Ebola Virus Disease and Forest Fragmentation in Africa

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

Contents

Executive Summary

Ebola Virus Disease (EVD): preparedness versus prevention

The current outbreak of EVD in West Africa had, as of August 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. In October 2014, the World Bank predicted that the economies of Guinea, Liberia and Sierra Leone could lose an estimated US$1.6billion in economic activity during 2015. The cost of the global response to the crisis has already run into billions of dollars, and the wider socio-economic impacts of this crisis will no doubt be felt for many years to come in the three worst-affected countries.

These countries and the global community are preparing to respond more effectively to future outbreaks of EVD after they occur, but there has been little discussion about reducing the risk of future outbreaks before they occur. However, with better comprehension of the factors that increase the risk of animal-to-human transmission of the Ebola virus, it should be possible to reduce the likelihood of new outbreaks.

To understand the countries and populations potentially at risk of future EVD outbreaks, Pigott *et al* (2014) re-evaluated the zoonotic niche for EVD in Africa, based on some broad assumptions, finding 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[i] and in those for which strong environmental suitability for outbreaks is predicted. However, they did not investigate the specific conditions in which index cases actually occurred.

This report summarises research conducted into the possible effects of forest fragmentation in increasing the risk of an outbreak of Ebola virus disease (EVD) in humans. The report assesses this in relation to knowledge of forest and land management in Guinée Forestière, bat ecology and the plans for post-EVD economic recovery for Guinea, Liberia and Sierra Leone. It is written for a non-technical, generalist audience - in particular policy makers planning post-EVD recovery and donors supporting research into emerging infectious diseases (EIDs), both of whose decisions may be influenced by this study's findings, which suggest that a specific range of forest fragmentation values correlates with a number of EVD outbreaks in humans.

Evidence versus myth

When the West African EVD outbreak began, important research on zoonotic diseases had already been underway as part of broader efforts to understand EIDs and emerging pandemic threats.[ii] Changes in land uses and vegetative cover had been widely hypothesised as significant contributing factors to EIDs, but little research had documented instances of the links.

With the swift and terrifying spread of EVD across Guinea, Liberia and Sierra Leone in 2014-15, wide-ranging but unsubstantiated, sometimes ideologically charged, hypotheses were proposed in scientific literature and especially the popular press. Evidence-based explanations had not had time to emerge.

Forest fragmentation conditions for the transmission of the Ebola virus to humans

This report advances one part of the evidence-base regarding the forest conditions in which EVD index cases appeared. It investigates the hypothesis that human activity in tropical African rainforests and the resulting loss, regrowth and fragmentation dynamics of forested landscapes create conditions favourable to the transmission of the Ebola virus from its reservoir host[iii] into the human population. The research focusses on the current outbreak in West Africa and six historical cases in Central Africa. For each, land-use and

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[i] Index case refers to the initial transmission of the virus from an animal host into the human population.
[ii] See for example https://www.usaid.gov/news-information/fact-sheets/emerging-pandemic-threats-program.
[iii] A reservoir host is a species that carries the pathogen while suffering little or no illness.

vegetation-cover trends were mapped surrounding the index case location and analysed for common patterns or trends which could indicate the interface required for transmission of the Ebola virus to humans from wildlife, and from bats in particular, which are hypothesised to be the reservoir host of the Ebola virus, or at least to play a part in its transmission.

The report looks also at how international donors and the governments of Guinea, Sierra Leone and Liberia currently prioritise 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. The study does not focus on ways to reduce the human-to-human transmission of this disease, which depend largely on social factors. This is a very important issue and is being looked at by a number of other organizations.

Findings

The index case for the West African EVD outbreak occurred in the village of Méliandou, located in Guéckédou Prefecture, Guinea. This region is covered in a dense, dynamic mosaic of spontaneous and managed forest types at various stages of succession, overwhelmingly influenced by human intervention. Few large blocks of forest remain in Guinée Forestière that have not been subjected to significant, recent human manipulation. Based on inference from studies of the large forest blocks, the forest-mosaic landscape in which the Méliandou outbreak occurred is significantly different from the other nearby blocks in terms of forest composition, structure, ecological functions and the wildlife present.

Analyses of satellite imagery between 1986 and 2014 revealed that the broader landscape around Méliandou experienced an overall net increase in forest cover of 0.9 percent. However, the immediate vicinity of Méliandou experienced a 12.5 percent net loss in forest during the same period. Furthermore, there were significant gains and losses in each area, indicating dynamic vegetative cover and forests at various stages of succession and subject to different degrees of human influence.

Modelling results followed by FRAGSTATS analyses revealed, tentatively, that a specific configuration of forest-fragmentation parameters correlated with six out of seven of the case studies analysed in this report. Specifically, EVD outbreaks in humans occurred in locations with high Shannon Diversity Index[iv] (SDI) values but low connectance[v] 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, and as forest patches become more isolated from one another, the risk of EVD outbreaks increases.

Bats are thought to be the likely reservoir host of the Ebola virus. Studies document 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. With forest fragmentation, 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 the remaining forest patches, where the risk of disease transmission between bats, other wildlife and humans entering these patches, increases dramatically.

Bats may not be the Ebola virus reservoir, or the reservoir from which humans are infected. They may be part of a more complex system of reservoirs and transmission chains between wild reservoirs and humans. However the forest fragmentation conditions, dynamics of forest loss/gain and mixes of successional forest stages analysed for bats could be

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[iv] SDI measures the even distribution of forest and non-forest patches in a landscape

[v] Connectance is defined by the number of functional joinings between forest patches of the corresponding patch type. A decrease in connectance indicates that forest patches are becoming more isolated from one another

conducive to other species and species assemblages, so when these species come into contact with each other and humans, human infection becomes possible, especially if particular environmental stresses are present. Such stresses could include reduced availability of food and nutrition, extreme climatic conditions, reduced shelter (like roosts or burrows) and increased competition, all of which could result in compromised immunological systems in wildlife and humans.

Post-EVD crisis recovery

Recovery plans for the EVD crisis justifiably emphasise strengthening health-care systems first and foremost. However they treat the next outbreak as "inevitable" with limited focus on finding ways to reduce the risk of the virus spilling into the human population in the first instance. In parallel, these plans focus economic recovery on a 'business-as-usual' approach, underpinned by a classic model that approaches sectors too much in isolation from one another so that, for example, potential impacts of agricultural or road development on forests and wildlife, and related zoonotic risks, may not be considered. This could end up undermining the fundamental objective of the recovery effort.

Recommendations and next steps

Improving forest and landscape management, and reducing risks of zoonotic EIDs, will not be resolved by isolated forest or wildlife-management projects. However without knowing the factors that increase the risk of Ebola virus transmission from wild host to humans, it would be unwise to make sweeping or specific recommendations. The causes of EVD outbreaks in humans are probably multiple; forest fragmentation is likely a significant factor, but not the *only* significant factor, combining with forest-succession dynamics, zoological and epidemiological factors, and possibly enhanced by cultural and economic elements.

EFA and the ERM Foundation recommend:

1. An **interdisciplinary focus group** should review existing knowledge about how land uses and forest fragmentation influence zoonoses, and identify appropriate, further questions to ask to solve the puzzle of what promotes Ebola virus transmission to humans. The group would serve as advisor and a 'reality check' for policy-makers so they may be properly informed and not act on speculation, hyperbole or untested ideologies. The group would also make recommendations how to apply a precautionary approach within current economic recovery plans to reduce the risk of future outbreaks.

2. The actors involved in planning economic recovery in the post-EVD crisis period should **integrate natural resources management and environment as core evaluation criteria into their programs**, and not treat them as box-ticking exercises, or consider their job done by funding an isolated, sector-specific 'forest and wildlife management' project with no structural links to other interventions. Current impact assessment and environmental and social safeguards have not always been adequate. Landscape-level planning, leading practice in impact assessment and independent, specialist reviews of sectoral plans are starting points.

3. **Large forest blocks should be protected from fragmentation within a landscape** so that wildlife-human contact is minimized, and that conditions are avoided for unusual species assemblages that increase the risk of transmission of the Ebola virus from its natural reservoir(s) to new host species including humans.

4. **The causal links between forest fragmentation, Ebola virus hosts and hosts' behaviour, and EVD outbreaks in humans should be assessed further** along with virological and immunological studies.

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 the United Kingdom, 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 works 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 advocacy, 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 United Kingdom and Ireland.

1. Introduction

As of mid-2015, the global response to the current outbreak of EVD in West Africa had focused 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, much discussion and reflection have focused 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 by avoiding transmission of the virus to the human population.

Apart from the emphasis on strengthening health-care systems, the majority of attention in post-EVD, economic recovery plans focusses on rebuilding the affected nations' 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 5). It is in response to a 'business as usual' approach that this report was prepared.

Research on emerging infectious, zoonotic diseases

Prior to the West African EVD outbreak, significant inter-disciplinary research had begun into emerging infectious diseases and pandemic threats. The research landscape included investigations of wild and domesticated faunal reservoirs of zoonotic pathogens involving virology, bacteriology, immunology, ecology, zoology, transmission pathways, geographic information systems (GIS), human interaction with animals and more. This information has been brought together in zoobiotic and risk-mapping exercises for certain diseases –see Morse *et al*. (2012) and Pigott *et al*. (2014), for example – although the complexity and inter-disciplinary nature of the problem make this a long-term research proposition.

