Exploring Causational Factors of Ebola Outbreaks in Western Africa

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Abstract

This research focused on using geographic information systems (GIS) as well as statistical analysis to explore causational factors of Ebola outbreaks in western Africa. The study area represented the continent of Africa, with statistical analysis being conducted for the countries of Sierra Leone, Guinea, and Liberia. Demographic data for the countries of Nigeria, Liberia, and Guinea was used to assess demographic factors in the study. An Ebola outbreak was recently declared over by the World Health Organization (WHO). The end date for the database used in the statistical tests was November 25, 2015. Using data from Sierra Leone, Guinea, and Liberia, statistical tests were performed to determine differences in the number of cases and deaths. Data included cumulative total number of cases and deaths for each report date (approximately one report per week), for each country starting on March 1, 2014 as well as the final overall total number of cases and deaths per country as of November 25, 2015. Using this data, an ANOVA test was performed on both weekly death counts and case counts to determine if a difference existed between the countries. Statistical analysis, spatial GIS analysis, and a review of literature revealed human-to-human contact, poverty, and medical practices are believed to be contributing factors in the spread of the Ebola virus.

Introduction

The Ebola Virus

Both the *Sudan Ebola virus* and the *Zaire Ebola virus* have ravaged the continent of Africa since surfacing in 1976. Both the *Zaire Ebola virus* strain and *Sudan Ebola virus* strain "cause hemorrhagic fever in humans and are associated with high case-fatality rates" (Leroy, Epelbion, Mondonge, Pourrut, Gonzalez, Muyembe-Tamfum, and Formenty, 2009).

Until recently, very little was known about the natural reservoir of the virus. It is believed that the *Epomophorous wahlbergi, Epomops franquetti, Hypsignathus monstrosus,* and *Myonycteris torquata* species of fruit bats are all possible natural reservoirs. During the migration season, they are hunted in Africa and are the main source of protein for some remote villages. With the increased likelihood that these species of fruit bats are the natural reservoir for the Ebola virus, education of the general public of how to prevent infection can begin and the number of large outbreaks may decrease over time (Leroy *et al.*, 2009).

Since the first outbreak in 1976, 24 more outbreaks have occurred, and approximately 9000 people have succumbed to the Ebola virus (Martinez, 2014). During that time, little has been learned about the natural reservoir of the virus. Ebola is a disease that needs to be controlled; therefore, it is important to

analyze the historical outbreak data in order to determine trends.

Most Recent Outbreak

On January 14, 2016 the WHO declared the Ebola epidemic over in Liberia. On December 29, 2015 the WHO declared the Ebola epidemic over in Guinea. As of writing, Sierra Leone remains on a 90-day period of enhanced surveillance following the declaration of the end of Ebola transmission on November 7, 2015 (European Centre for Disease Prevention and Control, 2015).

The most recent outbreak lasted from December 2013 until January 2016. During the epidemic it became a pressing concern to develop a vaccine. In addition to deaths in the United States and infections in the United Kingdom and Spain, the most recent outbreak left an estimated 11,300 people dead out of 29,000 cases in all afflicted countries in West Africa (as of November 25, 2015; Figure 1). The 2013-2016 Ebola outbreak in West Africa was so severe compared to previous outbreaks that it was declared an epidemic by the WHO on August 8, 2014 (WHO, 2015a). They declared the epidemic "to be a public health emergency of international concern" (WHO, 2015b).

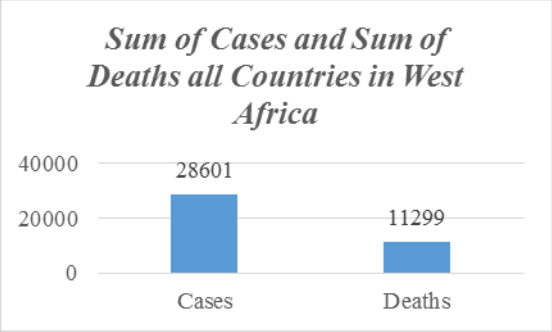

Figure 1. Sum of all cases and sum of all deaths from all afflicted countries in West Africa (WHO, 2015).

Areas Affected by the Recent Ebola Outbreak

The most recent outbreak was the 26th and worst outbreak of the Ebola virus that has plagued the world, and the 24th that has ravaged the continent of Africa. The virus caused most damage on the western coast of the continent in the countries of Sierra Leone, Guinea, and Liberia (Figure 2).

