with widespread and intense transmission; 2) To ensure emergency and immediate application of comprehensive Ebola response interventions in countries with an initial case(s) or with localized transmission; 3) To strengthen preparedness of all countries to rapidly detect and respond to an Ebola exposure, especially those sharing land borders with an intense transmission area and those with international transportation hubs [1]

United Nations (UN) – Formation of separate organization, the UN Mission for Ebola Emergency Response (UNMEER) which is aimed at stopping the outbreak, treating the infected, ensuring essential services, preserving stability, and preventing further outbreaks. They have also established the Ebola Multi-Partner Trust Fund to ensure a coherent UN system contribution to the overall response. [2]

United Nations Development Programme (UNDP) – Focused on three priorities: 1) Coordination and service delivery to improve payment delivery to Ebola workers; 2) Community mobilization and outreach to identify cases, trace contacts, and educate people on how the disease is spread and how to avoid contracting it; 3) Socio-economic impact and recovery to assess the development impact of Ebola on fiscal space and development spending, which will be used to inform recovery plans. [3]

Islamic Development Bank (IBD) – Have mobilized 51 million for the Ebola response, including a 35 million donation from the late King of Saudi Arabia. The Bank emphasized the need to align with national plans and harmonize with partners. Its assistance has focused on providing training and improving schools and health facilities.

Working Group on Land Use Change and Disease Emergence - Grew out of a special colloquium that convened international experts in infectious disease, ecology, and environmental health to assess the current state of knowledge and to develop recommendations for addressing these environmental health challenges. [4]

Others –Various academic research institutions and companies are studying the disease and/or developing products ranging from rapid diagnostics tests, and antimicrobial solutions, to mobile surveillance data tools among many others. [5]

---

[1] World Health Organization. "Ebola Response Roadmap." August 28, 2014.
[2] UN Mission for Ebola Emergency Response. EbolaResponse.UN.org.
[3] "Ebola Crisis in West Africa." United Nations Development Programme. UNDP.org
[4] Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J, Wolfe ND, Kilpatrick AM, Foufopoulos J, Molyneux D, Bradley DJ, Working Group on Land Use Change Disease Emergence Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environ Health Perspect. 2004;112:1092–1098
[5] UK Collaborative on Development Sciences. The Ebola Research Database. February 10, 2015.

Annex 2

Annex 2. Summary of Available Ecological Information on Bat Species Hypothesized to be Hosts or Reservoirs of Ebola Virus

Species	Range	Preferred Habitat	Diet	Breeding	Roosting	Other information
Hammer-headed Fruit Bat *Hypsignathus monstrosus*	Forested regions of central Africa from Senegal to northern Angola	Lowland forests (elevations less than 1,800 m), particularly riverine forests, swamps, mangroves, and palm forests	• Frugivore (primarily figs and cultivated fruits) • Considered a crop pest • Males forage long distances (up to 10 km) to locate the highest quality food. • Females rely on regular feeding locations that offer constant supply of lower quality food.	• Typical pattern is semi-annual breeding during the dry seasons • In some populations, breeding is not restricted to dry seasons and occurs year-round • Lek breeders - males cluster in groups (25-130 individuals) at specific locations known as mating arenas	• Fully nocturnal, roosting during the day in the forest canopy • Specific species of trees are not selected for roosting, although preferred roosts are used for long periods of time. • Roosts are generally 20–30 m above the ground	• Common throughout range • Compared with other bats, this bat is long-lived with an average life expectancy of thirty years in the wild • Regularly consumed as bushmeat • Asymptomatically infected with the Ebola virus
Franquet's Epauletted Bat *Epomops franqueti*	West Africa from Cote d'Ivoire through Niger, Nigeria and Cameroon, south to Angola and Zambia	Found in both forests and open country, relatively low to the ground (4 to 6 m above ground)	Primarily frugivorous, feeding mainly by night on fruit, nectar, and the petals of certain flowers	Semi-annual during dry season, timed to coincide the births with the start of the rainy seasons	• Not fully nocturnal • Roosts in trees and bushes by day while alert and easily disturbed	• Common throughout range • Not gregarious, occur alone or in groups of two or three • At night males perch by night in trees generally a 100 meters or so apart • Regularly consumed as bushmeat • Asymptomatically infected with the Ebola virus
Little Collared Fruit Bat *Myonycteris torquata*	West to central Africa	• Arboreal, occupying forest interior as well as edge • Also observed feeding in farmlands and gardens • Males use wooded	Primarily frugivorous, feeding on fruits of the genus Solanum (numerous cultivated species), also eat bananas and other fruit crops, and flowers of	Year round reproduction	Solitary roosters, although sometimes females roost with their offspring	• Common throughout range • Males migrate to the savannas during the wet season, timed with peak fruiting of shea trees (*Vitellaria paradoxa*) • Asymptomatically infected