With the current West African outbreak, the world has wanted to understand why in south-eastern Guinea, and why in December 2013? The desire for immediate answers has accelerated at times, and sometimes trumped, the systematic, scientific inquiry underway.

Slash-and-burn agriculture in Guinée Forestière

A frequent hypothesis in the literature on zoonotic diseases is that changes in vegetative cover, often associated with intensified and/or new land uses, are a (significant) contributing factor to the transmission of a zoonotic pathogen from a wild host to a human index case. The reasons behind this environmental trigger are not demonstrated, however, and appear to be based mainly on intuition and logical deduction. Forest loss or fragmentation, accompanied by hunting and the trade in bushmeat – e.g. Bausch and Schwartz (2014) and Wallace (2015) – drive contact between humans and wild reservoirs and lead to infections. In certain instances, particular EVD outbreaks in forested areas have been traced to infected bushmeat, possibly facilitated by penetration into formerly remote forests. The Ebola virus has been found in carcasses of dead, wild animals; see Leroy *et al*. (2004), Nkoghe *et al*. (2011) and Rouquet *et al*. (2005). However the hypothesis that bushmeat is a likely source of index-case infections does not appear borne out empirically, at least in the current West African outbreak (see Saez *et al*. (2014).

The current West African EVD crisis has been surrounded by conspiracy theories. Citizens of the three most-affected countries have attributed it to black magic, foreign organ-snatchers, deliberate and politically motivated genocide targeting ethnic groups from the opposition, and much more. Internationally, in particular in the popular press, it has been described as the tragic outcome of inhumane, neoliberal capitalism and the greed of a corrupt, political elite that combine to drive poor people ever further into dwindling forests and into contact with wild reservoirs of zoonotic pathogens, or that permit opportunistic hunters to come into contact with the same.

Without an evidence base to prove or disprove such theories, they will likely continue to propagate themselves, like the Ebola virus, from person to person. In the absence of evidence-based debate, policy-makers are well advised not to act on speculative hypotheses but to apply caution and focus on preparedness to respond to the next outbreak.

The focus of this report

This report seeks to advance one part of the evidence base regarding the forest conditions in which EVD index cases appeared. It investigates the hypothesis that human activity in tropical African rainforests and the resulting transformation, especially loss, regrowth and fragmentation dynamics of forested landscapes, 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 case, 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 hypothesised to be the reservoir host of the Ebola virus, or at least to play a part in its transmission.

The report looks also at how international donors and the governments of Guinea, Sierra Leone and Liberia currently prioritise 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.

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 is being looked at by a number of other organizations.

2. Zoonotic pathways and mechanisms

Introduction

Zoonoses are diseases or infections that are naturally transmissible from animals to humans. 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.[vi] 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 EID. 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 change 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. In 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 requires the construction of roads into formerly inaccessible forests, increasing the diversity of habitats in these forests, the wildlife that can exploit them, the contact between species within a given area[vii], and the ability of humans to come into contact with this wildlife.

Hunting is widespread in African forests in subsistence as well as industrial contexts. It radiates in a circular fashion outwards from 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 fragmented by roads serve to increase the interface between humans and vertebrate diversity in forested regions, which is likely to increase the frequency of human-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 (see Wolf *et al,* 2000).

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

[vii] This is known as the '**chorotype**', defined as the group of species whose distribution in space overlap more than expected at random.

The Ebola Virus

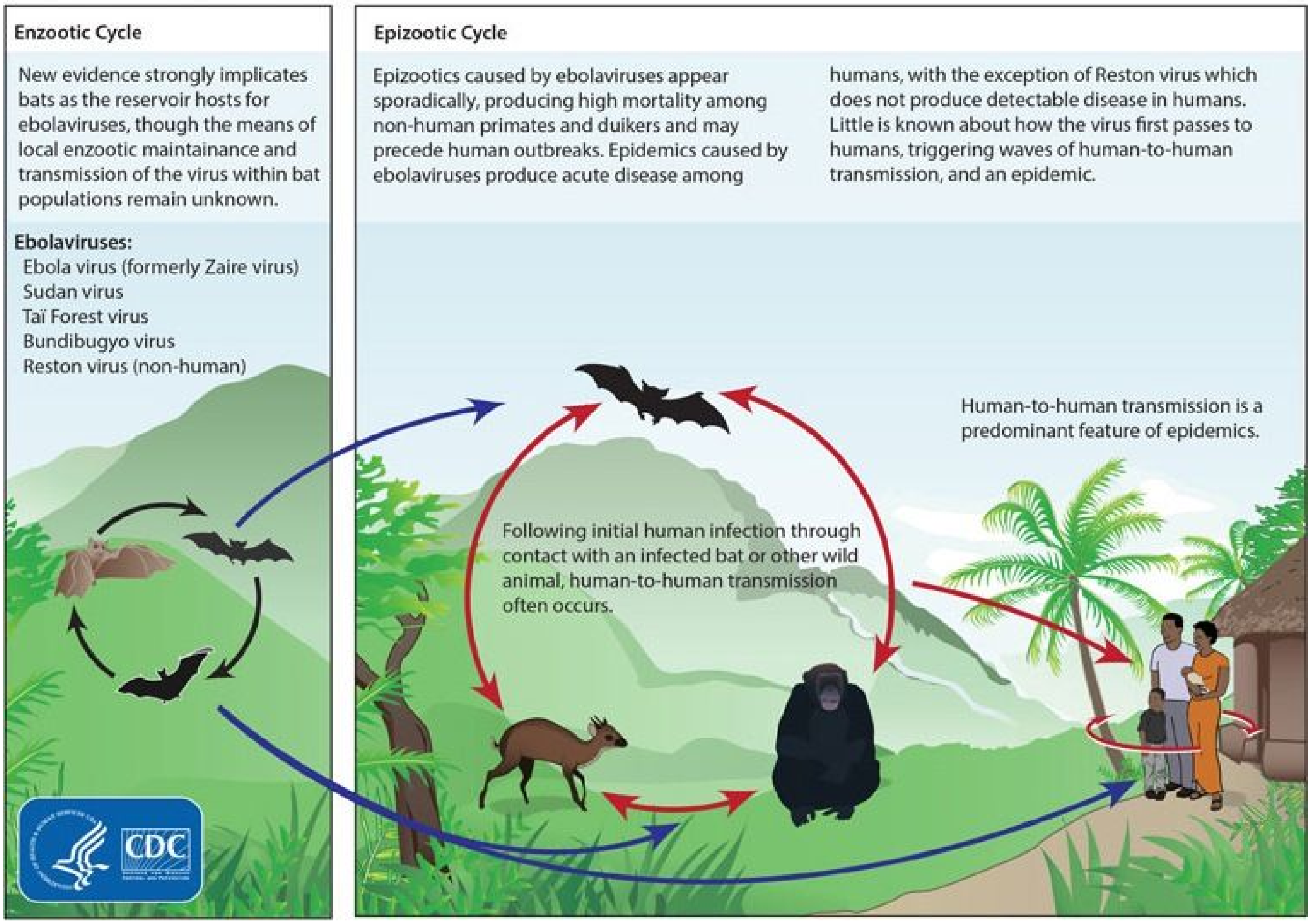
EVD is a complex zoonosis that is highly virulent in humans. The first recorded outbreak of EVD was in Zaire (now the Democratic Republic of Congo (DRC)) in 1976. During the past 39 years there have been numerous outbreaks with fatality rates ranging from 50 percent to 90 percent (see Table 1). The current 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, but it is nevertheless thought to have started from a single transmission, or "index case".

Wild animals are killed and frequently smoked in the forest, then sold in urban areas

The Ebola virus has not yet been isolated but limited evidence suggests bats could 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.*, 2005). 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 1). 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 strong environmental suitability for outbreaks is predicted.

Figure 1: Ebolavirus ecology



Source: Centers for Disease Control and Prevention (CDC)

Table 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

The 2013/14 outbreak of Ebola virus disease in West Africa and local land uses, subsistence patterns and forest management

Research undertaken at the location of the 2013/14 outbreak in Méliandou, 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,* 2014). The index case is believed to have been a 2-year-old boy from Méliandou 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 considered an unlikely source of the disease, too, 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.

Local residents in Méliandou reported an unusually long and arid dry season in 2013. Assuming bats are part of the transmission chain of the Ebola virus to humans, more research is required to understand if these drier ecologic conditions might have influenced the number, location or behaviour of Ebola virus-infected bats, the frequency with which they came into contact with other animals (wild or domestic) and humans, and/or bats', humans' and other animals' susceptibility to infection due to abnormal stresses or other factors.