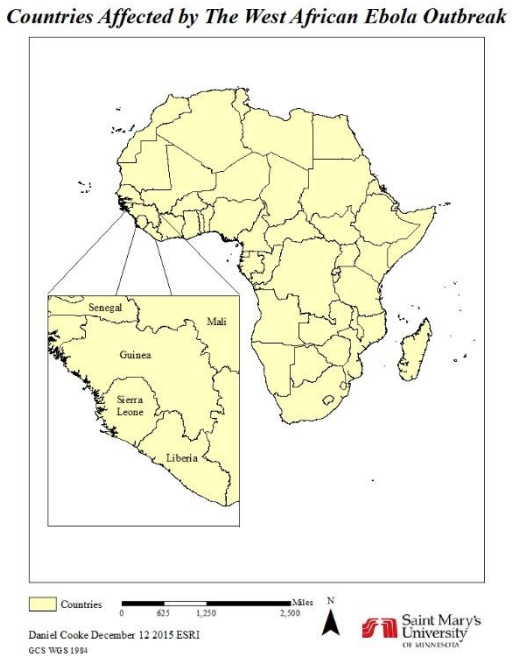

Figure 2. The most affected countries of Guinea, Sierra Leone, and Liberia in relation to the continent of Africa.

The most recent outbreak of Ebola had a 28% death rate in Sierra Leone, 66% in Guinea, and 45% in Liberia. "... [T]he epidemic has killed five times more than all other known Ebola outbreaks combined. More than 19 months on from the first confirmed case recorded on 23 March 2014, 11,314 people have been reported as having died from the disease" (British Broadcasting Corporation, 2015).

Demographics, Transmission, and Counts

Prior studies found Ebola outbreaks tend to occur in poverty-stricken nations, where their citizens do not have access to modern day medicine and where ancient traditions are still practiced today (Silver, 2014). Other studies suggest consumption of bush meat is the cause of transmission of the Ebola virus. The following information provides a basis as to why the chosen factors included in this study are important.

Sierra Leone, Liberia, and Guinea are some of the most impoverished nations in the world. With poverty rates nearing 90% in some areas (World Bank, 2011), many citizens do not have access to clean water, clean restrooms, or medical facilities. Figures 3 – 5 report the amount of poverty present in these nations.

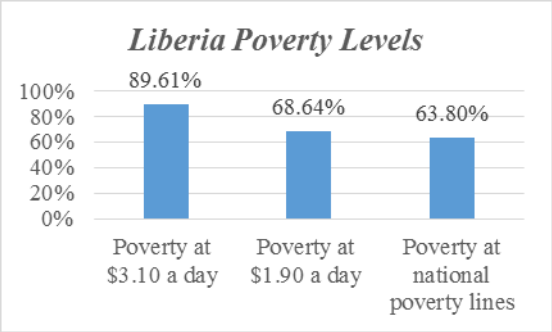

Figure 3. Liberia poverty levels showing poverty at $3.10 a day, poverty at $1.90 a day and poverty at the National Poverty Line (The World Bank, 2011).

Liberia, Sierra Leone and Guinea are some of the most impoverished countries on earth. The current Ebola epidemic hurts their economy. During an Ebola epidemic, the economy of the affected countries is likely to suffer. The spread of the virus can also be attributed to ritualistic practices by the people of the countries. Those practices include the ingestion of bush meat, body washing, and poor medical practices.

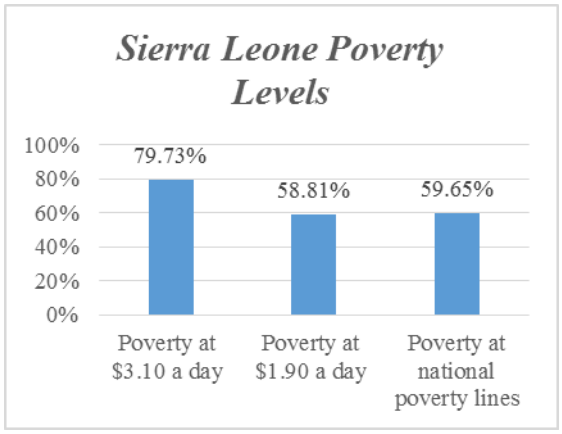

Figure 4. Sierra Leone poverty levels showing poverty at $3.10 a day, poverty at $1.90 a day and poverty at the national poverty line (The World Bank, 2011).

