Chinhoyi University of Technology

An analysis of host-carrier association, prevalence and community awareness of plague disease in south-western, Zimbabwe

BY

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Ecology and Environment in the School of Wildlife and Environmental Sciences at Chinhoyi University of Technology, Chinhoyi, Zimbabwe

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APPROVAL FORM

The undersigned certify that they have read and recommended to the School of Wildlife, Ecology and Conservation, Chinhoyi University of Technology, for acceptance, a thesis titled, "**An analysis of host-carrier association, prevalence and community awareness of plague disease in south-western, Zimbabwe**". Submitted by Annabel Banda in fulfilment of the requirements for the Doctor of Philosophy degree in Ecology and Environment.

25 April 2021

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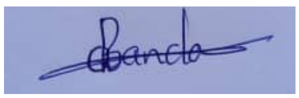
DECLARATION

I declare that this thesis is my own original work and has not been submitted for a degree in any other university



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Signature……………………………………………Date…………………….…………..

Annabel Banda

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ABSTRACT

Human-animal species interaction has increasingly become a subject of interest in community ecology as evidenced by the recent theory on species co-occurrences in interaction networks. However, a neglected area is that of understanding zoonotic disease host-carrier associations in tropical semi-arid savanna ecosystems, that is, the extent and impact of biotic interactions. Over time, however, humans have developed unique knowledge which helps in awareness and practices on zoonotic diseases like plague. The aim of this study was to analyze the diversity and host-carrier association, prevalence and local community awareness of plague disease in a semi-arid tropical savanna ecosystem of south-western Zimbabwe. Specifically, the objectives of this study were to: (i) analyse the diversity of rodents and fleas, and rodent-flea association, (ii) determine the prevalence of plague bacteria (*Yersinia pestis*) among captured rodents, and (iii) assess the level of awareness and practices of local communities on zoonotic disease management. This study followed a quasi-experimental design comprising of two study areas, Nkayi and Umzingwane districts. For the first and second objectives, rodents were captured using the removal trapping method, utilizing Sherman traps between April 2017 and April 2018. Using standard procedures rodents were euthanized and subsequently dislodging fleas from them. A two-way case study was used with a quasi-control site (Umzingwane district) and treatment (Nkayi district). Data were analysed using chi-square test of independence, Mann-Whitney *U* and graphical analysis. For the third objective, focus group discussions were used to collect data on community awareness and local practices on zoonotic disease in the two districts between July 2017 and April 2018. Thematic data analysis was done in Microsoft word. Results showed, firstly, a total of five (5) rodent species and four (4) flea species recorded in the study areas, with no significant differences in both species diversity between the study districts. The relative abundant rodent and flea species in Nkayi district were *Gerbilliscus leucogaster* (N= 65; relative abundance (RA) = 80.25) and *Xenopsylla brasiliensis* (N = 113; RA = 99.12). In Umzingwane district the RA of rodents was high for *Mastomys natalensis* (N = 70;

RA = 95.89) while fleas were highest for *Chiastopsylla rossi* (N = 20; RA = 41.67) and *Dinopsyllus ellobius* (N = 19; RA = 39.58). In Nkayi district, the flea species, *X. brasiliensis,* was mostly associated with four rodent species, namely, *M. natalensis, Saccostomys campestris, Gerbilliscus brantsi* and *G. leucogaster* whereas in Umzingwane district, all the recorded flea species, i.e., *X. brasiliensis*, *C. rossi*, *Ctenophthalmus calceatus* and *D. ellobius* were associated with only one rodent species, i.e., *M. natalensis*. Percentage Incidence Indices (PII) and Specific Flea Indices (SFI) for *X. brasiliensis* on *M. natalensis* was higher in Nkayi district compared to Umzingwane district. Noteworthy was the higher PII and SFI of *X. brasiliensis* on *G. leucogaster* in Nkayi district. Secondly, an overall low plague prevalence of 2.4% in the study area with only one study site, i.e., Umzingwane having a single *M. natalensis* rodent recorded as infected. Thirdly, most of the study focus group discussants were fairly aware of zoonotic diseases and reported that there were several management practices adopted by the local communities to manage zoonotic disease inclusive of plague. In conclusion, this study revealed a low and insignificant diversity of both rodents and flea species, variable rodents and fleas' species interactions in different areas, a low prevalence of plague disease associated with fair local awareness and diversified practises in zoonotic disease management, however, coupled with poor awareness of plague disease especially in Umzingwane district and poor uninformed practices on rodent population control. High relative abundance of *G. leucogaster* and *X. brasiliensis* in Nkayi district warrants for active plague surveillance system in the district. High PII and SFI of *X. brasiliensis* on *M. natalensis* and *G. leucogaster* further on gives the importance of the active surveillance system in the district. High relative abundance of *M. natalensis* in Umzingwane district also warrants the need for an active surveillance system in the district as well. Integrated disease management system covering monitoring of rodent-flea species interactions and associated population dynamics and plague prevalence would help minimise future emergence of plague disease in the study area and similar areas.

Key words: assessment; awareness and practices; diversity; plague disease; prevalence; rodent-borne

LIST OF ACRONYMS

AIDS	Acquired Immuno-Deficiency Syndrome
ARDS	Acute Respiratory Distress Syndrome
CDC	Centre for Disease Control
DIC	Disseminated Intravenous Coagulation
DRC	Democratic Republic of Congo
DVS	Department of Veterinary Services
ECDC	European Centre for Disease prevention and Control
ENM	Ecological Niche Model
ENSO	El Nino Southern Oscillation
FGDs	Focus Group Discussion(s)
HIV	Human Immuno-deficiency Virus
ISBN	International Standard Book Number
IKSs	Indigenous Knowledge Systems
LEK	Local Ecological Knowledge
LF	Lassa Fever
MH	Multiple Host
MLAWRR	Ministry of Lands, Agriculture, Water and Rural Resettlement
MoHCC	Ministry of Health and Child Care
MoPSE	Ministry of Primary and Secondary Education
PCR	Polymerase Chain Reaction
RDC	Rural District Council

SESs	Socio-Ecological Systems
WHO	World Health Organization
ZimStat	Zimbabwe National Statistical Agency
ZimVac	Zimbabwe Vulnerability Assessment Committee

DEDICATION

To my mother, **Constance Filicity Banda**,

Whose encouragement, love and advices will forever be cherished. Not forgetting **John Banda,** my father (the late) every day I reminisce the times we had, thank you daddy for the soldier training.

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Chapter 1

General Introduction

1.1 Background to the study

Identifying wildlife species that potentially serve as reservoirs of current or future zoonotic diseases is a crucial pre-emptive approach in minimizing zoonotic risk in humans (Han *et al*., 2015). Several studies have shown that terrestrial wildlife such as rodents harbour most re-emerging and emerging zoonotic diseases such as plague, leptospirosis and Hantavirus (Krijger, 2020). Rodents are often infected by zoonotic pathogens such as viruses, bacteria, and protozoa (Krijger, 2020). Several zoonotic diseases have been identified in rodents, and these include Hantavirus pulmonary syndrome, Haemorrhagic fever; Crimean-Congo, Hepatitis E, cowpox, Lassa fever (viral diseases); leptospirosis, Lyme disease, murine typhus, rickettsia pox, tularaemia and plague (bacterial diseases), not only but to mention a few (Meerburg *et al*., 2009). Rodents are considered to have greater diversity of zoonotic diseases probably because the order Rodentia has the highest species richness among terrestrial animals (over 2050 species) (Han *et al*., 2016). High species diversity has been shown to be associated with an increase in the risk of zoonotic disease (Hawlena *et al*., 2018).

Plague a bacterial zoonotic infectious disease mainly harboured by rodents and spread by fleas is a serious zoonotic diseases, particularly in its droplet infection state after infecting the lungs of vertebrate organisms (Dean *et al*., 2018; Bramanti *et al*., 2019). The pneumonic form can spread very fast through horizontally transmission (person to person) resulting in serious epidemics if not detected and treated early (WHO, 2017). Plague, therefore, is concomitantly a medical and public health menace. Human infection to plague may also occur when a plague outbreak occurs among commensal rats living in proximity to human habitats acquire the disease from wild rodents (ECDC, 2014; Ryan & Zermoglio, 2019). Although plague is mainly thought of as a disease of historical importance, there are increasing reports of its occurrence, particularly in Africa, South America, and India (WHO, 2016; Melman *et al*., 2019). These modern plague outbreaks could be due to high rodent infestations in the prevalent urban slams (Anjos *et al*., 2020). Low income communities often engage in subsistence agriculture, mining, animal husbandry and hunting as well as fetching firewood and water which increase chances of getting infected by the plague disease (Halliday *et al*., 2015).

Disease monitoring using wild animals, can offer early preventive measures for zoonotic diseases (Rocke & Friend, 2002). Two-thirds of emerging diseases over the past decade are animal in origin (zoonotic diseases) (Thompson, 2000; Acosta & Fernández, 2015) . Hence, predicting the emergence of zoonosis and the resulting public health and societal impact is critical for effective community health planning and management. Wild animal use in determining disease occurrence was used to monitor the presence of West Nile virus in North America using birds (Friend, 2006). Wild animal use in determining disease occurrence also has been fussy put into practical use for detecting influenza, arthropod transmitted viruses, and other diseases (Friend, 2006). Hence, managing, identifying, and preventing these zoonotic infectious diseases are an important focus for public health. However, the lack of knowledge on the pathways and mechanisms of emergence, transmission, and epidemiology of zoonotic disease hinder the development of animal monitoring as a community health prediction tool (Stephen *et al*., 2004).

Thus, the risk of infectious disease is affected by wildlife migration; habitat loss and degradation; changes in water availability or distribution; agricultural land use changes; increase in livestock production; urbanization; pesticide resistance in vectors; climate variability and change; trade and international travel, and the accidental or intentional introduction of pathogens (Wilcox & Jessop, 2009).

Moreover, the pattern and the extent of change of a particular infectious disease depend on the particular ecosystems affected, type of land-use change, disease-specific transmission dynamics, sociocultural changes and the susceptibility of human populations (Corvalan *et al*., 2005). Hence, there is need for determining the role of disease-specific transmission dynamics (rodent-flea diversity and association) and sociocultural change (local community awareness and practices impacts on zoonotic disease control) in Nkayi and Umzingwane districts. Corvalan *et al*. (2005) states that, climate and micro-environmental conditions have an impact on the pattern of microbe entry into human species, this is because of an existence of a relationship between living organisms including humans and the physical environment (human ecology). Abiotic factors alter the distant spread of microbes between humans and the reproductive and foraging behaviour of vectors of zoonotic pathogens (Corvalan *et al*., 2005). Climate and micro-environmental conditions on the infectious agent range and activities are largely changed by human-induced changes on the ecosystems and in physical environmental conditions (Corvalan *et al*., 2005).

There is greater qualitative variability in assorted host individuals, causing their parasites to be exposed to varying microclimatic conditions, thereby harbouring a diverse infra-community of parasites. Thus, for a parasite to reach the highest level of reproductive achievement it has to consider among host variation in choosing a host individual for utilizing (Krasnov *et al*., 2004). Jaffee *et al*. (1992: 495-506) state that, "*there are two most important qualitative insights from the study of disease in human and vertebrate populations; firstly, there is the common host threshold density, which is the level of hosts in the population required to ensure that the pathogen does not become locally extinct, and secondly, there is the transmission rate which depend upon host and pathogen population densities and this leads to temporal density-dependent parasitism*". In order to attain greater fecundity, parasites have to endure contending needs when assessing and spreading themselves among host individuals (Hawlena *et al*., 2005). In most instances, hosts provide parasites with places for living, for aging, and copulating, and as such can be considered the parasites specific place.

Rodent members of the family Muridae (inclusive of mice and rats) are dominant species in the whole world due to their ability to adapt and exploit new situations. Murids (mice and rats) have the ability to live in the wild and as commensal near or in human dwellings. In so doing have a greater chance of transmitting diseases to humans (zoonosis), thus being significant in public health due to their role as carriers or reservoirs for infections and diseases.

Plague in Zimbabwe is endemic in Lupane and Nkayi, that is, natural region IV in south-western parts of the country (Manungo *et al*., 1998). Region IV has been observed to be expanding, now covering some parts of Matabeleland South inclusive of Esigodini and the greater part of Gweru (Mugandani *et al*., 2012). The shifting of natural regions boundaries strongly points to evidence of climate variability and change (Mugandani *et al*., 2012). Although this region harbours plague foci its rodents and flea species identification information are scarce. Rodents and flea species identification has been conducted outside the foci (Zimba *et al*., 2012). In the country, plague surveillance system is weakly performed (Chikwenhere, 2006). However, the World Health Organization (WHO) urges each and every each country to put in place an active surveillance system on plague (Dennis *et al*., 1999), this involves picking up and testing dead rodents, investigating abundance of plague-prone hosts and determining vector fleas infestation rates on rodents (Eisen *et al*., 2020). It is rather important to keep an active surveillance system, especially after the discovery of multi-drug resistant bacterial plague (*Yersinia pestis*) in Madagascar (Lofty, 2015). Therefore, an integrated health approach would be ideal so as to provide decision makers with a firmer foundation from which to build evidence-based disease prevention and control plans that involve complex human-animal-environmental systems, and would serve as the foundation to train and support researchers needed to maintain and apply research capacity in the area (Stephen *et al*., 2004).

1.2 Problem Statement

The highest plague cases in Zimbabwe occurred in 1994 in Nkayi district (329 recorded cases and 28 deaths), with fewer cases reoccurring in 1997 in Nkayi, i.e., eight (8) recorded cases and two (2) deaths (Munyenyiwa *et al*., 2019). There were some reported plague cases in 1998, 1999 and 2012, although not clearly confirmed where they took place (Munyenyiwa *et al*., 2019). An area of concern given that there are a number of zoonotic diseases that mimics plague disease such as malaria, typhoid and Human Immunodeficiency Viruses/Acquired Immunodeficiency Syndrome (HIV/AIDS) in humans, thereby leading to under-reporting of plague disease, thus therefore the true burden being underestimated (Elelu *et al*., 2019). This lag or inconsistence in information reporting could lead to relaxation in behaviour and practices by both authorities and communities which subsequently can lead vulnerability to possible waves of plague infection.

There has not been any reported rodent surveillance in the 1990s up to this time. Rodents' active surveillance in plague bacteria (*Y. pestis*) antibodies detection, date back to year ≤1981 (Charlton & Palmer, 1975; Taylor *et al*., 1981). There is limited knowledge on rodent and flea diversity, species interaction (rodent-flea), and plague bacteria detection among rodents in plague endemic areas, e.g., south-western Zimbabwe. Despite the general hypothesis that increased rodent diversity likely leads to reduced occurrence of plague incidence due to dilution effect (Vora, 2008). Worryingly also is occurrence of plague after long period of quiescence (Dennis *et al*., 1999). Moreover as highlighted by Chikwenhere (2006), plague surveillance system is weakly performed in the country (Chikwenhere, 2006).

The poverty datum line in Zimbabwe is rapidly increasing (Herald, 2020). Thus, forcing people to be involved in many outdoor activities like small scale gold panning (Ncube-Phiri *et al*., 2015), district immigration of people and relying on rodents as alternative source of protein, this therefore exposes people to plague disease acquisition. The household fluidity (immigration of people), can result in those with prior knowledge of the plague especially in Nkayi district to be unavailable to transmit the knowledge to the new population and this increases the risk of infection and the spread of the disease. The research wants to address a number of problems like the presence of limited knowledge on rodent and flea diversity, species interaction (rodent-flea), and plague bacteria detection among rodents in plague endemic and non-endemic areas occuring in a similar agroecological zone. This thereby emphasising the importance of socialecological systems (SESs) and species co-occurrence theories contribution. Further on most diseases nowdays have have shared symptoms which therefore leads to their underreporting and as well poverty levels in Zimbabwe are increasing forcing people to do outside activities leading them to be vunerable to zoonotic diseases. It is therefore important to research on knowledge and practices on zoonotic diseases, thus Local Ecological Knowledge (LEK) theory contribution.

1.3 Objectives of the study

1.3.1Aim of the study

To analyse the ecological host-carrier association, prevalence and local community awareness of plague disease in a semi-arid tropical savanna ecosystem of Zimbabwe.

1.3.2 Specific objectives

(i) To determine the diversity of rodents, fleas and their association in a semi-arid tropical ecosystem, i.e., Nkayi and Umzingwane districts, Zimbabwe.

(ii) To establish the prevalence of *Y. pestis* among captured rodents in Nkayi and Umzingwane districts, Zimbabwe, and

(iii) To assess the awareness and practices of local communities on zoonotic disease management in Nkayi and Umzingwane districts, Zimbabwe.

1.4 Research questions

i. What is the diversity of rodents and fleas and the rodent-flea association in Nkayi and Umzingwane districts, Zimbabwe?

ii. What is the prevalence of *Y. pestis* among captured rodents in Nkayi and Umzingwane districts, Zimbabwe?

iii. What is the role of community awareness and practices on zoonotic disease management in Nkayi and Umzingwane districts, Zimbabwe?

1.5 Theoretical framework

The study has its basis on three theories SESs, theory of species co-occurrence and LEK. There are a few ecosystems with no people, like large wilderness areas seen with their intactness and very minimum population densities and there are no social systems without nature that is, SESs (Fischer *et al*., 2012). Socio-ecological systems comprise of intertwined or interlinked social, economic, ecological, cultural, political, technology and some other components, all trying to accentuate the integrated concept of humans-in-nature outlook (Petrosillo *et al*., 2015). The theory emanated from the recognition of close interaction between social-economic system and natural system. It is made up of many different components that interact to come up with a complex entity therefore its dynamic can only be explored using a holistic approach, since it does not focus on a detailed understanding of parts, but on how the components contribute to the dynamics of the whole system (Binder *et al*., 2013).

Species co-occurrence theory is a novel theory in the recent ecological networks that seeks to explain some of the causes of species distribution not well revealed by the abiotic effects but instead by biotic effects (Cazelles *et al*., 2015). Species distribution is proposed to be influenced by the ability of the organism's physiological tolerance to environmental conditions, but also by the interactions with other species (Hutchinson, 1957; Boulangeat *et al*., 2012). The prior postulate, i.e., physiological tolerance to environmental conditions has been well researched and well documented, thereby leaving a gap for the latter, i.e., the interactions with other organisms (Cazelles *et al*., 2015). In order to be able to interpret association data, express hypotheses for unlike community assembly mechanisms, and to encompass the analysis of species distributions currently focused on the relationship between occurrences and abiotic factors, there is need to put forward the theory of species co-occurrence (Cazelles *et al*., 2015). Researches contributing to the theory of co-occurrence are scarce; this study therefore wants to add on to this novel theory.

Humans are greatly involved in landscape change via their anthropogenic activities like cultivating of crops, clearing land for habitation, cutting trees for firewood and when doing mining activities. Moreover the landscape can change naturally as result of anthropogenic activities like climate change, tectonic plate movements, natural disasters like volcanoes and flooding (Khan *et al*., 2019; Tian & Stenseth, 2019). All these and many more will have an impact on rodents and associated flea diversity, subsequently perpetrating transmission and/or occurrence of rodent diseases like plague among/to humans. Farming, mining and rodent trapping activities are examples of SESs, since they are a result of the interface and co-evolution over centuries between people, which shaped the land through their activities, and the nature that in turn, gave people a variety of ecosystem services (Petrosillo *et al*., 2015). This research therefore takes on a socio-ecological approach where environmental studies are carried out simultaneously with social investigation, thus contributing to socio-ecological theory (Fischer *et al*., 2012).

In several ecosystems, structure and function are now established primarily by human relations, awareness, behaviours and knowledge so that nowadays it is more proper to think of SESs combining approaches from both environment and social systems (Milner-Gulland, 2012). Many communities are characterized by a well-developed system of LEK to assess the quality of ecosystems goods and services and to sustainably manage natural systems. LEK is defined as awareness, customs, and belief regarding ecological relationships that are gained through extensive personal observation of and interaction with local systems, and shared among local users (Berkes *et al*., 2000; Johannes *et al*., 2000; Davis & Ruddle, 2010 in Berkstrom *et al*., 2019). It has been widely used to compliment scientific information in wildlife conservation and management, particularly in community-based natural resources management programmes (Gandiwa *et al*., 2014; Milupi *et al*., 2017). The theory of LEK is derived from Indigenous Knowledge Systems (IKSs) (Mawere, 2010; Iniesta-Arandia *et al*., 2014; Kupika *et al*., 2019), which basically implies an intertwined set of awareness, skills and technologies present and developing around specific conditions of populations and villages indigenous to a certain geographic area (Ndangwa, 2007). This study contributed to SESs and LEK theories because it involved researches in environment and social interactions; however LEK is a component of both SESs and IKSs. Socio-ecological systems and LEK are rapidly transforming due to the socially, economically, culturally and institutional modification in the society. The first and second objectives: determination of the diversity of rodents and fleas and rodent-flea association in a semi-arid tropical ecosystem and establishment of the prevalence of *Y. pestis* among captured rodents in Nkayi and Umzingwane districts, Zimbabwe were contributing to two theories namely SESs and species co-occurrence. The third objective on assessment of the awareness and practices of local communities on zoonotic disease management in Nkayi and Umzingwane districts, Zimbabwe should add on to the LEK theory.

1.6 The conceptual framework of the study

Plague is a disease of wild rodents, i.e., it is an opportunistic disease among other animals and human beings. The transmission mostly occurs when infected fleas leave the infected dead body as a result of temperature lowering in a dead body (Nyirenda *et al*., 2017). Plague disease may spread among hibernating wild rodents as a result of infected fleas, contaminated soil (enzootic plague cycle), usually these rodents after hibernation in search of food they exchange fleas with other rodents (Figure 1.1). Additionally, rodent's population in the wild can increase if conditions are suitable this will favour an increase in competition among rodents', which results in some rodents leaving the wild environment and drawing closer to human dwellings, thus in the process becoming synanthropic rodents (Douangboupha *et al*., 2009). Synanthropic infected rodents are perpetrators of animal and human rodent-borne disease burden. Catastrophic events like fire and excessive rainfall can cause wild rodents to leave their habitat and join human beings' shelter, such a scenario as well can cause plague disease spread. Therefore, in this thesis, the focus is on the rodent-flea diversity, rodent-flea association, rodents as host of zoonotic plague bacteria (*Y. pestis*), as well as awareness and management practices use in the control of zoonotic disease (plague disease)-in a plague endemic area.

There exists a rodent interface in the wild environment where wild rodents and peri-domestic rodents like *M. natalensis* meet. At this interface that is where infected fleas are exchanged (pathogen transmission) or even direct transmission of plague is likely to occur (Chakma *et al*., 2015). When climatic conditions are ideal, the disease will spread among peri-domestic rodents, which in turn passes it on to domestic rodents like *Rattus rattus* thus again the disease will spread among susceptible rodents, this is the epizootic plague cycle (Yang, 2017). Epizootic cycle results in massive die offs of susceptible rodents, leaving behind infected fleas' thirst for their next feed. Infected fleas will further on move to domestic animals like cats and subsequently can even feed on people, thus completing the zoonotic plague cycle. Human beings can also acquire directly plague disease from the wild through handling wild rodents or when they are doing other activities in the bush like hunting, gold panning and clearing land for cultivation (Mills, 2006). The pictorial enzootic, epizootic and zoonotic cycles are illustrated by Ben-Ari *et al*. (2011). Plague in humans can occur in three forms namely, bubonic (affecting the lymphatic system), pneumonic (affecting the respiratory system) and septicemic (affecting the circulatory system). However, disease transmission is not only reliant on environment perturbation that may impact food availability and rodent population distribution, but also on social factors like capturing rodents for consumption, hence placing humans at higher risk of exposure (Salmón-Mulanovich *et al*., 2016). Understanding human communities' interaction with their surrounding ecosystems as well as community perceptions regarding the root causes of plague (knowledge) might contribute to understanding its endemicity (Rivière-Cinnamond *et al*., 2018). Moreover, an increase or decrease in the risk of zoonosis can occur as a result of the public's awareness, attitude and perception on zoonosis (Shirima *et al*., 2010). In, this thesis the focus is on rodent-borne zoonotic disease (plague disease) with high risk to humans. This study investigates rodent-flea diversity, rodent-flea association, *Y. pestis* prevalence and the use of awareness and practices in the control of zoonotic diseases with greater interest in plague disease in an endemic and non-endemic area.

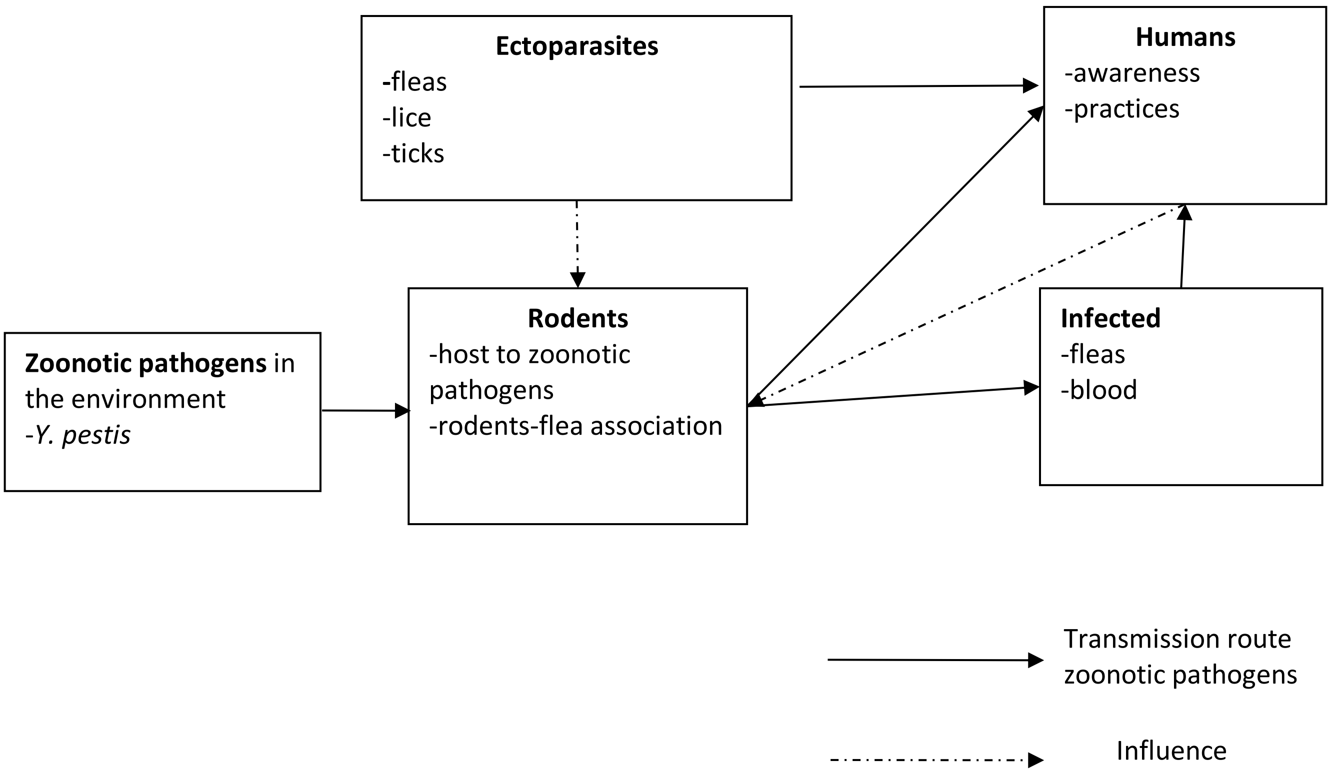

Figure 1.1. The study conceptual framework showing rodent presence, rodent-flea association, and potential transmission routes of rodent-borne zoonosis to humans. Adapted from Shirima *et al*. (2010); Salmon-Mulanovich *et al*. (2016) and Munyenyiwa *et al*. (2019).

1.7 Justification of the study

Scientific significance

Nkayi and Umzingwane districts occur in a similar agro-ecological zone, i.e., region IV. Studies on comparison of rodents and fleas' diversity in this region are limited as most studies on rodents and flea diversity in Zimbabwe have been done outside the plague foci (Zimba *et al*., 2010, 2011; Banda &

Zimba, 2016). Research on awareness and practices is very important as well as it assesses the level of knowledge and practice management competent, in so doing a pragmatic approach will be utilized to control zoonotic diseases outbreaks. WHO however urges each and every country to put in place an active surveillance system on plague (Dennis *et al*., 1999). It is rather important to keep an active surveillance system, especially after the discovery of multi-drug resistant *Y. pestis* in Madagascar (Lofty, 2015). Moreover, there are few studies that contribute to the SESs theory. The sustainability of SESs depends on their capacity to absorb uncertainty and cope with disturbances. This study integrates SESs and LEK theory in understanding the knowledge and management practices on zoonotic diseases.

