

# Prediction of Ebola Virus Disease (EVD) infestation trends across fruit bats migratory seasons

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## Research article

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# Abstract

**Background :** The majority of the rural populace of West and Central Africa participate actively in bushmeat commodity trade. The peak of this trade usually occurs during the migration of massive flocks of fruit bats. Unfortunately, this commercial period happens to coincide with the most conducive time for the spread of Ebola Virus Disease (EVD) which is transmitted by these fruit bats. We, therefore, conducted this study to predict EVD infestation trend among individuals who might be vulnerable and/or infected (hunters, vendors, and consumers of bushmeat) as a result of this seasonal bats migration.

**Methods:** A secondary data collected in Ghana and semi-structured questionnaires were administered to international students from 7 countries (Democratic Republic of Congo (DRC), Ghana, Liberia, Zambia, Gabon, Guinea, and Ivory-Coast) and responses collated were used in this study. Bivariate correlation, probabilistic transmission rate of EVD, and probabilistic model (P-SIR) were employed to predict susceptible and infected individuals.

**Results :** In all affected countries, it was observed that; there was a yearly bats' migration pattern. 80 % of all interviewees confirmed that hunting, trading and consuming of bats influenced the rapid spread of EVD. The bivariate correlation between fruit bats and people involved in the bushmeat commodity chain was significant ( $p < 0.05$ ) and the probability of infected bats were equally significant across the sampled countries. The estimated probabilistic rate was between 0.0099 and 0.01120, while individuals susceptible to EVD were predicted to be approximately between 5 and 45 (hunters), 0-18 f(vendors), and 25-90 (consumers).

**Conclusion :** The migratory season of fruit bats contributes to EVD transmission in the most affected countries. People should avoid bushmeat consumption or eradicate all activities leading to the interaction with fruit bats to reduce the spread of EVD (Ebola) especially during the migratory seasons. Policy-makers and government agencies should also put in mechanisms that will protect their citizens during the fruit bats season. **Keywords :** bushmeat commodity chain, Ebola, migration season, EVD, fruit bats

## Background

The spread of the Ebola Virus Disease (EVD) has imposed a considerable challenge to public health systems and influenced the prevalence of other infectious diseases in affected countries [1]. Fruit bats have been identified as the main source of EVD which peaks periodically in West and Central African countries, especially during their migratory seasons. EVD has led to more than 11, 310 deaths globally [2]. The migratory season of bats is equally a meat season in some of these countries as these fruit bats are a delicacy for most hunters and vendors. This migratory period of fruit bats is incidentally a commodity (bushmeat) trade boom for local hunters, vendors, and consumers [3]. It is almost difficult to convince consumers in these countries to avoid patronizing and trading fruit bats as, like fruit bats, the meat of other wild animals in both rural and urban areas of these countries are a source of income for households living in extreme poverty [4].

Migration of wild animals and hunting activities are the two major factors that promote the transmission of zoonotic diseases [5]. The resultant loss is a displacement of vital ecosystem services for human wellbeing [6]. Additionally, fruit bats apart from spreading EVD [7, 8], are also implicated in the spread of other deadly viruses such as henipaviruses [9, 10] and lyssaviruses [11]. However, it is yet to be established why the current weekly reports of the Ebola outbreak in Uganda and DRC do not indicate the source (s) of the spread; although there is a general consensus that EVD is primarily transmitted from bats to humans and between bats themselves [12]. Bats are extremely widespread and highly mobile species [13], and a huge flock of fruit bats reach and settle temporarily on the islands of Ndongo and Koumulele especially in mid-May, flying upriver Lulua in a southerly direction in DRC. This seasonal migration of bats has been ascribed to environmental conditions [14], changing food habits (increasing of insects and mammals) [15], and their pursuit of better climatic conditions (interchanging of rainy and dry seasons) [15, 16].