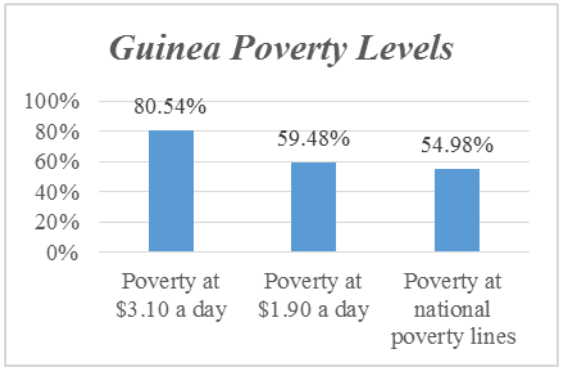

Figure 5. Guinea poverty levels showing poverty at $3.10 a day, poverty at $1.90 a day and poverty at the national poverty line (The World Bank, 2011).

In the affected countries body washing is still commonly practiced; although "[Ebola is] not easily transmitted... there's this ritual behavior [in some areas, where] they wash bodies by hand to prepare for burial- a loving way of sending the spirit in the next world. This kind of behavior brings people into very close contact with body fluids that are infected, and that is how people become infected. Typically these outbreaks are relatively easy to control if you can get people to stop washing dead bodies" (Silver, 2014). This body washing, and contact with infected fluids, continues to

contribute to the spread of the disease in West Africa today.

Due to the low income of these infected countries, it is common for many remote villages to hunt bush meat as a source of protein (Leroy *et al.*, 2009). Before 2009, it was believed the natural reservoir of the Ebola virus was great apes (gorillas, chimpanzees, etc.); however, after a study conducted in the Lula River valley found a direct link between fruit bats and the Ebola virus, it appeared less likely that the Great Apes of Africa were the natural reservoir of the virus.

The study found that each year there was a massive bat migration during the month of April along the Lula River (Leroy *et al.*, 2009). There were several species of fruit bats in the migration; "[two] of three species [are] suspected of being the reservoir of Ebola Zaire, namely *Hypsignathus Monstrosus* and *Epomops Franqueti*" (Leroy *et al.*, 2009). Both of these species of bats have overlapping habitats (Figure 6).

It was found that during this period the bats killed during the hunt represented an important source of protein, "mainly for men, postmenopausal women, and children. Indeed, women of child-bearing age are not allowed to eat bats, but it is often they who butcher, prepare and cook them" (Leroy *et al.*, 2009). Because of the direct contact with the fluids from infected bats, those who hunt the migratory bats are more susceptible to contracting the deadly virus. They often begin showing signs of the deadly hemorrhagic-filovirus as soon as 2 days or as late as 21 days after contracting the virus from an infected bat.

As discussed, a poor economy in an impoverished nation can exacerbate an Ebola outbreak, as well as the ingestion of bush meat, specifically the ingestion of fruit bat bush meat. Lastly, poor medical practices have also led to the spread of the virus across western Africa. The best example of poor medical practices is during the first Ebola outbreak in 1976, which was centered around the Yambuku Missionary Hospital (YMH). During the 1976 outbreak "YMH was the main source of transmission […] [it has been confirmed that the] reuse of needles [as well as] close body contact with infected individuals helped spread the virus […] The outbreak eventually ended with the closing of YMH and the quarantining [of] infected patients in their villages" (Reed, 2012).

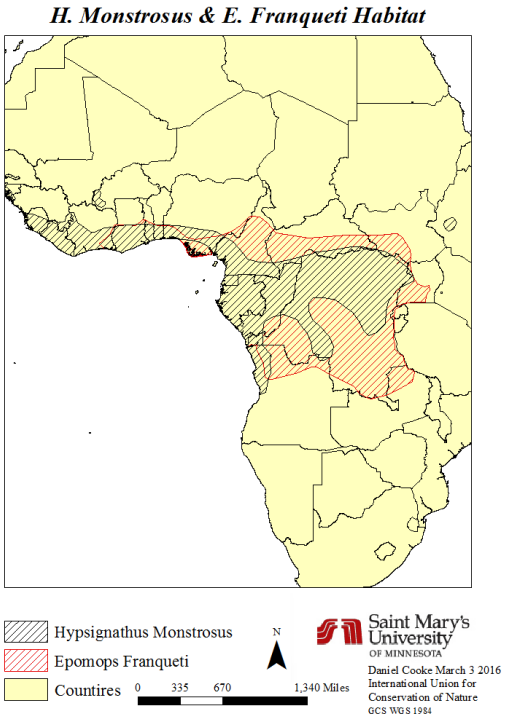

Figure 6. This map shows the habitat of the two fruit bat species *Hypsignathus Monstrosus* (black hatch) and *Epomops Franqueti* (red hatch). The data was downloaded from the International Union for Conservation of Nature (2015).