Bausch *et al* (2014) examine why the current outbreak in West Africa occurred in this location – Méliandou, Guéckédou Prefecture, Guinée Forestière – at a time when no previous cases of EVD had been recorded in West Africa. They claim that the Guinée Forestière region, and the needs of its people, had been neglected for many years and its forests plundered to the extent that little forest remains as people are forced to convert remaining forests to survive. Notwithstanding the relative economic neglect of Guéckédou Prefecture for decades, Bauch *et al.*'s explanations are contradicted by authors like Fairhead and Leach (1996) who describe how villagers in Guinée Forestière actively manage forest in their territories, maintaining a constant dynamic of agricultural fields, regenerating fallow and forest. Fairhead and Leach assert that rural villagers' practices promote forest cover rather than lead to forest loss.

This last theory has its critics, too. Thus it is unresolved whether there has been net loss or net gain in forest cover in Guéckédou Prefecture over the last century. However local land-use is undeniably dominated by a pattern of subsistence farming in which small patches of forest are cleared and farmed for a few years, after which they are generally abandoned and left fallow, although tree crops (e.g. wild palm oil) may be harvested from them for many years to come. When abandoned, fallow fields regenerate in successional stages, sometimes referred locally as low bush, high bush and finally high forest. At any stage in this succession, a farmer may return to the area, slash the vegetation, burn it and replant crops. The longer a farmer waits, generally the more fertility and beneficial structural properties are restored to the soil. On the other hand, the longer the farmer waits, the more labour or equipment is required to cut the area, which can be severely limiting locally, so much that mature forest is frequently not a farmer's first choice to clear.

Thus, the theory of subsistence farming and the rural poor penetrating inexorably into retreating forest frontiers does not appear to portray accurately the relatively populated prefectures of Guinée Forestière. When aided by mechanization such as industrial logging, however, penetration of mature forest has resulted in rapid occupation of newly cleared forest-land in Guinée Forestière such as the case of the Déré Forest (see FFI *et al.* 2002, Wright et al. 2006, and unpublished FFI reports 2003-04 on the Déré Forest).

In combination with the slash-and-burn techniques described above, villagers in Guinée Forestière frequently maintain forested areas nearby villages. These can be for agroforestry-style home gardens for food, medicines and other economically or culturally important species, for sacred groves for cultural purposes, and for other purposes. Further from villages, tree crops like rubber, palm oil, fruits (citrus, mango) and cola nuts are cultivated, as are shade-crops like coffee and cacao, grown under trees.

The landscape of Guinée Forestière can be described therefore as a dense, dynamic mosaic of spontaneous and managed forest types at various stages of succession, overwhelmingly influenced by human intervention. Relatively few large blocks of forest remain in Guinée Forestière that have not been subjected to significant, recent human manipulation; these tend to be in protected areas like the Ziama and Diécké Forêts Classées. From the perspective of faunal diversity, these forest blocks contain species no longer present in the broader landscape (see Wright *et al*. 2006). These forests differ significantly in composition, structure and ecological function from forests in the broader landscape (N'Zérékoré Forestry Centre, unpublished reports).

Differences in forests' composition, structure and function, and the wildlife they contain, are not readily visible from satellite imagery, and calculations of net loss or gain represent only the tip of the iceberg when understanding the diversity and dynamics within what may be classified as 'forest' in imagery analyses. However time-series imagery analyses can help crack the code.

3. Modelling Trends in forest fragmentation

In the absence of evidence-based, forest-cover studies of EVD outbreak locations, and recognising the complexities and limitations of satellite imagery analyses on their own, this research sets out to identify forest conditions that might 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 objective was to look for observable changes in forest fragmentation that correlate with EVD outbreaks, and for common ranges of specific forest-fragmentation parameters within which the risk of Ebola virus transmission to humans seems to increase. The modelling exercise did not investigate the reasons for subsequent human-to-human transmission of the Ebola virus.

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 (i) human population density and dynamics, cultural practices and subsistence activities, (ii) differences in forest types within the landscapes analysed, (iii) weather/climate, (iv) distributions (esp. analyses of chorotypes) of suspected disease-carrying species like bats, other rodents, primates and ungulates, and (v) stresses on humans and animals that might enhance their susceptibility to infections.

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 2 presents a map of all recorded historic, African EVD index cases in humans, and indicates which of these were analysed to identify levels of forest fragmentation and to investigate if a common type of fragmentation correlated with EVD index cases in the 30 or so years up to the outbreak (“time-series cases”) versus only in the year of the outbreak (“outbreak-year cases”). Table 2 lists and provides additional information on each of the selected case studies.

Logging in Guinée forestière

Imagery from the Landsat satellite program was used to classify forest fragmentation in the vicinity of the index cases. The range of Landsat satellites used in this analysis were Landsat 1-5 MSS, Landsat 4-5 TM, Landsat 7 ETM+, and Landsat 8. The common spectral resolution for all Landsat imagery used was 30 meters, which is the maximum resolution of the older Landsat 1-5 satellites. Each Landsat tile covers approximately 34,200 square kilometres, and one Landsat tile was used for each of the EVD index case studies. 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.

Figure 2: Map showing all recorded Ebola index (i.e. outbreak) events in Africa, and those selected for analysis in this study

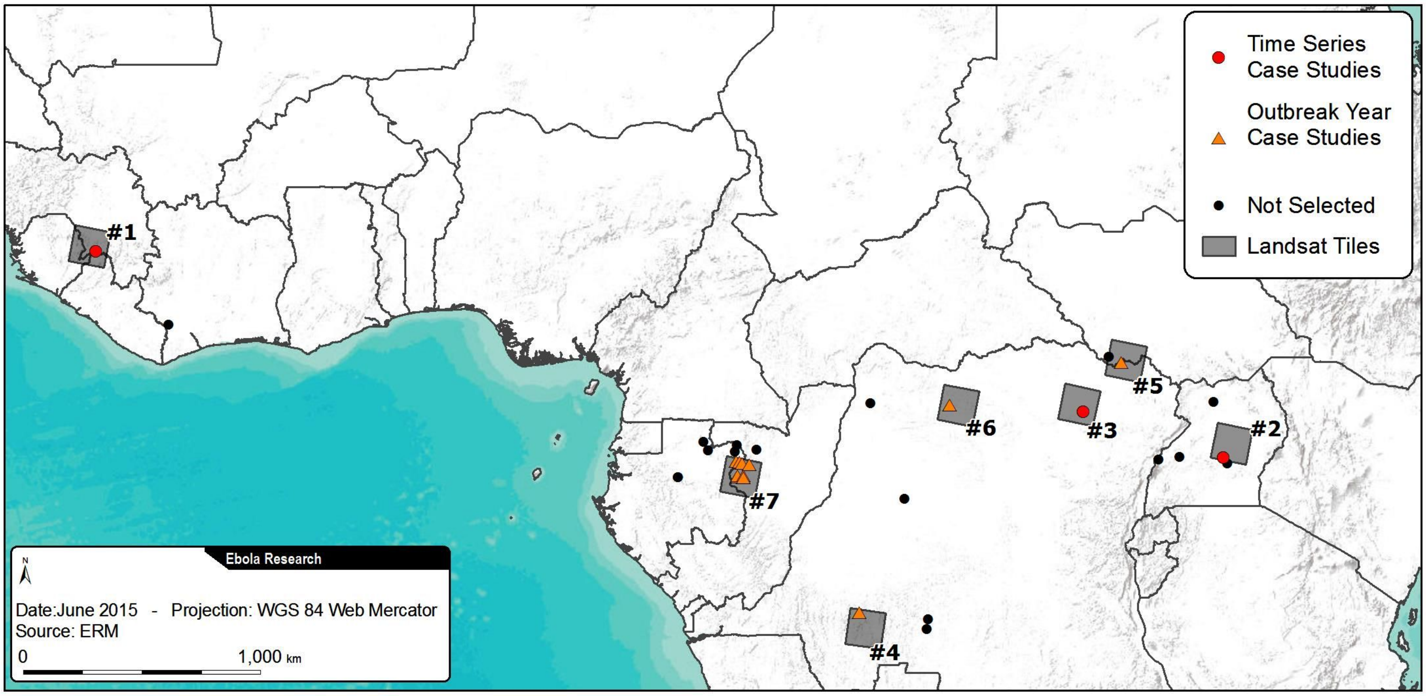


Table 2. List of time-series and outbreak-year index case studies targeted for analysis

Case #	Case study Level	Case Study	Outbreak Years(s)	Ebola Virus Strain	Local Population Density	# of Cases	# of Deaths
1	Time-series	Meliandou Village (Gueckedou Dist.), Guinea	2014	Zaire	Medium	27,505	11,220[viii]
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

Source: Mylne *et al.* (2014)

[viii] 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 cover 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 cover between the year of outbreak and earlier years, then the likelihood of forest cover playing a role in EVD outbreaks in humans would decrease. On the other hand, if a consistent, observable change was found in forest cover between the year of outbreak and earlier years, then the hypothesis that recent changes in forest cover 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 that correlated with EVD outbreaks in humans.