The study explores how anthropogenic activities may sustain the diversity of rodents and fleas within the communities in the different districts, thus feeding into the ecological / natural systems component of the SESs. This is quite crucial since reduced diversity of species especially rodents may result in increased plague occurrence as a result of reduced dilution effect. The study indirectly links the influence of social systems to natural/ ecological system, showing that the natural system does not exist as a single entity. Diversity of rodents and fleas may be affected by practices done by people when capturing rodents for consumption or for population control. It is important to understand *Y. pestis* occurrence during inter-epizootic condition in both the natural and social systems. This is very important since mostly plague occurrence in the natural systems implies occurrence in the social systems. Thus a holistic approach to the study of zoonotic diseases (plague disease) is undertaken; this is advancement in the SESs theory. Species co-occurrence theory has not been well contributed to, this theory tries to understand the biotic factors on the distribution of species, contrary to the usual many research done to assess the effect abiotic factors on the distribution of species. Biotic factors can impact distribution of species, especially in parasitism. Distribution results can indirectly reveal the distribution of a given disease. Zoonotic diseases awareness and practices has been greatly researched. Less researched on is the LEK information on rodent-borne disease with interest in plague disease. Adding to the existing body of knowledge in LEK information it is important to assess the knowledge and plague management practices existing in the local communities. Accordingly, this study was done in plague endemic and non-endemic places in Matabeleland provinces of Zimbabwe.

Socio-economic significance of the study

The information generated from the study will assist health personnel in predicting the possibilities of an outbreak of plague, utilising the diversity of rodents and fleas' results and *Y. pestis* prevalence outcome. The data generated from the study can potentially be used to develop rodents and flea control programs. This research is helpful to the management staff (environmental health officers; local council environment offices); it will assist them to exercise a pragmatic approach to control of rodents and flea populations and to be on the outlook of any possible plague outbreak, i.e., bridging the gap between researchers and the industry. Laboratory diagnosis of plague disease bacteria remains a challenge considering that most human cases occur in remote zones where access to health care is impossible (WHO, 2008). Further, this study explores peoples' knowledge and practices with respect to plague disease (WHO, 2018). The study places people at an ideal position to be conscious of plague disease, to enquire more from health workers and to be in a position to detect its occurrence thereby reducing its spread in case of an outbreak (WHO, 2008). This research provides a refresher to health workers, district hospital environment personnel and local people in Nkayi district, while in Umzingwane district it is more of educating these people.

Study area significance

Plague in Zimbabwe is endemic in Lupane and Nkayi (Manungo *et al*., 1998) that is, in region IV (Dennis *et al*., 1999). Due to the previous epidemics, thus it was expected to have plague hosts and carriers, people to be knowledgeable and having good management practices on plague. Further on region IV has been observed to be increasing, now covering some parts of Matabeleland South inclusive of Umzingwane district (Mugandani *et al*., 2012). Plague foci are not stagnant, thus keep on changing, therefore there is high possibility that plague disease could be detected outside the Nkayi and Lupane foci. Additional this study compares the diversity of rodents and fleas of areas within similar climatic conditions but differing in plague disease occurrence.

1.8 Study area

The study was conducted in Umzingwane and Nkayi districts in south-western Zimbabwe (Figure 1.2). The two districts occur in Natural region IV. The region has a mean minimum temperature range of 11-20°C and mean maximum temperature range of 19-26°C (Nyamapfene, 1991). Natural region IV is an extensive livestock production area with some drought tolerant crops such as sorghum (*Sorghum vulgare*) and millet rapoko (*Eleucine coracana*) being cultivated. Farmers do sometimes grow some short season maize (*Zea mays)* varieties. The rainfall range of the area is 450-600 mm and has soil groups 3 (vertisols group), 4 (siallitic group) and 5 (fersialitic group) (Mugandani *et al*., 2012) The two study area districts occur in different provinces, Nkayi district is in Matabeleland North and Umzingwane district is in Matabeleland South provinces.

1.8.1 Nkayi district description

Nkayi district population was estimated to be 109,135 in 2012 (Zimstat, 2013). Nkayi district comprises largely of rural households divided into 30 wards and consisting of 156 villages (Nkayi RDC, n.d in Zikhali, 2018). At the time of this study there was only one growth point in the district usually referred to as Nkayi business centre located in ward 29 (Zikhali, 2018). The household percentage poverty in Nkayi district was 95.5% (Zimstat, 2013; Zimvac, 2016 in Zikhali, 2018). The district has deep Kalahari sands occupying 60% of the area and the natural vegetation is typical dry savannah dominated by

Miombo woodland (Dube *et al*., 2014). Maize is the predominant crop grown, followed by small grains and a smaller portion of legumes. There are high rates of female-headed households in Nkayi (40%) reflecting the migration of men who seek economic opportunities in cities and neighbouring countries (Dube *et al*., 2014).

1.8.2 Umzingwane district description

Umzingwane district population was estimated to be 62,990 in 2012 (Zimstat, 2013). Umzingwane district area is inundated with bare granite hills. The hills are mosaic designed with patches of vegetation, flat land with sporadic flat rock structures and with soils which are course, sandy and low in fertility (Ncube-Phiri *et al*., 2015). There are about three common types of vegetation in Umzingwane district, viz, bushveld, commonly covered with *Acacia* whose height range from 1 to 5 m, there is the wooded grassland and the woodland with familiar *Terminalia* and *Combretum* trees, whose height is at most 5m (Ncube-Phiri *et al*., 2015). Umzingwane district is dominated by artisanal small-scale gold mining. Impoverishment, poverty level of 69.8% (Zimstat, 2013; Zimvac, 2016 in Zikhali, 2018), and frequent droughts in the area have caused Umzingwane inhabitants to partake in illegal gold mining, for instance, at Ncema dam, Nyankuni area, Nyawozibuhlungu river, Esigodini Agricultural Institute rivers' and dams and danger area near Khomani resettlement. Numbers 15, 27, 3, 17 represent Monki, Mathoba, Nhlekiyane and Crocodile wards, respectively.

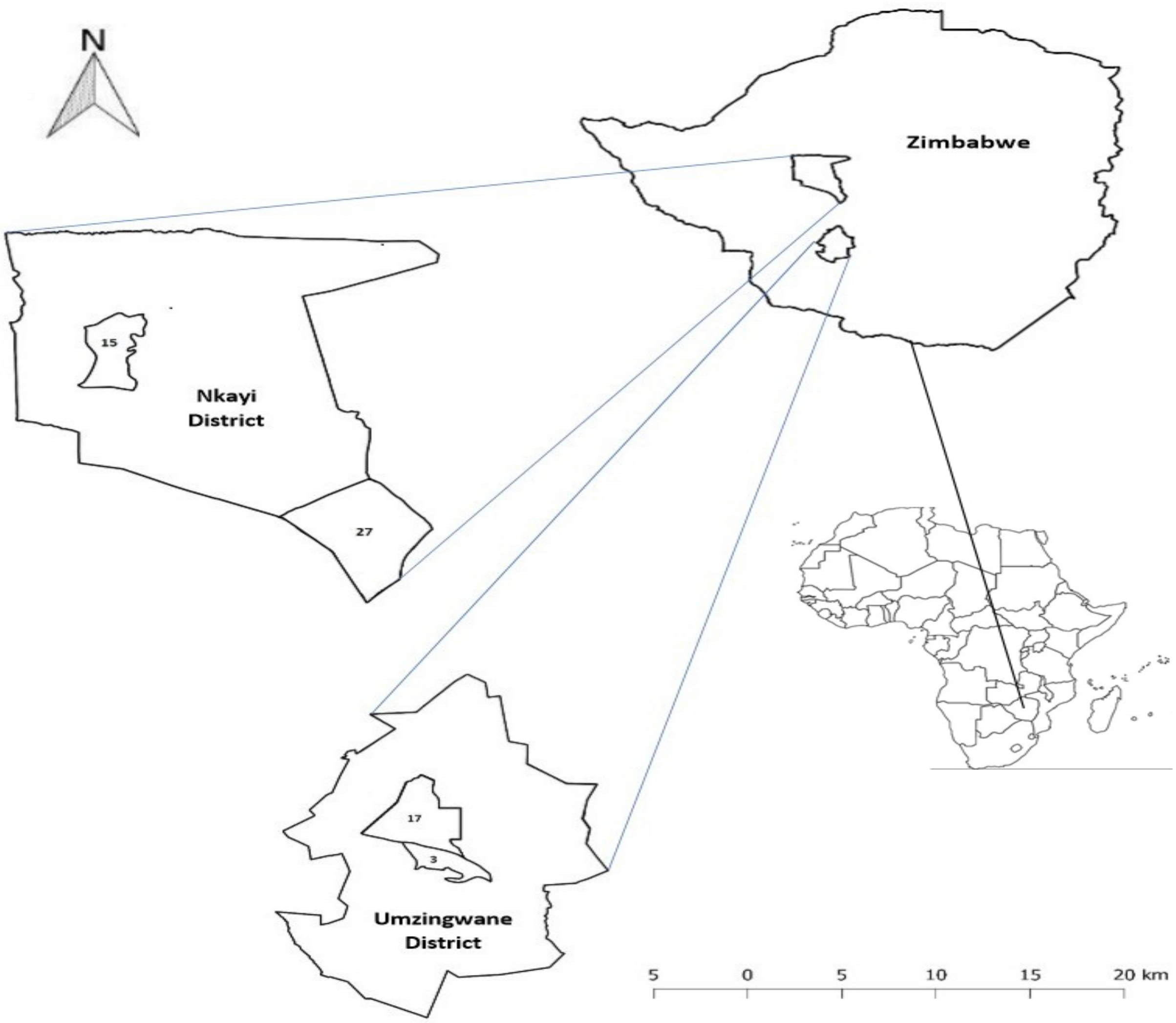

Figure 1.2 Location of Nkayi and Umzingwane Districts in Zimbabwe.

1.8.3 Study sites selection

In each district, two village areas were chosen based on human influxes due to local activities and history of plague occurrence. In Umzingwane district, Nhlekiyane and Crocodile villages were selected based on human activities like artisanal gold mining, these being in wards 3 and 17, respectively, while at Nkayi district the two communal areas chosen were Monki and Mathoba where plague cases were noted (*J. Sibanda pers. comm, to A. Banda, 2017*), these occur in ward 15 and 27. Purposive sampling (Gandiwa *et al*., 2014) was utilised to select four villages, two from Nkayi district (plague endemic area) and two from Umzingwane district (non-plague endemic area). This sampling method was utilised because not all villages within the communities (or wards) have had plague disease occurrence in Nkayi district and in Umzingwane district not all villages experience rampant mining activities.

1.9 Thesis outline

This is a hybrid thesis consisting of six Chapters. Chapter 1 is the general introduction, which provides the background of the study, statement of the problem, main and specific research objectives, research questions, the theoretical and conceptual frameworks, and justification of the study.

Chapter 2 provides a literature review of the study covering a summary of the rodent disease-causing pathogens and rodent species harbouring the pathogens observed in Africa, i.e., protozoans, trematoda, cestodes, nematodes, bacteria and virus. The Chapter goes on to describe the distribution of plague disease worldwide based on WHO (2016) and its prediction spread using modelling in Africa (Neerinckx *et al*., 2008). In this Chapter, the dominant rodent and flea species in African countries implicated in plague transmission were further investigated.

Chapter 3 reports on the rodent-flea diversity and association in Nkayi and Umzingwane districts. This is comparative study of the two districts, utilising removal trapping method to determine rodent and flea species diversity.

Chapter 4 consist of an empirical study which assess the presence of plague bacterium (*Y. pestis*) among captured rodents in Nkayi and Umzingwane districts. The study also takes a comparative approach in which Nkayi and Umzingwane district captured rodents' blood were detected for *Y. pestis* using Geimsa stain.

In Chapter 5, the study the awareness and practices on the management of zoonotic-plague disease in Nkayi and Umzingwane districts was investigated. A two-way case study approach was used with quasi-control site (Umzingwane district) and treatment site (Nkayi district). Purposive sampling was utilized to select four villages, two from Nkayi district and two from Umzingwane district. Chapter 6 provides the general discussion, integrates all the main findings and provides a conclusion and recommendations.

Chapter 2

Literature Review

2.1 Introduction

This Chapter evaluates some rodent zoonotic diseases occurring in Africa; plague disease distribution (worldwide and in Africa) and dominant rodent-flea species in Africa. There is need to understand the principal determinants of structure and diversity of species in ecological communities so as to protect and restore biodiversity (Hagenah, 2006). For instance having knowledge on rodent diversity will permit the design of appropriate management policies that will target endangered species while sparing the valuable ones (Singleton *et al*., 2005). The physiological tolerance to environmental conditions has been thought to influence distribution of species, however in addition the species interaction with other species can have an impact (Boulangeat *et al*., 2012). Interactions among species are thought to be either positive (+), negative (-) or neutral (0) for the species involved (Suselbeek, 2014). The intensity and presence of human plague in China has been suggested to have a positive association with the rodent species richness (Sun *et al*., 2019), although, ecological interactions between known species are often non-linear and thus complex (Hagenah, 2006).

Zoonotic diseases are infectious diseases that are naturally or vector borne transmitted from vertebrate animals to humans and vice versa (Wang & Crameri, 2014). These zoonotic diseases are caused by all types of pathogenic agents, including bacteria, parasites, fungi and viruses (Wang & Crameri, 2014). Zoonotic diseases are responsible for some of the dangerous and harmful epidemics (WHO, 2019). It has been realized that zoonotic diseases transmitted by arthropod vectors are greatly affected by climatic change, consequently there has been sporadic outbreaks of zoonotic diseases globally (Ogden, 2017). Global temperatures are increasingly rising and this has greatly contributed to the anthropogenic emission of greenhouse gases, thus predicted to have an effect on the distribution of vectors and increase vector-borne zoonotic diseases risk (Naicker, 2011). This effect of global warming is well revealed by the potential spread of zoonotic viral disease, transmitted by mosquitoes called Chikungunya, occurring in the following continents: Africa, Asia, Europe and The Americas (Wang & Crameri, 2014). Moreover, temperature increase has been observed to lead to increased transmission of leishmaniasis by sand flies (Ready, 2010). Additionally, China has been experiencing a zoonotic viral disease hosted by rodents called Hantavirus, implicated to be caused by anthropogenic human activities like climate change (Tian & Stenseth, 2019).

There are quite a number of human anthropogenic activities influencing zoonotic diseases acquisition by humans. Scenarios like human population explosion leads to encroachment of their settlements into natural habitats, this causes an increased number of contacts between humans and wildlife; thereby perpetrates ease of transmission of zoonotic diseases (Corvalan *et al*., 2005). For instance, in Malaysia, the transmission of malaria parasites (*Plasmodium knowlesi)* from Macaques (*Macaca*) to humans was a result of humans getting into wildlife area (Singh *et al*., 2004). Recently, the novel coronavirus (Covid-19) pandemic has been attributed to some horseshoe bats (*Rhinolophus*) from live wet markets where live animals are mostly sold in China (Rodriguez-Morales *et al*., 2020). Further, political instability evoking civil conflict and war leads to breakdown in healthcare infrastructure and public control measures. The breakdown in healthcare leads to an upsurge of infectious diseases in general as a result of poor vector control measures (Khan *et al*., 2019), for instance in the Democratic Republic of Congo (DRC) due to political unrest it is the second highest reporter of plague in Africa (Lofty, 2015).

Natural factors such as one of the global climatic phenomena, the El Nino-Southern Oscillation (ENSO), which consists of warm and hot phases, has aided to increased Rift valley fever outbreaks in East Africa (Gould & Higgs, 2009). Rift valley fever outbreaks are associated with times following heavy rainfall (Martin *et al*., 2008). The important mosquito vectors transmitting this disease are floodwater breeders and eggs are deposited when there are heavy rains (Martin *et al*., 2008). Vector capacity is increased due to heavy rainfall and outbreaks are more likely to occur if vertebrate reservoirs are available (Martin *et al*., 2008).

Although a worldwide increase in zoonotic diseases has been noticed there has been under documentation of Africa's zoonotic diseases because of paucity of healthcare and constrained public health care system as a result of inadequate funding and conflicts collapse (Naicker, 2011). Some additional factors contributing to this under documentation are maladministration, corruption, lack of developmental will and lack of research support. The following diseases share general similar symptoms; brucellosis, leptospirosis, rickettsiosis, bartonellosis, plague, Rift Valley fever and chikungunya, thus therefore in the tropic's clinicians face a challenge in correctly diagnosing these diseases (Halliday *et al*., 2015). Consequently, the true burden of endemic zoonosis is greatly underappreciated and awareness among clinicians and policy makers' remains limited (Halliday *et al*., 2015). There are quite several reasons why Africa is behind with zoonotic diseases documentation. Africa has few laboratories with the ability to execute direct pathogen isolation or detection in acutely ill patients by blood culture or by molecular diagnostic assays such as nucleic acid amplification by PCR (Petti *et al*., 2006 in Halliday, 2015). A huge number of biodiversity is unexplored in Africa, as has been seen by the discovery of yet unknown species of arenavirus, the Lujo virus in Zambia that lead to a nosocomial outbreak in South Africa (Briese *et al*., 2009).

Among humans, nonspecific symptoms such as fever, headache, fatigue, and joint or muscle aches are commonly associated with many endemic zoonosis and these symptoms are shared with non-zoonotic diseases or conditions such as malaria, typhoid fever and Human Immuno-deficiency Virus (HIV) which are likely to be readily considered by clinicians (Maudlin *et al*. 2009; Welburn *et al*. 2015 in Elelu *et al*., 2019). With the constant occurrence of zoonotic diseases, it is very crucial for interdisciplinary studies to help inform management practices and policy.

2.2. Species interactions in savanna ecosystems

A selection of populations of at least two unlike species that interrelate unswervingly or incidentally within a distinct geographic area is known as an ecological community and that is where organisms resides (Thompson *et al*., 2018). Organisms in an ecological community interact with each other and that is termed symbiosis. Hence there are three forms of symbiotic relationships at an anatomical level, viz mutualism, commensalism and parasitism (Casadevall & Pirofski, 1999). At some coarse level, interactions can be grouped as either intra-specific or inter-specific. When individuals of the same species interact it's called intra-specific interaction while inter-specific interaction occurs between two or more species. These interactions are crucial in pushing distribution patterns, local community assemblages and evolutionary deviations (Martínez *et al*., 2008). Species interaction forms the basis of most of the ecosystem properties and processes such as nutrient cycling and food webs. Consequently, ecological interactions between individual organisms and entire species assemblage are often difficult to define and measure and often depend on the scale and context of the interaction (Harrison & Cornell, 2008; Brooker *et al*., 2009). However, there are many classes of interactions among organisms found throughout many habitats and ecosystems. These classes of interactions can be used as a framework when studying an ecological community, thus allowing scientists to describe naturally occurring processes and helps in predicting how human anthropogenic activities can affect ecosystem properties and processes (Lang & Benbow, 2013).

In an ecological web species interaction comprise of four (4) main types of two way coarse interactions, namely mutualism, commensalism, competition, and predation (inclusive of herbivory and parasitism) (Schowalter, 2006). As a result of numerous linkages among species within a food web, thus changes to one species can have a far reaching effect. Brief descriptions of the interactions are to follow:

Mutualistic interaction-divided into (i) facultative and (ii) obligate mutualism, where (i) is valuable but not important to survival and reproduction of either organisms (ii) is beneficial to one or both associates (Schowalter, 2006). Mutualistic interaction usually involves both sides benefitting, i.e., pollination where the plant gains some gamete transfer whilst the insect get food in the form of nectar. Commensalism interaction-one species benefit whilst the other is neither harmed nor benefitted. For instance epiphytes, plants that uses their host for areal support whilst getting their nutrients from the atmosphere (Schowalter, 2006). Competition interaction-occurs when organism's needs are concentrated on similar resource in short supply, usually it leads to survival of the fittest, a weaker organism being out competed (Holomuzki *et al*., 2010). Competition is divided into three major forms, i.e., interference competition; exploitation competition categorized real competition and apparent competition (Holomuzki *et al*., 2010). Predation interaction- one organism the predator captures and kill another organism called the prey. In many cases the predator and prey are animals. The relationship between predators and prey result in stronger forces emanating, however, governing the behaviour and ecology of all organisms (Tyutyunov & Titova, 2020). Herbivory interaction - similar to predation but this one involves an animal feeding on all or part of photosynthetic plants. Unlike predation herbivory does not lead to death of the plant (Gurevitch *et al*., 2002).

Parasitism interaction-one individual the parasite benefits from another one the host, while harming the host in the process. The parasite does not seek its own food. There are divided into two groups, facultative group in which the organism has a choice of not choosing a particular host, while the second group the parasite has no choice, it has to feed on the host in order to complete a critical life cycle (Gupta, 2014). Parasitism is a burden to reproducing animals (pregnant). This is because during that time the hosts would be confined in one area, thus a ready available source of food for the parasite, subsequently the host young ones as well can be a source of food (Richner, 2010). Further on it is noted that host are usually co-infected by multiple parasite species thereby resulting in potentially overwhelming levels of complexity (Richner, 2010). An individual host thus is an ecosystem because it can contain/ harbour parasite organisms, commensal symbionts and host immune components which interact and compete with each other thereby influencing the condition of the host (Rynkiewicz *et al*., 2015). Like in free living organisms, the diverse communities of concurrent pathogenic and non-pathogenic species may interact directly or indirectly, both with each other and with their environment (the host). Interactions among these species can have a major consequence for the presence of a species, species abundance, invisibility of a host to a novel parasite and host response to infection (Rynkiewicz *et al*., 2015).

As a major factor limiting natural population increase thus parasitism plays a role in the equilibrium ecosystem. There is coadaptation between the parasite and the host because of strong genetic interactions between the two, thereby implying a specialized type of interspecific relationship (Hurtrez-Boussès *et al*., 2001). Some parasites are obligate whereas some are generalist thereby not affected by changes in host density caused by environmental changes (Martinez & Merino, 2011). Parasites with free living stages, especially without forms of resistance will also be affected by weather vagaries. Parasites are as well diluted by host species variation, not all of them (host) will be competent enough to allow completion of parasite cycle (Martinez & Merino, 2011). Noteworthy change in the geographical distribution of the hosts can open new associations for both parasites transported by hosts to new areas and for parasites that are present in a newly occupied area (Martinez & Merino, 2011).

Understanding the factors underpinning species coexistence and stability in complex ecosystem is the major goal in ecology (Allesina & Tang, 2012). It has been suggested that in generally, small, fast growing, short lived organisms having more or less general feeding traits are likely to persist over a long term in a highly disturbed area, i.e., fleas on rodents (Woodward *et al*., 2012). This research will seek to identify overall importance of parasite-host interaction to determine the dynamics of parasite (ectoparasite and endoparasite (*Y. pestis*)) and host populations. The results generated will add on to biodiversity, understanding the drives and results of variation in species numbers and abundance across spatial and temporal scale (Gregory & Keymer, 1989). There exists a gap in research of using species co-occurrence data (biotic variable) to determine the diversity / distribution of parasite species

2.3 Pathogenic-zoonotic diseases in rodents' species

About two thirds of emerging diseases are zoonotic in nature (Thompson, 2000). The outcome therefore implies that emerging zoonotic diseases are among the most important public health threats today (Mahy & Brown, 2000). Wild animals serve as a major reservoir for the transmission of zoonotic agents between humans and animals, hence playing a vital role in the epidemiology of zoonotic diseases (Odeniran & Ademola, 2016).

Rodents are a key mammalian group found in many environments throughout the world and constituting more than 40% of the known mammalian species (Krijger, 2020). Rodents scavenge for food and are coprophagous, they are at risk of ingesting infective agents of diseases, for example, parasite eggs and disease causing invertebrates (El-Sherbini & El-Sherbini, 2011). Therefore, rodents can acquire the five groups of disease agents currently known to humankind, thereby contributing to the emerging and re-emerging infectious zoonotic diseases (Friend, 2006). Furthermore, mechanical spread of parasites by rats may pose a particularly high risk for disease transmission in slums and informal settlements in urban and peri-urban areas where humans practice open defaecation and foraging animals live and wander freely (Archer *et al*., 2017). More than 30 million poor rural and urban dwellers in sub-Saharan Africa are dependent on meat from wild animals for rituals or for trade (Mukaratirwa, 2011 cited in Odeniran & Ademola, 2016), thus increasing the likelihood of acquiring zoonotic diseases.

Toxoplasma is a single zoonotic protozoan affecting most of the warm-blooded animals and some fish (Dubey *et al*., 2011). The protozoan infects quite a number of rodent hosts, including mice, squirrels and rats (Table 2.1), however, the prevalence of the parasite in Africa is not known. The transmission mechanism that could involve blood (trachyzoites), muscles (bradyzoites) and faeces (sporozoites) makes it easy for a wide variety of animals to be infected (Odeniran & Ademola, 2016). *Toxoplasma gondii* an intracellular apicomplexan protozoan has an exceptionally broad host range, making it one of the most "successful" protozoan parasites on earth (Boothroyd & Grigg, 2002 cited in Webster, 2007).

Table 2.1. Rodent's parasite species and eradication status

Parasite	Rodents	Host type	Number of host	References
Protozoan *Toxoplasma gondii*-toxoplasmosis *Leishmania*-leishmaniasis	Mice (*Mus musculus* and *Peromyscus species*); rabbits (*Sylvilagus flovidanus*); squirrels (*Sciurus* species); rats (*Rattus norvegicus* and *Sigmodon hispidus*); *Mastomys erythroleucus*; *Tatera gambiana*; *A. niloticus*	Intermediate host Reservoir	Multiple host (MH)	Zarnke *et al*., 2001; Boakye *et al*., 2005; Webster, 2007; WHO, 2010
Trematoda *Schistosoma mansoni*; *S. bovis*;*S. Matthei*-*schistosomiasis*	Six genera of rodents (Pelomys, Lophuromys, Mastomys, Aethomys, Dasymys and Rattus)	Intermediate host	MH	Schwetz, 1956; Hanelt *et al*., 2010
Cestodes *Echinococcus multilocularis*-*echinococcosis*	Small rodents	Intermediate host	MH	Odeniran & Ademola, 2016; WHO, 2018
Nematodes *Angistrongylus contonensis*-angiostrongyliasis, *Gongylonema sp*.-gongylonemiasis, *Calodium hepaticum*-hepatic capillariasis	Rodents *Rattus norvegicus*, *R. rattus*, *M. natalensis*	Accidental host	MH	De Bruyne *et al*., 2006; El-Sherbini & El-Sherbini, 2011; Archer *et al*., 2017
Bacteria *Y. pestis*- Plague Leptospirosis Rat-bite fever Salmonellosis Tularemia	Rodents *M. natalensis*, *R. rattus* *Arvicanthis abysinnicus*, *Lemniscomys striatus*, *Mus minutoides*, Musk rats, ground squirrels, beavers	Definitive host Reservoir	MH	Neerinckx *et al*., 2008; WHO, 2010; WHO, 2016; CDC, 2017
Virus Lassa fever Lymphocytic	*M. natalensis* species complex House mouse (*Mus musculus*)	Definitive host	MH	CDC, 2017

Chorio-meningitis				

Rodents are host to Leishmaniasis a vector-borne disease caused by blood and tissue dwelling protozoan parasite belonging to the genus *Leishmania* (CDC, 2020). Animal reservoirs like rodents are important for maintaining infectious in various places and hence playing a crucial role for zoonotic and rural disease transmission (Alemayehu & Alemayehu, 2017). Sylvatic (wild) rodents are some of the most common host, however the diseases transmitted to human population when human, flies and reservoir host like rodents share the same environment (Alemayehu & Alemayehu, 2017). In Africa, leishmaniasis is endemic to countries mostly in the North, Central, East and the Horn of Africa (Boakye *et al*., 2005).

Of the 12 species of Schistosoma found in Africa only four are regularly reported as infectious to humans; these are blood fluke (*Schistosoma. Mansoni*), bladder fluke (*Schistosoma haematobium*), *Schistosoma intercalatum* and *Schistosoma guineensis*. With respect to these four-overwhelming majorities of human cases infection by Schistosoma are caused by the first two, with which *S. mansoni*, is relatively commonly observed in African rodents, although usually at lower prevalence levels than seen in Latin American or Caribbean transmission settings (Hanelt *et al*., 2010).

Alveolar echinococcosis usually occurs in a wildlife cycle between foxes, other carnivores and small mammals (mostly rodents) (WHO, 2018). A number of herbivores and omnivores act as intermediate hosts of cestoda echinococcus, they become infected by ingesting the parasite eggs in contaminated food and water, and then the parasite develops into larval stages in the viscera (WHO, 2018). *Echinococcus multilocularis* is an alveolar echinococcosis form which together with cystic echinococcosis is of medical and public health relevance in humans (WHO, 2018).

Although bacterial diseases were partially controlled, multi-drug resistance has developed in these organisms, as has been seen with *Y. pestis* causative agent of plague (Chanteau *et al*., 1998; Lotfy, 2015). The main hosts for plague are rodents and the disease is transmitted mainly by ectoparasite fleas (Dean *et al*., 2018; Bramanti *et al*., 2019). There are many other important zoonotic viruses with a significant impact on public health that have emerged or re-emerged (Wang & Crameri, 2014). Some of the viral diseases harboured by rodents are lassa fever, lymphocytic and chorio-menengitis (Sambri *et al*., 2013). The geographical ranges of zoonotic pathogens such as West Nile virus, chikungunya virus and dengue virus are expanding, with movement of vectors into newly established habitats, this causes the mixing of previously isolated vectors and introduces the agents to new potential vectors (Sambri *et al*., 2013).

2.4 Plague Spatial Distribution

Plague epidemics have occurred in Africa, Asia, and South America continents but most human cases since 1990s have occurred in Africa (WHO, 2016). Almost all of the cases reported in the last 20 years have occurred among people living in small towns and villages or agricultural areas rather than in larger towns and cities (CDC, 2018). Plague one of the enumerable zoonotic diseases, transmitted from rodents to humans via direct or indirect means, worldwide distribution is shown in Figure 2.1. The red shaded areas in the figure show places with potential natural foci of plague based on historical and current information (WHO, 2016). Plague shows almost a worldwide distribution and has not yet been detected in Australia.

