IMPACTS OF RECREATIONAL INFRASTRUCTURE ON RODENT COMMUNITIES AND THEIR ASSOCIATED HAEMOPARASITES IN SERENGETI NATIONAL PARK, TANZANIA

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ABSTRACT

Rodents are a vital component of ecosystems influencing various ecological aspects such as community structure, stability, and diversity. However, they are very sensitive to environmental change, thus act as indicators of environmental suitability in their respective ecosystems. Rodents' haemoparasites are zoonotic and have great potential of causing rodent borne diseases when transmitted to humans. Recreational infrastructures constructed in protected areas to support leisure and recreation activities for tourists, may disrupt the natural environment of rodents and influence dynamism in their communities and associated haemoparasites, an may lead to transmission of these haemoparasites to the human communities. Capture- Mark- Release was used to collect data in Serengeti National Park to assess the effects of recreational infrastructure on rodent communities and their associated haemoparasites. Four transect lines of 100 meters; set 10 meters apart were used for setting traps in selected trapping sites; and capillary tubes were used to collect blood samples for assessment of prevalence of haemoparasites. A total of 128 rodents belonging to 9 species were captured, of which *Mastomys natalensis* was the dominant species (53.1%). Generally, areas with less active infrastructure had more diverse community, but lower breeding pattern. *Bacillus spp* was the only haemoparasite observed to prevail in 24% of all captured rodents, with higher prevalence in adult males. The study concludes that different recreational infrastructure with regards to visitors' occupancy do not affect rodent communities in their natural environment; rather the dynamism in rodent communities are influenced by the nature of the habitat and environment surrounding the infrastructure. Thus, we recommend that more detailed studies should be done in relation to potential agents of diseases within PAs. This would help in understanding if there are potential risks to tourists and wildlife, and solving them before any outbreak occurs, as the two communities have been found to interact.

DECLARATION

I, Happiness Charles Bupamba, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor been concurrently submitted in any other institution.

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I dedicate this work to the people that God put in my life to help me finish my studies in one way or the other, but most of all I dedicate it to my family as you were the main reason I took my Master’s in the first place and helped me see it all the way through. I can honestly say I wouldn’t have done it without you.

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LIST OF ABBREVIATIONS AND SYMBOLS

CMR	Capture Mark Release
COSTECH	Commission for Science and Technology
MNA	Minimum Number Alive
PAs	Protected Areas
PAST	Paleontological Statistical Software
SENAPA	Serengeti National Park
TANAPA	Tanzania National Parks
TAWIRI	Tanzania Wildlife Research Institute

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Recreational infrastructure such as, hotels, lodges, campsites, walking trails and roads, are manmade facilities that are designed to support leisure and recreation activities for tourists visiting protected areas (PAs). These facilities have been developed within PAs over the years (Zhong *et al.*, 2015), and have been known to play an important role in the tourism industry by accommodating and catering for tourists' needs.

Apart from being helpful in accommodating tourists' needs, these infrastructures may also have negative impacts on the environment (Erdogan and Tosun, 2009). For instance, during construction of roads and hotels, wildlife is directly affected by habitat destruction through fragmentation of food patches and restriction of wild animals' movement, hence denies the wildlife access to resources (Bennet *et al.,* 2011). After construction, roads can affect wildlife population through road mortality (Clark *et al.,* 2010). Moreover, the construction of recreational infrastructure in PAs may alter patterns of wildlife's natural behaviour, more specifically feeding behaviour and contact with humans (Orams, 2002). These impacts in turn may significantly affect the flora and fauna in different ecosystems.

Small mammals particularly rodents are a vital component of ecosystems, influencing various ecological aspects such as community structure, stability, and diversity (Dunstan and Fox, 1996). Because of their ability to delay maturity and reproduction in adverse conditions, rodents can act as indicators of environmental suitability in their respective ecosystems (Addessi *et al.*, 2011). Rodents have also been known to be carriers of agents of diseases; some of the diseases can be transmitted from animals to humans and vice versa, (Nyirenda *et al.*, 2017). Human disturbance has been known to facilitate interaction between humans and rodents, through such interactions, diseases which can be harmful and even fatal to both humans and rodents can easily be transmitted (Katakweba *et al.,* 2012).