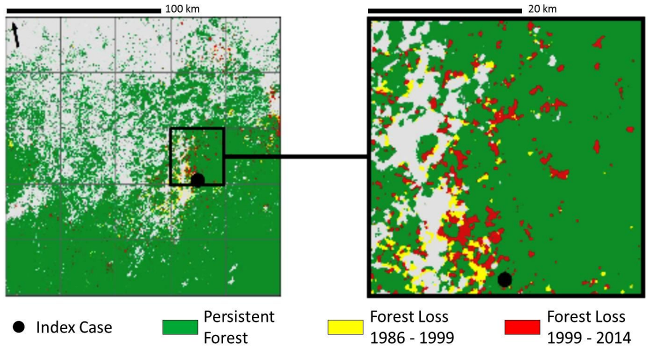
Classification of forest versus non-forest

Classification of forest versus non-forest used the software platform Idrisi on the Landsat satellite imagery. Each case study was separated into twenty-five 1:30,000-scale grids for comparison (see Figure 3). Ideally, the classification effort would have targeted more categories of land cover (e.g. old-growth forest, new-growth forest, barren land, grasslands, etc.), but achieving this level of detail would have required ground-truthing, which was not within the scope of this desk-based effort.

Forest versus non-forest classification was conducted using visual inspection to identify training regions on which Idrisi's supervised classification algorithm was then used to map the remaining landscape. Forests were defined by areas of groups of trees, not small shrubs or wetlands. In some case studies, areas of forests were easily recognizable, but in others it was difficult to discern between wetlands or grasses versus forests due to the coarseness of the imagery. In these cases, forests were defined by the areas in which tree crowns were visible and not more than 20 meters from each other. This technique was assisted by modern Google Earth imagery. This forest versus non-forest classification was repeated for the other two time-series case studies. The outbreak-year case studies were analysed for forest cover in the same way, but not for changes across time.

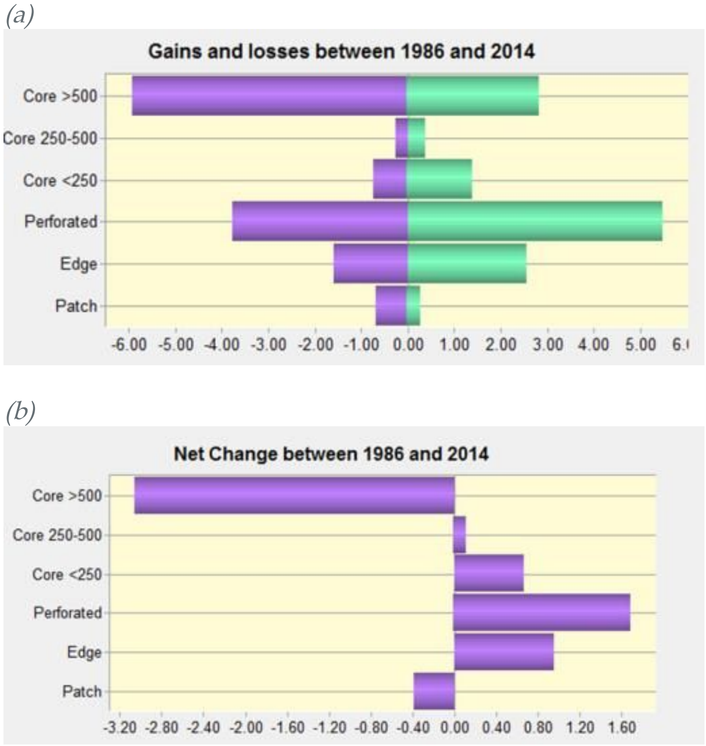
With the classification of forests at 15-year intervals, it is possible to investigate forest-cover changes over time. Figure 3 shows a traditional interpretation of land-cover change, presenting only forest loss from 1989 to 2014 both across the entire Landsat imagery tile (185 km X 185 km) and at the location of the Méliandou outbreak in Guinea in 2014 (37 km X 37 km). The overall study area shows a 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.

Figure 3: *Example of forest classification from "time-series case study 1" (2014, Méliandou village, Guinea)*



Change in forest cover is not, however, a unidirectional phenomenon: there are both gains and losses over time. Figure 4(a) displays overall gains and losses of different forest patch types between 1986 and 2014 in the 37 km X 37 km cell around Méliandou, which were calculated using the Landcover Fragmentation Tool (LFT v2.0), published by the University of Connecticut (Vogt *et al.* 2007). The dynamic nature of change in different sizes of forest blocks is apparent from this figure. For example, forest blocks greater than 500 acres, equivalent to 180 hectares (see ***Core >500*** in Figure 4a), gained in some areas between 1986 and 2014, but overall, large forest blocks lost more area than they gained. As seen in Figure 4(b), analysing net change in forest patch types between 1986 and 2014 reveals that there were substantial losses in large blocks of forests (see **Core >500** in Figure 4b) and observable gains in small to medium sized forest blocks, perforated forests and forest edge. Overall there was a modest net gain of 0.9% in forest cover across the entire Landsat tile over the 30 years leading up to the 2014 Méliandou outbreak.

Figure 4: *Graphic representation of gains/losses (a) and net change (b) in forest block size between 1986 and 2014 for the Landsat tile covering the Méliandou outbreak. The* **x***-axis represents percent change; the* **y***-axis shows forest patch type size in acres. One acre is equivalent to 0.36 hectares.*



The values shown in Figure 4 are calculated from the entire 34,200 km^2 Landsat tile covering the 2014 Méliandou outbreak. It does not indicate where gains and losses occurred at a local level. Figure 5, however, presents changes in percent of forest cover at a local level for the three modelled years of the Méliandou outbreak: 1986, 1999 and 2014. Grid cells C4 and D4, the two grid cells that encompass the Méliandou outbreak, experienced an overall decrease in forested area between each of the time-periods analysed:

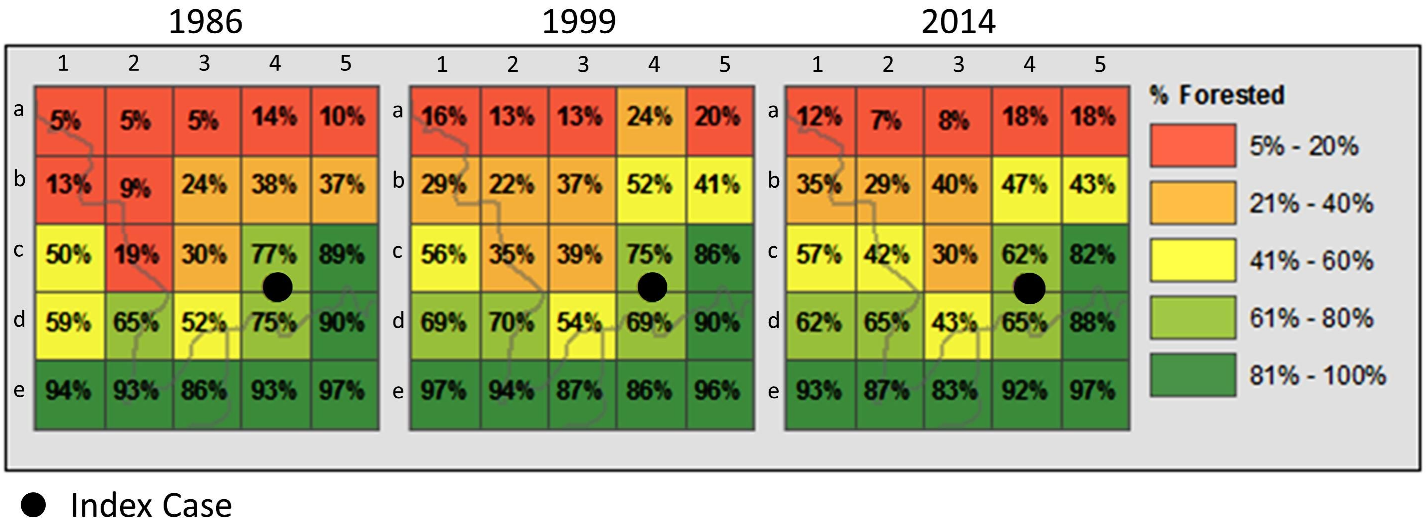
1. **30 years before EVD Outbreak (1986):** 77% & 75% forested – **Avg. = 76%**
2. **15 Year Before EVD Outbreak (1999):** 75% & 69% forested – **Avg. = 72%**
3. **year of EVD Outbreak (2014):** 62% & 65% forested – **Avg. = 63.5%**

Thus the two cells around the Méliandou outbreak, covering 2736 km^2, experienced a 12.5% loss in forest cover over the 30 years leading up to 2014. In comparison to other grid cells in Figure 5, the loss in forest cover observed around Méliandou was unusual when compared to the larger region covered by the Landsat tile. Of the 25 grid cells in Figure 5, 16 grid cells (or 64% of the area) witnessed either a net zero change or overall increase in forest cover between 1986 and 2014. Not including the outbreak grid cells of C4 and D4, seven additional grid cells in the south east of the Landsat tile experienced a net decrease in forest cover which, when averaged, amounted to a 4% decrease in forest cover across that area.

Thus forest cover loss from 1986 to 2014 in the two cells around the Méliandou outbreak – C4 and D4 – was significantly higher than anywhere else in the local landscape.