Research conducted in the Republic of Congo (RC) and Gabon between 2001 and 2003 showed an asymptomatic infection in fruit bats [3]. The apparent lack of knowledge of the causes of EVD among local hunters and consumers continue to hamper emergency interventions [3, 17]. Again, earlier studies have been limited to containment and control of EVD in affected countries [15, 18]. Additionally, research funding from these affected African countries has been restricted to identifying prior causes of new EVD, contact identification, contact tracing, and monitoring EVD spread at the expense of transmission of EVD from fruit bats during their migration periods [12, 24-26]. However, limited studies have been conducted on fruit bats migratory behavior and seasonality in the face of escalating environmental degradation and climatic variations [19-21]. Using a historical data with respect to EVD outbreaks in 1977 and 1979 in Sudan; 1994, 1996-1997 in Gabon, 2001-2003 in the Republic of Congo as neighboring countries [22] to model and predict outbreaks of EVD will be a useful tool for both researchers and stakeholders in the fight against EVD epidemic across these across countries.

Currently, susceptible, infectible and recovery (SIR) model is used as a potential model to predict the complication of endemic and epidemic infectious diseases, and it was recently used to predict the EVD outbreaks in other studies [23, 24]. The SIR model description, usefulness and resolution are highlighted by several studies [25-27]. Therefore, we used the SIR model in this study based on bushmeat commodity trade of bats by local hunters, vendors, and consumers and investigated the intensive effect of bats migration during the migration season by predicting susceptible and infected individuals to EVD transmission in the most affected countries.

## Methods

### Study area

We sampled countries in West and Central Africa where Ebola has been reported and transmitted by different infection sources, especially in the bushmeat commodity value chain that occur during the bat's migration seasons. We used data collected from the previous study conducted in Ghana on bushmeat

trade of bats, and its migration seasons [ 3] together with data collected from face-to-face interviews conducted with international students from West and Central Africa in China-Wuhan.

## **Study population**

The study population comprises individuals involved in the bushmeat commodity chain collected in Ghana [ 3] along with data of bats migration patterns in three countries (Ghana, Gabon, and the Democratic Republic of Congo) [ 7, 8] and international students living in Wuhan.

## **Sample size**

A total of 134 international students from DRC, Ghana, Liberia, Zambia, Gabon, Guinea, and Ivory-Coast were interviewed. The total individuals involved in bushmeat commodity chain were 393, clustered into three groups: 95 hunters, 48 vendors and 240 consumers.. Also, secondary data of tested bats were 5021 with 239 confirmed positives were considered in this study.

## **Data analysis**

The International Business Machine Statistical Package for Social Sciences (IBM-SPSS) was used to perform the bivariate correlation showing the relationship between fruit bats and individuals involved in the bushmeat commodity chain. Origin Statistical Package (ver. 2018) was used to plot the susceptible and infected individuals. We computed the probability of infected fruit bats and probabilities of human infection and the probabilistic transmission rate (since it was estimated in terms of probabilities). Even though, all individuals involved in the bushmeat commodity chain can be potentially susceptible, but by using transmission rate in simple SIR model as a parameter, we can predict the most likely susceptible and infected hunters, vendors, and consumers during the bat's migration season.

## **Infection Probability Estimation**

The probability of Ebola virus disease (EVD) transmission in bushmeat commodity chain in different countries was first determined by the ratio between infected bats in different tested samples in three countries and then associated with Bayesian conditional probability among key actors within the chain (hunters, vendors, and consumers). The dynamic probabilistic transmission rate of infection varies with the occurrence of migratory seasons of fruit bats as reported in some other infectious diseases [ 28]. Transmission rate estimated considering different conditions [ 25, 26] with the different data type [ 29]. We took into account the incubation period and contact rate (incubation  $\alpha = 4.23$  days and contact rate ( $\sigma = 0.128$ )) estimated from the data collected in Sierra Leona and Liberia in order to have an in-depth understanding of this transmission rate[ 23, 24]. Therefore, the transmission rate was used as the prior parameter in the SIR model. Since this parameter was estimated in probabilistic context, the SIR model named probabilistic SIR (P-SIR) was employed to predict susceptible and infected individuals (see Additional file 1).