		savannas in wet season • Primarily occupy forest canopy	kapok trees and tree beans			with the Ebola virus
Angolan Free-tailed Bat *Mops condylurus*	Much of sub-Saharan Africa, largely absent from the Congo Basin	Savanna habitats (both moist and dry), although sometimes encountered at forest edge and more recently in villages due to habitat loss	Purely insectivorous	Females give birth 3 times per year in synchrony with other females, with timing of pregnancies loosely correlated with rainfall patterns	Roosts in buildings (beneath roofs and overhangs), hollow trees, and rock crevices	• Common throughout range • Social and gregarious, living in large multi-male, multi-female colonies. Group ratios range between 3 and 21 females per male in a harem • Fully nocturnal, leaving their roosts at dusk to begin hunting • Solitary hunters, returning to roosts after feeding • Often roost with another species of molossid bat • Species anecdotally linked to 2014 outbreak and a prior outbreak but no serological evidence exists

Sources: To be inserted

Annex 3

BEHAVIOURAL RESPONSE OF BATS TO FOREST FRAGMENTATION

<u>Forage Availability</u>

Moderate levels of deforestation and forest fragmentation increase spatial diversity within the forest and increase the abundance of early successional plants, many of which produce small amounts of fruit over an extended period, rather than a seasonal boom. Consequently, moderate deforestation and/or fragmentation may increase overall food availability for certain bat species and contribute to higher reproductive rates and abundances for frugivorous bats that exploit early successional and understory fruiting plants. Further to this point, a study of breeding behaviour in bats within fragmented and non-fragmented landscapes showed that a large number of bat species in fragmented forested areas maintained continuous (year-round) breeding activity as opposed to seasonal breeding (Estrada, 2002). Year-round food availability in the highly variable fragmented landscape is thought to increase fecundity in populations in fragmented landscapes compared with intact ones.

An additional behavioural advantage that some bats possess is the capability of foraging in various strata of the vegetation (e.g. understory and canopy). This flexibility may allow these species, in contrast to other bat species with more specialized foraging requirements, to take advantage of the diversity of opportunities present in fragmented landscapes. Other species may prevail under fragmented landscape conditions as a result of their preference for edges and/or more open habitats than those offered by non-fragmented forest. The presence of high concentrations of plant species of the genera Piper and Solanum at the edges and interior of small forest fragments, and at the edges and more open areas in the habitat mosaic, may benefit frugivores that specialize on fruits from these genera.

Shade cocoa and coffee plantations are often used as stepping stones or even as preferred habitat by some bat species in heavily fragmented landscapes with little remaining natural forest. These plantations generally have higher bat abundance and species richness, total captures, and capture frequency than other modified habitats, probably because shade crops retain vertical stratification and multiple forage options, providing a more complex habitat than other modified areas. The canopy trees that shade the cacao and coffee shrubs provide day roosts for some bat species, a protective cover for flying bats and, together with the herbaceous plants, offer food resources that attract frugivorous and nectarivorous bats (Faria and Baumgarten YEAR?). As such, shade plantations may increase connectivity among forest fragments and allow more bats and more bat species to co-occur in these habitats than in other disturbed portions of a fragmented landscape.