Impacts of recreational infrastructure on large mammals can easily be detected and monitored, however it is not easy to do so for the small mammals such as the rodents (Datiko and Bekele, 2013). Human activities have a major influence in the rodent's survival (Mohammadi, 2010; Gomez *et al.*, 2012). This has been alongside factors such as predation, competition and food quality and quantity.

Thus, understanding the link between rodent communities and the impacts imposed by human activities through recreational infrastructure development is important because these interactions can lead into effects on both sides (Buzan *et al.,* 2016). Due to the growing tourism industry and the development of recreational infrastructure within PAs (SENAPA, 2016), it is important to assess the influence that these recreational infrastructures impose to the rodent communities, because ecological impacts of these infrastructures within PAs is often extended far beyond the surface covered by the road itself.

1.2 Problem Statement and Justification

There has been an increase in development of recreational infrastructure within the Serengeti National Park (SENAPA, 2016) which in turn affects the wildlife communities. Different studies have been done on rodent community structure within SENAPA including (Senzota, 1982; Magige and Senzota, 2006; Byrom *et al.,* 2010), these studies mainly focused on the habitats, feeding habits and even population dynamics of the small mammals in SENAPA at large. Despite this vast body of knowledge, there is still a knowledge gap on the influence of recreational infrastructure on small mammals' community, specifically rodents, given the fact that rodents are potential agents of transmitting diseases of economic importance to human beings. Addressing this gap is crucial to our understanding on the ecology of rodents. Therefore this study seeks to assess how the presence of recreational infrastructure in the national park affects rodent communities. Information from this study will be useful in shedding light on possible risk factors imposed to both the humans and rodents, around recreational infrastructure within the PAs so as to lessen interaction between the two.

1.3 Objectives

1.3.1 General objective

- To assess the impacts of recreational infrastructure on rodent communities and their associated haemoparasites in Serengeti National Park.

1.3.2 Specific objectives

i. To determine rodents' species richness, diversity and abundance around recreational infrastructure areas in Serengeti National Park.

ii. To assess the population structure and distribution of rodents around recreational infrastructure within Serengeti National Park.

iii. To estimate prevalence of potential haemoparasites in rodents around recreational infrastructure areas in Serengeti National Park.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Recreational Infrastructure

Recreational infrastructure such as, hotels, lodges, campsites, walking trails and roads, are manmade facilities that are designed to support leisure and recreation activities for tourists visiting (PAs). Over the years such infrastructures have facilitated the stay of tourists within different destinations including national parks, where tourists temporarily stay in the wild and view wildlife in their natural environment (Sumanapala, 2018). On a controlled and planned basis, the infrastructures serve for the good of the tourism industry but in the long term they can cause negative impacts to the wildlife (Alamgir, 2019). The recreational infrastructure help facilitate tourism but there has to be a balance between tourism activities and conservation (Gutiérrez, 2017), this is because when there is more recreational infrastructure, the tourism traffic will be high but in turn it will affect the wildlife in such PAs. Infrastructure development in the wild that has not been well planned can lead to negative impacts such as food dependency, to the wildlife including small mammals (Kisanga, 2019).

2.2 Rodent Biology and Ecology

Rodents are part of the large group of small mammals that fall under the order Rodentia with many of its species sharing biological and ecological features (Wilson and Reeder, 2005). With over 2000 living species of rodents out of the 5416 species of living mammals, rodents represent 40% of the total mammals, making them a rather rich group compared to the rest (IPM, 2016). Most of the rodents are nocturnal and few are diurnal, being nocturnal helps them avoid resource competition (Vadell *et al.*, 2010), but also avoid most of the predators that they would likely meet during the day time thus being left with a few night predators such as owls and other small carnivores.

Rodents have been known to have a rather fascinating ability to adapt to different environmental conditions. This includes their ability to conceive 24 hours after giving birth and withholding from conceiving during seasons of low food availability (Leirs *et al.,* 1994). The largest rodent species morphologically is the capybara, which is estimated to weigh 66 kg, while most rodents do not weigh more than 100 g and the smallest rodent is estimated to weigh around 3.75 g and it is said to be the Baluchistan pygmy jerboa (Waggoner, 2000). Rodents are found in diverse environment from natural environments, to human settlements (Single *et al.,* 2001).