# Results

## Summary of findings from the interview with participants

Out of 134 interviewees, 58 were females aged between 18-28 years while 76 were males aged between 18-39 years. It is important to note that, actors involved in the bushmeat commodity chain were all low-income earners with the bulk of their income from hunting and trading in wild animals.

**Table 1.** Summary of findings from a face-to-face interview

Country	Number	M.S		Transmission in M.S	
		Season	Participants (%)	Participants (%)	Participants (%)
DRC	41	July-Sept	22 (53.6)	1: 34 (82.9)	1: 41 (100)
		Oct-Dec	19 (46.4)	2: 8 (17.1)	
Gabon	22	Oct-Dec	22 (100)	1: 22 (100)	1: 22 (100)
Ghana	22	Oct-Dec	22 (100)	2: 22 (100)	2: 22 (100)
Guinea	10	April-June	10 (100)	1: 10 (100)	1: 10 (100)
Liberia	20	July-Sept	20 (100)	1: 16 (80)	1: 12 (60)
				2: 4 (20)	2: 8 (40)
Ivory-Coast	8	April-June	8 (100)	1: 8 (100)	1: 6 (75)
					2: 2 (25)
Zambia	9	January-March	9 (100)	1: 9 (100)	1: 6 (66.6)
					2: 3 (33.4)

1: agree and 2: disagree of the participants from various countries, Migration Season (M.S), bat's migration season and its contribution to influence the transmission of EVD

## Bats migration season

In the Ebola-affected countries and their surroundings, fruit bats migration season was confirmed as a major contributor to the spreading of the EVD. The respondents from seven countries confirmed different bats migration seasons. The respondents from DRC confirmed that the yearly bat's migration season is from July-September in some regions and from October-December in other regions. In Gabon and Ghana, the migratory season is from October-December, respectively. In Guinea, the migration season is from April-June, July-September (Liberia), April-June (Ivory Coast), and from January-March in Zambia [Table 1].

## Effect of migration season

The effects of this bats migration season as indicated by respondents in some countries are evident in the number of deaths and recovery with respect to the number of infected individuals within a family. Bivariate correlation between fruit bats and actors (individuals) involved in the bushmeat commodity chain were statistically significant at 0.05 level (p-value < 0.05, Table 2 and see additional file 2 for more detail of analysis).

**Table 2.** Effect of bats migration season in some countries (survival and death = 22) and correlation and probability of infection in the bushmeat commodity chain

Country	Infection in families	Survival	Death
DRC and Gabon	13	7	6
Liberia and Guinea	9	4	5
<i>Bivariate correlation between Fruit bats and people</i>		<i>P-value &lt; 0.05</i>	
Hunters	0.883	0.024	
Vendors	0.990	0.001	
Consumers	0.886	0.029	
The proportion of infected fruit bats tested in samples collected in some countries			
Country	Probability		
Gabon and DR. Congo	0.20293		
Ghana	0.12141		
Zambia	0.08556		

## Prediction of suspected and infected individuals during bats migration season

*Fig: (a) is the probabilistic transmission rate, (b) is number of susceptible individuals and (c) is number of infected individuals can be occurred during the migration season period.*

The estimated susceptible and infected individuals in bats migration season

With the assumption that the distribution of these flock of bats is normal, we estimated the Bayesian probabilities to obtain the probabilistic transmission rate of EVD for each actor involved in the bushmeat commodity chain. This ranged from 0.0099-0.0102 for hunters, 0.0100-0.01120 for vendors, and 0.01001-0.0102 for consumers, with the rate of transmission from vendors being significantly greater than those for consumers and hunters [Fig (a)]. The predicted susceptibility rate of hunters, vendors, and consumers (main bushmeat commodity chain actors) differ within and across bats migration seasons. The susceptible number of consumers are greater than vendors and hunters, ranging between 50 and 90 for

hunters, 0 and 18 for vendors, and 5-45 for consumers [Fig (b)]. The predicted number of actors (individuals) that might be infected during the bat's migration season was increasingly proportional to susceptible actor (individual) movement [Fig (c) and see additional file 3].