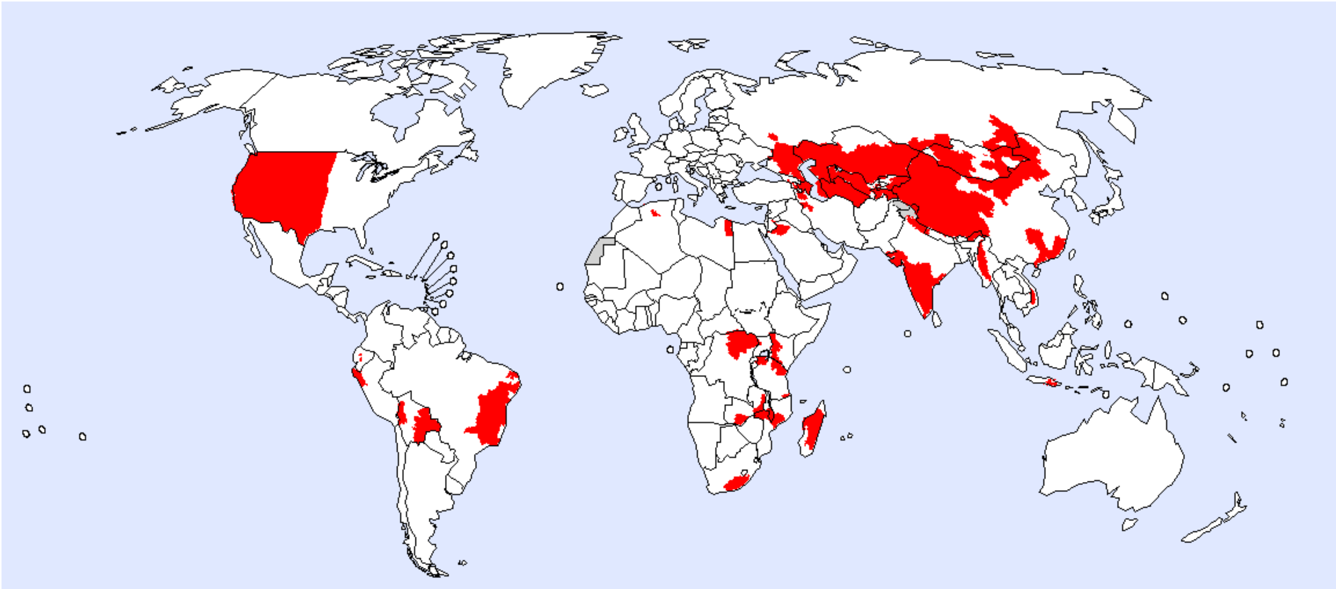

Figure 2.1 Global distribution of plague disease. Source: WHO (2016).

Thus, in Africa, human plague is still of public importance, since the continent has the highest plague occurrence as has been seen in Madagascar. Although the plague incidence has declined in the last two years at Madagascar, however, there has been an increase in the overall case fatality rate (23% in 2015) associated with the higher frequency of pneumonic forms (23.3%) (WHO, 2016). To show the distribution of plague in Africa, Neerinckx *et al*. (2008) performed an Ecological Niche Model (ENM). The outcome of the ENM revealed plague occurrence data set consisting of 45 unique localities from central (Democratic Republic of Congo (DRC) and Uganda), eastern (Tanzania, Malawi and Mozambique), and southern Africa (Botswana, Lesotho, Namibia, South Africa, Zambia and Zimbabwe). Quite a number of places where plague was never reported were predicted, for instance in Ethiopia, Nigeria and the Central African Republic (Neerinckx *et al*., 2008). Additionally, a large part of Madagascar and small areas along the coast of northern Africa were predicted as suitable for plague by the model.

Summing up the ENMs suggested that sub-Saharan African plague occurs in ecologically diverse landscapes under wide ranges of environmental conditions (Neerinckx *et al*., 2008). In almost in agreement with Neerinckx *et al*. (2008)'s model; Lofty (2015) reported that 28 countries in the African continent had plague. The countries most affected were DRC, Madagascar showing high endemicity, Mozambique, Uganda, and the United Republic of Tanzania (Lotfy, 2015).

2.5 Dominant rodent and flea species in Africa: implication for plague transmission

Multimammate rat (*Mastomys natalensis*) and house rat (*R. rattus*) are the most common rodent species in the African countries having their rodent and flea data easily accessible (Table 2.2). *Gerbillurus* specieswere second dominant rodent species. The most common flea species is *X. brasiliensis*, having *Xenopsylla cheopis* being second dominant, while thirdly there is *Dinopsyllus lypusus* and *Ctenophthalmus* species.

Table 2.1 Dominant rodent and flea species in Africa.

Country	Dominant rodent species and habitat type	Dominant flea species	References
Tanzania (East Africa) non-endemic foci	*M. natalensis* (S); *Mus spp*. (S)	*D. lypusus* (S); *X. brasiliensis* (S); *C. calceatus* (S)	McCauley *et al*., 2015
Uganda (East Africa), endemic foci	*R. rattus* (S, D); *A. niloticus* (S, P); *M. natalensis* (S, P);; *Lemniscomys spp* (P); *Lophuromys flavopunctatus* (P); *L. sikapusi* (P)	*Ctenophthalmus spp*. (S, D); *D. lypusus*(S, D); *X. brasiliensis* (S, D); *X. cheopis* (S); *X. nubica* (S); *Stivalius torvus* (S)	Borchert *et al*., 2007; Amatre *et al*., 2009; Eisen *et al*., 2012
Kenya (East Africa) not clear	Habitat type not clear, however rodent species with fleas were-; *Praomys dectroum*	*Listropsylla basilewskyi* (S)	Oguge *et al*., 2009
Zambia (Southern Africa) endemic foci	*Gerbillurus spp*. (P); *R. rattus* (P); *Mastomys spp* (P); Saccostomus spp (P)	*Xenopsylla spp*.	Hang'Ombe *et al*., 2012; Nyirenda *et al*., 2020
Zimbabwe (Southern Africa), non-endemic foci	*M. natalensis* (S, D); G. brantsi; *G. leucogaster* (S); *R. pumilio*(S); *R. rattus* (D); *S. campestris*	*X. brasiliensis* (S, D); *D. lypusus* (S, D); *C. calceatus* (S, D)	Banda *et al*., 2019; Zimba *et al*., 2010, 2012
Madagascar (Southern Africa) endemic foci	*R. rattus* (S, D)	*Synopsyllus fonquerniei* (S); *X. cheopis* (D); *X. brasiliensis*; *Pulex irritans* (D)	Miarinjara *et al*., 2016; ECDC, 2014
Namibia (West Africa)-not clear	(Rodent species collected from domestic, peridomestic and sylvatic habitats) *Gerbilliscus leucogaster; Gerbillurus paeba; Thallomys nigricauda; Rhabdomys pumilio*	(Flea species collected from domestic, peridomestic and sylvatic habitats) *Xenopsylla brasiliensis; Xenopsylla cheopis; Xenopsylla hirsute; Xenopsylla trispinis; Dinopsylla ellobius; Dinopsylla zuluensis; Epirimia aganipes; Listropsylla aricinae*	Mfune *et al*., 2013
Mali (West Africa) non-endemic foci	*M. natalensis* (D) *R. rattus* (D)	*X. cheopis* (D) *X. nubica* (D)	Schwan *et al*., 2016

NB: S-sylvatic (wild); P-peri-domestic; D-domestic; endemic foci (research done in a plague endemic place); non-endemic (research done outside the plague endemic foci.

In a study conducted in Morogoro, Tanzania, Massawe *et al*. (2008) found out that soil texture was an important factor influencing the abundance and distribution of *M. natalensis* in the field. The lowest capture of rodents occurred on sandy-clay soils and the highest capture was observed on both sandy-clay-loam and sandy-loam soils. As well, rainfall was observed to have an effect on rodent population abundance. Short early rains were observed to cause an increase in rodent population in both sandy-clay-loam and sandy-loam soils, while in sandy-clay soil they began to increase later in the season. During the dry season (from July to October 2000), Massawe *et al*. (2008) reported that population densities of rodents increased again among soil types. Based on the study, it was concluded that *M. natalensis* prefers loamy-textured soils compared to clay-textured soils. Even though soil type has an effect on rodent abundance, seasonality also determines the abundance of rodents (Makundi *et al*., 2005).

Makundi *et al*. (2005) observed that rodent abundance fluctuated seasonally, especially for *M. natalensis* in three localities and *G. leucogaster* in southwest Tanzania. In south-west Tanzania, population peaks of *M. natalensis* and *G. leucogaster* were reached in the dry season (June-September). In contrast, in central Tanzania, *M. natalensis* reached its peak during the months July-November and the species reproduced seasonally. Breeding activity of *M. natalensis* was observed to be associated with the onset of the rains and its population peaked in the dry season. *Mastomys natalensis* is known reservoir of plague (Isaacson *et al*., 1983).

Yersinia pestis was first spread by *R. rattus* (Roof, Ship or House rat) via ship voyages (Skinner & Chimimba, 2005). From ships, *R. rattus* went ashore thus passing the disease to wild rodents via fleas, and at present, the disease has quite a number of foci in different countries (Dennis *et al*., 1999). The environment has a great influence on flea abundance since three quarters of its life cycle is off host. The effects of both abiotic (Khokhlova *et al*., 2004) and biotic factors (Metzger & Rust, 1999; Krasnov *et al*., 2001; Osacar-Jimenez *et al*., 2001; Stark, 2002) on abundance of fleas have been investigated. *Xenopsylla brasiliensis* is native to Africa south of the Sahara. It is the most common vector of plague on the continent compared to *X. cheopis*. This species has spread to other parts of the world such as Brazil and India. It is a competent plague vector, especially in rural environments. *Xenopsylla brasiliensis* is intolerant of high temperatures but is resistant to drought conditions (Haeselbarth *et al*., 1966). It occurs on *R. rattus* and these have been responsible for transmitting plague world-wide. It also occurs on small mammals and this has made it difficult to determine its original wild host.

It is postulated that the original wild host were rats with climbing abilities which lived in hollow trees, on the surface under shelter or in similar situations, such as is found in the African Bush Rat (*Aethomys chrysophilus*), the multimammate Rat (*Praomys natalensis*), the Namaqua Rock Rat (*Micaelamys namaquensis*) and the Black tailed Tree Rat (*Thallomys paedulcus*) (Haeselbarth *et al*., 1966). *Xenopsylla cheopis* is a known common parasite of synanthropic rats, the House rat (*R. rattus*). It is found in all warmer areas of the world. It is a very efficient vector of *Y. pestis* and it is mainly responsible for transmission of plague among domestic rodents, and especially after the death of its natural host, to man (Hang'ombe *et al*., 2012).

2.6 African communities' awareness and practices on zoonotic diseases

Rodent-borne diseases that have earned pandemic or epidemic status are plague, Lassa fever and Tularemia (WHO, 2021). Countries with greater plague cases are the DRC, Madagascar and Peru (WHO, 2021). Lassa fever is an animal-borne (zoonotic), acute viral illness endemic in parts of West Africa including Sierra Leone, Liberia, Guinea and Nigeria (CDC, 2019). Most neighbouring countries are also at peril, as the animal vector for Lassa virus, the "multimammate rat" (*Mastomys natalensis*) is dispersed all over the region (CDC, 2019). This illness, Lassa fever was discovered in 1969 in Lassa town, in Borno state and was named after the town in Nigeria where the first cases occurred (CDC, 2019). Tularemia is a bacterial disease that can infect people and animals like rabbits, hares, and rodents which are especially vulnerable and often die in large numbers during outbreaks (CDC, 2018). People can become infected in several ways, including: tick and deer fly bites, skin contact with infected animals, drinking contaminated water, inhaling contaminated aerosols or agricultural and landscaping dust and laboratory exposure (CDC, 2018). Tularaemia has been reported in most countries of the northern hemisphere, but so far not from the southern hemisphere and it is endemic in Russian Federation, Kazakhstan and Turkmenistan, thus the African continent is not affected (WHO, 2007). Awareness and practices researches done in Africa on plague and Lassa fever will be assessed (Table 2.3).

Kugeler *et al*. (2017) did a multi-stage cluster-sampled survey in West Nile of Uganda to assess the knowledge of symptoms and causes of plague and health care-seeking practices among 420 households. A greater percentage (84%) of the respondents could accurately describe plague symptoms and as well a substantial percentage (75%) connected plague with fleas and dead rats (Table 2.3).

Table 2.2 Investigations on awareness and practices on plague and Lassa fever diseases among African countries.

Rodent-borne diseases	Region/Country	Awareness outcome	Practice outcome	References
Plague	West Nile of Uganda	-respondents were highly knowledgeable -a greater percentage (84%) of participants could accurately describe the plague symptoms -75% of respondents connected plague with fleas and dead rats	-many respondents showed good practices on plague -a greater number of respondents indicated that they would seek health at a clinic in case of a possible plague infection -most study respondents reported plague like symptoms but they rarely went to the clinic	Kugeler *et al*., 2017
Plague	Eastern Province of Zambia	-most of the respondents were poorly knowledgeable on plague disease -43.4% of the community respondents did not know the origins of the plague disease -a greater number of respondents were poorly knowledgeable on the relation of rats and fleas and plague disease - a higher number of the respondents believed that plague was as a result of witchcraft	-many respondents indicated poor practices on plague disease -greater number of respondents indicated not to favour the use of rodenticides because they were implicated to be used to poison people	Ngulube *et al*., 2006

Plague	Sinda and Nyimba districts of eastern Zambia	Awareness research not done	-many respondents showed poor practices on plague disease -most of the respondents indicated that they ate rodents as part of their regular diet -many participants indicated that some people carried rodents in small bags, hunters' pockets and in carcass skewers on the shoulder of the hunter	Nyirenda *et al*., 2017
Lassa fever (LF)	Abakalaki metropolis Nigeria	most respondents had greater knowledge of LF -respondents indicated that their main source of information were television and radio -a greater percentage of respondents indicated that rats could transmit LF to humans -a greater percentage of respondents showed poor knowledge on LF	-a higher number of respondents demonstrated good practices -fewer percentage of respondents ate rats	Ossai *et al*., 2020
LF	Ile-Ife southwest Nigeria	-most of the residents pointed out that the radio was their main source of information	-a greater number of residents showed poor practices on LF	Olowookere *et al*., 2017
LF	Kaduna state Nigeria	- most respondents had greater knowledge of LF	- a higher number of respondents demonstrated	Onwunhafua, 2018

		--a greater percentage of respondents indicated that rats could transmit LF to humans	good practices -most respondents revealed that they will go the hospital if they have LF symptoms -many of the respondents agreed that it is good to wash hands	

In case of possible plague, a higher number of respondents indicated that they would seek health at a clinic; sadly, though plague-like symptoms were reportedly common but people seldom went to the clinic. People in the plague-endemic region of Uganda had higher level of understanding of plague. Ngulube *et al*. (2006) did a study in Petauke, Eastern Province of Zambia where previously an outbreak of plague disease had occurred. The research was conducted to determine the knowledge, attitude and public health response towards plague. Of the community respondents, 43.4% did not know the origin of the plague disease (Ngulube *et al*. 2006). People were not knowledgeable on the relation of rats and fleas and plague disease. A greater number of the respondents believed that plague was a result of witchcraft. Respondents indicated not to favour the use of rodenticides because they were implicated to be used to poison people. In order to be able to control the outbreak of plague, witchcraft fears were removed by correctly diagnosing plague disease, this further aided collaboration between the formal health sector and the community and also between the Zambian health workers and their Mozambican neighbours (Ngulube *et al*., 2006).

Nyirenda *et al*. (2017) carried out a study to identify risk factors of plague using questionnaire interviews and conducting focus group discussion (FGD) in Sinda and Nyimba districts of eastern Zambia. A total of 144 were administered to individual respondents and 20 groups consisting of 181 discussants. The study concluded that the sociocultural human behavioural factors especially hunting, transportation, and preparation of rodents before their use for food exposed many villagers in the study area to flea bites and a result the risk of being infected with plague.

Ossai *et al*. (2020) carried out a study to determine the knowledge and preventive measures against lassa fever (LF) among heads of households in Abakaliki metropolis southeast

Nigeria. The researchers utilized a descriptive cross-sectional study using a four-stage sampling design. The majority of the respondents (60%) demonstrated good knowledge and preventive practices. Olowookere *et al*. (2017) carried out a study to assess the knowledge, attitude and practices towards lassa fever control and prevention among residents of IIe-Ife, southwestern Nigeria. Descriptive cross-sectional study was conducted among approved randomly selected adults using an interviewer administered questionnaire and data was analyzed using descriptive and inferential statistics. The study concluded that the knowledge, attitude, as well as preventive practices to lassa fever were poor, therefore it is obligatory to increase public education and improve hygienic practices. Onwunhafua (2018) carried out a study to determine the knowledge, attitude and practice relating to lassa fever among shop owners in a militatry barrack in Kaduna state, Nigeria. Structured questionnares were administered to 200 respondents by face to face interviews. The study concluded that the respondents had good knowledge, positive attitude and practices towards lassa fever.

2.7 Conclusion

The Chapter concludes that rodents harbour many zoonotic parasites like protozoans, trematodes, cestodes, nematodes, bacteria and viruses and most of the diseases caused by these parasites have not been eradicated to date. Plague is distributed worldwide except it is not found in Australia (WHO, 2016). Plague distribution in Africa was detected by the ENM and 28 countries were predicted to be plague disease carriers. *Mastomys natalensis* and *R. rattus* were observed to be the dominant rodent species in Africa, while the dominant flea species were *X. brasiliensis* and *X. cheopis*. African communities' awareness on plague and Lassa fever and their control practices towards these rodent-borne diseases varies greatly across countries pointing to the importance of research in many areas. In summary, there are quite a few African countries partaking in investigating on awareness, attitude and practices on plague and Lassa fever among their communities. There is need to expand research and contribute to the non-researched areas. In so doing management and policy makers will be well informed thereby taking a pragmatic approach in solving problems.

Chapter 3

An assessment of rodent-flea diversity and association in a semi-arid tropical ecosystem of south-western Zimbabwe

A modified version of this Chapter is published as:[1]

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3.1 Abstract

A comparative study was conducted to assess the trapping success, rodent-flea diversity and association in Nkayi and Umzingwane districts. Rodents were captured utilizing 90 Sherman live traps per a given village in April and August, 2017, for a period spanning 24 days and a total of 154 rodents were captured. Rodent trapping success was significantly higher in Nkayi district (30.00 %) compared to Umzingwane district (27.04 %) ($\chi^2 = 4.32$, df = 1, $P = 0.038$). There was no significant difference in rodent diversity between Nkayi district ($H' = 0.72 \pm 0.28$, mean, SD, n = 154) and Umzingwane district ($H' = 0.19 \pm 0.05$, Mann-Whitney U=0.00, $Z = 1.55$, P = 0.1210, n = 154). The relative abundant rodent and flea species in Nkayi district were *Gerbilliscus leucogaster* (n = 65; relative abundance (RA) = 80.25) and *Xenopsylla brasiliensis* (n = 113; RA = 99.12). In Umzingwane district the RA of rodents was high for *Mastomys natalensis* (n = 70; RA = 95.89) while for fleas were highest for *Chiastopsylla rossi* (n = 20; RA = 41.67) and *Dinopsyllus ellobius* (n = 19; RA = 39.58). Further, a total of 162 fleas were collected from the captured rodents. There was no significant difference in flea species diversity between Nkayi district ($H' = 0.05 \pm 0.07$, mean, SD, n = 162) and Umzingwane district ($H' = 1.11 \pm 0.11$, Mann-Whitney $U = 0.00$, $Z = -1.55$, $P = 0.121$, n = 162). *Xenopsylla brasiliensis* was associated with different rodent species in Nkayi district, whereas in Umzingwane district, *M. natalensis* was associated with different flea species. The Percentage Incidence Indices (PII) and Specific Flea Indices (SFI) for *X. brasiliensis* on *M. natalensis* was higher in Nkayi district compared to Umzingwane district. Noteworthy was the higher PII and SFI of *Xenopsylla brasiliensis* on *G. leucogaster* in Nkayi district. Overall, the results showed low and similar rodent and flea diversity in the two study districts. However, there were some variations in association between rodents and fleas.

3.2 Introduction

Co-occurrence data remains a neglected source of information in modelling species distributions irrespective of the historical importance in community ecology. Since medieval times a rodent-flea borne zoonotic disease called plague has always been notorious (CDC, 2019). Plague is caused by a bacterium called *Yersinia pestis* and is mainly spread among rodents and to other animals by infected fleas (Amatre *et al*., 2009). In most instances, rodents provide fleas with space for living, for aging, and copulating and as such can be considered the flea habitat patch (Hawlena *et al*., 2005). Understand plague disease ecology through research on the host-ectoparasite life cycle in specific natural environments is a necessity.

Plague in Zimbabwe was found to be endemic in Lupane and Nkayi, that is in natural region IV (Manungo *et al*., 1998). Zimbabwe was divided into 5 agro-ecological zones in 1960 (Mugandani *et al*., 2012). Region IV has been observed to be expanding, now covering some parts of Matabeleland South inclusive of Umzingwane district and the greater part of Gweru (Mugandani *et al*., 2012). Although this region harbours plague foci its rodents and flea species identification information are back dated 1982 where information about rodent species involved in *Y. pestis* harbouring was investigated (Taylor & Pugh, 1982). The World Health Organization (WHO) however encourages each and every country to establish an active surveillance system on plague (Dennis *et al*., 1999).

Previous studies have shown that human disturbed habitats are the greatest risk for acquisition of rodent-borne diseases (Mills, 2006; Naicker, 2011). Further it was observed in Madagascar that wild rodents plague incidence occurred as a result of predominantly semi-arid regions and the end of the dry season (Andrianaivoarimanana *et al*., 2013).

The present study assessed the rodent-flea diversity and their association in Nkayi and Umzingwane districts, south-western Zimbabwe. Although both districts occur in the same agriculture region IV zone, they however, differ in plague disease occurrence with Nkayi district being a plague disease endemic area whilst Umzingwane district is reported as not (Munyenyiwa *et al*., 2019). The present study assessed the rodent-flea diversity and their association in Nkayi and Umzingwane districts, south-western Zimbabwe. Although both districts occur in the same agricultural region IV, they however, differ in plague disease occurrence with Nkayi district being a plague disease endemic area whilst Umzingwane district is reportedly not (Munyenyiwa *et a*l., 2019). Is it possible that the diversity of rodents and fleas and the association of rodents and fleas is the same for the two districts since they are in a similar agro-ecological zone? The information generated from the study will potentially assist health personnel in surveillance and potential predictions for future possibilities of an outbreak or high-risk areas of plague disease. Further, the study results could potentially be used to develop rodents and flea control programs.

3.3 Materials and Methods

3.3.1 Study area

The study was conducted in Umzingwane and Nkayi districts in south-western Zimbabwe (Chapter 1, Figure1.2). The two districts occur in the same agro-ecological region IV which covers 7 628 km^2 (Mugandani *et al*., 2012). Natural region IV is an extensive livestock production area with some drought tolerant crops such as sorghum (*Sorghum vulgare)* and millet rapoko (*Eleucine coracana)* being cultivated, although short season maize (*Zea mays)* varieties are also cultivated. Nkayi district is located in Matabeleland North province whereas Umzingwane district is located in Matabeleland South province. Plague confirmed human cases outbreak distribution in Zimbabwe was in 1974-1975 and was confined along the Shangani River in Matabeleland North (Taylor *et al*., 1981), this thereby justifies capturing rodents in Monki community which is near the Shangani River and Mathoba community which also encountered plague cases occurrences. Whilst the selection of the study areas in Umzingwane was based on infiltration of the area by gold panners, whose rampant deforestation activities promote plague occurrence in the area. In Umzingwane district Nhlekiyane and Crocodile communal areas were selected, while at Nkayi the two communal areas chosen were Mathoba and Monki. Clearance to undertake the study was sort at Chinhoyi University of Technology (Appendix 1).

3.3.2 Research design and data collection

3.3.2.1 Research design, rodents and fleas' collection

This study followed a quasi-experimental design comprising of two strata, i.e., districts and then two villages in each district: Nkayi district (Mathoba and Monki villages) and Umzingwane district (Crocodile and Nhlekiyane villages). Trapping of rodents was conducted in April and August 2017, the gap in between the trapping stretched so as to reduce rodents' shyness and allow for rodent species breeding (Smithers, 1975). Rodents were trapped using live Sherman traps in the crop-fallow-bush habitat (Taylor *et al*., 2012). Each trapping session utilized 15 Sherman traps in an area for three consecutive days that is 45 traps (3 days x 15 traps). Sherman traps were baited with a mixture of peanut butter and maize bran. Traps were placed 10 metres apart so as to cover a variety of habitats, thus increasing the chance of capturing different rodent species (Kimaro *et al*., 2014) and were visited each morning between 6 am and 7 am.

Rodents were identified following illustrations by Smithers (1975). Fleas were dislodged from rodents and stored in Eppendorf tubes containing 70% alcohol (Mfune *et al*., 2013). Eppendorf tubes were labelled, (with date, rodent species and trapping location) and taken to the laboratory for further processing. Rodents' cadavers were buried in a pit of about 50 cm deep.

3.3.3 Fleas processing and identification

Flea processing and identification was conducted at the University of Zimbabwe, Harare, Zimbabwe in the Department of Biological Sciences, Entomology Laboratory, in January 2018. Flea processing procedure followed Mfune *et al*. (2013). Using the approaches by Haeselbarth *et al*. (1966), morphological descriptions and illustrations of flea species was done using a dissecting microscope and a compound light microscope; Phillip Harris model, Findel education limited, Nottinghamshire, England, United Kingdom. Data for both rodents and flea species was tabulated in a field data sheet (Appendix 2).

3.3.4 Data analysis

Trapping success was calculated using the following formulae after Dennis *et al*. (1999):

$$Trapping\ success = \frac{no.of\ animals\ caught}{trapping\ period} \times \frac{100}{no.of\ traps\ set\ per\ period}$$

The Chi-square (χ^2) test of independence was used to determine the significance difference among the trapping success in STATISTICA version 10 for Windows (StatSoft, 2010). Diversity of rodents and fleas were calculated for each district following the Shannon-Wiener (H') index measure of diversity (Krebs, 2009). The significance difference of rodents and fleas' diversities between the districts was determined using the Mann-Whitney *U*. Association between rodents and fleas were assessed by graphical analysis. Relative abundance was calculated as the ratio of the total number of organisms of a particular species caught divided by the overall total number of all the species caught multiplied by hundred (100).Percentage Incidence Indices (PIIs) and Specific flea Indices (SFIs) were calculated (Bahmanyar & Cavanaugh, 1976) to determine the agro-ecological zone (district) effect on flea population density on different rodents species captured.

Formulas for PII and SFI are:

$$PII = \frac{Total\ No.of\ specific\ rodent\ hosts\ infested\ by\ a\ specific\ flea\ species}{Total\ No.of\ specific\ rodent\ hosts\ trapped}\ X\ 100$$

$$SFI = \frac{Total\ No.of\ specific\ fleas}{Total\ No.of\ specific\ rodent\ hosts\ trapped}$$

3.4 Results

3.4.1 Rodent trapping success and species diversity

A total of 154 rodents were captured with 81 in Nkayi district and 73 in Umzingwane district. The average trapping success was significantly different ($\chi^2 = 4.32$, df = 1, $P = 0.038$) and higher in Nkayi district (30.00%) compared to Umzingwane district (27.04%). A total of five rodent species were recorded in the study sites (Table 3.1, figure 3.1). The relative abundance of *Gerbilliscus leucogaster* was higher in Nkayi district, while in Umzingwane district *Mastomys natalensis* was higher instead. There was a non-significant difference in rodent diversity between

Nkayi district (H' =0.72 ± 0.28; mean, SD) and Umzingwane district (H' = 0.19 ± 0.05) (Mann-Whitney U =0.00, z = 1.55, P = 0.121).