More recently there has been an increase in support from the WHO as well as the World Organization of Family Doctors (WONCA). Education provided by the WONCA-WHO started in 1978; that year they started the Health for All

program. “The Health for All programme was enunciated through the Declaration of Alma Ata […] the Declaration said that health is a state of complete physical, mental and social wellbeing” (Strasser, 2003).

The three countries that were the most heavily affected by the most recent outbreak were Guinea, Liberia and Sierra Leone. Until recently, daily case and death counts were reported to the WHO (Figure 7). As the number of cases continued to grow, the number of deaths during this epidemic also continued to grow (Figure 8). As shown in both Figures 7 and 8, both Sierra Leone and Liberia suffered from the the Ebola virus.

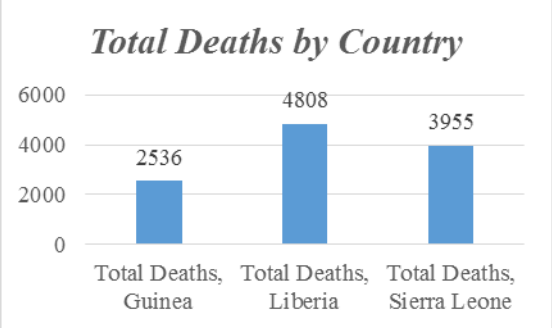

Figure 7. Total deaths by country from March 25, 2014 to November 25, 2015.

Data

Data gathering for this work was conducted with a minimum of two goals in mind. Those goals were to have a dataset of outbreaks, as well as a dataset of African country demographics. Fortunately, both of those datasets were available. Data collection consisted of a three-part process including the following steps: 1) locating a data source where outbreak data was readily available; 2) finding a source of demographic data for the affected countries; and lastly, 3) obtaining spatial data for GIS analysis.

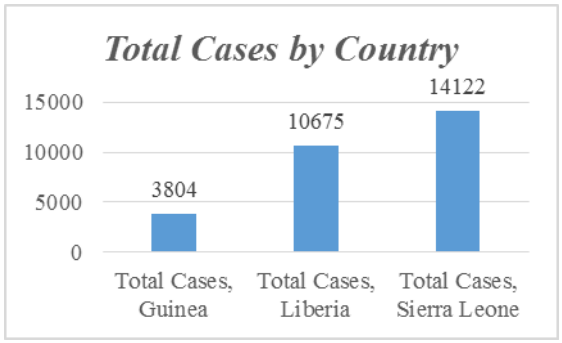

Figure 8. Total cases by country from March 25, 2014 until November 25, 2015.

Data Collection

Outbreak Data

Outbreak data was collected from the Humanitarian Data Exchange. The Humanitarian Data Exchange dataset consisted of 9 attributes:

1. WHO Report Date: The date of the reports started on March 25, 2014 and ended on November 25, 2015.
2. Total Cases Guinea: Cumulative number of cases of Ebola in Guinea since the beginning of the outbreak.
3. Total Deaths Guinea: Cumulative number of deaths caused by Ebola in Guinea since the beginning of the outbreak.
4. Total Cases Liberia: Cumulative number of cases of Ebola in Liberia since the beginning of the outbreak.
5. Total Deaths Liberia: Cumulative number of deaths caused by Ebola in Liberia since the beginning of the outbreak.
6. Total Cases Sierra Leone: Cumulative number of cases of Ebola in Sierra Leone since the beginning of the outbreak.
7. Total Deaths Sierra Leone: Cumulative number of deaths caused by Ebola in Sierra Leone since the beginning of the

outbreak.

8. Total Cases: Cumulative number of cases of Ebola since the beginning of the outbreak in Guinea, Liberia, and Sierra Leone.
9. Total Deaths: Cumulative number of deaths caused by Ebola since the beginning of the outbreak in the countries of Guinea, Liberia, and Sierra Leone.

Statistical analyses were conducted on this dataset, and graphics were created from this dataset to display the differences in cases and deaths by country.

Demographic Data

Demographic data was also collected from multiple sources, but only for the countries of Sierra Leone, Guinea, Nigeria, and Liberia. Income data was collected from the World Bank website. This data showed poverty levels in the three countries. The World Bank's data consisted of five attributes: Country Name, Country Code, Indicator Name, Indicator Code, and Year.

Demographic data for ethnicity, mortality, population, and religion was downloaded from Digital Globe Analytics. The demographic data collected from Digital Globe Analytics had 11 attributes for each shapefile. Multiple maps were created for analysis, however it was determined that statistical analysis was more beneficial.