## Discussion

Recent studies provide the understanding of the importance of migratory seasons of fruit bats for local hunters, and impoverished individuals for either the purpose of consumption or trade of bats. Those same studies also showed how several local dwellers, most bat hunters, vendors, and consumers are the major victims of the Ebola virus disease (EVD) during peak bats migratory seasons [ 30-33]. Conversely, some countries endure long-term spread of EVD during the bat's migration season owing to the rather environmentally-induced protracted bats migratory periods [ 34]. Those facts impose burdens to the vulnerable populace living in most affected-Ebola low-income countries, however, the current study highlights seasons of bats migration for different affected countries, and predict the level of human susceptibility and infection that could be as a result of this migration season (s).

The results from the semi-structured questionnaire administered to respondents from different African countries confirmed bat's migration seasons in the most affected countries; DR Congo, Gabon, Liberia, Guinea, and potentially susceptible countries (Zambia, Ivory Coast, and Ghana). In DR Congo, the respondents confirmed two-yearly bats migration seasons, from July-September and October-December. This may be ascribed to the different time zones in that country and the busy commercial activities of bushmeat traders including hunters, vendors, and consumers as 82.6 % confirmed the transmission of EVD in those seasons. Even though, EVD may occur outside the migration season, the EVD outbreak deteriorated in 2018 mostly during those seasons (July-September and October-December) in DR Congo. This is consistent with results by [ 3, 35]. Similarly, Gabon and Ghana have the same bats migratory season which starts from October to December; but unlike Ghana which has never recorded Ebola outbreak before, the first outbreak in Gabon occurred after human interaction with bats in this season [ 35].

However, in Guinea, the migration season starts from April to June; therefore, it is most probable that EVD transmission was influenced by this seasonal migratory pattern by bats. In Liberia, the bats migratory season starts from July to September, and thus, it can be deduced that EVD transmission may have been influenced by bats movement during the migration season. Unlike DR Congo, other countries like the Ivory Coast have a shorter bats migratory season (from April to June). In Zambia, respondents indicated that bats migratory season happens between January and March. This, however, contradicts report by Richet that bats migration season in Zambia occurs from October to December [ 36]. Notwithstanding, respondents revealed that commercial activities of bushmeat actors (bats) during this migration season favor the spread of EVD.

The relationship between fruit bats migratory seasons and individuals involved in the bushmeat commodity chain in different clusters is statistically significant (p-values < 0.05). By correlating this

relationship with the probability of infected fruit bats increases EVD risks thus increasing the probabilistic rate of infection across the various bushmeat commodity chains. The estimated Bayesian probabilities for hunters, vendors, and consumers' clusters were used to estimate the probability transmission rates of EVD which tended to increase with respect to time. However, it is important to note that the rate of transmission from vendors is greater than those from consumers and hunters. The predicted susceptibility and infection among hunters, vendors, and consumers differed across and within migratory seasons. The susceptibility of consumers was found to be greater than that of vendors and hunters.

Making a policy that would reduce people's involvement in the bushmeat commodity chain is a very difficult but important step that can be achieved by either a central government or a local government. One bat is sold for US \$ 0.88, and around 128, 000 bats are hunted per year [ 3]. Nutritionally, bats are a protein source for smallholders/rural dwellers in low-income localities and therefore the apparent difficulty for stakeholders to discourage people from consumption of fruit bats [ 3].

Though the difference between susceptible and infected individuals might seem to be wide, precautionary measures should always be considered since even a few infected individuals could greatly spread the virus in a region. Governments should invest more resources in socio-economic services aimed at maintaining a viable public healthcare system. However, by using the information on bats migration season and the SIR-prediction model from this study, we can confidently predict the next migration season and avoid new EVD outbreak.