Table 3.1 Diversity of rodent species in Nkayi and Umzingwane Districts

Rodent species	**Nkayi district**		**RA**	**Umzingwane district**		**RA**
	Mathoba	Monki	OP	Crocodile	Nhlekiyane	OP
1. *Mastomys natalensis*	3	3	7.41	42	28	95.89
2. *Saccostomys campestris*	1	2	3.70	1	1	2.74
3. *Gerbilliscus brantsi*	3	3	7.41	1	0	1.37
4. *Gerbilliscus leucogaster*	40	25	80.25	0	0	0
5. *Lemniscomys Griselda*	0	1	1.24	0	0	0
Species diversity (H') index	0.52	0.92	-	0.22	0.15	-

†RA-relative abundance; OP-overall percentage

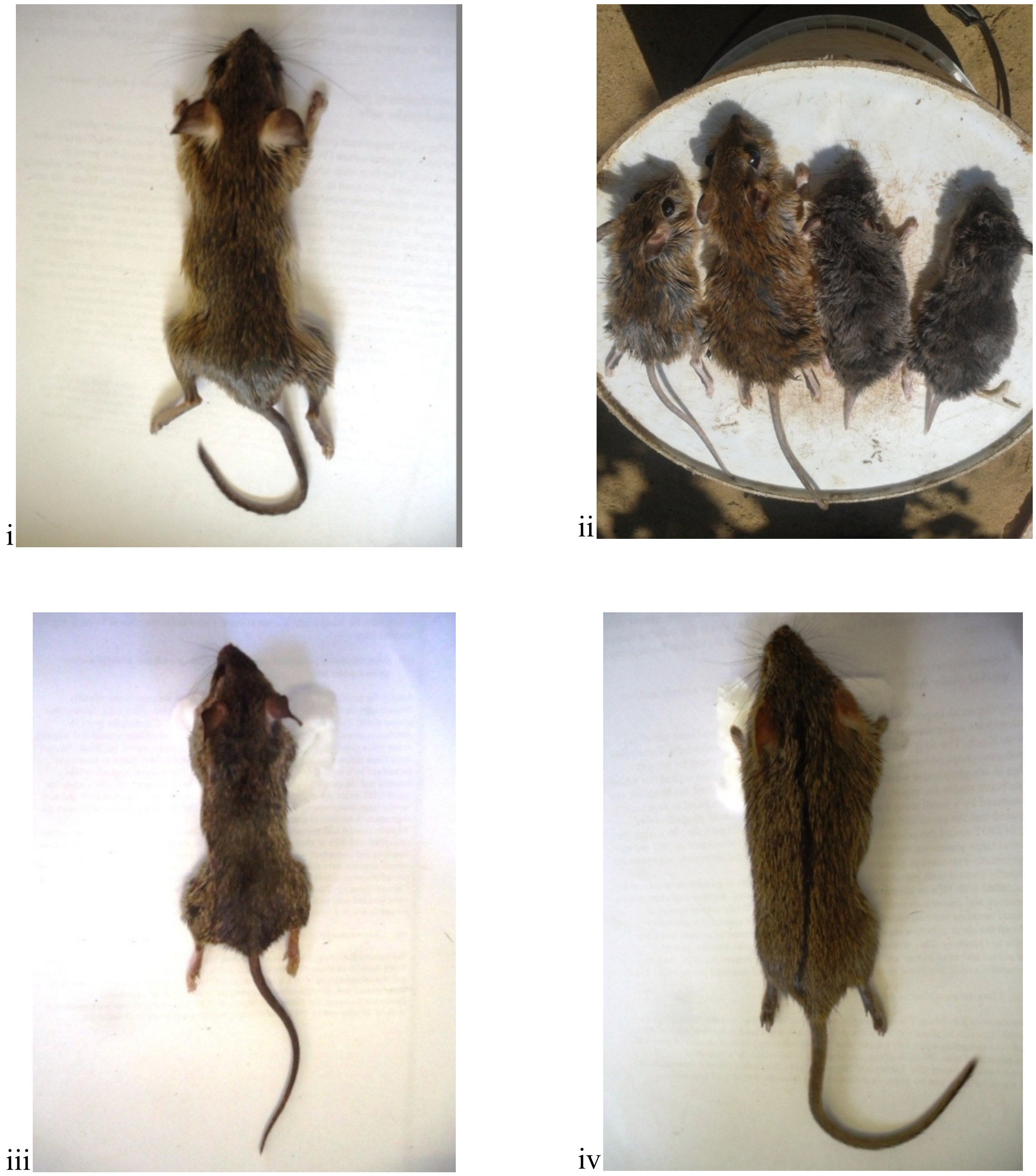

Figure 3.1 Rodent species captured in the study sites (i) *G. leucogaster*, (ii) *G. brantsi* (two left) and *S. campestris* (two right), (iii) *M. natalensis*, and (iv) *L. griselda*. Photo credits: A. Banda, August 2017.

Total relative seasonal abundance of rodent species

The rodents' total relative abundance was high in Nkayi district during Hot/ wet season, while in Umzingwane district it was high during the Cold/dry season (Table 3.2).

Table 3.2 Total relative seasonal abundance of rodent species in Nkayi and Umzingwane districts

Rodent species	Nkayi district	Umzingwane district	Nkayi district	Umzingwane district
	Hot/wet season		Cold/ dry season	
M. natalensis	3	20	3	50
G. leucogaster	0	-	35	-
G. brantsi	3	-	4	1
S. campestris	4	-	-	2
L. griselda	28	-	1	-
Total	38	20	43	53
Total relative seasonal abundance	65.52	34.48	44.79	55.21

3.4.2 Flea species diversity and association with rodents

A total of 162 fleas were collected from the 154 captured rodents, i.e., Nkayi district (114) and Umzingwane district (48) with four (4) flea species being recorded in the study area (Table 3.3, Figure 3.2). The relative abundance of *Xenopsyllus brasiliensis* was higher at Nkayicompared to Umzingwane district (Table 3.3). While in Umzingwane district the relative abundance of *Chistopsylla rossi* and *Dinopsyllus ellobius* were higher instead (Table 3.3). There was no significant difference in flea species diversity between Nkayi district ($H' = 0.05 \pm 0.07$) and Umzingwane district ($H' = 1.11 \pm 0.11$) (Mann-Whitney $U = 0.00$; $z = -1.55$; $P = 0.121$). In Nkayi district, *X. brasiliensis* flea species were associated with four of the five rodent species, in the same district there was co-occurrence of *Tatera leucogaster* with *D. ellobius* whereas in Umzingwane district all the flea species were associated with only one rodent species, i.e., *Mastomys natalensis* (Figures 3.3 and 3.4).

Table 3.3 Flea species diversity in Nkayi and Umzingwane districts.

Flea species	**Nkayi district**		**RA**	**Umzingwane district**		**RA**
	Mathoba	Monki	OP	Crocodile	Nhlekiyane	OP
1. *Ctenophthalmus calceatus*	0	0	0	2	0	4.17
2. *Chistopsylla rossi*	0	0	0	9	11	41.67
3. *Dinopsyllus ellobius*	0	1	0.88	6	13	39.58
4. *Xenopsyllus brasiliensis*	66	47	99.12	2	5	14.58
Species diversity (*H'*) index	0	0.10	-	1.19	1.03	-

†RA-relative abundance; OP-overall percentage

Figure 3.2 Flea species recorded in the present study, i.e., (i) *X. brasiliensis*, (ii) *D. ellobius*, (iii) *C. rossi*, and (iv) *C. calceatus*. Photo credits: A. Banda, August 2017.

Flea species total relative seasonal abundance

Flea species total relative seasonal abundance were higher in both seasons in Nkayi district compared to Umzingwane district (Table 3.4).

Table 3.4 Total relative seasonal abundance of flea species

Flea species	Nkayi district	Umzingwane district	Nkayi district	Umzingwane district
	Hot/wet season		Cold/dry season	
X. brasiliensis	9	2	104	5
C. calceatus	-	-	-	2
D. ellobius	1	4	-	15
C. rossi	-	1	-	19
Total	10	7	104	41
Total relative seasonal abundance	58.82	41.18	71.72	28.28

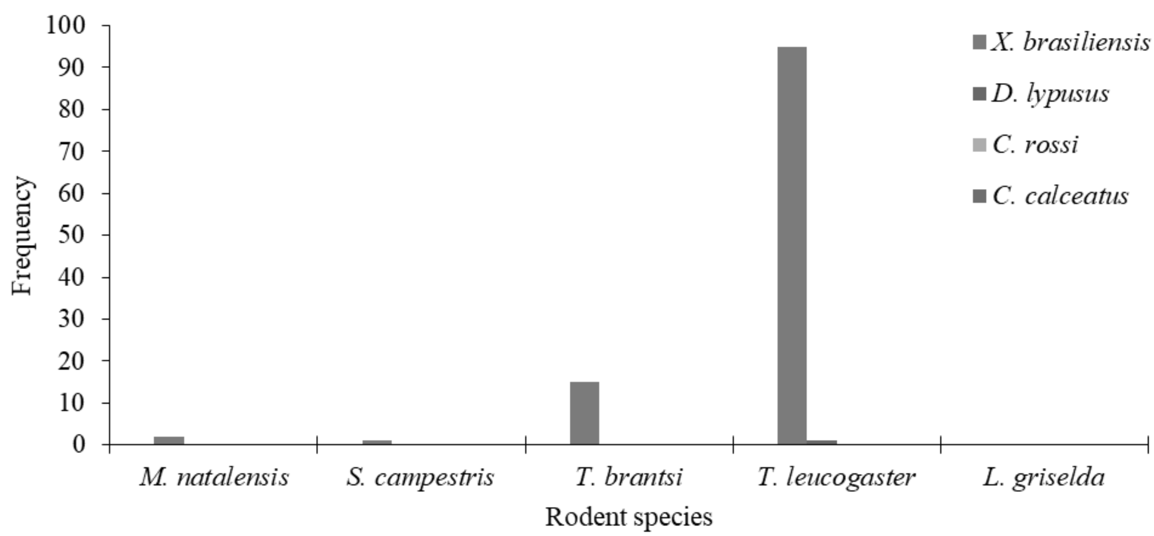

Figure 3.3 Rodents and fleas association in Nkayi District, south-western Zimbabwe.

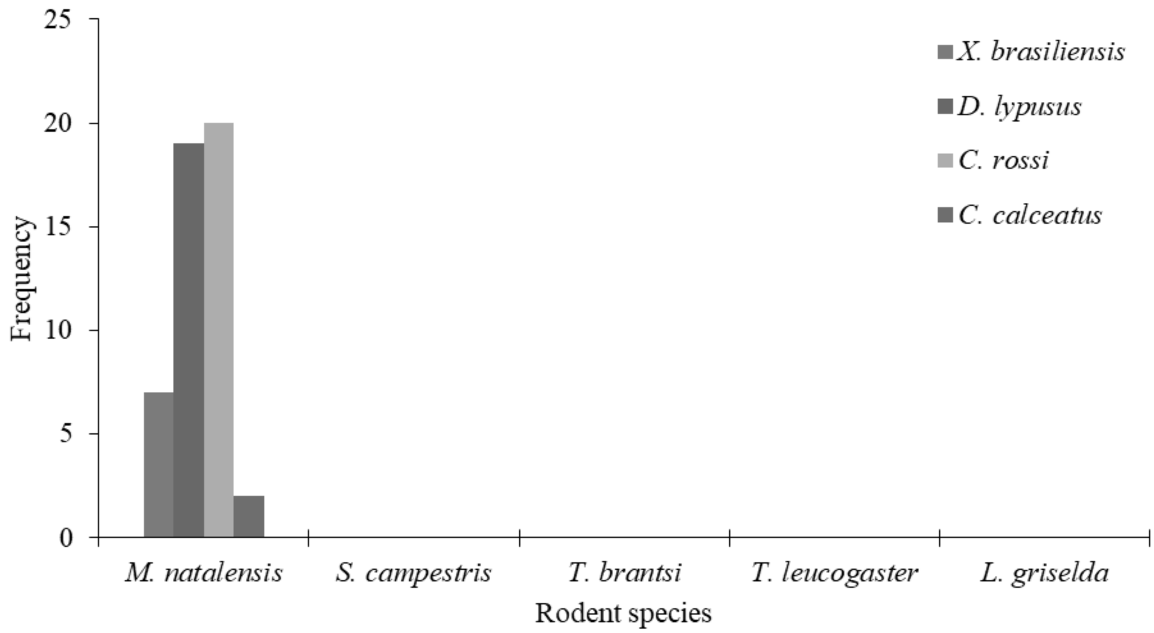

Figure 3.4 Rodents and fleas association in Umzingwane District, south-western Zimbabwe.

Flea species PII and SFI in Nkayi and Umzingwane district

In Nkayi district there was high *X. brasiliensis* PII and SFI on *M. natalensis* compared to Umzingwane district (Table 3.5). At Nkayi district there was high PII and SFI of *X. brasiliensis* on *G. leucogaster* and *G. brantsi*. However some of the rodent species (*G. leucogaster*) and flea species (*X. brasiliensis* on *G. brantsi*) were not recorded in Umzingwane district to make a proper comparison. *Saccostomys campestris* in Nkayi district also had a minimal PII and SFI, while in Umzingwane district no fleas were detected on these rodents. Noteworthy was the presence of *D. lypusus* on *G. leucogaster* in Nkayi district. In Umzingwane district fleas collected on *M. natalensis* were quite diverse, however their indices were quite minimal. Greater interest were *D. lypusus* and *C. rossi* higher PII and SFI as opposed to *C. calceatus* PII and SFI.

Table 3.5 Fleas Percentage Incidence Indices (PII) and Specific Flea Indices (SFI) for Nkayi and Umzingwane districts

	Nkayi district	Umzingwane district	Nkayi district	Umzingwane district	Nkayi district	Umzingwane district	Nkayi district	Umzingwane district
Rodent species	*Mastomys natalensis*		*Gerbilliscus leucogaster*		*Gerbilliscus brantsi*		*Saccostomys campestris*	
Flea species								
X. brasiliensis PII	16.67	7.14	53.85	-	66.67	-	33.33	-
X. brasiliensis SFI	0.67	0.1	1.45	-	2.33	-	0.33	-
D. lypusus PII	-	20.00	1.54	-	-	-	-	-
D. lypusus SFI	-	0.24	0.15	-	-	-	-	-
C. rossi PII	-	21.43	-	-	-	-	-	-
C. rossi SFI	-	0.29	-	-	-	-	-	-
C. calceatus PII	-	1.43	-	-	-	-	-	-
C. calceatus SFI	-	0.03	-	-	-	-	-	-

3.5 Discussion

The study showed significant difference in trapping success, however no significant differences in rodent species diversity and flea species diversity in the two districts were observed. This study recorded a high mean trapping success in both study sites of over 28% an indication of moderate to high rodent population in the study area. Generally, a high trapping success of over 10% has been attributed to high rodent populations (Sridhara, 2006). Although the study recorded no significant differences in diversity of rodents between the two study districts, there were some unique patterns in occurrence of rodent species in the two study districts. Of particular note was the high abundance of *G. leucogaster* and *G. brantsi* (gerbils) in Nkayi district compared to Umzingwane district. In contrast, *M. natalensis* had a high abundance in Umzingwane district compared to Nkayi district. It is likely that the deep Kalahari sands in Nkayi could be positively influencing the proliferation of gerbils (*G. brantsi* and *G. leucogaster*) species which like to dig and clean their burrows consistently whereas in Umzingwane district there are shallow sandy textured soils, brown and red clays which can be a challenge when burrowing (Sibanda *et al*., 2014). Elsewhere, soil type has been observed to have an impact on rodent population in Morogoro, Tanzania (Massawe *et al*., 2008). Rodent species like *M. natalensis*, which are semi-commensal, are likely to influx into human habitat in their vicinity when populations are high because of competition, if this happens people in such an area will be at great risk of acquiring zoonotic diseases like plague when outbreaks occur in the rodent population (Coetzee, 1975).

Human-induced disturbances such as mining activities, uncontrolled fires, rodent harvesting for bush-meat by local people, vegetation cover disturbances and proximity to protected areas have been reported to influence population densities of rodents and diversities in other studies (Fiedler, 1990; Massawe *et al*., 2008; Sibanda *et al*., 2014; Chirima *et al*., 2018) and thus may warrant future investigation in the study area to ascertain their impact on the rodents population dynamics and diversity.

This study recorded a distinct association of rodents and fleas despite the non-significant difference in flea diversity. *Xenopsylla brasiliensis* was the most abundant flea species in Nkayi district and it was associated with four of the five rodent species that were recorded in this study. In contrast, in Umzingwane district, only one rodent species, i.e., *M. natalensis* was associated with all the four flea species recorded in this study. *Chiastopsylla rossi*, *D. ellobius* and*X. brasiliensis* species were indicated by Haeselbarth, (1966) in Zimba *et al*. (2010) to be effective transmitters of plague to humans, thereby requiring urgent monitoring (Munyenyiwa *et al*., 2019). The Kalahari sandy soils in Nkayi District offer a xeric environment which is preferred by *X. brasiliensis* (Zimba *et al*., 2010). Soil greatly influences flea abundance because almost all developmental stages of fleas are found in the soil, that is the eggs, larvae, pupa and adults (Stark, 2002; Blagbuen & Dryden, 2009; Bitam *et al*., 2010). Soil texture affects both developmental time and survival of pre-imaginal stages of fleas through differences in soil moisture (Krasnov *et al*., 2001). However, there are possibilities that *X. brasiliensis* is actually spreading from the plague endemic foci to non-plague endemic foci since there are in the same agro-ecological region IV, thus somehow taking over the district slowly, as plague foci are dynamic (Dennis *et al*., 1999; Andrianaivoarimanana *et al*., 2013). *Mastomys natalensis* was associated with different flea species in Umzingwane district as it has been reported that *M. natalensis* is able to occupy any kind of habitat, in so doing thus acquiring different flea species

(Smithers, 1975). The PII and SFI of *X. brasiliensis* was high in Nkayi district in most of the rodents captured, this is a great threat to human health.

Generally, the study recorded low and nearly similar rodent and flea diversities of the two districts, this could be attributed to similarities in the environmental conditions since there are in the same agro-ecological region IV. With reference to Tobler's First Law of Geography which states that everything is related to everything else, but near things are more related than distant things (Tobler, 2004), the relatively similar agro-ecological zone in the study sites could have contributed to the non-significant differences in rodent and flea diversity. Diversity indices of around one (1) and below are indications of low species diversity and this could be attributed to the generally low rainfall especially in semi-arid regions of Zimbabwe, an important driver of trophic levels in semi-arid ecosystems (Gandiwa, 2013). The role and extent of species diversity for both rodents and fleas and their association especially in plague disease occurrence is of interest given that greater rodent diversity has been attributed to reduce plague disease occurrence in people due to the dilution effect (Vora, 2008). Hence, long-term studies would be essential to help establish the spatial diversities of rodents and fleas in the study area.

3.6 Conclusion

This study recorded low and similar diversities of rodents and fleas in Nkayi and Umzingwane districts in south-western Zimbabwe. There were variations in rodent-flea species association in the two districts. In Nkayi district *X. brasiliensis* flea species was associated with different rodent species whereas in Umzingwane district, all the recorded flea species were associated with only one rodent species, i.e., *M. natalensis.* It is, thus, essential to investigate the influence of rodent-flea association on the plague prevalence in the study area and elsewhere.

Chapter 4

Prevalence of plague among rodents captured in a semi-arid tropical system of Zimbabwe

<u>*A modified version of this Chapter was published as:*</u>

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4.1 Abstract

This study assessed the prevalence of plague bacterium (*Yersinia pestis*) among rodents captured in Umzingwane and Nkayi districts, south-western Zimbabwe. A total of 44 rodents were captured for three consecutive days per trapping session in the study sites using removal trapping method in April 2018. Captured rodents were euthanized and blood samples collected. The Giemsa stain method was used to detect plague bacteria. Overall, only one rodent species, *M. natalensis*, tested positive in Umzingwane district, thus yielding a prevalence rate of 2.3% for the entire study area. These results points to a low prevalence of plague disease in the study area and the importance to ensure an active surveillance and monitoring system.

4.2 Introduction

Plague, a disease caused by the bacilli bacterium, *Yersinia pestis,* primarily affects rodents, mainly transmitted from one host to another through bites of infective fleas (Rivière-Cinnamond *et al*., 2018). There are, however, other alternative transmission routes like ingestion and direct contact which do not normally play a role in the maintenance of plague bacterium in the animal reservoirs (Perry & Fetherston, 1997). Fleas are generalist in their feeding behaviour, thus in the absence of rodents they seek alternative hosts like wild and domestic animals, as well as people (Gage & Kosoy, 2005). Thus, some flea species, for instance, *Xenopsylla brasiliensis* are implicated as effective plague transmitters (Chikwenhere, 2006). Alternatively, plague can be acquired by humans by handling infected rodents or by droplet infection, although, humans do not play a role in the long-term survival of the plague bacterium (Perry & Fetherston, 1997). In most cases plague outbreak causes great population decrease in rodents of some species within its local and established ranges (Barnes, 1993 cited in Thiagarajan *et al*., 2008). However, some rodents' hosts act as reservoirs of the disease in the enzootic environment allowing low levels of the pathogen circulation (Gage & Kosoy, 2005). Among humans, if the bacterium is inoculated in the body it multiplies and may spread via three ways, namely: the lymphatic system to the lymph nodes (bubonic plague), blood system (septicemic plague), and the respiratory system (pneumonic plague) (Perry & Fetherston, 1997).

The first cases of human plague in Zimbabwe were recorded in 1974, the cases showed a complicated combination of plagues (Munyenyiwa *et al*., 2019). Since then up to 1985 there were 89 cases noted, of which 23 deaths occurred (Dennis *et al*., 1999). Subsequent plague human cases were recorded in 1994 and 1997, where the highest cases of plague were noted with about 400 cases and 30 deaths confirmed at Nkayi and Lupane districts, Matabeleland North (Manungo *et al*., 1998; Gage *et al*., 1999). In 2012 latest plague was detected in Zimbabwe but there was no full report of the disease (Munyenyiwa *et al*., 2019). Unavailability of active plague surveillance may have adverse repercussions, as an epidemic can occur undetected (WHO, 2016). Plague foci are dynamic and keep on emerging and re-emerging (Andrianaivoarimanana *et al*., 2013), hence the importance of research to establish any potential new plague foci.

Plague bacterium can be hosted by a number of rodents and some small mammals. It was detected in multimammate mouse (*Mastomys natalensis*) and *Gerbilliscus* species in Tanzania (Ziwa *et al*., 2013). Furthermore, small mammals such as rabbits (*Sylvilagus flovidanus)*, marmots (*Marmota*) and chipmunks (*Sciurus* species) were shown to maintain plague in the wilderness (Gage & Kosoy, 2005). Surveying diseases among free ranging wild animal populations may provide an early warning system for the presence of a disease. There is generally less active plague surveillance in Zimbabwe (Chikwenhere, 2006), despite the few publications on rodents and fleas which largely focus on rodent and flea species diversity (Zimba *et al*., 2010; Zimba *et al*., 2012). Therefore, this study aims to fill the gap in knowledge on plague prevalence in Zimbabwe and assess the prevalence of plague bacteria among rodent species in Nkayi and Umzingwane districts. These two districts are the same agro-ecological zone but differ in their plague occurrence, one is plague endemic (Nkayi district) while the other is plague non-endemic (Umzingwane district) (Dennis *et al*., 1999; Munyenyiwa *et al*., 2019), thus what is the basis of their differences for instance. A question arises, 'What is the prevalence of *Y. pestis* among captured rodents in Nkayi and Umzingwane districts, Zimbabwe?' Since the two districts are in a similar agro-ecological zone, could it be possible that there is no difference in prevalence of *Y. pestis* among captured rodents in Nkayi and Umzingwane districts, Zimbabwe.

4.3 Materials and methods

4.3.1 Study area

The study was conducted in north-western Zimbabwe in Nkayi and Umzingwane districts natural region IV (see Chapter 1, Figure 1.2). The annual rainfall range of the region is 450-600mm (Mugandani *et al*., 2012). Region IV consists of three soil groups, namely, vertisols, siallitic and fersialitic (Nyamapfene, 1991). Nkayi district has deep Kalahari sands occupying 60% of the area whereas Umzingwane districts soils are derived from granite rocks being coarse, sandy and low in fertility (Renaudin & Patinet, 2010). The most common type of vegetation at Nkayi is broad leafed woodlands, teak (*Baikiaea plurijuga*) and *Brachystegia* spp. (Dube *et al*., 2014). Umzingwane district is characterised by three types of vegetation which are bushveld, mainly covered with *Acacia* ranging between 1-5 m high; wooded grassland and woodland covered by *Terminalia* and *Combretum* genus trees. The grasslands are the main source of grazing land (Renaudin & Patinet, 2010).

In Nkayi district most of the local rural community members are engaged in extensive livestock production and cultivation of some drought tolerant crops such as sorghum (*Sorghum vulgare*) and millet rapoko (*Eleucine coracana*). However, farmers do sometimes grow some short season maize (*Zea mays*) varieties. Nkayi district's (boundary extents 18.992ºS, 28.9005ºE, area = 4 381km^2) population was reported to be 109,135 people (23 persons per km^2) while Umzingwane district (boundary extent-20.347°S, 28.9499°E, area = 2780 km^2) had 62,990 people (23 people km^{-2}) (Zimstat, 2013). Nkayi district comprise of 30 wards, which are further divided into 156 villages (Nkayi RDC n.d cited in Zikhali, 2018), whereas Umzingwane district has 20 wards and 107 villages (Umzingwane RDC n.d).

4.3.2 Data collection

This study followed a quasi-experimental design comprising of two strata, i.e., districts and then two villages in each district. In Nkayi district the two villages studied were Mathoba and Monki villages, while in Umzingwane district were Crocodile and Nhlekiyane villages.

4.3.2.1 Trapping and processing rodents

All the trapping procedures and further processing of rodents were carried out following Dennis *et al*. (1999) with some adjustment. The adjustments were as follows: Dennis *et al*. (1999) indicate that the traps should be 20metres apart, however, Zimba *et al*. (2010) and Mfune *et al*. (2013) used 10 metres spacing however there is no reason indicated by the researchers why the reduction in spacing, therefore we used 10 metres apart following the latest publications. Gage *et al*. (1999) discourages the use of chloroform as a euthanizer, indicating its cancerous effects and the fears of it interfering with attempts to isolate plague bacteria from sample materials. However, chloroform was used in this study because is readily available in the local industries and also can kill other disease-causing organisms/micro-organisms (*M. Zimba personal communication to A. Banda*).

Rodent trapping was conducted in April 2018 and set by observing rodent activity such as maize cob consumption and/or clearly constructed tracks and warrens. Rodents were captured in villages, i.e., habitats including bushes using 15 Sherman live traps placed about 10 metres apart in transects (Kimaro *et al*., 2014). Three transects were placed in uncultivated places near fields in each study village. On the first day of sampling, traps were set late afternoon and then inspected the following morning between 6 am and 7 am before it was too hot to reduce stress in captured rodents. Traps were left open for three consecutive days per village, i.e., 45 traps inclusive of which productive traps were replaced in the morning following Kimaro *et al*. (2014). Traps with captures were taken to a central processing point in each study village, in an open area, for euthanisation of rodents using chloroform, species identification and blood sample collection. Rodents' cadavers were buried in a pit of about 50 cm deep.

4.3.2.2 Identification of rodents and blood processing

Rodents were identified according to the illustrations and descriptions by Smithers (1975). Identifications were confirmed with the Natural History Museum, Bulawayo, Zimbabwe. Blood samples were firstly processed by conducting blood smears. These blood smears were processed by injecting blood from the syringe onto a clean slide and then evenly spreading the blood horizontally by moving another slide attached to the blood on the slide. The blood smears were left to dry prior to being taken to Chinhoyi University of Technology, Wildlife Laboratory, Chinhoyi, Zimbabwe where they were subsequently fixed by submerging in methanol (Hoppe & Lassen, 1978). This was done to prevent cells from bursting when they were placed in staining solution. The slides were flooded with Giemsa stain (Dennis *et al*., 1999) for 20 minutes to allow the dye to be absorbed by the microorganisms and were rinsed with water thereafter. Using a compound light microscope (Phillip Harris model, Findel education limited, Nottinghamshire, England, United Kingdom), processed slides were viewed searching for bipolar coccobacilli or a safety pin shaped bacillus (WHO, 2008). Laboratory data sheet (Appendix 3) was used to gather data for further use in data analysis.

4.3.3 Data Analysis The prevalence of *Y. pestis* in rodents' blood samples was calculated as the number of *Y. pestis* positive rodent individuals divided by the total number of rodents examined multiplied by 100 (Dennis *et al*., 1999). Diversity of rodents and fleas were calculated for each district following the Shannon-Wiener (H') index measure of diversity (Krebs, 1994).

4.4 Results

A total of 44 rodents were captured in the two study districts, i.e., Nkayi (23; $H' = 0.89$) and Umzingwane (21; $H' = 0.62$) (Tables 4.1). Twenty three (23) rodents were caught in Nkayi district and 21 in Umzingwane district i.e., 17 *Mastomys natalensis* (Smith, 1834), 6 *Gerbilliscus brantsi* (Smith, 1836), 4 *Gerbilliscus leucogaster* (Peters, 1852) and 17 *Saccostomys campestris* (Peters, 1846). Only one rodent, i.e., *M. natalensis,* caught in Umzingwane district tested positive for the bacterial plague indicating an overall prevalence of plague of 2.4% in the study area.

Table 4.1 Rodents captured species diversity and prevalence of bacterial plague in the study area.

Rodent species	Nkayi district			Umzingwane district			Overall prevalence (%)
	# of rodents captured	# of rodents that are positive for *Y. pestis*	Prevalence (%)	# of rodents captured	# of rodents that positive for *Y. pestis*	Prevalence (%)	
M. natalensis	0		0	17	1	5.9	5.9
S. campestris	4	0	0	2	0	0	0
T. brantsi	4	0	0	2	0	0	0
T. leucogaster	15	0	0	0	0	0	0
Species diversity (*H'*)	0.89	-	-	0.62	-	-	-
Total / Average (%)	23	0	0	21	1	4.8	2.4

Notes: - denotes not applicable

4.5 Discussion

This study is among the first to report the presence of plague bacteria among rodents in Umzingwane district, although it was low prevalence. Generally, Umzingwane district was previously classified as non-endemic to the disease. This finding point to the dynamism in species interactions among rodents and fleas, spatial temporal changes in disease occurrence associated with changing climate and likely difficulty in detecting bacterial plague in rodents. Elsewhere, plague bacteria were reported as being difficult to detect in rodents and fleas associated with prairie dog rodents' colonies (*Cynomys*) at Thunder Basin National Grassland in Wyoming, United States of America (Thiagarajan *et al*., 2008). Thus, it was suggested that where possible plague determination investigations could be conducted in incidences where noticeable rodent die-offs (Thiagarajan *et al*., 2008). Since time immemorial *M. natalensis* was observed not to easily succumb to plague bacteria, thus termed an enzootic host (Neerinckx *et al*., 2008; Ziwa *et al*., 2013). Thus, some of the caught species may not be ideal host for *Y. pestis*, for instance *T. leucogaster* was observed to easily succumb to *Y. pestis* closely related bacilli *Y. pestis* tuberculosis subsp. *pestis* (Isaacson *et al*., 1983).