Quantifying net forest loss is a grossly simplified measurement. It does not allow a nuanced analysis of forest fragmentation, which is only partially a function of forest cover. More importantly, the analysis of forest fragmentation potentially allows identification of a specific fragmentation footprint, i.e. how a forest is spatially distributed, aggregated or organized. Understanding how a forest is fragmented provides potential insights into how EVD reservoir species and the human population may interact in ways that promote transmission of the Ebola virus.

Figure 5: Graphic representation of changes in forest cover percent by grid cell between 1986 and 2014. The black dot is Méliandou, the index case's location.



1986

	1	2	3	4	5
a	5%	5%	5%	14%	10%
b	13%	9%	24%	38%	37%
c	50%	19%	30%	77%	89%
d	59%	65%	52%	75%	90%
e	94%	93%	86%	93%	97%

1999

	1	2	3	4	5
a	16%	13%	13%	24%	20%
b	29%	22%	37%	52%	41%
c	56%	35%	39%	75%	86%
d	69%	70%	54%	69%	90%
e	97%	94%	87%	86%	96%

2014

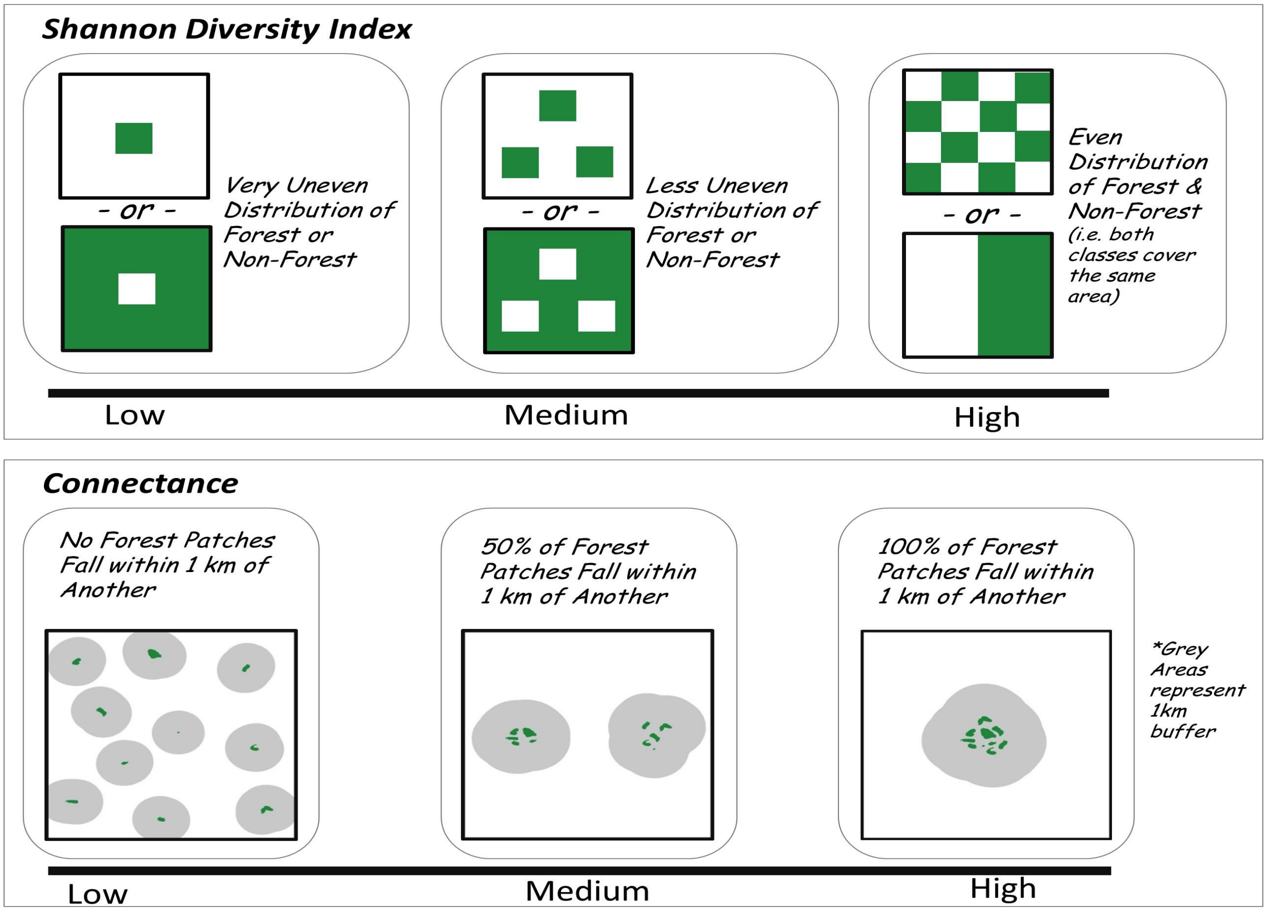
	1	2	3	4	5
a	12%	7%	8%	18%	18%
b	35%	29%	40%	47%	43%
c	57%	42%	30%	62%	82%
d	62%	65%	43%	65%	88%
e	93%	87%	83%	92%	97%

Forest fragmentation analysis

Forest fragmentation metrics were calculated using the program FRAGSTATS. Seventeen analytical metrics were run in FRAGSTATS, namely Shannon Diversity Index (SDI), connectance, contagion, IJI, cohesion, division, mesh, split, PR, PRD, RPR, SIDI, MSIDI, SHEI, SIEI, MSIEI and AI.[ix] All metrics were run on the EVD outbreak grid cell and on another randomly selected grid cell in the larger tile that did not overlap with the EVD outbreak cell. A non-parametric Mann-Whitney test was then run comparing the values of the randomly selected gird cell against the EVD-outbreak grid cell for all 17 FRAGSTAT metrics to identify which had significant differences between the two grid cells. From this analysis, SDI and connectance were identified as having the highest significant differences between the two grid cells, and were retained for further analysis.

SDI measures the proportional 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 even, and decreases as the proportional distribution of forest and non-forest patches is increasingly uneven. For a given number of classes, the maximum value of the SDI is reached when all classes have the same area.

Figure 6: *Graphic representation of connectance and the Shannon Diversity Index*



[ix] See McGarigal 2015 for descriptions on these metrics.

Connectance is defined by the number of functional joinings between forest patches where “functional joining” signifies if each pair of forest patches is connected or not, based on a user-specified distance criterion. Here, forest patch is defined as any type of discrete forested area of any type identified in the Landsat forest vs. non-forest classification, analysed in Figure 4. A standard threshold distance of 1000 meters defined what constituted forest patches that were ‘connected’ versus ‘not connected’: pairs of forest patches that were further than 1000 meters from one another did not have a function joining, while patches that were within 1000 meters of one another did have a function joining. This process was automated for all possible pairings of forest patches. 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.

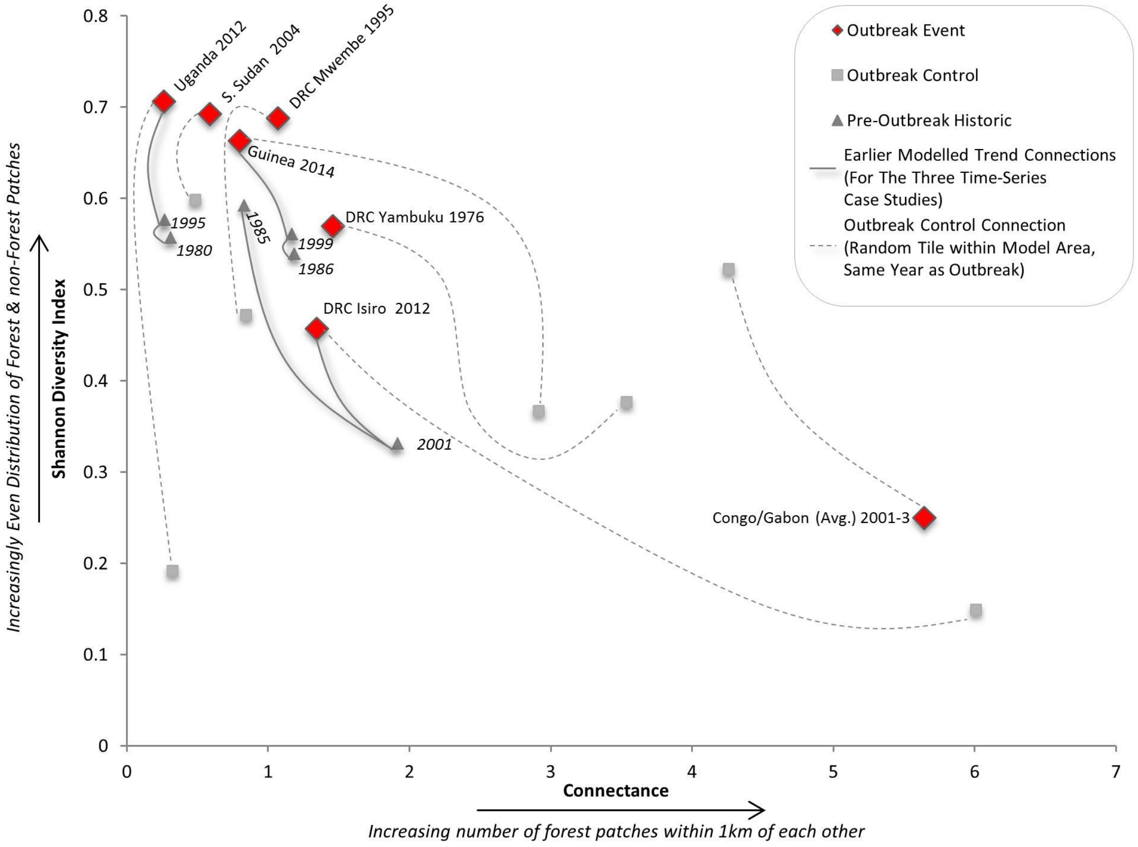
The goal of the FRAGSTATS analysis was to understand trends in these metrics in the 37km X 37km grid in which the index case occurred within the outbreak-location tile, i.e. the overall 185km X 185km tile. Another 37km X 37km grid cell that did not contain the index case was randomly selected from the 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. Due to time constraints, this exercise was conducted only once for each case study, although repeating it would have provided statistical validation (or otherwise) of the uniqueness of EVD outbreak cells within the broader landscape.