GIS Data

The GIS data used for this project was collected from multiple sources and consisted of shapefiles, geodatabases, comma-separated values (CSV) files and Microsoft Excel spreadsheets. The sources include Environmental Science Research Institute, Inc. (Esri), Digital Globe Analytics, The WHO, and the International Union for Conservation of Nature (IUCN) Red List of Threatened Species data portal. This data was used in ArcGIS Desktop 10.1 and 10.2 to perform GIS analysis to determine the contributing factors of Ebola spreading in western Africa.

Methods

Discussions in this section include the statistical analysis completed on the datasets included case and death counts from the countries of Sierra Leone, Guinea, and Liberia. In order to complete statistical analysis for this project, the Data Analysis Add-In in Microsoft Excel 2013 was used. Maps were created using Esri ArcGIS Desktop10.1 and 10.2 to display habitat ranges for the bats species *Epomophorous wahlbergi, Epomops franquetti, Hypsignathus monstrosus,* and *Myonycteris torquata.*

Statistical Analysis

Analysis of Variance (ANOVA)

The first statistical test that was run on the data was a Single Factor Analysis of Variance (ANOVA). The dataset that was used contained cumulative totals of the number of Ebola cases for each country: Guinea, Liberia, and Sierra Leone. The data existed for a total of 90 weeks, between the dates of March 1, 2014 and November 25, 2015. From the cumulative totals, the number of new cases per day was estimated. For example, if the total number of cases increased by 4 since the previous report 4 days prior, an average value of 1 new case per day (4 new cases / 4 days) was assigned to that report. Dates from March 1, 2014 to March 24, 2014 were removed from the dataset, because

all afflicted countries had a value of 0; it was not until March 25, 2014 that 86 cases were reported in Guinea. On March 27, 2014 all afflicted countries had reported cases of Ebola: Guinea with 103, Liberia with 8, and Sierra Leone with 6. The factor tested was country, with the null hypothesis that the average number of new cases per day was the same between the three countries (Liberia, Sierra Leone, and Guinea) during the 90 week time period. What was expected was that there would be a difference and that the country of Sierra Leone would consistently have the highest numbers of new cases caused by the Ebola virus because of the poverty levels of the country as well as poor medical practices.

Results

The ANOVA found that there was a statistically significant difference between the countries regarding the average number of new cases per day (p-value=0.00045). The country with the highest average new cases by day was Sierra Leone with 27.66, followed by Liberia with 24.53 new cases per day and Guinea with 7.56 new cases per day (Table 1).

Figure 9 is a line graph illustrating the cumulative data analyzed in the Single Factor ANOVA. It shows the variation in case rate for the countries of Guinea, Liberia and Sierra Leone. Figure 10 illustrates a line graph depicting cumulative number of deaths.

Table 1. Mean number of new cases by day for the countries of Guinea, Liberia, and Sierra Leone. There is a statistically significant difference with a p-value of 0.00045.

Groups	Average
New Cases by Day, Guinea	7.56
New Cases by Day, Liberia	24.53
New Cases by Day, Sierra Leone	27.66

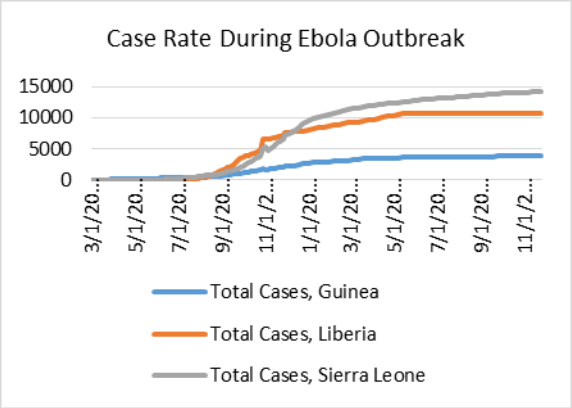

Figure 9. The cumulative total of Ebola cases in Guinea, Liberia, and Sierra Leone. The dates range from March 1, 2014 to November 25, 2015.

