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SHORT COMMUNICATION

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

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1 | INTRODUCTION

Co-occurrence data still remain a neglected source of information in modelling species distributions irrespective of the historical importance in community ecology. Since mediaeval 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 ageing, and copulating and as such can be considered the flea habitat patch (Hawlena et al., 2005). Understanding 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 five (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 to 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 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 programmes.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was conducted in Umzingwane and Nkayi districts in south-western Zimbabwe. The two districts occur in the same agro-ecological region IV which covers 7628 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.

2.2 | Research design and data collection

2.2.1 | Research design, rodents and fleas' collection

This study followed a quasi-experimental design comprising of two strata, that is 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 trapping span was 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 utilised 15 Sherman traps in an area for three consecutive days that is 45 traps (3 days × 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 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.

2.2.2 | Fleas processing and identification

Flea processing and identification were 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). Thereafter, using a dissecting microscope flea species were identified following the morphological descriptions and illustrations by Haeselbarth et al. (1966).

2.3 | Data analysis

Trapping success was calculated using the following formulae

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

(Dennis et al., 1999). 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 was calculated for each district following the

TABLE 1 Diversity of rodent species in Nkayi and Umzingwane districts

	Nkayi district		Umzingwane district	
Rodent species	Mathoba	Monki	Crocodile	Nhlekiyane
1. *Mastomys natalensis*	3	3	42	28
2. *Saccostomys campestris*	1	2	1	1
3. *Tatera brantsi*	2	3	1	0
4. *Tatera leucogaster*	40	25	0	0
5. *Lemniscomys griselda*	0	1	0	0
Species diversity (*H′*) index	0.52	0.92	0.22	0.15

TABLE 2 Flea species diversity in Nkayi and Umzingwane districts

	Nkayi district		Umzingwane district	
Flea species	Mathoba	Monki	Crocodile	Nhlekiyane
1. *Ctenophthalmus calceatus*	0	0	2	0
2. *Chistopsylla rossi*	0	0	9	11
3. *Dinopsyllus ellobius*	0	1	6	13
4. *Xenopsyllus brasiliensis*	66	47	2	5
Species diversity (*H′*) index	0	0.10	1.19	1.03

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 was assessed by graphical analysis.

3 | RESULTS

3.1 | 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 1). There was a non-significant difference in rodent diversity between Nkayi district ($H' = 0.72 \pm 0.28$; mean, SD) and Umzingwane district ($H' = 0.19 \pm 0.05$) (Mann–Whitney $U = 0.00$, $z = 1.55$, $p = 0.121$).

3.2 | Flea species diversity and association with rodents

A total of 162 fleas were collected from the 154 captured rodents, that is Nkayi district (114) and Umzingwane district (48) with four (4) flea species being recorded in the study area (Table 2). 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, *Xenopsyllus brasiliensis* flea species were associated with four of the five rodent species, and in the same district there was co-occurrence of *Tatera leucogaster* with *Dinopsyllus ellobius* whereas in Umzingwane district all the flea species were associated with only one rodent species, that is *Mastomys natalensis* (Figures 1 and 2).

4 | DISCUSSION

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 *T. leucogaster* and *T. 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 (*T. brantsi* and *T. 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, and 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 bushmeat 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. *X. 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, that is *M. natalensis*, was associated with all the four flea species recorded in this study. *C. rossi* and *D. ellobius*. *X. brasiliensis* species were indicated by Haeselbarth et al. (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