Little evidence of fragment-size effects on bat species richness and capture frequency has been found (Estrada et al, 1993; Schulze et al, 2000; Faria 2010). Small and large fragments in various studies showed similar species richness and bat capture frequency. In fact, bat assemblages in small mature stands usually include species commonly associated with continuous and well-preserved forest (Fenton et al, 1992; Medellin et al, 2000). This study among others suggests that specific attributes of a given forest fragment such as maturity, plant species diversity, structural complexity, and vegetative density likely have a more significant role in dictating the level and type (transient vs. resident) of use by bats (Eveyln, Bernard, Faria, Ripperger, Kalko YEARS?) than fragment size or configuration.

Movement Patterns

Bat tolerance to habitat loss and fragmentation is likely to be related to their ability to traverse open areas to reach other forest fragments or other vegetation types, and to use resources within the habitat matrix (Estrada and Coates-Estrada, 2001; Law et al, 1999; Schulze et al, 2000). There is a negative relationship between the sensitivity of species to habitat fragmentation and the body size of individuals. Large species are more prone to exploit more isolated fragments or "habitat islands" than small species and body size is positively correlated with the size of activity range in some bats (Fleming et al, 1972). Forest fragmentation could then naturally select for some of the largest bat species (typically fruit bats), which are more able to use isolated forest patches than smaller bats because of their larger activity range (Cosson, 1999).

Individually, forest fragments may be unsuitable for holding large populations of bats, but collectively they may support, as a result of their close spatial proximity, a large bat population and a large array of bat species in the local landscape (Estrada et al, 1993). Small forest fragments are thought to be used as stepping stones by bats en route to larger fragments or other preferred habitats. In one study, high recapture rates among widely dispersed forest fragments documented that individual bats regularly travel variable distances across the open landscape. Species probably differ in the scales at which they interact with the environment because of differences in their mobility, habitat requirements, and life-history characteristics (Kotliar and Wiens, 1990; Andren, 1994; With and Crist, 1995).

Roosting Requirements

Roosting habitat may be a limiting resource for some bat species that have specialized roost requirements. Unfragmented primary forests contain mature and dead trees that provide roosting refugia in tree hollows and foliage that are not present elsewhere and therefore can be population limiting for species that have very specific roost requirements and are not adaptable to other roost types (e.g. human structures, roofs, etc.) (Kunz and Lumsden, 2003).

For other species that are more generalized in their roosting requirements, availability of roosting sites does not seem to play a crucial role in population regulation. Many fruit bats have very generalized roosting requirements and can exploit caves, tree cavities, foliage, and anthropogenic features probably as a function of their occurrence in the environment and so are not limited by availability of roost sites (Kunz, 1982).

It is important to recognize that these features are all interconnected (landscape composition influences forage availability which in turn influences roosting behaviour, etc.) and so cannot be considered in isolation. For example, canopy frugivores (e.g. Artibeus) can travel long distances in search of ripe fruits, minimizing the influence of landscape configuration on abundance and increasing the area within which they can roost, whereas understory frugivores (e.g. Carollia and Rhinophylla) often roost at sites that are close to multiple feeding areas in closed canopy forest as well as in other habitats (i.e. secondary forest and abandoned fields)

Recommendations for additional research into the Ebola virus reservoir host

Many avenues could be used to further and more intentionally assess the potential linkages among forest fragmentation, host behaviour, and EVD outbreak events. In addition to the recommendations for additional research in Section 4, there are numerous other topics that require better understanding, including but not limited to:

- Field studies, including both observational and experimental studies, should be conducted to learn more about the behaviour of potential bat hosts and their specific responses to different aspects of fragmentation and how those responses may relate to human exposure and transmission of the Ebola virus.
- The role of bats in African forests needs to be better understood in order to predict how changes in bat populations and bat behavior will affect future forest regeneration across the landscape.
- Further research is needed to understand how ecological features of a forest, forest composition, and spatial dynamics of forest fragments interact to influence bat behavior and presence.