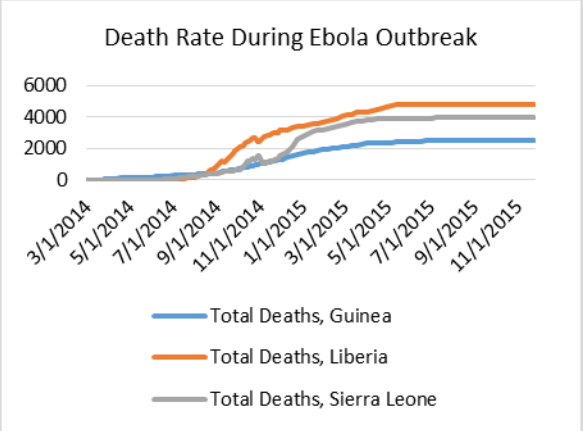

Figure 10. The cumulative number of Ebola deaths in Guinea, Liberia, and Sierra Leone. The dates range from March 1, 2014 to November 25, 2015.

To further illustrate the differences between countries, a map showing total gross domestic product for 2014 for the afflicted countries and population centers was created (Figure 11).

Linear Regression Graph

Lastly a linear regression graph was created to investigate if a trend in the death rate for Ebola has emerged over time. As seen in Figure 12, a decrease in total percentage of cases resulting in death since the *Ebola virus* first appeared on the scene occurred. This data consists of all data from afflicted countries from all outbreaks.

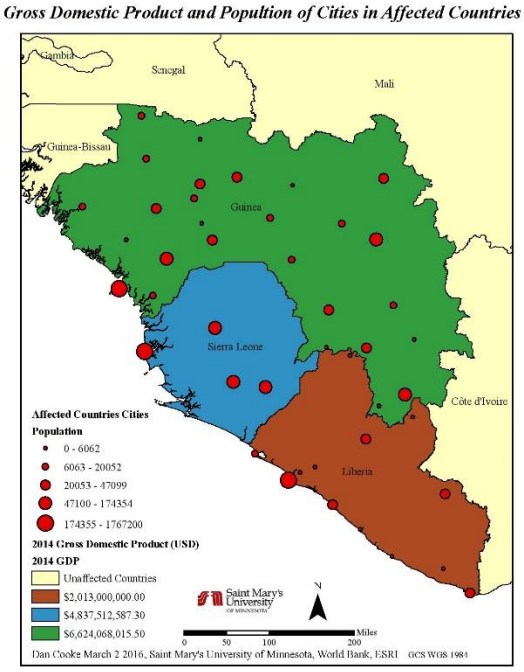

Figure 11. Gross domestic product for the countries of Guinea, Sierra Leone, and Liberia as well as population centers. The population ranges are from 0-6062, 6063-20052, 20053-47099, 47100-174354, 174355-1767200. The gross domestic product of Liberia is $2,013,000,000 (USD), Sierra Leone is $4,837,512,587.30 (USD) and Guinea is $6,624,068,015.50 (USD). This data was downloaded from the World Bank and Esri.

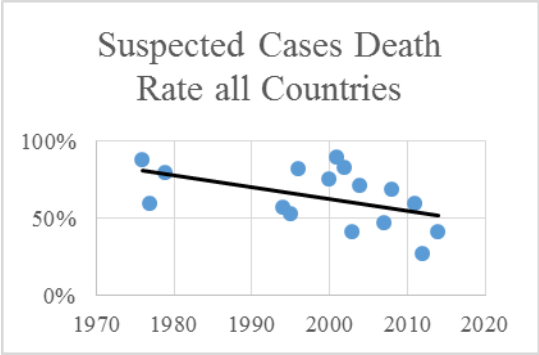

Figure 12. This graph shows the death rate for the total suspected cases for all countries affected by *Ebola* since the first outbreak. The x axis is the afflicted year, and the y axis is the percentage of the cases resulting in death. Compiled data was collected through the CDC website (2015).

Spatial Analysis

Spatial analysis was an integral part of this project. The spatial analysis looked at several factors of this study, but most notably the habitat range of the bat species *Epomophorous wahlbergi, Epomops franquetti, Hypsignathus monstrosus* and *Myonycteris torquata.* These bat species habitats were studied because they have all been considered natural reservoirs for both the *Ebola Zaire* and the *Ebola Sudan* viruses. African countries were mapped to determine where they overlapped with the bat species habitat (Figures 13, 14, 15, 16). If there was an overlap, there was a high probability of an Ebola epidemic occurring in the country (Leroy *et al*., 2009).

As illustrated in Figures 13-16, *Epomophorous wahlbergi, Epomops franquetti, Hypsignathus monstrosus* and *Myonycteris torquata* habitat covers the equatorial region of the continent. Due to its habitat encompassing all of the most recently affected countries as well as previously effected countries, the most likely culprit for infecting the people of Sierra Leone, Guinea and Liberia is *Myonycteris torquata* (Figure 16).