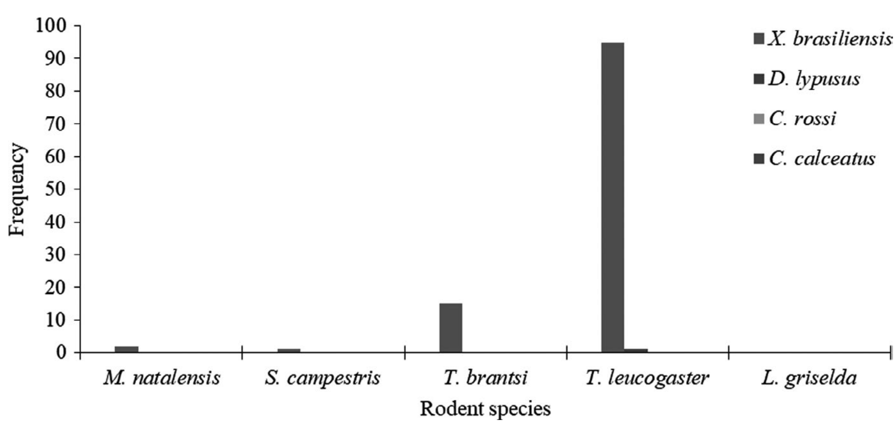

FIGURE 1 Rodents and fleas association in Nkayi district, south-western Zimbabwe

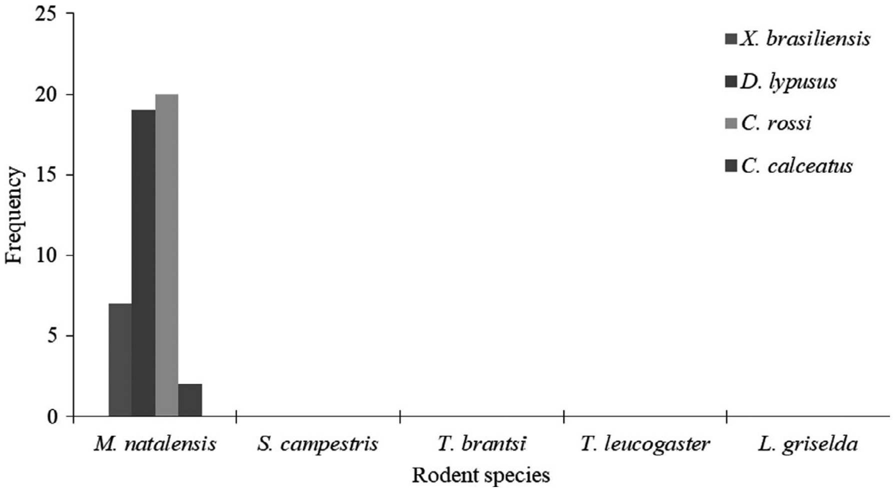

FIGURE 2 Rodents and fleas association in Umzingwane district, south-western Zimbabwe

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; Blagburn & 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). *M. 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).

Generally, the study recorded low and similar rodent and flea diversities in the study area, an indication of similarities in the environmental conditions. Tobler's First Law of Geography states that everything is related to everything else, but near things are more related than distant things (Tobler, 2004). Thus, the relatively similar agro-ecological zone in the study sites could have contributed to the non-significant differences in rodent and flea diversities. 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.

5 | CONCLUSION

This study recorded low and similar diversities of rodents and fleas in Nkayi and Umzingwane districts in south-western Zimbabwe. However, the study recorded variations in rodent-flea species association. 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.

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CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

Data are available from corresponding author upon reasonable request.

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REFERENCES

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
Bitam, I., Dittmar, K., Parola, P., Whiting, M. F., & Raoult, D. (2010). Fleas and flea-borne diseases. *International Journal of Infectious Diseases*, *14*(8), e667–e676. https://doi.org/10.1016/j.ijid.2009.11.011
Blagburn, B. L. & Dryden, M. W. (2009). Biology, treatment and control of flea and tick infestations. *Veterinary Clinics of North America Small Animal Practice*, *39*(6), 1173–1200. https://doi.org/10.1016/j.cvsm.2009.07.001
CDC. (2019). Ecology and transmission. Centers for Disease Control and Prevention (CDC). https://www.CDC.gov/plague/transmission/index.html
Coetzee, C. G. (1975). The biology, behaviour, and ecology of Mastomys natalensis in southern Africa. *Bulletin of the World Health Organization*, *52*(4-6), 637–644.
Chirima, A., Mundy, P., Ncube, N., & VanRooyen, A. F. (2018) . Vegetation changes in the Miombo woodlands in Northwestern Zimbabwe: A case study of Nkayi district 1990 to 2017. In A. Chirima (Ed.), *Vegetation* (pp. 43–57). INTECH. https://doi.org/10.5772/intechopen.72466.
Dennis, D. T., Gage, K. L., Gratz, N., Poland, J. D., & Tikhomirov, E. (1999). *Plague manual: epidemiology, distribution, surveillance and control*. (Issues 51–52). Geneva: World Health Organisation. http://www.who.int/csr/resources/publications/plague/WHO_CDS_CSR_EDC_99_2_EN/en
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
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
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.
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
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., 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
Krebs, C. J. (2009). *Ecology: The experimental analysis of distribution and abundance*. 6th ed. Pearson Benjamin Cummings.
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*, 173–176.
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
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*, 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
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
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.
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, H. E. (2010). STATISTICA for windows. StatSoft Inc, Tulsa.
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., 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., & Pugh, A. (1982). Plague in Zimbabwe: A review of the situation in 1982. *Central African Journal of Medicine*, *28*(10), 249–253.
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/
Vora, N. (2008). Impact of anthropogenic environmental alterations on vector-borne diseases. *MedGenMed Medscape General Medicine*, *10*(10), 1–7.
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. December. https://doi.org/10.1089/vbz.2010.0095

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