Results

Initial results from the modelling suggest that a specific range of forest fragmentation values correlates with several EVD outbreaks in humans (see Figure 7). This is a potentially significant observation and may be a step towards isolating an indicator of where new EVD outbreaks are more likely to occur.

The patterns indicated in Figure 7 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. In total, there is a cluster of six case studies (Uganda 2012, S. Sudan 2004, Guinea 2014, DRC Yambuku 1976, DRC Isiro and DRC Mwembe 1995) that fall within a range of 0.48 to 0.71 Shannon’s Diversity Index and 0.2 to 1.4 connectance.

***Figure 7**: Scatterplot comparing Shannon Diversity Index vs. Connectance*



The Isiro outbreak in the DRC is included in this cluster with some reservation. Fragmentation values of this case study in 1985 had been within a narrower range for the cluster than during the year of the recorded EVD outbreak (2012). This observation could indicate merely that the Isiro outbreak area had a fragmentation pattern in 1985 that placed it at high risk for an outbreak, even if none was recorded until 2012. Regardless, additional investigation is warranted into why the Isiro 2012 case study lies at the edge of the cluster, or if there were errors in the modelling effort or the spatial accuracy of the outbreak location.

The tight cluster of outbreaks in Congo/Gabon between 2001 and 2003 is a significant outlier to the pattern found in the other case studies. This is not unexpected as there are likely several factors that influence where and when an EVD outbreak occurs in humans. Another reason for the outlier is that the accuracy of where EVD index cases were recorded may be poor, or transmission of the virus from wild host to human may have occurred far from where the index case was recorded. It is possible that by incorporating a third metric into this analysis such as contagion (the third-most significant variable according to the non-parametric test explained above), the correlation between SDI, connectance and EVD index cases can be further refined.

However, due to time constraints, incorporating additional variables was not possible for this report.

Figure 7 indicates 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 7 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 7 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 a particular combination of forest-fragmentation values serves as a threshold at which the risk of Ebola virus transmission from an 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 hypothesis of a correlation between locations of EVD index cases and protected areas

Pooley, Fa and Nasi (2015) warn that a state of paranoia could emerge surrounding the wildlife that could harbour the Ebola virus, resulting in demonizing these animals and leading to their persecution or the destruction of their habitat. As cited previously, Leroy *et al.* (2004), Nkoghe *et al.* (2011) and Rouquet *et al.* (2005) all cite EVD outbreaks in humans in which transmission of the virus occurred from large mammals found in large forest blocks. In a pessimistic scenario, this could lead to protected areas being considered reservoirs of the Ebola virus (and other zoonotic diseases) and targeted accordingly. Such a 'guilty' verdict might fit conveniently with the objectives of those who seek to downgrade or declassify protected areas and open them up to other uses.

A supplementary analysis was therefore 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.

Thirty three EVD index-case locations were analysed 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. [X]

[X] www.protectedplanet.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 discernible 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 statistically not more likely to occur within or near protected areas than far from them, and the initial hypothesis appears false.

4. Host behaviour and land-cover trends

Behavioural response of bats to forest fragmentation

Section 2 mentions that certain bat species are hypothesised to be a host reservoir for the Ebola virus. The present section summarizes 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.

It is critical to bear in mind that bats may not be the reservoir from which humans are infected, or they may be merely one part of a more complex system of reservoirs and transmission chains between wild reservoirs and humans. However the forest fragmentation conditions, dynamics of forest loss/gain and mixes of successional stages analysed for bats could be conducive to other species and chorotypes, so that when they come into contact with each other and humans, human infection becomes possible, especially if particular environmental stresses are present.

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. Many other forest taxa and species are largely absent from highly fragmented landscapes. (See Laurance *et al*, 2002; Law and Dickman, 1999; Turner and Corlett, 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 *et al*, 2004; Faria, 2006). 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, 2004). 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 fragmented forest habitats present in a given landscape.

Fruit bats are one of the species hypothesised to be the reservoir host of the Ebola virus

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, 2004). 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 (Peters *et al*, 2006).

In essence, less specific dietary requirements, higher mobility, and generalized roost preferences all facilitate low sensitivity to the 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 1 contains a summary of the available ecological information on the four species that have been hypothesized as hosts of the Ebola virus. 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 its roost sites.

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

The landscape analysis suggests that as the proportional distribution of forest versus non-forest becomes more equal and as isolation of forest patches becomes greater, the risk of Ebola virus transmission to humans increases. Further, the results for two of the three time-series case studies assessed (Uganda 2012 and Guinea 2014) indicate that recent changes in forest fragmentation around the index cases' locations enhanced the fragmentation conditions associated with EVD outbreaks in humans in six out of seven case studies. The Guinean outbreak (2014) was furthermore accompanied by significant changes in forest to non-forest, and non-forest to forest.

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.

As previously stated, 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 shortages, they can be immunocompromised and 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.

As stated earlier, even if bats are not critical to the transmission of the Ebola virus to humans, or if they are only one of several critical vectors in a transmission chain, the factors above could operate on the (other) reservoirs and vectors of the Ebola virus and increase the likelihood of viral transmission to humans.

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

Additional information on bats' foraging, roosting and movement patterns is contained in Annex 2.

5. Post-Ebola recovery planning

Context of the Méliandou EVD Outbreak

As far back as records go, Guinée Forestière's rural population has worked predominantly in agriculture, dominated by subsistence farming, although tree crops have appeared to play increasingly important roles in rural households' incomes over the past decades. Demographic growth, in particular following the return of politically exiled people starting in the mid-80s, and periodic spikes in refugees from neighbouring Liberia and Sierra Leone, affected both urban and rural populations. In this context, rural development priorities focused relatively little on forest and natural-resource management outside of protected areas, but rather on food production, infrastructure, rural credit, health, education and income-generating activities.

In Guinée Forestière in the 1980s and 1990s, the N'Zérékoré Forestry Centre led several initiatives to restore and protect several larger *forêts classées* like Diécké, Ziama, Mont Béro and Pic de Fon. However, forests outside formally protected areas were frequently the object of aggressive, often unregulated, commercial forestry. However by the '00s, most commercial forestry operations had closed and only one industrial forestry company operated, Forêt Forte, pursuing mainly salvage logging of scattered trees in the community-managed, agricultural landscape.

Annex 3 provides more information on donor funding and government policy priorities in Guinea in the years leading up to the EVD outbreak to build up a picture of the conditions in which the transmission of the Ebola virus occurred to a human host. This backdrop might provide additional clues on contributing factors to Ebola virus transmission events.

Widespread awareness campaigns about bushmeat have been part of the responses to the Ebola virus.

Global Response

The overwhelming response to the current EVD outbreak in West Africa has focused on mitigating controls rather than preventative controls - in other words, being better prepared to respond to the next outbreak rather than reducing the risk of it happening. 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. [xi] [xii] [xiii] 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. [xiv]

[xi] Hamilton, Charlie. "An Insurance Outbreak." The Africa Report. May 2015

[xii] World Health Organization. "Ebola Response Roadmap." August 2014

[xiii] UN Mission for Ebola Emergency Response. EbolaResponse.UN.org

[xiv] Ebola Crisis in West Africa" United Nations Development Programme. UNDP.org

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

Almost no efforts focus on preventative controls for future EVD outbreaks. Despite many hypotheses and sometimes speculative and non-evidence-based assertions, without knowing the factors that increase the risk of Ebola virus transmission from wild host to humans, it would be unwise to take sweeping actions. The plan 'Recovering from the Ebola Crisis' (UN, World Bank, EU, AfDB, 2015) makes reference to changing natural resources management and managing the landscape to reduce the likelihood of future outbreaks, but it specifies no tangible measures and recommends no resources for it. Perhaps more importantly, outside of immunologists, almost no one is asking the question: what can be done to reduce the risk of a future outbreak.