Since there were no die offs observed during the sampling time, it may imply that an inter-epizootic period could have been in existence during which *Y. pestis* cannot be recovered from fleas, rodents, or any other host (Rivière-Cinnamond *et al*., 2018). Instead it was proposed in Iran and Madagascar that the bacteria could remain in existence in the soil, however, one study recommended that the transmission route by exposure of susceptible mice to *Y. pestis* contaminated soil seems doubtful under natural conditions because the infectious period was short lived and the transmission efficiency low (Boegler *et a*l., 2012). Thus, during plague quiescent times it is likely that detecting *Y. pestis* is by mere chance.

In northern Tanzania, 517 wild, peri-domestic and commensal small mammals, inclusive of rodents and wild carnivores were captured but only three of these mammals tested positive for *Y. pestis*, an indication for the need for large samples to fully get a good picture of the infection status of a rodent population (Ziwa *et al*., 2013). There can, however, be possibilities that *Y. pestis* is concentrated on certain rodent body organs as was reported in a study in Mongolia, where *Y. pestis* were detected in spleen samples, while liver samples from rodents tested negative using Polymerase Chain Reaction (PCR) (Riehm *et al*., 2011). This therefore points to the importance of a large sample associated with diversified samples from the rodent body parts to enhance the chances of detection of the representative infection status of populations.

4.6 Conclusion

This study provides a snapshot of plague bacteria in south-western Zimbabwe and shows a low prevalence of plague bacteria infection in rodents (2.3%) in the study area with only one rodent species, i.e., *M. natalensis* testing positive. The study provides the first evidence of plague bacteria infection in a rodent species in Umzingwane district, a non-endemic region for the plague diseases. Hence, it is recommended that *M. natalensis* species occurrence in and near household premises should be minimised, so as reduce plague transmission to humans or their companion animals like dogs and cats..

Chapter 5

Local community awareness and practices on zoonotic-plague disease management in Nkayi and Umzingwane Districts, south-western Zimbabwe

A slightly modified version of this Chapter is published as[3]*:*

[3] Banda, A., Gandiwa, E., Muboko, N., Mutanga, Chiedza N. and Mashapa, C. (2022). Local community awareness and practices on Yersinia pestis plague disease management in Nkayi and Umzingwane districts, south-western Zimbabwe. *Ecosystems and People, 18:1, 164-173.*DOI 10.1080/26395916.2022.2037714

5.1 Abstract

This study investigated the level of awareness and practices of local communities on *Yersinia pestis* plague disease in Nkayi and Umzingwane districts, south-western Zimbabwe. The research used a two-way case study where Umzingwane district was used as a quasi-control site and Nkayi district the treatment site. Purposive sampling was used to select four villages, i.e., two from Nkayi district (plague endemic area) and two from Umzingwane district (non-plague area). Data were collected through focus group discussions involving 35 respondents held between August 2017 and April 2018. The study respondents confirmed some awareness of zoonotic diseases albeit limited knowledge on specific rodent-borne diseases. Respondents from areas that had previous plague outbreaks (Nkayi district) were more knowledgeable of the disease compared to those from areas without previous known outbreaks (Umzingwane district). Several practises, e.g., use of traps, keeping domestic cats (*Felis catus*), and use of rodenticides to control rodents and educating people on plague disease were highlighted from both study sites as local plague management strategies. Overall, the study results indicated that the awareness and practices employed by local people in the study area are generally influenced by local contextual factors and past experiences.

Key words: case study; local community awareness; plague disease control; plague endemic area

5.2 Introduction

Zoonotic diseases are defined as diseases or infections transmitted between non-human vertebrate animals and humans (WHO, 2020). Diseases which are obscured, affecting mostly the rural poor that live in remote places far from health service centres are termed neglected diseases (Boutayeb, 2007). These diseases were once limited to rural areas but are now emerging in cities, for example, the plague outbreaks in Antananarivo town in Madagascar (Nkengasong, 2019).

Plague disease (caused by *Yersinia pestis* bacteria) is regarded as a neglected disease and has been reported in 28 African countries, with eight (8) countries currently having active foci (Lotfy, 2015). Over shadowing by other major global infections (e.g., viral infections like Chikungunya, Ebola and financial constraints are possible reasons for plague neglect among African countries (Naicker, 2011). Plague diseases' main hosts are rodents and it can be transmitted to humans via direct or indirect routes, such as contact with infected rodents or being blood fed on by infected fleas (Dennis, Gage, Gratz, Poland, & Tikhomirov, 1999). However, rodents also harbour several other infectious diseases like *leptospirosis, leishmaniasis, salmonellosis*, and viral haemorrhagic fevers (Dennis, Gage, Gratz, Poland, & Tikhomirov, 1999). Four forms of plague diseases are commonly known, namely, (a) bubonic, (b) septicaemic, (c) pneumonic, (d) pharyngeal (Washington State Department of Health, 2019). The first three forms of plague have the following common characteristics; symptoms or signs of fever (abrupt or acute), headache, chills and weaknesses (Washington State Department of Health, 2019), while for (d) pharyngitis and cervical lymphadenitis develops (CDC, 2021; Washington State Department of Health, 2019). With a fatality rate of eight 8 to 10%, appropriate antibiotics and supportive care is useful for treating plague disease (Washington State Department of Health, 2019).

There are several determinants that expose people to the plague and some of these are the effects of poverty. For instance, high poverty levels to some sections of the society in Zimbabwe have been reported (Herald, 2020; ZimVAC, 2021) and this has led some of the affected people to engage in outdoor small scale economic activities for survival such as artisanal gold panning (Ncube-Phiri et al., 2015), unsafe farming and firewood fetching practices (Mashapa et al., 2019), unfortunately some of these activities raise the chances of acquiring plague disease as contact between people and rodents increases (Barcellos & Sabroza, 2001; Halliday et al., 2015). Environmental change and habitat fragmentation, associated with land-use change can result in changes in the microbial community, with the potential for shifting patterns of transmission of zoonotic pathogens to humans (Goldberg et al., 2008). An earlier study has identified anthropogenic disturbed habitats as the greatest risk for acquiring rodent borne diseases (Mills, 2006). People may rely on rodents for protein supplements, since rodents are known to be a delicacy in Africa (Fiedler, 1990), in so doing they may acquire plague disease. However, disease transmission is not only limited to environmental factors but social factors such as hunting rodents for consumption can place human health at risk (Salmón-Mulanovich et al., 2016).

A number of factors affect the state of best practices and knowledge, especially local ecological knowledge, on the management of plague disease and some of these include the state of flux and fluidity of people as they migrate due to hardships or poverty. This usually results in people with prior knowledge of plague disease to be displaced. This in turn affects the people's level of perceptions and attitudes. Shirima et al. (2010) reported that people's attitudes and perceptions on zoonosis are influenced by the level of public awareness about the disease within a given locality. This points to the need for equipping local communities and development partners with necessary skills to promote behavioural change and equip African countries to manage emerging and re-emerging zoonotic diseases more efficiently (Nkengasong, 2019).

Local ecological knowledge (LEK) assessment has been widely conducted in natural resource conservation and socio-ecological systems (Gandiwa et al., 2014; Kupika et al., 2019; Lima et al., 2017; Tarakini et al., 2018). However, this type of assessment is limited with regard to plague diseases (Ngulube et al., 2006; Salmón-Mulanovich et al., 2016; Kugeler et al., 2017; Nyirenda et al., 2017) . Accordingly, the present study assessed the levels of LEK with relation to plague disease awareness and management practices in south-western Zimbabwe.

LEK is defined as knowledge obtained by local communities which are unique to a particular custom in a given society (Senanayake, 2006; Milupi et al., 2017). To improve local zoonotic disease management, the sharing of LEK can be helpful as it guarantees the continuity of information to subsequent generations of people (Ossai et al., 2020). LEK may be dispersed verbally by elderly people to younger people as they grow or may also be acquired through observations (Edwards & Heinrich, 2006; Milupi et al., 2020).

Nkayi district is among the three districts (Hwange and Lupane districts included) that have had plague outbreaks in Zimbabwe. Between 1974 and 1975 plague outbreaks in Nkayi were confined to the Shangani River (Munyenyiwa et al., 2019). Between 1981 and 1985, human cases were recorded in Matabeleland North Province, Zimbabwe, and *Tatera leucogaster* was again found positive with *Y. pestis* (Dennis et al., 1999). Nkayi district and Umzingwane district are in the same agro-ecological region IV experiencing similar semi-arid climatic conditions which were observed to be ideal for plague disease occurrence (Andrianaivoarimanana et al., 2013). Understanding human community interactions with their immediate ecosystems and their knowledge and perceptions on zoonotic diseases can provide insights on their endemicity in an area (Athni et al., 2021; Rivière-Cinnamond et al., 2018). Endemicity of a disease in an area can result in improved knowledge of it (Rakotosamimanana et al., 2021). It is therefore necessary to assess the readiness of people in curbing plague disease in case it re-emerges as it has been observed to do (Dennis et al., 1999; Melman et al., 2019; WHO, 2016). Plague disease shares signs/symptoms with malaria, typhoid, Human Immuno-deficiency Virus (HIV)/Acquired Immuno-Deficiency Syndrome (AIDS), thus therefore posing a challenge to diagnose by both health practitioners and people (Elelu et al., 2019). The objectives of this study were to; (i) investigate the local people's level of awareness and practices with relation to plague diseases management, and (ii) assess the use of LEK and its influence on common practices related to plague diseases management in Nkayi (plague endemic area) and Umzingwane (plague non-academic area) districts, south-western Zimbabwe. What is the role of community awareness and practices on plague disease management in Nkayi and Umzingwane districts, Zimbabwe?

5.3 Materials and methods

5.3.1 Study area

The study was carried out in four villages, two in Nkayi and two in Umzingwane districts, south-western Zimbabwe (see Chapter 1, Figure 1.2). Both districts occur in natural region IV with mean minimum and maximum temperature and rainfall ranges of 11-20^{o}C and 19-26^{o}C and 450-650 mm, respectively (Mugandani *et al*., 2012). Nkayi district's (boundary extents 18.992^{o}S, 28.9005°E, area = 4 381km^2) population was reported to be 109,135 people (23 persons per km^2) while Umzingwane district (boundary extent -20.347°S, 28.9499°E, area = 2780 km^2) had 62,990 people (23 people km^{-2}) (Zimstat, 2013). Umzingwane district is largely constituted of artisanal small-scale gold miners while Nkayi district is dominated by small scale farmers who mainly grow maize and legumes for subsistence (Phiri, 2011; Dube *et al*., 2014). At the time of the study, Nkayi district had about 17 health facilities (this includes hospitals) (Zikhali, 2018), while Umzingwane district had 18 health facilities (this includes one hospital and a proposed clinic) (Umzingwane RDC, n.d). Nkayi district had 90 primary schools and 35 secondary schools (Nkayi RDC n.d), whereas in Umzingwane district had 17 secondary schools and 45 primary schools (Umzingwane RDC n.d). Nkayi district comprise of 30 wards, which are further divided into 156 villages (Zikhali, 2018), while Umzingwane district has 20 wards and 107 villages (Umzingwane RDC, nd). There is a high prevalence of female-headed households in Nkayi (40%) mainly due to the migration of men who seek economic opportunities in cities and neighbouring countries (Dube *et al*., 2014).

5.3.2 Research approach

A multi-method qualitative design was adopted (Collier & Elman, 2008) with explanatory and exploratory oriented questions used to gather cross-sectional data. The study adopted a two-way case study (Zainal, 2007) which involved a quasi-control site (Umzingwane district) with no previous record of plague disease outbreak. The Nkayi district was the treatment due to the presence of previous records of plague disease in this area (Munyenyiwa *et al*., 2019). Purposive sampling (Gandiwa *et al*., 2014) was utilised to select four villages, two from Nkayi district (plague endemic area) and two from Umzingwane district (non-plague endemic area). Mathoba and Monki villages in Nkayi district were highlighted by the senior health technician to be some of the villages that experienced plague (*Sibanda pers. comm*., 2017). Monki village lies near the Shangani River, where plague diseases was confined between 1974 and 1975 (Munyenyiwa et al., 2019). Crocodile and Nhlekiyane villages in Umzingwane district were observed to be having high influx of people undertaking illegal gold mining in the past (*Banda pers. observ*., 2017). Anthropogenic activities perpetrated by humans have been observed to be drivers to different rodent epidemics (Bordes et al., 2015; Halliday et al., 2015).

5.3.3 Data collection and sample selection

Data were collected using focus group discussions (FGDs) from August 2017 to April 2018 in two villages per district [(Mathoba and Monki villages – Nkayi) and (Crocodile and Nhlekiyane villages – Umzingwane)]. Focus group discussions were used because they provide collective responses and clarify the significances habits that perpetrate the feelings, attitudes and behaviours of members in a community (Rabiee, 2004). Prior to respondents' selection and conducting FGDs, permission to undertake the study was obtained from the respective local district councils. Next, we approached traditional leadership i.e. village heads who facilitated purposive selection of the focus group discussants.. Each focus group had at least eight (8) people. A total of four FGDs were held, i.e., two in each district, totalling 35 people (Table 5.1).

Table 5.1 Characteristics of the focus group discussants in Nkayi and Umzingwane districts.

Variable		Nkayi district				Umzingwane district			
		Mathoba		Monki		Crocodile		Nhlekiyane	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Sex	Female	5	63	4	50	4	50	5	45
	Male	3	38	4	50	4	50	6	55
Age (years)	<20	0	0	1	13	0	0	0	0
	21-40	0	0	0	0	4	50	2	18
	41-60	3	38	2	25	1	13	2	18
	61-80	4	50	4	50	2	25	6	55
	>80	1	13	1	13	1	13	1	9
Level of education	Primary	6	75	6	75	2	25	6	55
	Secondary school	2	25	2	25	6	75	5	45
	College and above	0	0	0	0	0	0	0	0
Main occupation	Subsistence farming	0	0	4	50	5	63	7	64
	Sole trader	0	0	1	13	0	0	1	9
	Health and education professionals	0	0	2	25	0	0	0	0
	Small-scale mining	0	0	0	0	1	13	0	0
	Pensioner	0	0	0	0	1	13	2	18
	Unemployed/Unoccupied	8	100	1	13	1	13	1	9

We controlled for uniformity of ethnic values among the focus group discussants by standardising that respondents should have stayed within the study area for ≥5 years (Rabiee, 2004) and discussions were conducted at the homesteads of village heads; which was convenient for most discussants. Each focus group had a facilitator, i.e., the principal investigator, a question reader and a notes taker who were selected among the discussants (Appendix 5.1). The question reader and notes taker were oriented by the facilitator on what to do. Focus group discussions were guided by a focus group discussion guide (Appendix 5.2) with some open-ended questions in the native language (Ndebele). The focus group guide contained questions on awareness and practices on zoonotic, rodent-borne and plague diseases.

Local Ecological Knowledge variables investigated included: (i) awareness on zoonotic disease, (ii) zoonotic disease control measures, (iii) presence of rodent vendors, (iv) knowledge of types of rodent-borne diseases, (v) rodent-borne disease that had occurred, (vi) norms and taboos associated with rodent consumption, (vii) organizations involved in the awareness campaigns and (viii) native name for plague and flea bites occurrence. Practices recorded included: (i) practices done after knowing about zoonotic diseases, (ii) local diagnoses and treatment of zoonosis, (iii) harvesting of rodents, (iii) interacting with rodents, (iv) controlling and controlling methods of rodents' population, and (v) any plague cases and if they were there, when did they occur. Pretesting of the focus group guide was carried out in April 2017 at Habane Township (Umzingwane district) with non-study area respondents to ensure that all questions were explicit before a final version of questionnaires was prepared for sampling. The focus group guide had brief description of scientific words in the questionnaires, for example elaborating, zoonotic disease, rodents and plague disease. Participants' consent to participate in the study was obtained verbally.

5.4 Data analysis

Most of the field transcribed data were screened word for word and recorded data were transcribed verbatim in the native Ndebele language. Data were translated into English prior to processing and were cleaned by removing unclear responses, before documenting the final output. Thematic analysis was conducted in Microsoft Word; a thematic coding framework was designed based on the major themes found in the responses. Open ended responses with multiple responses were presented as percentages of responses either in the respective districts or in the respective villages. Confidence Intervals (CI) were used to determine the range of the mean of focus group participants (FGP) per a specific village and specific variable i.e awareness and practices responses using Microsoft Excel.

5.5 Results

5.5.1 Local communities awareness of plague

Most focus group discussants in Nkayi district (58.33%) had heard of zoonotic diseases, while in Umzingwane district (27.7%) a much lower percentage of study respondents reported to be aware of zoonotic diseases. Rabies was the common zoonotic disease mentioned, other zoonotic diseases highlighted were anthrax and plague. The Department of Veterinary Services (DVS) under the Ministry of Lands, Agriculture, Water, Fisheries and Rural Resettlement (MLAWFRR) was the main organisation involved in zoonotic awareness as mentioned by all the discussants. The Ministry of Health and Child Care (MoHCC) was also reported to be involved in zoonotic diseases awareness by only one (n =1; 12.5%) focus group discussant in Mathoba village. Most (n = 10; 90.9%) of the Nhlekiyane village focus group discussants indicated that they did not recall any zoonotic disease occurrence.

Only one Mathoba focus group discussant (n = 1; 12.5%) was able to identify plague as a rodent-borne disease, whilst the Nhlekiyane, Crocodile and Monki focus group discussants could not identify any rodent-borne disease(s) irrespective of indicating awareness of the rodent-borne disease. Respondents from Crocodile and Monki villages reported the existence of rodent vendors in their communities, while those from Nhlekiyane and Mathoba villages reported no existence of rodent vendors. There were no norms or taboos that were associated with rodent consumption which were mentioned by all focus group discussants (Table 5.2).

Table 5.2 Zoonotic disease awareness among focus group participants in study villages

Variable	Sub-variable	Nkayi district		Umzingwane district	
		Mathoba	Monki	Crocodile	Nhlekiyane
Disease	Rabies	x	x	x	x
	Anthrax		x	x	
	Plague	x	x		
Awareness organisation	Division of Veterinary Service (DVS)	x	x	x	x
	Ministry of Health and Child Care (MoHCC)	x			
	Ministry of Primary and Secondary Education (MoPSE)		x		
	World Vision (non-governmental organisation)	x			
knowledge of zoonotic diseases	Yes	x	x	x	
	No			x	x
Zoonotic diseases encountered	Anthrax	x	x	x	
	Plague	x			
	Rabies	x	x	x	
Presence of rodent vendors	Yes		x	x	
	No	x			x
Norms and taboos on rodents' eating	None	x	x	x	x
	Present				
Interacting with rodents	Yes	x	x	x	x
	No				
Where do they interact with rodents	Home	x		x	x
	Field			x	x
	Wild	x	x	x	
Have heard about plague	Yes	x	x		
	No			x	x
Any plague occurrence, when	Yes	x	x		
	No			x	x

	1994-1995	x			
Native name for plague	Umkhuhlane wamagundwane		x		
Experiencing flea bites	Yes			x	x
	No	x	x		
Time of day when bitten by fleas	Anytime			x	x
	Night			x	
Flea bite season	Hot/dry				x
	Cold/dry			x	

Notes: x represent a positive response; blank - no response

Study respondents from all four villages reported that they commonly interacted with rodents in various ways, both in their homesteads and in the wilderness, i.e., in Nkayi district a greater number of study respondents reported interacting with rodents, while in Umzingwane a fair number also reported interacting with rodents. Study respondents from Umzingwane district have not heard about plague diseases, whereas in Nkayi district highlighted to have heard about plague disease and mentioned its previous occurrence between 1994 and 1995. Study respondents at Monki village in Nkayi stated that they had a native name for plague, i.e., "*Umkhuhlane wamagundwane*" (rats' disease). A lower number of discussants from Umzingwane district mentioned the presence of flea bites in hot/dry and cold/dry season, while only one person from Nkayi district acknowledged the same.

At 95% confidence the true average mean on plague awareness of the focus group participants in the respective villages lied between 41.21-58.79 (Mathoba village), 54.01-72.46 (Monki village), 35.73-62.87 (Crocodile village) and 35.67-80.42 (Nhlekiyane village). The Confidence Interval (CI) in Nkayi district villages was narrow compared to Umzingwane district villages CI. This could be an indication of greater variability of responses by Umzingwane district participants

5.5.2 Local community plague disease control practices

Some of the practices for controlling zoonosis mentioned by study respondents included dipping, chemical injections, indoor chemical spraying, keeping cats (*Felis catus*) and visiting health service facilities (Table 5.3).

Table 5.3 Zoonotic diseases management practices among focus group participants in study villages.

Variable	Sub variable	Nkayi District		Umzingwane District	
		Mathoba	Monki	Crocodile	Nhlekiyane
Zoonotic disease management practices	Vaccinating animals	x	x	x	x
	Dipping				x
	Disease treatment		x		
	Indoor spraying	x			
	Keeping domestic cats			x	
	Visiting health facilities	x			
Local diagnosis of zoonotic diseases	Rabies among people	x	x	x	
	Rabies in domestic dogs	x	x	x	
	Anthrax among people	x	x	x	
Local treatment of zoonotic diseases	None for people	x	x	x	x
	None for animals			x	
Rodents a delicacy	Yes	x	x	x	x
	No				
Rodents harvesting methods	Cages				x
	Traps	x	x	x	
	Domestic dogs	x	x	x	
	Catapult	x		x	
	Big stones			x	
	Bucket system	x		x	
Controlling mice/rats' population	Yes	x	x	x	x
	No				
Rodents controlling methods	Traps	x	x	x	x
	Rodenticides	x		x	x
	Cats	x	x	x	
	Bucket system			x	

Presence of local plague treatment	Yes	x	x	x	x
	No				
Plague management	Killing mice/rats	x		x	x
	Suspects taken to hospital	x		x	
	Educating people	x	x	x	

Notes: x represent a positive response; blank - no response

Respondents gave variable responses on the extent of being able to diagnose anthrax in humans, i.e., Monki (*n* = 1; 12.5%), Mathoba (*n* = 3; 37.5%), Nhlekiyane (*n* = 0; 0%) and Crocodile (*n* = 2; 25%), also being able to diagnose rabies in dogs (*Canis lupus familiaris*), Crocodile (*n* = 3; 37.5%) and Nhlekiyane (n=4; 36.4%). In contrast, some respondents from Mathoba village (*n* = 4; 50%) mentioned that they could not diagnose any zoonotic disease and relied on health service institutions. Most focus group discussants from both districts indicated that they could not treat people with zoonotic diseases.

A lower proportion of the focus group participants from both districts mentioned that some local people consumed rodents, noteworthy was in Umzingwane district were a greater number of participants in Nhlekiyane village indicated none consumption of rodents (*n* = 10; 90.9%). Use of dogs and traps for hunting rodents or rabbits were some of the methods reported by focus group discussants. Respondents indicated that they controlled rodents through use of traps, rodenticides and domestic cats. Some of the approaches to minimise plague disease suggested by study respondents included reducing rodent population by using rodenticides, traps and cats, taking suspected plague cases to hospital and promoting health care education on plague disease. At 95% confidence the true mean on plague management practices of the focus group participants lied between 34.88-57.62 (Mathoba village), 42.25-66.68 (Monki village), 33.43-57.82 (Crocodile village) and 36.75-64.57 (Nhlekiyane village). The CI in both districts was narrow and this may imply less variability in responses in both districts.

5.6 Discussion

There was difference in plague disease awareness but no difference in plague disease management practices. Study respondents exhibited higher knowledge on some zoonotic diseases, lower knowledge on rodent-borne disease and plague disease. Respondents demonstrated good practices on some zoonotic disease management, fair practices on management of rodent-borne diseases and plague diseases. In general, respondents from both Nkayi and Umzingwane districts were aware of some zoonotic diseases like rabies and anthrax. Rabies and other zoonotic diseases such as anthrax as indicated by other studies elsewhere are diseases well-known especially among cattle owners in Zimbabwe (Chikerema et al., 2013; Gadaga et al., 2016). Accordingly, the study area lies in an agro-ecological zone that is dominated by cattle rearing in Zimbabwe (Mugandani et al., 2012), thus the high vigilance of the DVS and its associated awareness programmes. The high level of awareness among study participants signified the effectiveness of awareness programmes and mass media (radio, television and newspapers) in disseminating information to people across the study area (Gadaga et al., 2016). Noteworthy was the relative variation in local awareness on plague disease for instance, which has been observed to be something common among human communities given the inherent dilution in culture, norms, religion and education from one area to another (Adlina et al., 2013). Elsewhere as well, relative variations and low level of knowledge on rodent-borne diseases was reported in Madre de Dios, Peru (Salmón-Mulanovich et al., 2016).

The study results recorded that local people have developed strategies over the years which have been incorporated in the daily practices to minimise exposure and transmission of zoonotic diseases and these practises include reducing rodent densities around the households either biologically or using rodenticides as chemical control. Evidence of human consumption of rodents was recorded in this study as has been reported before in tropical regions where some rodent species are consumed as a source of protein (Fiedler, 1990).

Local people usually derive information through life experiences with events from stories passed over time as oral evidence across generations (Berkström et al., 2019; Gilchrist et al., 2005). This was evident in this study as participants from Nkayi district, a district with previous outbreak of plague (Manungo et al., 1998; Dennis et al., 1999), had a good awareness of the disease compared to those from Umzingwane district.

Some study respondents reported the occurrence of flea bites during hot/dry and cold/dry seasons, such seasonal flea bite variations particularly in the summer and winter was also reported by Zimba et al. (2012). The study confirmed the importance of LEK in shaping people's awareness and practices over time and its ability to complement scientific evidence where such evidence is not readily available (Hopping et al., 2016). However, due to the existing programmes on various educational subjects, communities can also get knowledge about events that never occurred in their local environments.

The study highlighted villagers to have adopted the keeping of cats as a low-cost method of controlling rodents in their homesteads. Domestic cat ownership as a rodent control method has been reported elsewhere, e.g., Madre de Dios, Peru (Elton, 1953; Mahlaba et al., 2017; Salmón-Mulanovich et al., 2016). Companion animals, primarily domestic cats and dogs can either be reservoirs/host of zoonosis or carriers of zoonotic disease vectors like fleas and ticks to humans from infected wild animals thereby presenting health risks (Friend, 2006; Kruse et al., 2004; Overgaauw et al., 2020). However, the same companion animals play an important role as indicators for plague outbreaks in cases they fall sick (Manungo et al.,1998) as these have a higher interaction with rodents and are also highly sensitive to emerging diseases (Friend, 2006). Hence, developing an integrated disease surveillance and management system is essential to ensure that any potential outbreak is controlled.

The study focused on a small geographic area which limits generalisation to other areas within the agro-ecological region IV. Time and funding limitations somehow influenced the sampling intensity as per the original plan despite meeting the study overall objectives. There was limited access to recent plague cases data, thus the researchers study sites in Nkayi were informed by 1994 plague data (unpublished) and personal communication with the principal environmental health technician and other key informants (Sibanda, 2017).This type of study also did not warrant large geographic areas as it was about people's level of awareness and practices of which any acceptable sample would suffice.

5.7 Conclusion

The study investigated the local people's level of awareness and practises on plague disease management in Nkayi and Umzingwane districts, south-western Zimbabwe. The study concludes that Monki and Mathoba focus group discussants had fair awareness on plague disease as opposed to Nhlekiyane and Crocodile. Considering when plague occurred in Nkayi district that implies the observed awareness could be a result of LEK as well. Occurrence of a disease in an area also helps people acquire awareness of it, thereby improving on their skills of combating it. Villages from both districts demonstrated fair plague management skills. Rodents' consumption and population control may place them at risk of acquiring plague disease if not done on informed decision.

It was concluded that mere good practices like controlling rodents using cats, traps and rodenticides can aid in reduced occurrence of plague disease among humans, even with limited knowledge on plague disease, its outbreak among humans was minimal in both plague endemic and non-endemic areas. The study recommended the following; (i) developing an integrated system for plague disease surveillance, monitoring and management encompassing LEK and conventional scientific approaches for the study area, and (ii) creating an inventory of the intangible cultural heritage of the study areas and help document this for future references as this may complement the scientific approaches to disease surveillance and management.