Rodents fall into different feeding groups, they can be herbivorous, omnivores, insectivorous and some are resourceful generalists, and others are specialized predators (Bergstrom, 2013). This helps them in foraging on a variety of food items such as seeds, invertebrates, plants and fruits (Waggoner, 2000; Connior, 2011). According to Single *et al.* (2001), the continues growing of pairs of incisors helps rodents during feeding, defending themselves in time of danger and even digging of burrows that they use for hiding or as shelter.

Ecologically, rodents are a vital component of ecosystems, influencing various ecological aspects such as community structure, stability, and diversity (Dunstan and Fox, 1996). Rodents also play a key role in connecting links between trophic levels (Ofori, *et al.*, 2015) as they are key prey for many carnivores and raptors (Davidson *et al.,* 2012). Moreover, rodents are host of parasites and reservoir of different pathogens

(Karuaera, 2011) that can in turn lead to spread of diseases such as plague, but they also act as biological indicators (Avenant, 2011).

2.2.1 Rodent species' diversity, abundance, distribution and population structure

Different factors affect diversity of species including, geographical factors such as dispersal distance, biological factors such as competition, facilitation and predation and environmental factors such as resource availability (Byrom *et al.,* 2015). These factors in turn lead the rodent community to belong to different species in a given area (Timbuka and Kabigumila 2006).

According to Massawe *et al*. (2008), the soil texture is seen to influence population abundance of the rodents. But then soil texture can also be affected by whether the area is disturbed or undisturbed, bringing back the linkage between abundance and nature of the area. According to Datiko *et al*. (2013), different factors affect the abundance of species in an area including, competition, resource availability and predation of wildlife in particular species.

Habitat change can also play a great role in the distribution and population structure of rodents (Russo *et al.,* 2016). This is because of the complexity of environment in relation to rodent species' conditional preferences. In such cases this may lead to the rodents being unequally distributed and of different population structure as one moves from the disturbed areas to undisturbed parts. The distribution can also be equal or unequal due to the tendency of rodents using their habitats in relation to environmental variables, species requirements and biological interactions (Gomez *et al.,* 2012).

2.3 Rodents as Hosts of Haemoparasites

Haemoparasites or blood parasites are the type of parasites that spend most of their lives in animals' blood streams. Transmission of such parasites can be through different vectors that carry the pathogens from the rodents to the humans for example, the vectors include fleas, trypanosomes and ticks (Fyumagwa *et al.*, 2009). . The transmission can be done in different ways such as through breathing or ingestion of contaminated food or water and feeding on infected rodents, and this is often associated with poor hygiene (Katakweba *et al.*, 2013). The transmission of the pathogens from rodents leads to different rodent-borne diseases including; plague caused by *Yersinia pestis*, Hantavirus pulmonary syndrome caused by *Sin Nombre virus*, leptospirosis caused by *Leptospira*, brucellosis caused by *Brucella*, murine typhus caused by *Rickettsia typhi*, tick typhus, tularaemia caused by *Francisella tularensis* and relapsing fever caused by *Borrelia*, and Trypanosomiasis (Young *et al.*, 2017). The prevalence of such pathogens can change due to human activities that lead to the changes in abundance of the rodent species that act as carriers (McCauley *et al.*, 2015).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location of the study area

The study was conducted in Serengeti National Park (SENAPA) from July to October 2020. SENAPA is the third largest national park in Tanzania after Nyerere and Ruaha National Parks respectively**.** It is found in the North-western part of Tanzania, within Mara and Simiyu regions. According to SENAPA (2010), the park covers 14 763 square kilometres and is located at 2°20’S 34° 34’E of Tanzania, ranging from 920m to 1850 m above sea level, with a mean temperature varying from 13 to 28°C. The Park is bordered to the North by Maasai Mara National Reserve in Kenya, to the South East by the Ngorongoro Conservation Area, to the South West by Maswa Game Reserve, to the East by Loliondo Game Controlled Area and to the West by Ikorongo and Grumeti Game Reserves. The vegetation in the park includes; grassland plains, savannah, riverine forests and woodlands. Data was collected from the central part of SENAPA called Seronera (Figure 1). SENAPA was chosen as a study area because it is the most visited park in Tanzania, receiving about 350 000 visitors annually, making it have a larger and diverse number of recreational infrastructures to accommodate such visitors.