Across the continent of Africa, religion was found to play a key role in the spread of the disease; the ritualistic practice of body washing, the daily call to prayer, and Sunday mass all bring people together providing opportunity for the virus to spread (Leroy *et al.*, 2009). Religious centers in the city of Freetown, Sierra Leone were mapped to determine the levels of variability in religion throughout the region. The religions in the region include Christianity, Judaism, and Islam (Figure 17).

Discussion

The Ebola epidemic in western Africa was recently declared over by the WHO (WHO, 2015a).

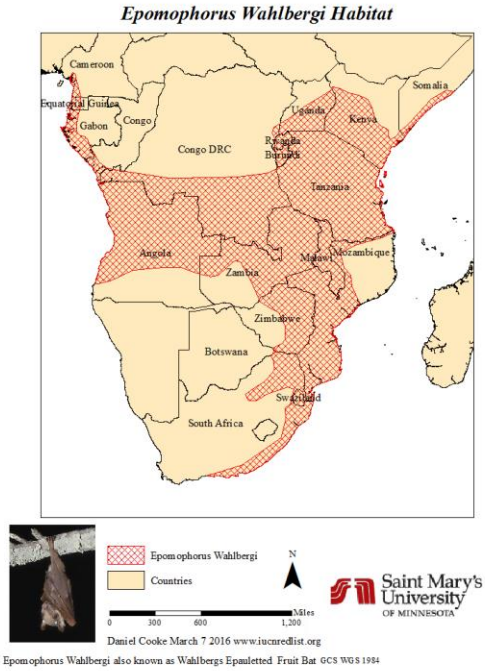

Figure 13. The habitat of the bat species *Epomophorus wahlbergi*. This data was downloaded from the IUCN Red List of Threatened Species data portal (published 2008).

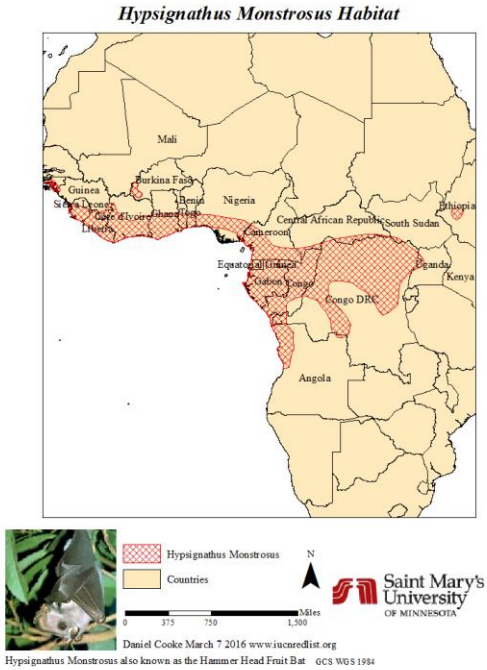

Figure 15. The habitat of the bat species, *Hypsiganthus monstrosus.* This data was downloaded from the IUCN Red List of Threatened Species data portal (published 2008).

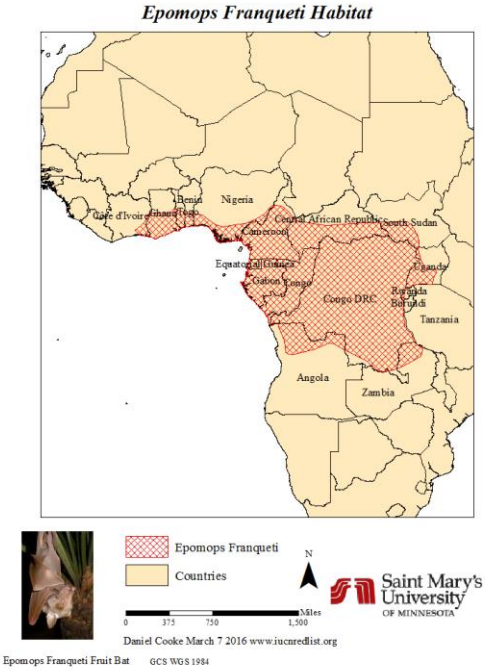

Figure 14. The habitat of the bat species, *Epomops franqueti.* This data was downloaded from the IUCN Red List of Threatened Species data portal (published 2008).