Chapter 6

General Discussion, Conclusion and Recommendations

6.1 Introduction

This study aimed at analysing the ecological host-carrier association, prevalence and local community awareness of plague disease in a semi-arid tropical savanna ecosystem of Zimbabwe. Specifically, the study objectives were to: (i) determine the diversity of rodents and fleas and rodent-flea association; (ii) establish the prevalence of *Y. pestis* among captured rodents, and (iii) assess the level of awareness and practices of local communities on plague disease in Nkayi and Umzingwane districts, in Zimbabwe. The study established that there were no significant differences in the diversity of rodents and fleas. *Xenopsylla brasiliensis* was observed to be associated with different rodent species in Nkayi district, while in Umzingwane district *M. natalensis* was associated with different flea species. Low prevalence of *Y. pestis* among rodents was found to be low in Umzingwane district, while in Nkayi district, no rodent was found positive to *Y. pestis*. In Nkayi district respondents were well aware of plague disease compared to Umzingwane district. There were similar and fair practices on plague disease management presented by respondents from both districts. This Chapter provides an overview of the main findings of the study and discusses these in relation to theoretical framework outlined in Chapter 1. Further, aspects on the societal contribution of the study and implication for management, limitations of the study, conclusion and recommendations are provided.

6.2 Summary of findings and discussion

6.2.1 Rodents and flea diversity, and their association

In Chapter 3 Nkayi district yielded more rodent captures compared to Umzingwane district. The rodent trapping success was significantly different. A total of five rodent species were captured in the study sites. Of interest was the abundant *T. leucogaster* in Nkayi district, while in Umzingwane district there was abundant *M. natalensis* instead. Nkayi district also recorded more flea species compared to Umzingwane district. The study recorded no significant differences in the rodents and flea diversity between the two study sites. However, there was the high rodent diversity at Nkayi district compared to Umzingwane district, while on the contrary flea diversity was higher in Umzingwane district compared to Nkayi district. The findings thus show that sometimes during inter-epizootic, i.e., plague quiescent times, plague endemic areas would be exhibiting high diversity of rodents although interrelated with lower flea species diversity. Noteworthy is the flea species *X. brasiliensis* related with many different rodent species in Nkayi district, while in Umzingwane district instead there was an abundant rodent species *M. natalensis* interdependent with different flea species.

On the contrary Zimba *et al*. (2012), found no significant differences in the trapping success in the two sampling sites studied situated in agro-ecological zone II, i.e., Hatcliffe and Dzivarasekwa in Harare. *M. natalensis* was observed to be abundant in greatly modified habitats (Assefa & Chelmala, 2019), thus based on these results Umzingwane is highly modified compared to Nkayi district which offers a less manipulated habitat for rodents. A landscape with pressure from high human population can have reduced rodent diversity as a result of human anthropogenic activities like monocropping Agriculture practice (Hurst *et al*., 2013; Balestrieri *et al*., 2017). In line with this research findings, Eisen and co-workers (Eisen *et al*., 2012) similarly found no significant difference in rodent diversity between a plague endemic and plague non-endemic sites, although the study concentrated on the differences in elevation sites of the two sampling places. Further, their study noted a significantly greater diversity of fleas in a plague endemic area (higher elevation) compared to non-plague endemic area (lower elevation), the findings though contradict with this study. On the contrary, in this study, fleas were highly diverse outside the plague foci compared to inside foci, although no significance difference was noted.

The long-term conservation of *Y. pestis* transmission cycle is limited to foci that are ecological favourable (Dennis *et al*., 1999), implying that in Umzingwane district the area enables plague to be maintained. There are two theories trying to explain the exact mechanisms by which *Y. pestis* is preserved and the causes liable for the epizootic spread like (i) enzootic theory and (ii) metapopulation hypothesis (Moore *et al*., 2015). The enzootic theory claims that there are host species in the wild showing varied response to *Y. pestis* infection accountable for the upkeep of *Y. pestis* in the enzootic cycle (Gage & Kosoy, 2005; Eisen & Gage, 2009). Those host species resistant to *Y. pestis* maintain a crop of resistant flea species, when time is conducive the disease will spill over to epizootic species, i.e., susceptible species, which subsequently will be transmitted to humans (Gage & Kosoy, 2005). On the other and the meta population hypothesis claims that *Y. pestis* may be maintained in susceptible population without need for reservoir or enzootic reservoirs (Moore *et al*., 2015). Ecologically, this implies that during plague inter-epizootic the conditions in a certain country are not similar with another country, for instance West Nile region condition (Eisen *et al*., 2012) compared with Zimbabwe region condition as observed in this study.

6.2.2 Prevalence of *Y. pestis* among captured rodents

In Chapter 4, it was outlined that a total of four (4) rodent species were captured in the study sites. A single *M. natalensis* species tested positive for *Y. pestis* in Umzingwane district, thus the district having a higher prevalence of plague compared to Nkayi district. The study provides a snapshot of findings, showing *Y. pestis* occurrence in non-plague endemic rodent fauna (Umzingwane district), whilst absent in the plague endemic area (Nkayi district). There was high prevalence of plague disease in rodents captured in Umzingwane district compared to those captured in Nkayi district. Thus, plague disease occurrence in the rodent fauna can also occur outside the plague endemic foci as long as the other non-endemic area (Umzingwane district) also exhibits similar climatic conditions with the plague endemic area (Nkayi district). Trapping success from both districts of rodents was below the 10%, implying that it indicated lower rodent population (Sridhara, 2006). No significant difference was noted between the trapping successes. There are a number of possible reasons for such an occurrence. Rodents trappability differs according to the species, for instance some rodent species like Norway rats (*Rattus norvegicus*) are difficult to trap (Taylor *et al*., 1974). A combination of Intrinsic factors and experience of individual rodents can contribute to difficulties in trapping some rodents' species(Khan, 1992; Crowcroft & Jeffers, 2009;). Rodents' sex and level of maturity can play a part in the trappability of an individual (Drickamer *et al*., 1999). Extrinsic factors like humidity, temperature and vegetation cover can have an effect on the mice trappability (Drickamer *et al*., 1999; Davis *et al*., 2003). The bait type used might have had an influence on the population of rodents caught, the fact that it was uniform could have caused negative effect, rodents' have been observed to have a bait preference (Yabe, 1979; Robards & Saunders, 1998). Bait shyness might have developed among the rodents, of which this has been observed to have an impact (Thomas & Taylor, 2002).

A number of factors could have caused the observed low prevalence of plague diseases among the rodents in the districts. Season could have had an effect on the observed prevalence, like in cattle were disease prevalence was observed to be influenced by season, with the highest prevalence occurring in summer, followed by the rainy season and winter season in Chittagong district of Bangladesh (Badruzzaman *et al*., 2014). Like, what is stated by the key principle of veterinary epidemiology, disease occurrence in a population follows a specific pattern, it is more likely to be in certain members of the population, at certain times, and in specific locations (Smith, 2005; Dohoo *et al*., 2010). The age and sex of the rodents could have an effect on the low prevalence of plague disease, for instance sheep and goat pox was observed to affect males and older animals (Fentie *et al*., 2017), while some researchers observed an increased prevalence of brucellosis in yaks (*Bos grunniens*) with age.

6.2.3 Community awareness, practices and knowledge on zoonotic disease conclusion

In Chapter 5 a greater number of discussants in Umzingwane district were aware of zoonotic diseases compared to Nkayi district discussants. Discussants were very well familiar with Rabies in addition other diseases mentioned were anthrax, plague, foot and mouth and avian flu. Zoonotic awareness campaigns were mentioned to be actively undertaken by the DVS under MLAWRR. To a lesser extent MoHCC was mentioned by a discussant in Nkayi district to be also involved in the awareness campaigns. Educating people on zoonotic diseases was one of the ways mentioned by focus group discussants to be effective in preventing zoonotic diseases. Focus group discussants were not aware of rodent-borne diseases as shown by one discussant being able to mention plague disease as a rodent borne disease. MoHCC and MoPSE were organizations mentioned to be involved in rodent borne diseases awareness campaigns. Some focus group discussants highlighted the existence of rodent vendors in their communities. They were no taboos or norms associated with rodent consumption mentioned by focus group discussants. Respondents mentioned that they interact with rodents in many places. Most of the respondents in Umzingwane district have not heard of plague disease, whereas in Nkayi district most of the respondents have heard of the disease. Nkayi district discussants had a native name for plague disease, they called it, 'umkhuhlane wamagundwane'. Flea bites were mentioned to be occurring during hot/dry and cold/dry season.

Practices mentioned by respondents to be used to control zoonosis were dipping, injecting domestic animals, indoor spraying, keeping cats and visiting health facilities. Rabies and anthrax were the two diseases mentioned to be diagnosed by respondents, in both people and domestic animals. All discussants alluded that they couldn't treat any zoonotic diseases. Rodents were a delicacy for some of the people in the districts. Dogs and traps were some of the methods of capturing rodents indicated by respondents. Rodents at home were mentioned to be controlled by traps, rodenticides and domestic cats. Ways of reducing plague disease mentioned by focus group discussant were the use of rodenticides, traps and cats and taking plague suspects to hospital and promoting health education among people.

The study thus showed that respondents from both districts had knowledge of some zoonotic diseases especially those that affect their livestock. However, their knowledge on rodent-borne diseases was limited. Nkayi district communities had some knowledge on plague disease compared to Umzingwane district. When a disease occurs in an area, people tend to have a native name for it, this is quite useful for quick disease control in case of an outbreak. Practices being done by the communities do help to curb some zoonotic diseases, however the rodent consumption practice may put them at risk of acquiring rodent-borne diseases like plague.

Africa lags in investigating the awareness, attitudes and practices on specific zoonotic diseases. For instance, there has been little research on plague disease and Lassa fever in Nigeria, Zambia and Uganda (Ngulube *et al*., 2006; Nyirenda *et al*., 2017; Kugeler *et al*., 2020). Fiedler, (1990) highlighted that rodents were African delicacy, in line with the research findings of this study rodents are a delicacy to some people in Zimbabwe as well, since no taboos or norms noted. This utilisation of rodents as relish will assist in conserving some wild animal population in the country (Brashares *et al*., 2004). Not only, in order to reduce over exploitation of these rodents domestication may be another ideal route to take and this may improve people's livelihoods by an additional income (Okorafor *et al*., 2012). Respondents from both districts mentioned a lot of and common zoonotic disease management practices (Table 5.3) this shows shared knowledge among people irrespective of districts, hence most likely to be passed on to the subsequent generation. Contributing to LEK also is the local diagnosis of some zoonotic diseases like rabies in both people and dogs and anthrax among people. This available knowledge will help reduce the occurrence of these diseases. Respondents form both districts mentioned many rodents harvesting and controlling methods. Improvement and additional methods were observed, most likely being a sign of increased use of these animals as alternative protein source. Use of cats as a way of controlling rodent's population at home was common among districts, the use of this method may serve peoples time checking on rodents instead time will be diverted to other house chores. However, although the method is fairly good, people need to be made aware of the possible implication of sick cats in their home, as indicated by Manungo et al. (1998) presence of sick cats at homes may imply or indicate plague existence. Noteworthy mentioned by respondents from both districts was the need for educating people about the plague disease. This is a good sign that people are yearning for more knowledge. This was further revealed by limited knowledge on rodent borne disease; this could possibly be attributed to that the rightful department is not carrying out awareness campaigns. Rodent control responsibility was placed under local councils' environment departments. There is need to research further on the initiatives by local councils towards curbing either rodent population increase or influx.

6.3 Contribution to science

Rodents and flea abundance are affected by both abiotic and biotic conditions (Krasnov *et al*., 2005; Amatre *et al*., 2009). Abiotic conditions comprise of rainfall, temperature, humidity, soil type, only to mention a few, whereas biotic factors include bacteria, virus, fungi and parasites. These factors can either directly or indirectly affect rodent or flea population distribution (Hutchinson, 1957; Boulangeat *et al*., 2012; Cazelles *et al*., 2015). Research has shown that medium to high rainfall, for instance, can result in rodent and/or flea population fluctuations (Salkeld & Stapp, 2009; Moore *et al*., 2015). If rainfall increases it affects the available vegetation, thus providing more food and variable habitats for the rodents' fauna *(Guidobono et al*., 2018). However, if it becomes too excessive, rodents can either die by drowning or they tend to move to human dwellings instead. If the latter happens, diseases may be acquired by humans. Soil type can also affect rodent abundance as observed with *M. natalensis* high population on loamy textured soils as compared to sandy clay soils (Massawe *et al*., 2008). Abiotic factors, like acquisition of *Y. pestis* by some rodent species, could result in their population dwindling. Flea abundance can be affected by temperature for instance, high temperature has been shown to cause flea population increase, while decrease in temperature results in decrease in the flea population (Krasnov *et al*., 2001). The occurrence of biotic factors such as *Y. pestis* in fleas can cause their population to decrease in the long run. *Y. pestis* blocks the oesophagus of the flea, preventing it from feeding well; therefore the flea will die of starvation.

Rodents' diversity is mostly affected by presence of diverse ecological niches. If an area is less disturbed it tends to favour rodent diversity as was observed at Nkayi district. The same can be speculated with fleas, thus presence of several different flea niches, flea diversity is encouraged. Flea niches mostly could be affected by soil mosaic types, since fleas spend about three quarters of their lives in the soil (van der Mescht, 2015). This study has shown that plague bacteria occurrence is dynamic and is not only concentrated in endemic areas. The soil types and vegetation types of Nkayi and Umzingwane districts differ and this could be another contributing factor to the difference in rodents and flea species fauna. Chapter 3 and 4 findings contributed to these two theories socioecological systems (SESs) and species co-occurrence. There was no significant difference in rodent and diversity noted, however of interest was the diversity of rodents in the plague endemic district compared to the non-endemic and noteworthy is the higher diversity of fleas in Umzingwane and Nkayi district. These differences can be attributed to human activities, i.e., anthropogenic activities. The research showed that rodents and flea distribution can be attributed to biotic factors as well. In Umzingwane district for instance *M. natalensis* harboured different flea species, implying the rodent species is a generalist when it comes to occupying shelters thereby acquiring different flea species along the way. Thus, in places where *M. natalensis* is abundant, one would have to expect a diverse array of flea species. *X. brasiliensis* is a generalist flea species, feeding on different types of rodent species. This flea species seems not to facilitate other flea species, thereby showing lesser cohabitation with other flea species. Thus, if this species is more in an area, reduced flea diversity is to likely to be expected.

The greater number of fleas among higher diversity rodent fauna could be due to the presence of rodents with long pelages which promote flea multiplication and the presence of well-constructed burrows by *T. leucogaster* and occupation of less disturbed area which provides good microclimate for flea growth and development (Hieronimo *et al*., 2014; Chapter 3). Even though rodents show greater diversity in an area, it does not guarantee greater diversity of associated fleas. A lower diversity of fleas could be due to inability of some flea species to facilitate some other flea species. Facilitation among flea species involves suppression of host immune defences (Krasnov *et al*., 2005; Chapter 3). Greater flea diversity and the presence of a good plague reservoir like *M. natalensis* tends to influence pathogen occurrence in a given area, as was shown by the presence of a *Y. pestis* positive rodent in Umzingwane district (Neerinckx *et al*., 2008; Ziwa *et al*., 2013; Chapter 4). The presence of an efficient plague bacteria ectoparasite transmitter like *X. brasiliensis* and the detection of the bacteria in *M. natalensis* reservoir could result in an increased occurrence of plague in the rodent fauna and among humans and their livestock.

Avoiding contact with rodents and controlling rodent populations can decrease the disease burden in humans, however, this is not encouraged when there is a plague epizootic in the rodent fauna (Andrianaivoarimanana *et al*., 2013; Chapter 4). Controlling rodent populations during an epizootic leaves behind blood hungry fleas seeking for alternative hosts, thus humans as well can be fed on during such times, therefore it is better to control flea fauna instead during plague epizootic (Ben-Ari *et al*., 2011). Rodent prevention which involves controlling rodent population, for instance was observed to offer a short-term solution to rodent population control. When the controlling strategy ceases, rodent population was seen to increase (Buckle *et al*., 2017).

Occurrence of a certain phenomenon in an area can cause inhabitants of that area to come up with ways of mitigating the existing problem in the long run and with time the developed skills are passed on to the next generation, i.e., LEK. This study as well contributed to LEK theory, showing greater awareness on zoonotic diseases, with great knowledge on Rabies and Anthrax, those diseases that often affect people's livestock. The DVS showed that it played a greater part in raising these diseases awareness. There was limited knowledge on rodent borne diseases and fair knowledge on plague disease. Nkayi discussants had fair knowledge on plague disease unlike Umzingwane district discussants. Since plague disease once occurred in Nkayi district, it thereby shows that knowledge on this disease is being passed from generation to generation. People, however fair to poor practices on rodent borne, were doing good practices on managing zoonotic diseases and people were carrying out plague disease.

Focus group discussants revealed that rodents were a delicacy among people and that there were no norms or taboos surrounded with rodent consumption among people. This habit can be a risk for acquiring rodent borne diseases. Rodents population in and around homesteads was shown to be controlled, this is a good way of controlling plague, however when there is an epizootic this behaviour has to be abandoned, since killing of rodents will result in fleas feeding on humans and their livestock instead. This means people need to be made aware when should they control rodent population. These three theories have an impact therefore in human lives and the natural system. This study overall contributes to SESs theory as it investigated both the natural system and the social system.

The research findings showed greater awareness and good management practices on zoonotic diseases among focus group discussants. In contrast with this research findings Kelly *et al*. (2018) reported limited awareness on zoonotic disease, especially among informally educated and illiterate farmers, of which most of them were women. Further, on the research revealed high-risk practices being done by farmers although being aware of zoonotic diseases. Additionally, Alho *et al*. (2018), found out that an average number of pet owners, were aware of transmittable diseases between animals and humans, however the exact zoonotic diseases name were poorly known. A small percentage of the dog pet owners mentioned to have suffered from diseases acquired from their pets. Anthrax and Rabies were well known zoonotic diseases among respondents, the reason for this could be that Veterinarians reported these diseases mostly to public health resulting in them being greatly made aware of. Veterinarians have been reported elsewhere to be involved in public health zoonotic disease awareness by constantly offering reports on such diseases (Venkat *et al*., 2020). Although respondents mentioned that they were well aware of rodent-borne diseases, only one gave a name of a rodent-borne disease, this is an indication that respondents were not knowledgeable of rodent-borne, thus in agreement with a research done in Peru where respondents couldn't name a specific rodent-borne disease (Salmón-Mulanovich *et al*., 2016).

The research findings showed that the animal health sector was highly vibrant in zoonotic disease awareness among the districts. There is need for these two sectors to work jointly in raising zoonotic awareness's since most of these diseases are share by both their units (animals and people). In conjunction with the research findings, a research carried out among health care providers in southwest Ethiopia also showed a higher percentage of respondents advocated for a joint venture on zoonotic awareness campaigns by both human and animal health sectors (Gemeda *et al*., 2016). The research further highlighted that the involvement of both sectors together was only limited to joint outbreak response. Respondents showed that one way or the other they controlled rodents population by using different exterminating methods like use of traps and rodenticides else as well it was found out that at least three quarters of the respondents practiced some rodent control rodent in their homes (Eisen *et al*., 2013).

6.4 Study implications for society and management

Most discussants advocated for education on rodent-borne diseases. Increasing awareness and knowledge on a given disease could help humans to come up with the rightful rodent prevention methods, thereby decreasing the disease burden among humans (Bonnefoy *et al.*, 2008; Chapter 5). Human awareness and practices can lessen or worsen plague occurrence in an area. Thus, in addition to other factors rodents, flea diversity and human awareness and practices influence plague transmission from wild rodents to fleas.

In the original framework description, enzootic, epizootic and zoonotic cycles were mentioned and some of our findings can disturb these cycles. In order to reduce plague transmission in the enzootic and epizootic cycle there would be less manipulation of rodent habitat, this will assist in increasing rodents' diversity, in so doing reducing the proliferation of *M. natalensis* a good plague reservoir (Chapter 3; 4). Additionally, the study shows that reduced flea diversity, results in reduced incidence of plague in the rodent fauna (Chapter 3), this also has to do with reduced rodent habitat disturbance, so that there is less diversity of flea microclimatic conditions. To curb plague transmission to humans (zoonotic cycle) people would have to be educated on plague transmission routes, flea population control on both premises or on their livestock and rodent population control, i.e., undertaking effective awareness campaigns against plague disease (Chapter 5).

6.5 Limitations of the study

The study was focused to a small geographic area which limits generalisation to other areas within the agro-ecological region IV. Time and funding limitations somehow influenced the sampling intensity as per the original plan despite meeting the study overall objectives. There was limited access to recent plague cases data, thus the researchers study sites in Nkayi were informed by 1994 plague data.

6.6 Conclusion

In this study no significant differences in the diversity of rodents and fleas in the two districts were observed. The *X. brasiliensis* flea species at Nkayi district were associated with many different rodent species. The *M. natalensis* rodent species in Umzingwane district was associated with different flea species. Plague causing bacteria *Y. pestis* was detected in *M. natalensis* species caught in Nhlekiyane village under Umzingwane district showing a marginal prevalence of plague diseases in rodents compared to Nkayi district. Focus group discussants in both districts showed greater knowledge of zoonotic diseases, especially on rabies and anthrax. Nkayi district focus group discussants showed fair knowledge on plague disease compared to respondents from Umzingwane district. Focus group discussants in both districts mentioned a lot of ways being used to reduce zoonotic diseases transmission from animals, for instance injecting and dipping livestock (Dennis *et al*., 1999; Gage *et al*., 1999).

6.7 Recommendations

a) Rodents populations in and around home premises may be regulated by having domestic cats, however these cats need to be de-ectoparasitized using a powdery or wet insecticide, so as to remove fleas and other ectoparasites acquired during the rodents' hunt.

b) Surveillance of plague needs to encompass various stakeholders inclusive of the veterinary and public and human health departments.

c) Plague prevalence determination may be extended to domestic animals like the African chickens (*Gallus gallus domesticus*) and rabbits (*Oryctolagus cuniculus domesticus*).

References

Acosta, R., & Fernández, J. A. (2015). Revista Mexicana de Biodiversidad Flea diversity and prevalence on arid-adapted rodents in the Oriental Basin ,. *Enfermería Universitaria*, *86*(4), 981–988. https://doi.org/10.1016/j.rmb.2015.09.014

Adlina, A. H., Jawan, J. A., Sri Rahayu, I., Normala, O., & Mohd Hadzrul, M. (2013). Traditional Knowledge and Environmental Conservation among Indigenous People in Ranau, Sabah. *Global Journals Incorporated USA*, *13*(3), 4–12.

Alemayehu, B., & Alemayehu, M. (2017). Leishmaniasis: A Review on Parasite, Vector and Reservoir Host. *Health Science Journal*, *11*(4), 1–6. https://doi.org/10.21767/1791-809x.1000519

Alho, A. M., Lima, C., Colella, V., Madeira De Carvalho, L., Otranto, D., & Cardoso, L. (2018). Awareness of zoonotic diseases and parasite control practices: A survey of dog and cat owners in Qatar. *Parasites and Vectors*, *11*(1), 1–7. https://doi.org/10.1186/s13071-018-2720-0

Allesina, S., & Tang, S. (2012). Stability criteria for complex ecosystems. *Nature*, *483*(7388), 205–208. https://doi.org/10.1038/nature10832

Amatre, G., Babi, N., Enscore, R. E., Ogen-Odoi, A., Atiku, L. A., Akol, A., Gage, K. L., & Eisen, R. J. (2009). Flea diversity and infestation prevalence on rodents in a plague-endemic region of Uganda. *American Journal of Tropical Medicine and Hygiene*, *81*(4), 718–724. https://doi.org/10.4269/ajtmh.2009.09-0104

Andrianaivoarimanana, V., Kreppel, K., Elissa, N., Duplantier, J. M., Carniel, E., Rajerison, M., & Jambou, R. (2013). Understanding the Persistence of Plague Foci in Madagascar. *PLoS Neglected Tropical Diseases*, *7*(11), 1–8. https://doi.org/10.1371/journal.pntd.0002382

Anjos, R. O., Mugabe, V. A., Moreira, P. S. S., Carvalho, C. X., Portilho, M. M., Khouri, R., Sacramento, G. A., Jr, N. R. R. N., Reis, M. G., Kitron, U. D., Ko, A. I., Costa, F., & Ribeiro, G. S. (2020). *Transmission of Chikungunya Virus in an Urban Slum , Brazil*. *26*(7).

Archer, C. E., Appleton, C. C., Mukaratirwa, S., Lamb, J., & Corrie Schoeman, M. (2017). Endo-parasites of public-health importance recovered from rodents in the Durban metropolitan area, South Africa. *Southern African Journal of Infectious Diseases*, *32*(2), 57–66. https://doi.org/10.1080/23120053.2016.1262579

Assefa, A., & Chelmala, S. (2019). Comparison of rodent community between natural and modified habitats in Kafta-Sheraro National Park and its adjoining villages, Ethiopia: implication for conservation. *The Journal of Basic and Applied Zoology*, *80*(1). https://doi.org/10.1186/s41936-019-0128-9

Athni, T. S., Shocket, M. S., Couper, L. I., Nova, N., Caldwell, I. R., Caldwell, J. M., Childress, J. N., Childs, M. L., De Leo, G. A., Kirk, D. G., MacDonald, A. J., Olivarius, K., Pickel, D. G., Roberts, S. O., Winokur, O. C., Young, H. S., Cheng, J., Grant, E. A., Kurzner, P. M., … Mordecai, E. A. (2021). The influence of vector-borne disease on human history: socio-ecological mechanisms. *Ecology Letters*, *24*(4), 829–846. https://doi.org/10.1111/ele.13675

Badruzzaman, A. T. M., Siddiqui, M. S. I., Faruk, M. O., Lucky, N. S., Zinnah, M. A., Hossain, F. M. A., & Rahman, M. M. (2014). Prevalence of infectious and non-infectious diseases in cattle population in Chittagong district of Bangladesh. *International Journal of Biological Research*, *3*(1), 1. https://doi.org/10.14419/ijbr.v3i1.3760

Bahmanyar, M., & Cavanaugh, D. . (1976). *Plague Manual*.

Barcellos, C., & Sabroza, P. C. (2001). The place behind the case: leptospirosis risks and associated environmental conditions in a flood-related outbreak in Rio de Janeiro.

Cadernos de Saúde Pública / Ministério Da Saúde, Fundação Oswaldo Cruz, Escola Nacional de Saúde Pública, *17 Suppl*, 59–67. https://doi.org/10.1590/s0102-311x2001000700014

Ben-Ari, T., Neerinckx, S., Gage, K. L., Kreppel, K., Laudisoit, A., Leirs, H., & Stenseth, N. C. (2011). Plague and climate: Scales matter. *PLoS Pathogens*, *7*(9), 5–10. https://doi.org/10.1371/journal.ppat.1002160

Berkström, C., Papadopoulos, M., Jiddawi, N. S., & Nordlund, L. M. (2019). Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Frontiers in Marine Science*, *6*(MAR), 1–10. https://doi.org/10.3389/fmars.2019.00130

Binder, C. R., Hinkel, J., Bots, P. W. G., & Pahl-Wostl, C. (2013). Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecology and Society*, *18*(4). https://doi.org/10.5751/ES-05551-180426

Boakye, D. A., Wilson, M., & Kweku, M. (2005). A review of leishmaniasis in west Africa. *Ghana Medical Journal*, *39*(3), 94–97. http://www.ncbi.nlm.nih.gov/pubmed/17299551%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1790817

Boegler, K. A., Graham, C. B., Montenieri, J. A., McMillan, K., Holmes, J. L., Petersen, J. M., Gage, K. L., & Eisen, R. J. (2012). Evaluation of the Infectiousness to Mice of Soil Contaminated with Yersinia pestis-Infected Blood. *Vector Borne Zoonotic Diseases*, *12*(11), 948–952. https://doi.org/10.1089/vbz.2012.1031

Bonnefoy, X., Kampen, H., & Sweeney, K. (2008). Flies. In *Public Health Significance of Urban Pests*. World Health Organisation. https://doi.org/10.1007/978-3-319-13884-8_31

Borchert, J. N., Mach, J. J., Linder, T. J., Angualia, S., Borchert, J. N. ;, & Mach, J. J. ; (2007). Invasive rats and bubonic plague in northwest Uganda. *Managing Vertebrate*

Invasive Species, *3*(August), 282–293. http://digitalcommons.unl.edu/nwrcinvasive

Bordes, F., Blasdell, K., & Morand, S. (2015). Transmission ecology of rodent-borne diseases: New frontiers. *Integrative Zoology*, *10*(5), 424–435. https://doi.org/10.1111/1749-4877.12149

Boulangeat, I., Gravel, D., & Thuiller, W. (2012). Accounting for dispersal and biotic interactions to disentangle the drivers of species distributions and their abundances. *Ecology Letters*, *15*(6), 584–593. https://doi.org/10.1111/j.1461-0248.2012.01772.x

Boutayeb, A. (2007). Developing countries and neglected diseases : challenges and perspectives. *International Journal for Equity in Health*, *6*(20), 4pp. https://doi.org/10.1186/1475-9276-6-20

Bramanti, B., Dean, K. R., Walløe, L., & Stenseth, N. C. (2019). *The Third Plague Pandemic in Europe*. 1–8.