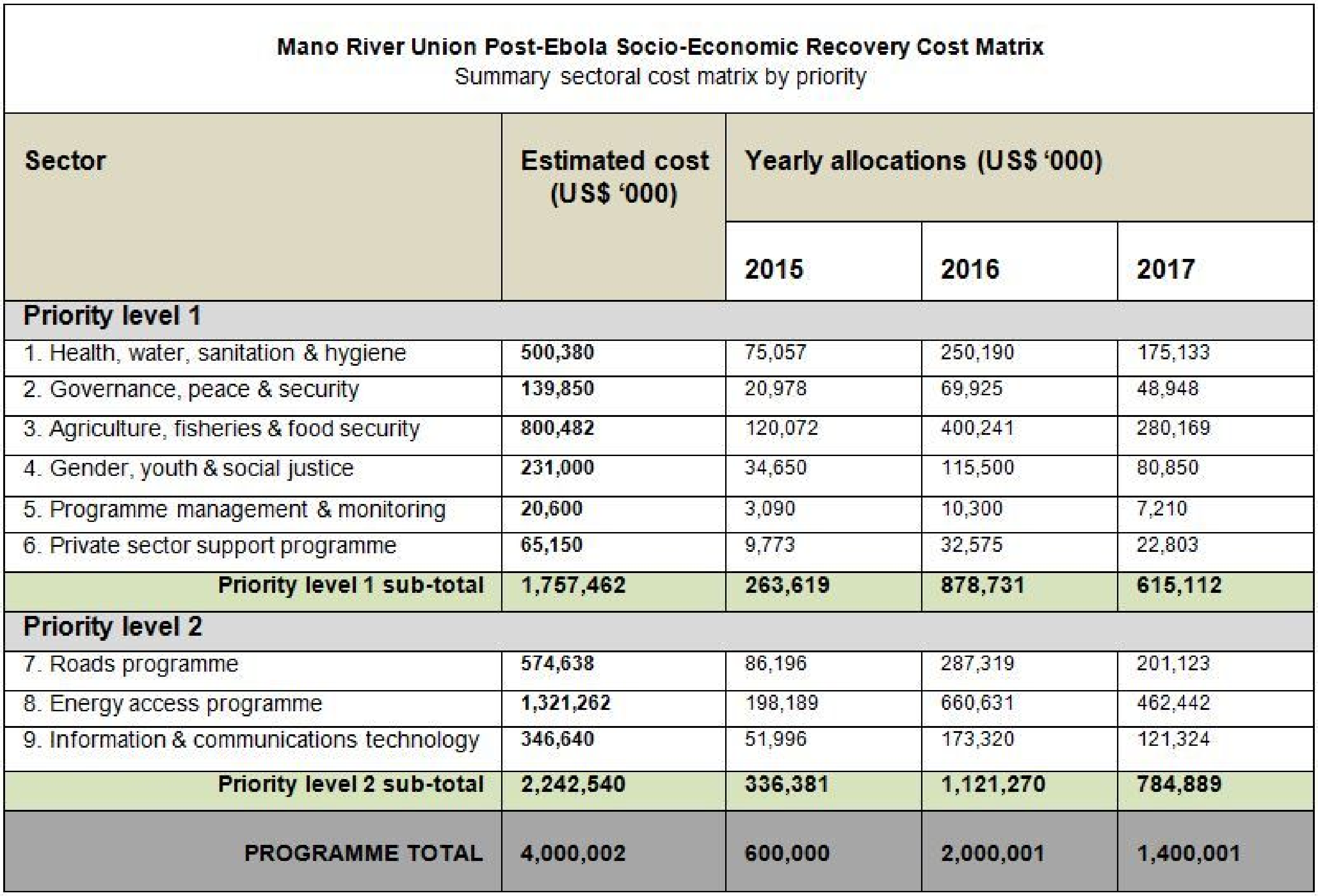
Mano River Union Sub-regional Programme for Post-Ebola Socio-economic Recovery

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 Table 3).

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 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 programmes 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 ways to reduce the risk of future outbreaks of EVD or for any environmental protection measures that could support this.

[xv] Recovering from the Ebola Crisis: A summary Report. March 2015

Table 3: *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 & hygiene	500,380	75,057	250,190	175,133
2. Governance, peace & security	139,850	20,978	69,925	48,948
3. Agriculture, fisheries & food security	800,482	120,072	400,241	280,169
4. Gender, youth & social justice	231,000	34,650	115,500	80,850
5. Programme management & 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	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: Mano River Union Secretariat

Post-EVD Recovery Planning in Guinea

The Guinean Ebola Recovery Plan[xvi] 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.

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

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$1.24 billion), which represents 48 percent of the total budget. Thirteen percent (US$343million) is allocated to "Economic sectors", of which "Agriculture" forms the largest portion (US $152million), 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$1.71 million 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".

Post-EVD Recovery Planning in Sierra Leone

The National Ebola Recovery Strategy for Sierra Leone[xvii] (March 2015) sets out the government's recovery strategy for implementation 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 maintaining zero infections (US$424.9 million), restoring access to basic healthcare (US$370.3 million), getting children back to school (US$ 128.9 million) and improving access to water, hygiene and sanitation (US$ 59.9 million). Initiatives to restore economic growth and output include US$83million for reactivating agricultural and rural livelihoods, US$30.8million 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 in the list of key deliverables to forest or wildlife management, or to the need for improved management of natural resources to reduce the risk of zoonotic disease outbreaks.

Post-Ebola Recovery Planning in Liberia

The overall objective of Liberia's 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)[xviii] 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 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 from 2015 to 2017. In light of the downturn in the mining sector, agriculture – including forestry and palm oil plantations – 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$150 million 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".[xix]

[xvii] National Ebola Recovery Strategy for Sierra Leone. Government of Sierra Leone. (March 2015).

[xviii] Republic of Liberia Agenda for Transformation: Steps for Liberia Rising. 2013

[xix] Paragraph 37 in the Economic Stabilization and Recovery Plan for the Republic of Liberia (April 2015)

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

6. Next Steps and recommendations

Post-EVD recovery planning is an opportune moment to adopt a precautionary approach towards the management of natural resources in moist, tropical Africa, especially forests and wildlife. The causes of EVD outbreaks in humans are likely multiple; forest fragmentation is likely a significant factor, but not the *only* significant factor, combining with forest-succession dynamics, zoological and epidemiological factors, and possibly enhanced by cultural and economic elements.

EFA and the ERM Foundation therefore recommend the following:

1. An **interdisciplinary focus group**, consisting of development planners, tropical forest management professionals, satellite imagery/GIS specialists, zoologists (especially bat specialists), and epidemiologists, should review existing knowledge about how land uses and forest fragmentation influence zoonoses, and identify appropriate, further questions to ask to solve the puzzle of what promotes Ebola virus transmission to humans. The group would serve as advisor and a 'reality check' for policy-makers so they may be properly informed and not act on speculation, hyperbole or hidden agendas. Finally the group would make recommendations how to apply a precautionary approach within current economic recovery plans to reduce the risk of future outbreaks.

2. The actors involved in planning economic recovery in the post-EVD crisis period – notably donors, executing agencies and local implementing partners – should **integrate natural resources management and environment as core evaluation criteria into their programs**, and not treat them as box-ticking exercises, or consider their job done by funding an isolated, sector-specific 'forest and wildlife management' project with no structural links to other interventions. With the imminent transition from the Millennium Development Goals to the Sustainable Development Goals, it is not only a priority, it is imperative to the success of future development investment to assess the impacts, positive and negative, of development interventions on natural resources like forests, water and wildlife, and the feedback loops between altered natural environments and the human environment. Current impact assessment and environmental and social safeguards have not always been adequate. Landscape-level planning, leading practice in impact assessment and independent, specialist reviews of sectoral plans are starting points.

3. With regard to specific, forest-management measures to assist post-EVD recovery efforts to reduce the risk of future outbreaks, this study was limited to identifying a correlation between certain forest-fragmentation parameters and EVD index cases, and suggesting avenues for further study. However the authors feel this information points with confidence to one preliminary recommendation: **large forest blocks should be protected from fragmentation within a landscape** so that wildlife-human contact is minimized, and that conditions are avoided for unusual chorotypes yet to be identified that increase the risk of transmission of the Ebola virus from its natural reservoir(s) to new host species including humans.