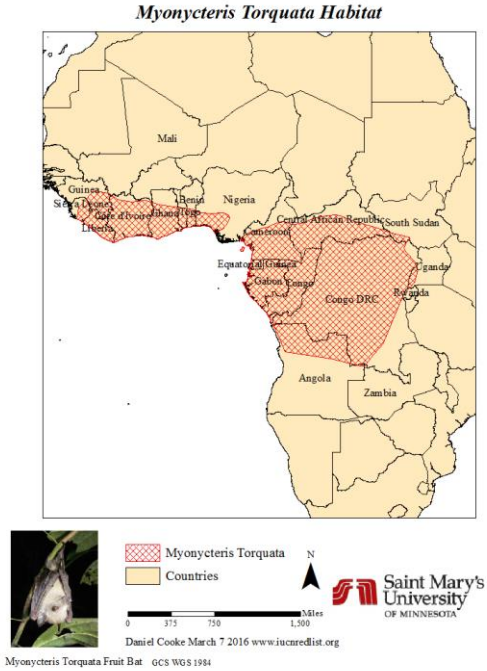

Figure 16. The habitat of the bat species *Myonycteris torquata.* This data was downloaded from the IUCN Red List of Threatened Species data portal (published 2008).

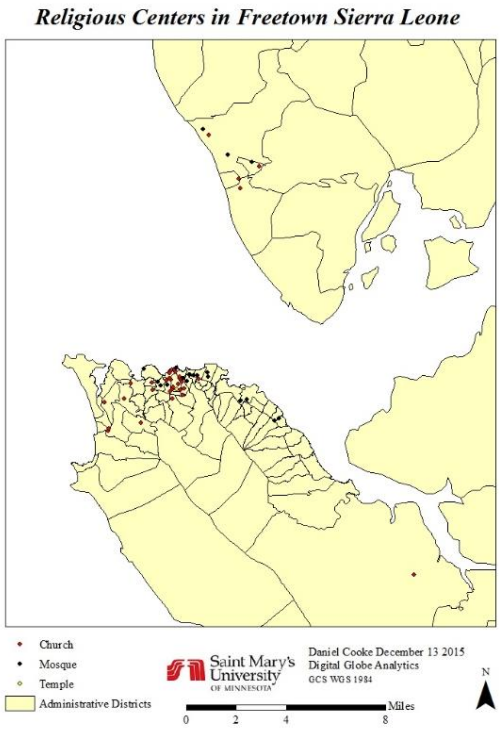

Figure 17. Different religious centers in the city of Freetown in the country of Sierra Leone. The citizens practice Christianity (church, red), Islam (mosque, blue) as well as Judaism (temple, yellow). However, some citizens keep their ancient rituals of body washing after converting to these religions. The 2010 data was downloaded from the Association of Religion Data Archives.

This disease disappears for several years at a time, and then comes back with a vengeance. Since 1976, "we've had 27 outbreaks around the globe" (Greenberg, 2014). The most recent outbreak "in West Africa is the largest and most complex Ebola outbreak since the Ebola virus was first discovered in 1976. There have been more cases and deaths in this outbreak than all others combined. It has also spread between countries starting in Guinea then spreading across land borders to Sierra Leone and Liberia" (WHO, 2015a). The three most heavily affected countries have just come out of years of turmoil, and conflict. Guinea, Liberia and Sierra Leone also have very weak health care systems. They lack human as well as infrastructural resources required to combat an epidemic of this proportion (WHO, 2015a).

The Ebola virus is believed to be contracted through the ingestion of bush meat, most likely the ingestion of migrating fruit bats. Fruit bats are "an important food source" (Leroy *et al.*, 2009). Human transmission happens through fluids with infected individuals or infected animals, symptoms present as early as 2 days or as late as 21 days from point of contact (Leroy *et al.*). Human-to-Human transmission occurs through poor medical practices, ancient religious practices (such as body washing) and the reuse of equipment without sterilizing it.

The most recent outbreak in West Africa has taken thousands of lives. Because of this, a vaccine is currently being developed at the Center for Disease Control in Atlanta, Georgia. If the vaccine does work, the Ebola virus may be eradicated in the future, but the natural reservoir may never be known without further study.

Conclusion

The key conclusion to draw from this study is that very little is known about the Ebola virus. Although 27 outbreaks have occurred since 1976, it seems society continues to learn more about the virus on a daily basis. Men and women across the world work tirelessly to develop a vaccine, to learn more about the virus in order to decrease its affects during the next epidemic.

Overall, the virus has an infection period of 2 to 21 days; the natural reservoir is most likely in one of the fruit bat species *Epomophorous wahlbergi*, *Epomops franquetti*, *Hypsignathus monstrosus* or *Myonycteris torquata*. Finding the natural reservoir is just the first of many steps that must be taken in

order to control this deadly virus.

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