Brashares, J. S., Arcese, P., Sam, M. K., Coppolillo, P. B., Sinclair, A. R. E., & Balmford, A. (2004). Bushmeat hunting, wildlife declines, and fish supply in West Africa. *Science*, *306*(5699), 1180–1183. https://doi.org/10.1126/science.1102425

Briese, T., Paweska, J. T., McMullan, L. K., Hutchison, S. K., Street, C., Palacios, G., Khristova, M. L., Weyer, J., Swanepoel, R., Egholm, M., Nichol, S. T., & Lipkin, W. I. (2009). Genetic detection and characterization of Lujo virus, a new hemorrhagic fever-associated arenavirus from southern Africa. *PLoS Pathogens*, *5*(5), 1–8. https://doi.org/10.1371/journal.ppat.1000455

Buckle, A., Broome, R., Bull, S., Christopher, P., Davies, M., Prescott, C., & Ward-Thompson, D. (2017). *Campaign for Responsible Rodenticide Use (CRRU) UK The UK Rodenticide Stewardship Regime* (Issue January). https://doi.org/10.13140/RG.2.2.25068.56969

Casadevall, A., & Pirofski, L. A. (1999). Host-pathogen interactions: Redefining the basic concepts of virulence and pathogenicity. *Infection and Immunity*, *67*(8), 3703–3713. https://doi.org/10.1128/iai.67.8.3703-3713.1999

Cazelles, K., Araújo, M. B., Mouquet, N., & Gravel, D. (2015). A theory for species co-occurrence in interaction networks. *Theoretical Ecology*, *9*(1), 39–48. https://doi.org/10.1007/s12080-015-0281-9

CDC. (2017). *Rodents*. Centers for Disease Control and Prevention. https://www.cdc.gov/rodents/diseases/direct.html

CDC. (2018). *Plague*. Centers for Disease Control and Prevention (CDC). https://www.cdc.gov/rodents/disease

CDC. (2019). *Ecology and transmission*. Centers for Disease Control and Prevention (CDC). https://www.cdc.gov/plague/transmission/index.html

CDC. (2020). *Parasite-Leishmaniasis*. Centers for Disease Control and Prevention. https://www.cdc.gov/parasites/leishmaniasis/gen_info/faqs.html

CDC. (2021). *Protect yourself from plague*. Centers for Disease Control and Prevention. https://www.cdc.gov/plague/resources/235098_Plaguefactsheet_508.pdf

Chakma, S., Picard, J., Duffy, R., Constantinoiu, C., & Gummow, B. (2015). A Survey of Zoonotic Pathogens Carried by Non-Indigenous Rodents at the Interface of the Wet Tropics of North Queensland, Australia. *Transboundary and Emerging Diseases*, *64*. https://doi.org/10.1111/tbed.12360

Chanteau, S., Ratsifasoamanana, L., Rasoamanana, B., Rahalison, L., Randriambelosoa, J., Roux, J., & Rabeson, D. (1998). Plague, a reemerging disease in Madagascar. *Emerging Infectious Diseases*, *4*(1), 101–104. https://doi.org/10.3201/eid0401.980114

Charlton, R. W., & Palmer, A. W. (1975). Plague in Rhodesia. *Central African Journal of Medicine*, *21*(5), 103–108.

Chikerema, S. M., Matope, G., & Pfukenyi, D. M. (2013). Awareness and Attitude Toward

Zoonoses with Particular Reference to Anthrax Among Cattle Owners in Selected Rural Communities of Zimbabwe. *Vector-Borne and Zoonotic Diseases*, *13*(4), 243–249. https://doi.org/10.1089/vbz.2011.0916

Chikwenhere, G. (2006). Rodents and human diseases in Zimbabwe. *Rats and Human Health in Africa: Proceedings of an International Workshop on Rodent-Borne Diseases and the RatZooMan Research Project*, *May*, 1–46.

Collier, D., & Elman, C. (2008). Qualitative and Multi-Method Research: organizations, publication, and reflections on integration. In *Oxford Handbook of political methodology* (pp. 780–795).

Corvalan, C., Hales, S., McMichael, A., Butler, C., Campbell-Lendrum, D., Confalonieri, U., Leitner, K., Lewis, N., Patz, J., Polson, K., Scheraga, J., Woodward, A., & Younes, M. (2005). Ecosystems and human well-being: Health Synthesis- A Report of the Millennium. In *World Health Organization*. https://apps.who.int/iris/bitstream/handle/10665/43354/9241563095.pdf;jsessionid=5E210B826B63C259059D3D7235BCF7F7?sequence=1

Crowcroft, P., & Jeffers, J. (2009). Variability in the behaviour of wild house mice (Mus musculus L.) towards live traps. *Proceedings of the Zoological Society of London*, *137*(4), 573–582. https://doi.org/10.1111/j.1469-7998.1961.tb06090.x

Davis, S. A., Akison, L. K., Farroway, L. N., Singleton, G. R., & Leslie, K. E. (2003). Abundance Estimators and Truth: Accounting for Individual Heterogeneity in Wild House Mice. *The Journal of Wildlife Management*, *67*(3), 634–645. https://doi.org/10.2307/3802720

De Bruyne, A., Ancelle, T., Vallee, I., Boireau, P., & Dupouy-Camet, J. (2006). Human trichinellosis acquired from wild boar meat: a continuing parasitic risk in France. *Euro Surveillance : Bulletin Européen Sur Les Maladies Transmissibles = European*

Communicable Disease Bulletin, *11*(9), 11–13. https://doi.org/10.2807/esw.11.37.03048-en

Dean, K. R., Krauer, F., Walløe, L., Lingjærde, O. C., Bramanti, B., Stenseth, N. C., & Schmid, B. V. (2018). Human ectoparasites and the spread of plague in Europe during the Second Pandemic. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(6), 1304–1309. https://doi.org/10.1073/pnas.1715640115

Dennis, D. T., Gage, K. L., Gratz, N. G., Poland, J. D., Tikhomirov, E., & Control, W. H. O. E. D. (1999). *Plague manual : epidemiology, distribution, surveillance and control / principal authors: David T. Dennis ... [et al.]* (p. WHO/CDS/CSR/EDC/99.2). World Health Organization.

Dennis, D. T., Gage, K. L., Gratz, N., Poland, J. D., & Tikhomirov, E. (1999). Plague manual--epidemiology, distribution, surveillance and control. In *Plague Manual: Epidemiology, Distribution, Surveillance and Control* (Vol. 74, Issues 51–52, p. 447).

Dohoo, I., Martin, W., & Stryhn, H. (2010). *Veterinary epidemiologic research* (2nd ed.). Prince Edward Island-Canada, VER Inc.

Douangboupha, B., Brown, P. R., Khamphoukeo, K., Aplin, K. P., & Singleton, G. R. (2009). Population dynamics of rodent pest species in upland farming systems of lao PDR. *Kasetsart Journal - Natural Science*, *43*(1), 125–131.

Drickamer, L. C., Feldhamer, G. A., Mikesic, D. G., & Holmes, C. M. (1999). Trap-response heterogeneity of house mice (Mus musculus) in outdoor enclosures. *Journal of Mammalogy*, *80*(2), 410–420. https://doi.org/10.2307/1383289

Dube, T., Tui, S. H., & Rooyen, A. Van. (2014). Socioeconomics Discussion Paper Series Baseline and Situation Analysis Report : Integrating Crop and Livestock Production for Improved Food Security and Livelihoods in Rural Zimbabwe. *ICRISAT - Socioeconomics Discussion Paper Series*, *29*.

Dubey, J. P., Hill, D. E., Rozeboom, D. W., Rajendran, C., Choudhary, S., Ferreira, L. R., Kwok, O. C. H., & Su, C. (2011). High prevalence and genotypes of Toxoplasma gondii isolated from organic pigs in Northern USA. *Veterinary Parasitology*, *188*(1–2), 14–18. https://doi.org/10.1016/jvetpar.2012.03.008

ECDC. (2014). *Rapid risk assessment-Plague outbreak*. European Centre for Disease Prevention and Control. https://www.readkong.com/page/plague-outbreak-august-november-2014-madagascar-5540137

Edwards, S. E., & Heinrich, M. (2006). Redressing cultural erosion and ecological decline in a far North Queensland aboriginal community (Australia): The Aurukun ethnobiology database project. *Environment, Development and Sustainability*, *8*(4), 569–583. https://doi.org/10.1007/s10668-006-9056-1

Eisen, R. J., Atiku, L. A., Mpanga, J. T., Enscore, R. E., Acayo, S., Kaggwa, J., Yockey, B. M., Apangu, T., Kugeler, K. J., & Mead, P. S. (2020). An Evaluation of the Flea Index as a Predictor of Plague Epizootics in the West Nile Region of Uganda. *Journal of Medical Entomology*, *57*(3), 893–900. https://doi.org/10.1093/jme/tjz248

Eisen, R. J., Borchert, J. N., Mpanga, J. T., Atiku, L. A., MacMillan, K., Boegler, K. A., Montenieri, J. A., Monaghan, A., & Gage, K. L. (2012). Flea diversity as an element for persistence of plague bacteria in an east African plague focus. *PLoS ONE*, *7*(4), 1–8. https://doi.org/10.1371/journal.pone.0035598

Eisen, R. J., Enscore, R. E., Atiku, L. A., Zielinski-Gutierrez, E., Mpanga, J. T., Kajik, E., Andama, V., Mungujakisa, C., Tibo, E., MacMillan, K., Borchert, J. N., & Gage, K. L. (2013). Evidence that rodent control strategies ought to be improved to enhance food security and reduce the risk of rodent-borne illnesses within subsistence farming villages in the plague-endemic West Nile region, Uganda. *International Journal of Pest Management*, *59*(4), 259–270. https://doi.org/10.1080/09670874.2013.845321

El-Sherbini, G. T., & El-Sherbini, E. T. (2011). The role of insects in mechanical transmission of human parasites. *Iranian Red Crescent Medical Journal*, *13*(9), 573–574. https://doi.org/10.5812/kowsar.20741804.2253

Elelu, N., Aiyedun, J. O., Mohammed, I. G., Oludairo, O. O., Odetokun, I. A., Mohammed, K. M., Bale, J. O., & Nuru, S. (2019). Neglected zoonotic diseases in nigeria: Role of the public health veterinarian. *Pan African Medical Journal*, *32*(January). https://doi.org/10.11604/pamj.2019.32.36.15659

Elton, C. S. (1953). The use of cats in farm rat control. *The British Journal of Animal Behaviour*, *1*(4),151–155.https://doi.org/https://doi.org/10.1016/S0950-5601(53)80015-8

Fentie, T., Fenta, N., Leta, S., Molla, W., Ayele, B., Teshome, Y., Nigatu, S., & Assefa, A. (2017). Sero-prevalence, risk factors and distribution of sheep and goat pox in Amhara Region, Ethiopia. *BMC Veterinary Research*, *13*(1), 1–8. https://doi.org/10.1186/s12917-017-1312-0

Fiedler, L. A. (1990). Rodents as a food source. *Proceedings of the Fourteenth Vertebrate Pest Conference 1990*, *March*, 149–155. https://digitalcommons.unl.edu/vpc14

Fischer, J., Hartel, T., & Kuemmerle, T. (2012). Conservation policy in traditional farming landscapes. *Conservation Letters*, *5*(3), 167–175. https://doi.org/10.1111/j.1755-263X.2012.00227.x

Friend, M. (2006). Disease Emergence and Resurgence : The Wildlife-Human Connection. In *Disease Emergence and Resurgence: The Wildlife-Human Connection* (Issue May, p. 400pp). USGS National Wildlife Health Center in cooperation with the U.S. Fish and Wildlife Service.

Gadaga, B. M., Etter, E. M. C., Mukamuri, B., Makwangudze, K. J., Pfukenyi, D. M., & Matope, G. (2016). Living at the edge of an interface area in Zimbabwe: Cattle owners, commodity chain and health workers' awareness, perceptions and practices on zoonoses.

BMC Public Health, *16*(1), 1–10. https://doi.org/10.1186/s12889-016-2744-3

Gage, K. L., & Kosoy, M. Y. (2005). Natural history of plague: Perspectives from more than a century of research. *Annual Review of Entomology*, *50*(February), 505–528. https://doi.org/10.1146/annurev.ento.50.071803.130337

Gandiwa, E. (2013). Top-down and bottom-up control of large herbivore populations: A review of natural and human-induced influences. *Tropical Conservation Science*, *6*(4), 493–505. https://doi.org/10.1177/194008291300600404

Gandiwa, E., Zisadza-Gandiwa, P., Muboko, N., Libombo, E., Mashapa, C., & Gwazani, R. (2014). Local People's Knowledge and Perceptions of Wildlife Conservation in Southeastern Zimbabwe. *Journal of Environmental Protection*, *05*(06), 475–481. https://doi.org/10.4236/jep.2014.56050

Gemeda, D. H., Sime, A. G., Hajito, K. W., Gelalacha, B. D., Tafese, W., & Gebrehiwot, T. T. (2016). Health Care Providers' Knowledge and Practice Gap towards Joint Zoonotic Disease Surveillance System: Challenges and Opportunities, Gomma District, Southwest Ethiopia. *BioMed Research International*, *2016*. https://doi.org/10.1155/2016/3942672

Gilchrist, G.,Mallory,M.,& Merkel, F. (2005).Can Local Ecological Knowledge Contribute to Wildlife Management ?Case Studies of Migratory Birds.*Ecology and Society*,*10*(1), 20.

Goldberg, T. L. (2008). Forest Fragmentation as Cause of Bacterial Transmission among Nonhuman Primates, Humans, and Livestock, Uganda. *Emerging Infectious Diseases*, *14*(9), 1375–1382. https://doi.org/10.3201/eid14.9.071196

Gould, E. A., & Higgs, S. (2009). Impact of climate change and other factors on emerging arbovirus diseases. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *103*(2), 109–121. https://doi.org/10.1016/j.trstmh.2008.07.025

Gregory, R. D., & Keymer, A. E. (1989). The ecology of host–parasite interactions. *Science Progress (1933-)*, *73*(1 (289)), 67–79. http://www.jstor.org/stable/43423801

Guidobono, J., Cueto, G., Teta, P., & Busch, M. (2018). Effect of environmental factors on the abundance variations of two native rodents in agricultural systems of Buenos Aires, Argentina. *Austral Ecology*, *44*(1), 36–48. https://doi.org/10.1111/aec.12650

Gupta, N. (2014). *Parasite-host interactions*. Www.Researchmedia.Eu95. https://www.researchgate.net/publication/256295060_Parasite-Host_Interactions_-_Exploiting_the_Host

Gurevitch, J., Scheiner, S., & Fox, G. (2002). The Ecology of Plants. In *Journal of Vegetation Science - J VEG SCI* (Vol. 14).

Haeselbarth, M. ., Segerman, J., & Zumpt, F. (1966). *The arthropod parasites of vertebrates in Africa south of the Sahara (Ethopian region)* (F. Zumpt (ed.); 13th ed.). South African Institute for Medical Research.

Hagenah, N. (2006). *Among Rodents and Rhinos : Interplay between Small Mammals and Large Herbivores in a South African Savanna*.

Halliday, J. E. B., Allan, K. J., Ekwem, D., Cleaveland, S., Kazwala, R. R., & Crump, J. A. (2015). One health: Endemic zoonoses in the tropics: A public health problem hiding in plain sight. *Veterinary Record*, *176*(9), 220–225. https://doi.org/10.1136/vr.h798

Han, B. A., Kramer, A. M., & Drake, J. M. (2016). Global Patterns of Zoonotic Disease in Mammals. *Trends in Parasitology*, *32*(7), 565–577. https://doi.org/10.1016/j.pt.2016.04.007

Han, B. A., Schmidt, J. P., Bowden, S. E., & Drake, J. M. (2015). Rodent reservoirs of future zoonotic diseases. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(22), 7039–7044. https://doi.org/10.1073/pnas.1501598112

Hanelt, B., Mwangi, I. N., Kinuthia, J. M., Maina, G. M., Agola, L. E., Mutuku, M. W., Steinauer, M. L., Agwanda, B. R., Kigo, L., Mungai, B. N., Loker, E. S., & Mkoji, G. M. (2010). Schistosomes of small mammals from the Lake Victoria Basin, Kenya: New species, familiar species, and implications for schistosomiasis control. *Parasitology*, *137*(7), 1109–1118. https://doi.org/10.1017/S0031182010000041

Hang'Ombe, B. M., Nakamura, I., Samui, K. L., Kaile, D., Mweene, A. S., Kilonzo, B. S., Sawa, H., Sugimoto, C., & Wren, B. W. (2012). Evidence of Yersinia pestis DNA from fleas in an endemic plague area of Zambia. *BMC Research Notes*, *5*(1), 72. https://doi.org/10.1186/1756-0500-5-72

Harrison, S., & Cornell, H. (2008). Toward a better understanding of the regional causes of local community richness. *Ecology Letters*, *11*(9), 969–979. https://doi.org/10.1111/j.1461-0248.2008.01210.x

Hawlena, H., Abramsky, Z., & Krasnov, B. R. (2005). Age-biased parasitism and density-dependent distribution of fleas (Siphonaptera) on a desert rodent. *Oecologia*, *146*(2), 200–208. https://doi.org/10.1007/s00442-005-0187-0

Hawlena, H., Messika, I., Kedem, H., Garrido, M., Halle, S., Dong, Q., Fuqua, C., & Clay, K. (2018). Manifold implications of host species diversity on parasite occurrence: a community perspective. In J.-K.-A. J. Jacob & J. Eccard (Eds.), *6th International Conference of Rodent Biology and Management & Rodents et Spatium* (p. 122).

Herald. (2020, June 10). Poverty datum line rises. *The Herald*. https://www.herald.co.zw/poverty-datum-line-rises-3/

Hieronimo, P., Kimaro, D. N., Kihupi, N. I., Gulinck, H., & Mulungu, L. S. (2014). Land use determinants of small mammal abundance and distribution in a plague endemic area of Lushoto District , Tanzania relationship between land use types and practices and small mammal abundance and distribution in the West Usambara Mountains in Tanzan. *Tanzania Journal of Health Research*, *16*(3), 1–12. https://doi.org/10.4314/thrb.v16i3.8

Holomuzki, J. R., Feminella, J. W., & Power, M. E. (2010). Biotic interactions in freshwater benthic habitats. *Journal of the North American Benthological Society*, *29*(1), 220–244.

https://doi.org/10.1899/08-044.1

Hoppe, B. R., & Lassen, E. D. (1978). Blood Smears and the Use of Wright' s Stain. *Iowa State University Veterinarian*, *40*(3), 113–116. https://lib.dr.iastate.edu/iowastate_veterinarian

Hopping, K. A., Yangzong, C., & Klein, J. A. (2016). Local knowledge production , transmission , and the importance of village leaders in a network of Tibetan pastoralists coping with environmental. *Ecology and Society*, *21*(1).

Hurst, Z. M., McCleery, R. A., Collier, B. A., Fletcher, R. J., Silvy, N. J., Taylor, P. J., & Monadjem, A. (2013). Dynamic Edge Effects in Small Mammal Communities across a Conservation-Agricultural Interface in Swaziland. *PLoS ONE*, *8*(9), 1–9. https://doi.org/10.1371/journal.pone.0074520

Hurtrez-Boussès, S., Meunier, C., Durand, P., & Renaud, F. (2001). Dynamics of host-parasite interactions: The example of population biology of the liver fluke (Fasciola hepatica). *Microbes and Infection*, *3*(10), 841–849. https://doi.org/10.1016/S1286-4579(01)01442-3

Hutchinson, E. E. (1957). Concluding Remarks. *Cold Spring Harbor Symposia on Quantitative Biology*, *22*, 415–427. https://doi.org/10.1101/SQB.1957.022.01.039

Isaacson, M., Taylor, P., & Arntzen, L. (1983). Ecology of plague in Africa: Response of indigenous wild rodents to experimental plague infection. *Bulletin of the World Health Organization*, *61*(2), 339–344.

Jaffee, B., Phillips, R., Muldoon, A., & Mangel, M. (1992). Density-dependent host-pathogen dynamics in soil microcosms. In *Ecology* (pp. 495–506). Ecological society of America. https://doi.org/10.2307/1940755

Kelly, T. R., Bunn, D. A., Joshi, N. P., Grooms, D., Devkota, D., Devkota, N. R., Paudel, L. N., Roug, A., Wolking, D. J., & Mazet, J. A. K. (2018). Awareness and practices relating to zoonotic diseases among smallholder farmers in Nepal. *Ecohealth*, *15*(3), 656–669. https://doi.org/10.1007/s10393-018-1343-

Khan, J. A. (1992). Efficiency of 'wonder' trap against 'roof' rat, rattus rattus L. *Applied Animal Behaviour Science*, *34*(1), 175–180. https://doi.org/https://doi.org/10.1016/S0168-1591(05)80065-6

Khan, M. A., Khan, S., Ankita, Ahmed, I., & Masood, N. (2019). Comparison of age estimates from Sagittae, Lapilli and Sterisci in Spotted snakehead, Channa puncta (Bloch, 1793) collected from the River Ganga. *Xenobiotics, Environnement and Functional Biology*, *August*, 141–149. https://www.researchgate.net/publication/331859527_Khan_et_al_2019

Khokhlova, I. S., Spinu, M., Krasnov, B. R., & Degen, A. A. (2004). Immune responses to fleas in two rodent species differing in natural prevalence of infestation and diversity of flea assemblages. *Parasitology Research*, *94*(4), 304–311. https://doi.org/10.1007/s00436-004-1215-4

Kimaro, D. N., Msanya, B. M., Meliyo, J., Hieronimo, P., Mwango, S., Kihupi, N. I., Gulinck, H., & Deckers, J. A. (2014). Anthropogenic soils and land use patterns in relation to small mammal and flea abundance in plague endemic area of Western Usambara Mountains, Tanzania. *Tanzania Journal of Health Research*, *16*(3), 1–12. https://doi.org/10.4314/thrb.v16i3.9

Krasnov, B. R., Khokhlova, I. S., Burdelova, N. V., Mirzoyan, N. S., & Degen, A. A. (2004). Fitness consequences of host selection in ectoparasites: Testing reproductive patterns predicted by isodar theory in fleas parasitizing rodents. *Journal of Animal Ecology*, *73*(5), 815–820. https://doi.org/10.1111/j.0021-8790.2004.00860.x

Krasnov, B. R., Khokhlova, I. S., Fielden, L. J., & Burdelova, N. V. (2001). Development rates of two Xenopsylla flea species in relation to air temperature and humidity.

Medical and Veterinary Entomology, *15*(3), 249–258. https://doi.org/10.1046/j.0269-283x.2001.00295.x

Krasnov, B. R., Mouillot, D., Shenbrot, G. I., Khokhlova, I. S., & Poulin, R. (2005). Abundance patterns and coexistence processes in communities of fleas parasitic on small mammals. *Ecography*, *28*(4), 453–464. https://doi.org/10.1111/j.0906-7590.2005.04182.x

Krebs, C. J. (1994). *Ecology: The Experimental Analysis of Distribution* (4th ed.). HarperCollins College.

Krebs, C. J. (2009). *Ecology: The Experimental Analysis of Distribution and Abundance* (6th ed.). Pearson Benjamin Cummings.

Krijger, I. M. (2020). *Rodent-borne health risks in farming systems*. https://doi.org/10.18174/505135

Kruse, H., Kirkemo, A.-M., & Handeland, K. (2004). Wildlife as Source of Zoonotic Infections. *Emerging Infectious Diseases*, *10*(12), 2067. https://doi.org/10.3201/EID1012.040707

Kugeler, K. J., Apangu, T., Forrester, J. D., Griffith, K. S., Candini, G., Abaru, J., Okoth, J. F., Apio, H., Ezama, G., Okello, R., Brett, M., & Mead, P. (2017). Knowledge and practices related to plague in an endemic area of Uganda. *International Journal of Infectious Diseases*, *64*(2017), 80–84. https://doi.org/10.1016/j.ijid.2017.09.007

Kugeler, K. J., Apangu, T., Forrester, J. D., Kevin, S., Candini, G., Abaru, J., Okoth, J. F., Apio, H., Ezama, G., Okello, R., Brett, M., & Mead, P. (2020). Knowledge and practices related to plague in an endemic area of Uganda. *Integrative Journal of Infectious Disease*, *64*, 80–84. https://doi.org/10.1016/j.ijid.2017.09.007.Knowledge

Kupika, O. L., Gandiwa, E., Nhamo, G., & Kativu, S. (2019). Local ecological knowledge on climate change and ecosystem-based adaptation strategies promote resilience in the

Middle Zambezi Biosphere Reserve, Zimbabwe. *Scientifica*, *2019*. https://doi.org/10.1155/2019/3069254

Lang, J. M., & Benbow, M. E. (2013). Species inyteractions and competition. *Nature Education and Knowledge*, *4*(4), 8.

Lima, M. S. P., Oliveira, J. E. L., de Nóbrega, M. F., & Lopes, P. F. M. (2017). The use of Local Ecological Knowledge as a complementary approach to understand the temporal and spatial patterns of fishery resources distribution. *Journal of Ethnobiology and Ethnomedicine*, *13*(1). https://doi.org/10.1186/s13002-017-0156-9

Lofty, W. M. (2015). Current perspectives on the spread of dengue in India. *Research and Reports in Tropical Medicine*, *6*, 21–30. https://doi.org/10.2147/RRTM.S63522

Lotfy, W. (2015). Current perspectives on the spread of plague in Africa. *Research and Reports in Tropical Medicine*, *May*, 21. https://doi.org/10.2147/rrtm.s63522

Mahlaba, T. A. M., Monadjem, A., McCleery, R., & Belmain, S. R. (2017). Domestic cats and dogs create a landscape of fear for pest rodents around rural homesteads. *PLoS ONE*, *12*(2), 1–9. https://doi.org/10.1371/journal.pone.0171593

Mahy, B. W. J., & Brown, C. (2000). Emerging zoonoses crossing the species barrier. *Revue Scientifique et Technique*, *19*(1), 33–40. https://doi.org/10.20506/rst.19.1.1212

Makundi, R. H., Massawe, A. W., & Mulungu, L. S. (2005). Rodent population fluctuations in three ecologically heterogeneous locations in northeast, central and south-west Tanzania. *Belgian Journal of Zoology*, *135*(SUPPL.1), 159–165.

Manungo, P., Peterson, D. ., Todd, C. ., Mthamo, N., & Pazvakavambwa, B. (1998). Risk factors for contracting plague in Nkayi district , Zimbabwe. *Central African Journal of Medicine*, *44*(February 2020), 173–176.

Martin, V., Chevalier, V., Ceccato, P., Anyamba, A., De Simone, L., Lubroth, J., de La Rocque, S., & Domenech, J. (2008). The impact of climate change on the epidemiology and control of Rift Valley fever. *Revue Scientifique et Technique (International Office of Epizootics)*, *27*(2), 413–426.

Martínez, J. E., Martínez, J. A., Zuberogoitia, I., Zabala, J., Redpath, S. M., & Calvo, J. F. (2008). The effect of intra- and interspecific interactions on the large-scale distribution of cliff-nesting raptors. *Ornis Fennica*, *85*(1), 13–21.

Martinez, J., & Merino, S. (2011). Host-parasite interactions under extreme climatic conditions. *Current Zoology*, *57*(3), 390–405. https://doi.org/10.1093/czoolo/57.3.390

Mashapa, C., Gandiwa, E., & Muboko, N. (2019). Socio-economic and ecological outcomes of woodland management in mutema-musikavanhu communal areas in save valley, southeastern lowveld of Zimbabwe. *Journal of Animal and Plant Sciences*, *29*(4), 1075–1087.

Massawe, A. W., Rwamugira, W., Leirs, H., Makundi, R. H., Mulungu, L., Ngowo, V., & Machang'u, R. (2008). Soil type limits population abundance of rodents in crop fields: case study of the multimammate rat Mastomys natalensis Smith, 1834 in Tanzania. *Integrative Zoology*, *3*(1), 27–30. https://doi.org/10.1111/j.1749-4877.2008.00070.x

Mawere, M. (2010). Journal of Sustainable Development in Africa (Volume 12, No.7, 2010). *Journal of Sustainable Development in Africa*, *12*(7), 209–221.

McCauley, D. J., Salkeld, D. J., Young, H. S., Makundi, R., Dirzo, R., Eckerlin, R. P., Lambin, E. F., Gaffikin, L., Barry, M., & Helgen, K. M. (2015). Effects of land use on plague (Yersinia pestis) activity in rodents in Tanzania. *American Journal of Tropical Medicine and Hygiene*, *92*(4), 776–783. https://doi.org/10.4269/ajtmh.14-0504

Meerburg, B. G., Singleton, G. R., & Kijlstra, A. (2009). Rodent-borne diseases and their risks for public health Rodent-borne diseases and their risks for public health. In *Critical Reviews in Microbiology* (Vol. 35, Issue 3). https://doi.org/10.1080/10408410902989837

Melman, S. D., Ettestad, P. E., Vinhatton, E. S., Ragsdale, J. M., Takacs, N., Leonard, P. M., Master, S. S., Lucero, V. S., Kingry, L. C., Petersen, J. M., Division, R., Fe, S., Services, V. D., Fe, S., & Collins, F. (2019). Human case of bubonic plague resulting from the bite of a wild Gunnison's prairie dog during translocation from a plague endemic area. *Zoonoses Public Health*, *65*(1), e254–e258. https://doi.org/10.1111/zph.12419.Human

Mfune, J. K. E., Kangombe, F., & Eiseb, S. (2013). Host specificity, prevalence and intensity of infestation of fleas (Order Siphonaptera) of small mammals at selected sites in the city of Windhoek, Namibia. *International Science and Technology Journal of Namibia*, *1*(June), 64–77.