Annex 4

REFERENCES

Bausch DG, Schwarz L (2014) "Outbreak of Ebola Virus Disease in Guinea: Where Ecology Meets Economy" PLoS Negl Trop Dis 8(7): e3056. doi:10.1371/journal.pntd.0003056

Calvignac-Spencer, Sébastien; Schulze, Jakob M.; Zickmann, Franziska and Renard, Bernhard Clock "Rooting further demonstrates that Guinea 2014 EBOV is a member of the Zaïre lineage" PLoS Curr Outbreaks doi: 10.1371/currents.outbreaks.c0e035c86d721668a6ad7353f7f6fe86 (2014) http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4073806/?report=printable

Deutsch, Mike. (2009). Status Report on the Bakoun Forest Reserve Republic of Guinea, West Africa. http://www.frameweb.org/adl/en-US/4276/file/584/Bakoun_Study_Report_2009-1.pdf

Jones, Kate E., Patel, Nikkita G, Levy, Marc A., Storeygards, Adam, Balks, Deborah, Gittleman, John L., Daszak, Peter. "Global trends in emerging infectious diseases" Nature 451, 990-993 (2008) doi:10.1038/nature06536 http://www.nature.com/nature/journal/v451/n7181/full/nature06536.html

Karesh, William B.; Dobson, Andy; O Lloyd-Smith, James; Lubroth, Juan; Dixon, Matthew A.; Bennett, Malcolm; Aldrich, Stephen; Harrington, Todd; Formenty, Pierre; Loh, Elizabeth H; Machalaba, Catherine C; Jason Thomas, Mathew; Heymann, David L."Ecology of Zoonosis: natural and unnatural histories" The Lancet, Volume 280, Issue 9857, Pages 1936-1945 (2012) http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(12)61678-X.pdf

Leroy E.M., Kumulungui B, Pourrut X, Rouquet P, Hassanin A, et al. (2005) Fruit bats as reservoirs of Ebola virus. Nature 438: 575– 576.

Mylne, A, *et al.* (2014) A comprehensive database of the geographic spread of past human Ebola outbreaks. Scientific Data 1:140042, doi: 10.1038/sdata.2014.42

Ng S, Basta NE, Cowling BJ. Association between temperature, humidity and ebolavirus disease outbreaks in Africa, 1976 to 2014. Euro Surveill. 2014;19(35):pii=20892. Available online: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=20892

Pinzon JE, Wilson JM, Tucker CJ, Arthur R, Jahrling PB, Formenty P. Trigger events: enviroclimatic coupling of Ebola hemorrhagic fever outbreaks. Am J Trop Med Hyg. 2004;71(5):664-74. (2004)

Almudena Marí Saéz *et al. "***Investigating the zoonotic origin of the West Africa Ebola outbreak" EMBO Molecular Medicine Vol 7, No 1, (2015) http://onlinelibrary.wiley.com/doi/10.15252/emmm.201404792/pdf

Morse, S. S., Mazet, J. A. K., Woodhouse, M., Parish, C.R., Carroll, D., Karesh, W.B., Daszak, P. (2012) **"**Prediction and prevention of the next pandemic zoonosis" Lancet 2012; 380: 1956–65. Lancet, 380(9857) 1956–65. doi: 10.1016/S0140-6736(12)61684-5 http://www.ecohealthalliance.org/writable/publications/zoonoses3.pdf

Ng S, Basta NE, Cowling BJ. Association between temperature, humidity and ebolavirus disease outbreaks in Africa, 1976 to 2014. Euro Surveill.

2014;19(35):pii=20892. Available online:
http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=20892

Pigott *et al.* "Mapping the zoonotic niche of Ebola virus disease in Africa" eLife 2014;3:e04395. DOI: 10.7554/eLife.04395.
http://elifesciences.org/content/early/2014/09/05/eLife.04395

Quammen, David. Spillover: Animal infections and the next human pandemic (2012)

Sayer, J. A., A. Green, and D. Bourque. 1992. "Benin and Togo." In J. A. Sayer, C. S. Harcourt, and N. M. Collins (eds.), *The Conservation Atlas of Tropical Forests: Africa* (IUCN and Simon & Schuster, 1992)

USAID, Guinea Biodiversity and Tropical Forests 118/119 Assessment (2007)
http://pdf.usaid.gov/pdf_docs/PNADK880.pdf

Wolfe *et al.* "Deforestation, hunting and the ecology of microbial emergence"Global Change & Human Health, volume 1, no. 1 (2000)
http://www.jhsph.edu/research/affiliated-programs/walter-reed-johns-hopkins-cameroon-program/documents/Papers/Wolfe5.pdf