To the best of our knowledge, this study is the first to highlight and predict susceptibility and infection spread among key commodity actors (individuals) during bats migration season in some affected countries. This study identified hunting, trading, and consumption of bats as major triggers of the transmission of EVD from bats to people in affected countries, and the influence of bats migratory season as a probabilistic contributor to new EVD transmissions [ 22]. This call for governments and relevant policy-makers to strategically implement policies to protect their citizens from contracting EVD. We generally predicted susceptibility and infection rate across and among individuals involved bushmeat trade (bats) using a secondary data and a semi-structured interview guide during bats migratory seasons. Future study should focus on predicting infected individuals and survivors of the EVD during fruit bats migration seasons. It will be interesting to study why some countries with fruit bats seasonal migration have never recorded an Ebola outbreak.

## Conclusions

This study assesses fruit bats migration seasons, estimates the probabilistic transmission rate of EVD and then predicted susceptibility and infection rate of individuals in the most affected countries. Hunting, trading and consuming fruit bats were identified as major activities leading to new transmissions of EVD. Bayesian conditional probability distribution has been used to obtain the probabilistic transmission rate, and then the probabilistic SIR model was used to predict a number of susceptible and infected individuals among hunters, vendors, and consumers. These predicted numbers indicate the negative

effect of fruit bats migration seasons in the most affected countries. Therefore, people should be sensitized to reduce direct or indirect contacts with fruit bats and governments should provide healthcare programs for citizens. However, knowing the next bat's migration season and its impact could inform effective policies to prevent new EVD (s).

## **Declarations**

### **List of abbreviation**

EVD: Ebola Virus Diseases

SIR: Suspected Infected Recovery

P-SIR: Probabilistic Suspected Infected Recovery

### **Ethics approval and consent to participate**

The study was approved by the China University of Geosciences (Wuhan) Faculty of Statistics and Research Committee of School of Mathematics and there was no Committee's reference number. Permission was also sought from the Wuhan International students association (WISA) committee. All participants provided written, informed consent to participate in the study.

### **Consent for publication**

Not applicable

### **Availability of Data and materials**

All computational dataset are available in the additional files.

### **Competing Interest**

The authors declare that there is no competing interest in the study.

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There is no available funding for this study.

### **Author's contributions**

JP Namahoro and HJ Xiao contributed equally to analyzing and interpreting the data presented in the study and writing the manuscript. All authors read and approved the final manuscript.

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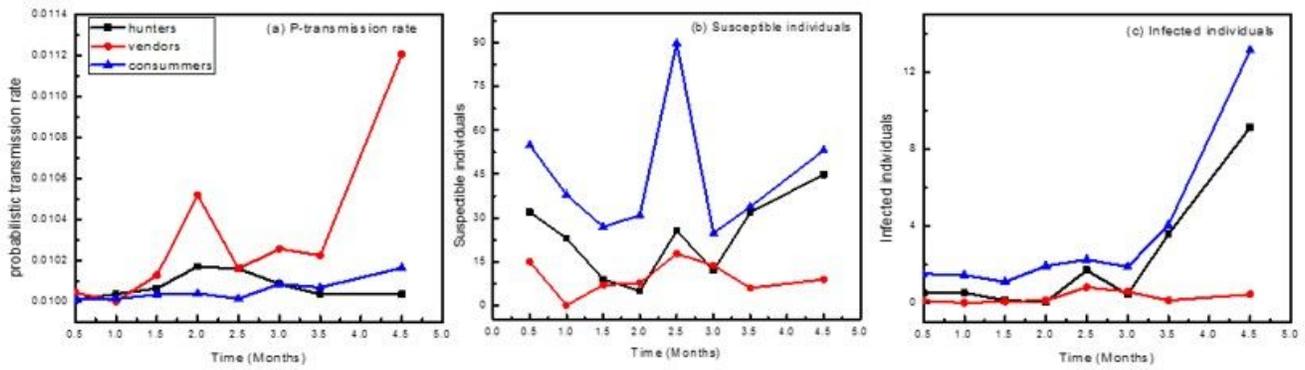
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## Figures



**Figure 1**

(a) is the probabilistic transmission rate, (b) is number of susceptible individuals and (c) is number of infected individuals can be occurred during the migration season period.

## Supplementary Files

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