Mills, J. N. (2006). Biodiversity loss and emerging infectious disease: An example from the rodent-borne hemorrhagic fevers. *Biodiversity*, *7*(1), 9–17. https://doi.org/10.1080/14888386.2006.9712789

Milner-Gulland, E. J. (2012). Interactions between human behaviour and ecological systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1586), 270–278. https://doi.org/10.1098/rstb.2011.0175

Milupi, I., Somers, M. J., & Ferguson, J. W. H. (2017). *Local Ecological Knowledge and Community- based Management of Wildlife Resources : A Study of the Mumbwa and Lupande Game Management Areas of Zambia*. *December*. https://doi.org/10.4314/sajee.v.33i1.3

Moore, S. M., Monaghan, A., Borchert, J. N., Mpanga, J. T., Atiku, L. A., Boegler, K. A., Montenieri, J., MacMillan, K., Gage, K. L., & Eisen, R. J. (2015). Seasonal fluctuations of small mammal and flea communities in a Ugandan plague focus: Evidence to implicate Arvicanthis niloticus and Crocidura spp. as key hosts in Yersinia pestis transmission. *Parasites and Vectors*, *8*(1). https://doi.org/10.1186/s13071-014-0616-1

Mugandani, R., Wuta, M., Makarau, A., Chipindu, B., Gweru, S. R., Pleasant, M., &

Pleasant, M. (2012). Re-Classification of Agro-Ecological Regions of Zimbabwe in Conformity With Climate Variability and Change. *African Crop Science Journal*, *20*(2), 361–369. https://doi.org/10.4314/acsj.v20i2

Munyenyiwa, A., Zimba, M., Nhiwatiwa, T., & Barson, M. (2019). Plague in Zimbabwe from 1974 to 2018: A review article. *PLoS Neglected Tropical Diseases*, *13*(11), 1–17. https://doi.org/10.1371/journal.pntd.0007761

Naicker, P. R. (2011). The impact of climate change and other factors on zoonotic diseases. *Archives of Clinical Microbiology*, *2*(2), 2–7. https://doi.org/10.3823/226

Ncube-Phiri, S., Ncube, A., Mucherera, B., & Ncube, M. (2015). Artisanal small-scale mining: Potential ecological disaster in Mzingwane District, Zimbabwe. *Jamba: Journal of Disaster Risk Studies*, *7*(1). https://doi.org/10.4102/jamba.v7i1.158

Ndangwa, N. (2007). Indigenous Knowledge Systems and Their Relevance for Sustainable Development: A Case of Southern Africa. *Indigenous Knowledge Systems and Sustainable Development: Relevance for Africa*, *1*(July 2007), 167–172. http://www.krepublishers.com/06-Special Volume-Journal/S-T & T-00-Special Volumes/T & T-SV-01-Africa-Web/T & T-SV-01-15-167-07-Noyoo-N/T & T-SI-15-167-07-Noyoo-N-Tt.pdf

Neerinckx, S. B., Peterson, A. T., Gulinck, H., Deckers, J., & Leirs, H. (2008). Geographic distribution and ecological niche of plague in sub-Saharan Africa. *International Journal of Health Geographics*, *7*(November). https://doi.org/10.1186/1476-072X-7-54

Ngulube, T. J., Mwanza, K., Njobvu, C. A., & Muula, A. S. (2006). Knowledge, attitudes and public health response towards plague in Petauke, Zambia. *Tropical Doctor*, *36*(4), 223–225. https://doi.org/10.1258/004947506778604779

Nkengasong, J. N. (2019). How African can quell the next disease outbreaks: As mobility increase, so must investiments in national public-health institutions and local leadership.

Springer Nature, *567*, 147.

Nyamapfene, K. W. (1991). *The Soils of Zimbabwe*. Nehanda Publishers.

Nyirenda, S. S., Hang'ombe, B. M., Machang'u, R., Mwanza, J., & Kilonzo, B. S. (2017). Identification of risk factors associated with transmission of plague disease in Eastern Zambia. *American Journal of Tropical Medicine and Hygiene*, *97*(3), 826–830. https://doi.org/10.4269/ajtmh.16-0990

Odeniran, P. O., & Ademola, I. O. (2016). Zoonotic parasites of wildlife in Africa: A review. *African Journal of Wildlife Research*, *46*(1), 1–13. https://doi.org/10.3957/056.046.0001

Ogden, N. H. (2017). Climate change and vector-borne diseases of public health significance. *FEMS Microbiology Letters*, *364*(19), 1–8. https://doi.org/10.1093/femsle/fnx186

Oguge, N., Durden, L. A., Keirans, J., Balami, H., & Schwan, T. (2009). Ectoparasites (sucking lice, fleas and ticks) of small mammals in southeastern Kenya. *Medical and Veterinary Entomology*, *23*(4), 387–392. https://doi.org/10.1111/j.1365-2915.2009.00820.x

Okorafor, K. A., Okete, J. A., Andem, A. ., & Eleng, I. E. (2012). Assessment of grasscutters ' (Thryonomys Swinderianus) sellers and hunters conservation knowledge , rate of hunting and methods of hunting in Oyo State , Nigeria Scholars Research Library. *European Journal of Zoological Research*, *1*(4), 86–92.

Olowookere, S. A., Adegbenro, C. A., Idowu, A., Omisore, A. G., Shabi, O. M., Ikem, U. R., Ekwere, G. A., & Oderinde, I. F. (2017). Knowledge Attitude and Practices Toward Lassa Fever Control and Prevention Among Residents of Ile-Ife, Southwest Nigeria. *International Quarterly of Community Health Education*, *37*(2), 107–112. https://doi.org/10.1177/0272684X17701261

Onwunhafua, E. U. (2018). Knowledge, attitude and practice relating to lassa fever among shop owners in four community markets in a military barrack in Kaduna State, Nigeria.

Journal of AIDS & Clinical Research, *09*, 6113. https://doi.org/10.4172/2155-6113-c1-027

Ossai, E. N., Onwe, O. E., Okeagu, N. P., Ugwuoru, A. L., Eze, T. K., & Nwede, A. S. (2020). Knowledge and preventive practices against Lassa fever among heads of households in Abakaliki metropolis, Southeast Nigeria: A cross-sectional study. *Proceedings of Singapore Healthcare*. https://doi.org/10.1177/2010105819899120

Overgaauw, P. A. M., Vinke, C. M., Hagen, M. A. E. van, & Lipman, L. J. A. (2020). A One Health Perspective on the Human–Companion Animal Relationship with Emphasis on Zoonotic Aspects. *International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 3789*, *17*(11), 3789. https://doi.org/10.3390/IJERPH17113789

Perry, R. D., & Fetherston, J. D. (1997). Yersinia pestis - Etiologic agent of plague. *Clinical Microbiology Reviews*, *10*(1), 35–66. https://doi.org/10.1128/cmr.10.1.35

Petrosillo, I., Aretano, R., & Zurlini, G. (2015). Socioecological Systems. In *Reference Module in Earth Systems and Environmental Sciences* (pp. 1–7). https://doi.org/10.1016/B978-0-12-409548-9.09518-X

Rabiee, F. (2004). Focus-group interview and data analysis. *Proceedings of the Nutrition Society*, *2004*, 655–660. https://doi.org/10.1079/PNS2004399

Rakotosamimanana, S., Rakotoarimanana, F. J., Raharimanga, V., Taglioni, F., Ramamonjisoa, J., Randremanana, R. V., Rajerison, M., & Rakotomanana, F. (2021). Influence of Sociospatial determinants on knowledge, attitudes and practices related to the plague in a population living in endemic areas in the central highlands, Madagascar. *BMC Public Health*, *21*(1), 1–11. https://doi.org/10.1186/s12889-021-11101-3

Renaudin, B., & Patinet, J. (2010). *Environmental Impact Assessment (EIA)- ACF Zimbabwe* (Issue June).

Richner, H. (2010). Reproductive Behavior and Parasites: Vertebrates. In M. D. Breed & J.

B. T.-E. of A. B. Moore (Eds.), *Science Direct Life Sciences* (pp. 49–53). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-08-045337-8.00134-0

Riehm, J. M., Tserennorov, D., Kiefer, D., Stuermer, I. W., Tomaso, H., Zöller, L., Otgonbaatar, D., & Scholz, H. C. (2011). Yersinia pestis in small rodents, Mongolia. *Emerging Infectious Diseases*, *17*(7), 1320–1322. https://doi.org/10.3201/eid1707.100740

Rivière-Cinnamond, A., Santandreu, A., Luján, A., Mertens, F., Espinoza, J. O., Carpio, Y., Bravo, J., & Gabastou, J. M. (2018). Identifying the social and environmental determinants of plague endemicity in Peru: Insights from a case study in Ascope, la Libertad. *BMC Public Health*, *18*(1), 1–11. https://doi.org/10.1186/s12889-018-5062-0

Robards, G. E., & Saunders, G. (1998). Food preferences of house mice (Mus domesticus) and their implications for control strategies. *Wildlife Research*, *25*(6), 595–601. https://doi.org/10.1071/WR97109

Rocke, T. E., & Friend, M. (2002). Wildlife disease in the Colorado Delta as an indicator of ecosystem health. In D. J. Rapport, W. L. Lasley, D. E. Rolston, N. O. Nielsen, C. O. Qualset, & A. B. Damania (Eds.), *Managing for Health Ecosystems* (p. 1152pp). CRC Press. https://www.routledge.com/Managing-for-Healthy-Ecosystems/Rapport-Lasley-Rolston-Nielsen-Qualset-Damania/p/book/9781566706124

Rodriguez-Morales, A. J., Katterine Bonilla-Aldana, D., Tiwari, R., Sah, R., Rabaan, A. A., & Dhama, K. (2020). Covid-19, an emerging coronavirus infection: Current scenario and recent developments - An overview. *Journal of Pure and Applied Microbiology*, *14*(1), 5–12. https://doi.org/10.22207/JPAM.14.1.02

Ryan, S. J., & Zermoglio, F. (2019). Plague in a Changing Environment: A literature review for Madagascar. In *Atlas* (Issue September). file:///C:/Users/gti9o/Downloads/2019_USAID_ATLAS_Madagascar Plague Lit

Review (1).pdf

Rynkiewicz, E. C., Pedersen, A. B., & Fenton, A. (2015). An ecosystem approach to understanding and managing within-host parasite community dynamics. *Trends in Parasitology*, *31*(5), 212–221. https://doi.org/10.1016/j.pt.2015.02.005

Salkeld, D. J., & Stapp, P. (2009). Effects of weather and plague-induced die-offs of prairie dogs on the fleas of northern grasshopper mice. *Journal of Medical Entomology*, *46*(3), 588–594. https://doi.org/10.1603/033.046.0325

Salmón-Mulanovich, G., Powell, A. R., Hartinger-Peña, S. M., Schwarz, L., Bausch, D. G., & Paz-Soldán, V. A. (2016). Community perceptions of health and rodent-borne diseases along the Inter-Oceanic Highway in Madre de Dios, Peru. *BMC Public Health*, *16*(1), 1–10. https://doi.org/10.1186/s12889-016-3420-3

Sambri, V., Capobianchi, M., Charrel, R., Fyodorova, M., Gaibani, P., Gould, E., Niedrig, M., Papa, A., Pierro, A., Rossini, G., Varani, S., Vocale, C., & Landini, M. P. (2013). West Nile virus in Europe: Emergence, epidemiology, diagnosis, treatment, and prevention. *Clinical Microbiology and Infection*, *19*(8), 699–704. https://doi.org/10.1111/1469-0691.12211

Schowalter, T. D. (2006). 8 - Species Interactions. In T. D. Schowalter (Ed.), *Insect Ecology (Second Edition)* (Second Edi, pp. 213–249). Academic Press. https://doi.org/https://doi.org/10.1016/B978-012088772-9/50033-9

Schwan, T. G., Lopez, J. E., Safronetz, D., Anderson, J. M., Fischer, R. J., Maïga, O., & Sogoba, N. (2016). Fleas and trypanosomes of peridomestic small mammals in sub-Saharan Mali. *Parasites and Vectors*, *9*(1), 1–7. https://doi.org/10.1186/s13071-016-1818-5

Schwetz, J. (1956). Role of wild rats and domestic rats (Rattus rattus) in Schistosomiasis of man. *Transaction of Royal Society of Tropical Medicine and Hygiene*, *50*(3), 275–282.

https://doi.org/10.1016/0035-9203(56)90034-7

Shirima, G. M., Fitzpatrick, J., Kunda, J. S., Mfinanga, S., Kazwala, R. R., Kambarage, D. M., & Sarah, C. (2010). The Role of Livestock Keeping in Human Brucellosis Trends in Livestock Keeping Communities in Tanzania. *Tanzanian Journal of Health Research*, *12*(3), 10pp. https://doi.org/10.4314/thrb.v12i3.51261

Sibanda, S., Masaka, M., & Chirima, A. (2014). Effect of small scale gold mining on vegetation species diversity in Umzingwane. *Environmental Science Indan Journal*, *9*(2), 71–84.

Singh, B., Kim Sung, L., Matusop, A., Radhakrishnan, A., Shamsul, S. S. G., Cox-Singh, J., Thomas, A., & Conway, D. J. (2004). A large focus of naturally acquired Plasmodium knowlesi infections in human beings. *Lancet (London, England)*, *363*(9414), 1017–1024. https://doi.org/10.1016/S0140-6736(04)15836-4

Singleton, G. R., Sudarmaji, Jacob, J., & Krebs, C. J. (2005). Integrated management to reduce rodent damage to lowland rice crops in Indonesia. *Agriculture, Ecosystems and Environment*, *107*(1), 75–82. https://doi.org/10.1016/j.agee.2004.09.010

Skinner, J. D., & Chimimba, C. (2005). The Mammals of the South African Sub-Region. In *The Mammals of the Southern African Subregion, 3rd Edn*. https://doi.org/10.1017/CBO9781107340992

Smith, R. D. (2005). *Veterinary Clinical Epidemiology* (3rd ed.). CRC Press. https://doi.org/10.1201/9781420058239

Smithers, R. H. N. (1975). *Guide to the rats and mice of Rhodesia, Salisbury* (1st ed.). Trustees of the National Museums and Monuments of Rhodesia.

Sridhara, S. (2006). *Vertebrate Pests in Agriculture: An Indian Scenario*. Scientific Publisher.

Stark, H. E. (2002). Population dynamics of adult fleas (Siphonaptera) on hosts and im nests of California vole. *Journal of Medical Entomology*, *39*(6), 818–824.

https://doi.org/10.1603/0022-2585-39.6.818

StatSoft. (2010). *STATISTICA for Windows*. StaSoft Inc.

Stephen, C., Artsob, H., Bowie, W. R., Drebot, M., Fraser, E., Leighton, T., Morshed, M., Ong, C., & Patrick, D. (2004). Perspectives on emerging zoonotic disease research and capacity building in Canada. *Canadian Jpurnal of Infectious Diseases and Medical Microbiology*, *15*(6), 339–344. https://doi.org/10.1155/2004/238126

Sun, Z., Xu, L., Schmid, B. V., Dean, K. R., Zhang, Z., Xie, Y., Fang, X., Wang, S., Liu, Q., Lyu, B., Wan, X., Xu, J., Stenseth, N. C., & Xu, B. (2019). Human plague system associated with rodent diversity and other environmental factors. *Royal Society Open Science*, *6*(6). https://doi.org/10.1098/rsos.190216

Suselbeek, L. (2014). Of Mice and Oaks: Conditional outcomes in a seed-dispersal mutualism. In *Wageningen University*. Wageningen University.

Tarakini, T., Guerbois, C., Wencelius, J., Mundy, P., & Fritz, H. (2018). Integrating Local Ecological Knowledge for Waterbird Conservation: Insights From Kavango-Zambezi Transfrontier Conservation Area, Zimbabwe. *Tropical Conservation Science*, *11*. https://doi.org/10.1177/1940082918803810

Taylor, K. D., Hammond, L. E., & Quy, R. J. (1974). The reactions of common rats to four types of live-capture trap. *Journal of Applied Ecology*, *11*(2), 453–459. https://doi.org/10.2307/2402199

Taylor, P., Gordon, D. ., & Isaacson, M. (1981). The status of plague in Zimbabwe. *Annals of Tropical Medicine and Parasitology*, *75*(2), 165–173. https://www.tandfonline.com/doi/abs/10.1080/00034983.1981.11687424

Taylor, P. J., Downs, S., Monadjem, A., Eiseb, S. J., Mulungu, L. S., Massawe, A. W., Mahlaba, T. A., Kirsten, F., Maltitiz, E. V, Malebane, P., Makundi, R. H., Lamb, J., & Belmain, S. R. (2012). Experimental treatment control studies of ecologically based rodent management in Africa: balancing conservation and pest management. *Wildlife Research*, *39*(1), 51–61. https://doi.org/10.1071/WR11111

Taylor, P., & Pugh, A. (1982). Plague in Zimbabwe: A review of the situation in 1982. *Central African Journal of Medicine*, *28*(10), 249–253.

Thiagarajan, B., Bal, Y., Gage, K. L., & Cully, J. F. (2008). Prevalence of Yersinia pestis in rodents and fleas associated with black-tailed prairie dogs (Cynomys ludovicianus) at Thunder Basin National Grassland, Wyoming. *Journal of Wildlife Diseases*, *44*(3), 731–736. https://doi.org/10.7589/0090-3558-44.3.731

Thomas, B. W., & Taylor, R. H. (2002). A history of ground-based rodent eradication techniques developed in New Zealand, 1959-1993. In C. . Veitch & M. . Clout (Eds.), *Turning the tide: the eradication of invasive species* (pp. 301–310). IUCN SSC Invasive Species Specialist Group.

Thompson, A. R. C. (2000). Emerging parasite zoonoses. *International Journal of Parasitology*, *30*(12–13), 1217–1430. https://www.sciencedirect.com/journal/international-journal-for-parasitology/vol/35/issue/11

Thompson, P. L., MacLennan, M. M., & Vinebrooke, R. D. (2018). Species interactions cause non-additive effects of multiple environmental stressors on communities. *Ecosphere*, *9*(11), e02518. https://doi.org/10.1002/ecs2.2518

Tian, H., & Stenseth, N. C. (2019). The ecological dynamics of hantavirus diseases: From environmental variability to disease prevention largely based on data from China. *PLoS Neglected Tropical Diseases*, *13*(2), 1–19. https://doi.org/10.1371/journal.pntd.0006901

Tobler, W. (2004). On the first law of geography:A reply. *Annals of the Associations of American Geographers*, *94*, 304–310. https://doi.org/10.1111/j.1467-8306.2004.09402003.x/

Tyutyunov, Y. V, & Titova, L. I. (2020). From Lotka–Volterra to Arditi–Ginzburg: 90 Years of Evolving Trophic Functions. *Biology Bulletin Reviews*, *10*(3), 167–185. https://doi.org/10.1134/S207908642003007X

van der Mescht, L. (2015). *Exploring mechanisms that shape Siphonaptera composition and distribution patterns on small mammals across South Africa* (Issue December).

Venkat, H., Yaglom, H. D., Adams, L., Service, I., Development, P., & Officer, E. F. (2020). *HHS Public Access*. *Ci*, 1–17. https://doi.org/10.1016/j.prevetmed.2019.104711.Knowledge

Vora, N. (2008). Impact of anthropogenic environmental alterations on vector-borne diseases. *MedGenMed Medscape General Medicine*, *10*(10), 1–7.

Wang, L. F., & Crameri, G. (2014). Emerging zoonotic viral diseases. *OIE Revue Scientifique et Technique*, *33*(2), 569–581. https://doi.org/10.20506/rst.33.2.2311

Webster, J. P. (2007). The effect of Toxoplasma gondii on animal behavior: Playing cat and mouse. *Schizophrenia Bulletin*, *33*(3), 752–756. https://doi.org/10.1093/schbul/sbl073

WHO. (2007). *WHO guidelines on tularaemia: epidemic and pandemic alert and response* (A. Tärnvik, U. University, & S. Umeå (eds.)). WHO Press. http://www.who.int/csr/resources/publications/WHO_CDS_EPR_2007_7.pdf

WHO. (2008). Interregional meeting on prevention and control of plague. *Antananarivo, Madagascar 1-11 April 2006*, *April 2006*, 1–65. http://www.who.int/csr/resources/publications/WHO_HSE_EPR_2008_3/en/

WHO. (2016). Plague around the world, 2010-2015. *Weekly Epidemiological Record / Health Section of the Secretariat of the League of Nations*, *91*(8), 89–93. https://www.who.int/wer/2016/wer9108.pdf?ua=1

WHO. (2017). *Plague*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/plague

WHO. (2018). *Echinococcosis*. World Health Organization. http://www.who.int/news-room./fact-sheet

WHO. (2020). *Zoonoses*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/zoonoses

WHO. (2021). *Emergencies: Disease outbreaks*. Pandemic, Epidemic Diseases. https://www.who.int/emergencies/diseases/en/

Wilcox, B., & Jessop, H. (2009). Ecology and environmental health. In H. Frumkin (Ed.), *Environmental Health: From Global to Local* (2nd ed., Issue April 2015, pp. 3-48.). Jossey-Bass, Wiley & Sons.

Woodward, G., Gessner, M. O., Giller, P. S., Gulis, V., Hladyz, S., Lecerf, A., Malmqvist, B., McKie, B. G., Tiegs, S. D., Cariss, H., Dobson, M., Elosegi, A., Ferreira, V., Graça, M. A. S., Fleituch, T., Lacoursière, J. O., Nistorescu, M., Pozo, J., Risnoveanu, G., … Chauvet, E. (2012). Continental-scale effects of nutrient pollution on stream ecosystem functioning. *Science*, *336*(6087), 1438–1440. https://doi.org/10.1126/science.1219534

WORLD VIEW How Africa can quell the next disease outbreaks. (2017).

WSDH. (2019). *Plague-Reporting and surveillance guidelines* (Issue December).

Yabe, T. (1979). The relation of food habits to the ecological distributions of the Norway rat (Rattus norvegicus) and the roof rat (R. rattus). *Japanese Journal of Ecology*, *29*(3), 235–244. https://doi.org/10.18960/seitai.29.3_235

Yang, R. (2017). Plague: Recognition, Treatment, and Prevention. *Journal of Clinical Microbiology*, *56*(1), e01519-17. https://doi.org/10.1128/JCM.01519-17

Zainal, Z. (2007). *Case study as a research method*.

Zarnke, R. L., Dubey, J. P., Ver Hoef, J. M., McNay, M. E., & Kwok, O. C. H. (2001). Serologic survey for Toxoplasma gondii in lynx from interior Alaska. *Journal of Wildlife Diseases*, *37*(1), 36–38. https://doi.org/10.7589/0090-3558-37.1.36

Zikhali, W. (2018). Perspectives of Infrastructure Development: an Analysis of Three Wards in Nkayi District, Zimbabwe. *IMPACT: International Journal of Research in Applied, Natural and Social Sciences (IMPACT: IJRANSS)*, *6*(6), 33–46. http://www.impactjournals.us/journals.php?id=14&jtype=2&page=59

Zimba, M., Loveridge, J., Pfukenyi, D. M., & Mukaratirwa, S. (2012). Seasonal abundance and epidemiological indices of potential plague vectors dinopsyllus lypusus (Siphonaptera: Hystrichopsyllidae) and ctenophthalmus calceatus (Siphonaptera: Ctenophthalmidae) on rodents captured from three habitat types of hatcliffe and d. *Journal of Medical Entomology*, *49*(6), 1453–1459. https://doi.org/10.1603/ME11231

Zimba, M., Pfukenyi, D., & Mukaratirwa, S. (2010). Seasonal Abundance of Plague Vector Xenopsylla brasiliensis from Rodents Captured in Three Habitat Types of Periurban Suburbs of Harare , Zimbabwe. *Vector -Borne and Zoonotic Diseases*, *11*(8), 1187–1192. https://doi.org/10.1089/vbz.2010.0095

Zimstat. (2013). *Census 2012: Preliminary report*. 123.

ZimVAC. (2021). *V A C Z I M B A B W E*. https://fscluster.org/zimbabwe/document/2021-rural-livelihood-assessment-report

Ziwa, M. H., Matee, M. I., Hang'Ombe, B. M., Lyamuya, E. F., & Kilonzo, B. S. (2013). Plague in Tanzania: An overview. *Tanzania Journal of Health Research*, *15*(4). https://doi.org/10.4314/thrb.v15i4.7

Appendices

Appendix 1 Clearance letter

CHINHOYI UNIVERSITY OF TECHNOLOGY

P. Bag 7724, Chinhoyi ☎: 263-67-22203-5 : 263-67- 27214 E-mail : nmuboko@cut.ac.zw

Department of Wildlife Ecology and Conservation

RESEARCH PERMISSION AND ETHICAL CLEARANCE CERTIFICATE (No. 04/17)

10 April 2017

Student Name..........................ANNABEL BANDA...
Student Number...................... **C 15126149 J** ....
Programme..............................DOCTOR OF PHILOSOPHY (DPhil)....................................

Approved Research Title: Rodent-flea-human interaction and associated plague disease in south-western Zimbabwe

TO WHOM IT MAY CONCERN

We hereby confirm that the above mentioned student is registered at Chinhoyi University of Technology for the programme indicated. The proposed study is within the Departmental research themes and met the ethical requirements; hence it was approved by the Departmental Higher Degrees Committee.

The Specific objectives of the research study are to:

Specific objectives of the study:

1. To determine the diversity and abundance of rodents and associated fleas in a semi-arid tropical ecosystem of Zimbabwe.
2. To assess the prevalence of *Y. pestis* among captured rodents in a semi-arid tropical ecosystem of Zimbabwe.
3. To establish local community awareness, practices and knowledge on zoonotic, rodent-borne and plague diseases in a semi-arid tropical ecosystem of Zimbabwe.
4. To predict the occurrence of plague disease across the landscape of Zimbabwe

NB Sampling and data collection commenced in April 2017.

CHINHOYI UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF WILDLIFE ECOLOGY & CONSERVATION
10 APR 2017
P.O BOX 7724
CHINHOYI, ZIMBABWE

Kind Regards

Signature ....

Date:..............................

Name: Prof N. Muboko (**Chairperson Department of Wildlife Ecology and Conservation)**

Appendix 2 Field data sheet

Date of sampling	**Place of sampling**	**Rodent species caught**	**No. of fleas**	**Identified flea species**

Appendix 3 Laboratory data sheet

Date and place of capture	**Rodent species caught**	**Y. pestis +ve/ -ve**	**Total No. of fleas**	**Flea species identified**

Appendix 4 Nhlekiyane (Umzingwane district) focus group discussants

Photo credits: A. Banda, August 2017.

Appendix 5 Villagers focus group questionnaire

Ground rules

To allow everyone an opportunity to express their opinion, I would like to go over some ground rules:

- The discussion should take approximately 45 minutes
- Please only one person speaks at a time and avoid side conversation
- Please allow everyone the opportunity to answer each question if they wish so
- Please keep what is discussed confidential; we encourage this so that everyone feels that they can express an opinion freely
- Please state your research marker (for example A1, A2) before you make a comment. This aids the transcription process.

Characteristics of the focus group

How many people Female ☐ Males ☐

Age

Socio-economic status

Income ☐

Education ☐

Occupation ☐

Time start ☐ end ☐

Zoonotic diseases are diseases, which are transmitted from animals to humans or vice versa.

1. In the past have you ever heard of zoonotic diseases? If yes can we have name (s)
2. How did you come to know about these zoonotic disease(s)
3. How has human practices changed ever since getting the knowledge on zoonosis?

4. Name any organization (Governmental or non-Governmental) involved in zoonotic diseases awareness campaigns.
5. Had there been any cases of zoonotic disease(s) among people. Yes/ No. Yes which disease did people suffer from?
6. How do you locally identify or diagnose zoonotic diseases, in people or animals
7. How do you locally treat people or animals affected by zoonotic diseases

Rodents differ from other mammals by possessing a pair of continuously growing, chisel-like incisor teeth at the front, which are constantly kept sharp by abrasion against each other and by gnawing. There is the presence of a space (diasterma) between the incisor and the cheek teeth on both sides.

8. Are rodents a delicacy to some people? Yes/ No
9. How do people harvest rodents or mice in the area?
10. Do we have people who capture rodents or mice for sell in the area? Yes/ No
11. Give any norms or taboos associated with rodents or mice consumption in the area.
12. Do you interact with rodents or mice? Yes/ No. If yes, Where? How?
13. If mice or rats population is too high do you control them at home? Yes/ No. If yes how do you control them?
14. Do you ever get bites from fleas? When during the day or night. In which season are the bites more pronounced? Cold/dry season, hot/ dry season, hot/ wet season.

There are quite a number of diseases that can be got from rodents.

15. Give name(s) of any disease(s) that people attribute to rodents or rodents outbreak.
16. Had there been any health awareness of rodent borne disease(s)? Yes/ No. If yes, when and by who?

Plague is a disease caused by a bacterium called *Yersinia pestis*. This disease is zoonotic in nature. Plague in humans can occur in three forms, which are septicemic, pneumonic and bubonic.

17. Have you ever heard about plague? Yes/ No
18. What native name has been given to this disease?
19. Had there been cases of the disease in the local area. Yes/ No. If yes, when and where?
20. Can you locally treat plague?
21. How best can plague be controlled?
22. As you can see most diseases are basically zoonotic in nature. How best can we control them?

Closing

Thank you all for coming today and discussing these issues. Your opinions have been given an excellent insight into this research outcome.