4. **The causal links between forest fragmentation, Ebola virus hosts and hosts' behaviour, and EVD outbreaks in humans should be assessed further** and with greater focus through, *inter alia*:

    I. Field studies, including both observational and experimental studies, to learn more about the behaviour of bats and other potential Ebola virus hosts, their specific responses to different aspects of forest fragmentation, and how those responses may relate to transmission of the Ebola virus to humans,

II. Studies on the role of bats in African forests to predict how changes in bats' populations and behaviour affect forest regeneration across the landscape,

III. Research on how ecological features of a forest, forest composition, and spatial dynamics of forest fragments interact to influence bats' and other potential, Ebola-virus hosts' behaviour and presence,

IV. Further forest classification and fragmentation analyses on the remaining EVD outbreak locations. This would increase the number of case studies from seven to 21. Having a larger sample size would allow a more robust understanding of the potential fragmentation thresholds identified by the current analysis,

V. Analysis of more nuanced types of land-cover beyond forest vs. non-forest such as mature forest, secondary forest types at different stages of regeneration, young fallow, barren land, grasslands, agricultural land, etc. By classifying a greater number of land-cover categories, it may be possible to refine patterns identified in this first analysis or discover more meaningful correlations between mosaics of land-cover types and EVD outbreaks,

VI. The locations of EVD outbreaks could be investigated to confirm their spatial accuracy in comparison to where the index infection occurred, especially for the outliers observed by this study,

VII. Study of the chorotypes found in the fragmented forest types that correlated with index-case locations. These should be mapped against zoobiotic maps of species known to or suspected of hosting the Ebola virus, in particular species not negatively impacted by the virus,

VIII. Analysing additional grid cells outside of those with known EVD index cases but in the larger Landsat tiles to test statistically the uniqueness of the grid cells with EVD index cases, and

IX. Research on the environmental stresses, such as relating to climate or availability of roost/dens and food, which could lead to compromised immune systems in Ebola virus hosts/vectors, and in humans.

A large number of virological and immunological studies should be undertaken to complement the zoological and forest-related topics above, however the authors are not in a position to advise on their content.

Annexes

Annex 1

i. 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	Primarily frugivorous, feeding on fruits of the genus Solanum	Year round reproduction	Solitary roosters, although sometimes females roost with	Common throughout range Males migrate to the savannas during the wet season, timed with peak fruiting of shea trees

		farmlands and gardens Males use wooded savannas in wet season Primarily occupy forest canopy	(numerous cultivated species), also eat bananas and other fruit crops, and flowers of kapok trees and tree beans		their offspring	(Vitellaria paradoxa) Asymptomatically infected 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

Annex 2

ii. Behavioural repsonse of bats to forest fragmentation

Bats are widely hypothesised to be the reservoir host, or one of the reservoir hosts, of the Ebola virus. However, it is important to bear in mind that bats may not be the reservoir from which humans are infected, or they may merely be one part of a more complex system of reservoirs and transmission chains between wild reservoirs and humans.

Forage availability

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, 2007). 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) 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).

Annex 3

iii. Agriculture and forest loss in Guinea

This annex is based on a compilation of secondary sources and is not necessarily always consistent with the authors' opinions, which are presented in the main text.

The majority of Guinea's population is rural, with more than 70 percent working in agriculture, livestock, fisheries, forestry and small-scale mining. 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 seek to meet their 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. Aggressive, often 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 shorten fallow periods and into land not recently cultivated, including mature forests, to meet their 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 the influence of a given ministry. 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).

A USAID publication estimated that at the turn of the millennium, deforestation in Guinea was occurring recently at an annual rate of 0.5 percent, or 35,000 hectares of forest per year (USAID, 2007). This was in part an outcome of an unregulated approach to land use, energy production (firewood 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.

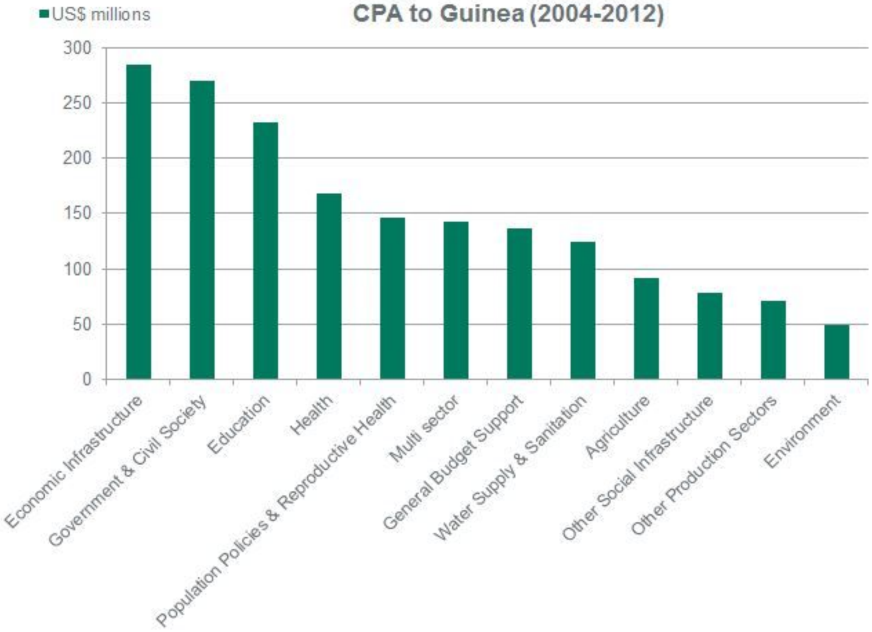
Donor funding priorities in Guinea

A number of donor organizations actively support natural resource management and conservation in Guinea. In the 1990s and 2000s, Germany supported the N'Zérékoré Forestry Centre to implement forest, wildlife and protected area management initiatives, as well as promote sustainable forestry in several *forêts classées* of Guinée Forestière. 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.

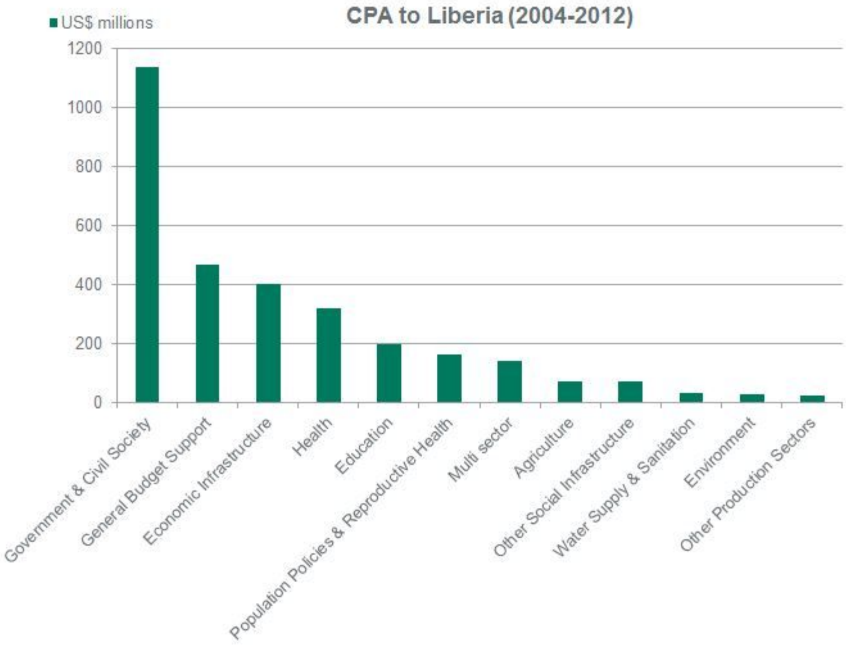
Funding for environmental protection and natural resource management has consistently ranked at or near the bottom of sectoral funding in Guinea. The same is true for Liberia and Sierra Leone (see Figure 8).

Figure 8: Country Programmable Aid [xx] (CPA) to Guinea, Liberia and Sierra Leone (2004 – 2012)

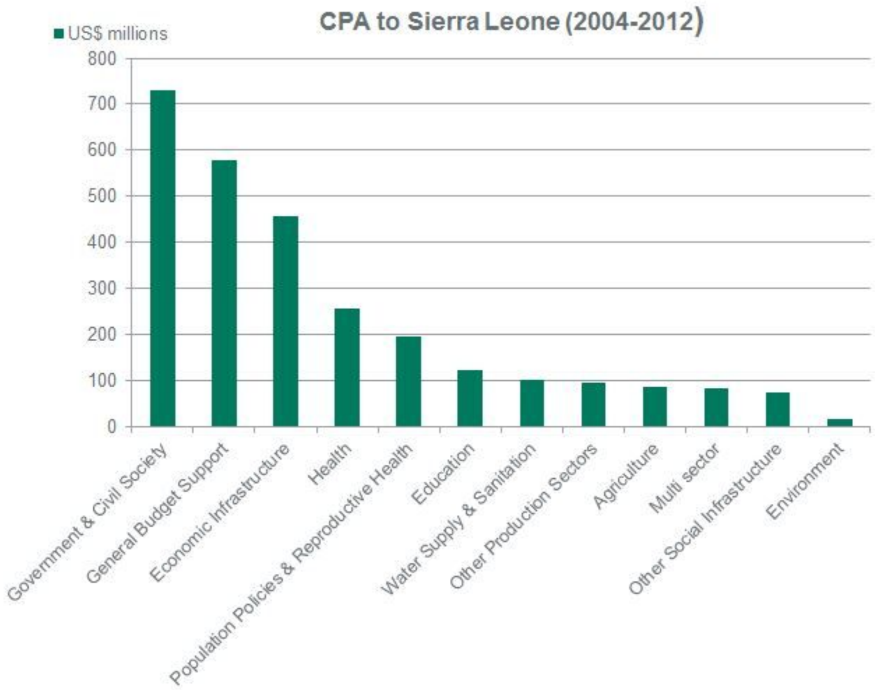
8a



8b



8c



[xx] **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)

Annex 4

iv. References

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