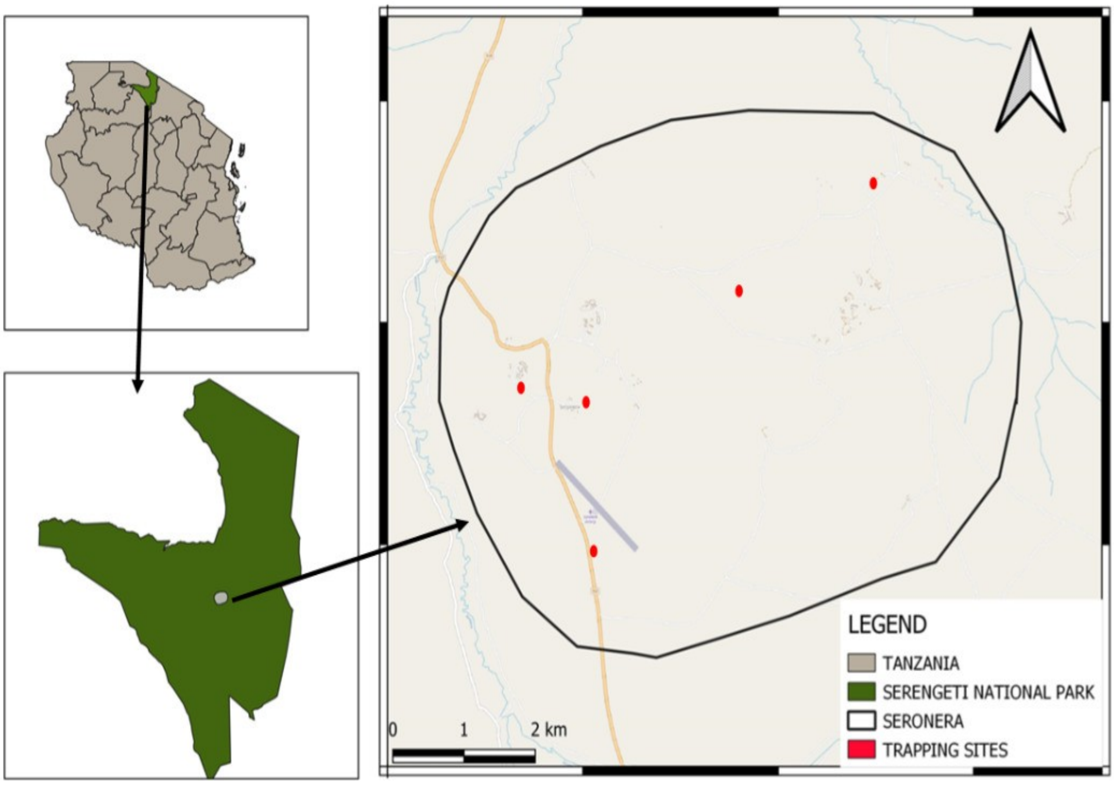

Figure 1: Map of the Serengeti National Park showing the trapping sites at Seronera

3.1.2 Recreational infrastructure in Serengeti

Recreational sites considered in this study included campsites, lodges and roadways; within Serengeti National Park there are 22 camping sites, which include mobile tented campsites and permanent campsites, five lodges, and four main roadways leading to the four main gates, that facilitate tourism (SENAPA, 2016). Data was collected at the infrastructure around Seronera area, which includes Seronera Wildlife Lodge, Pimbi Campsite, Nyani Campsite, Seronera Airstrip Roadway, Youth Hostel and a control area without any infrastructure.

3.2 Sampling Procedure

Selection of recreational the infrastructure, was done systematically by choosing two of the largest and busiest lodges and two permanent and mobile campsites, a roadway and a site without any infrastructure (control area) which were located inside the park.

3.3 Research Design

Capture- Mark Release technique was used to collect data of rodent species, where by traps (Sherman traps) were set on transect lines. Transect lines were set in accordance with the nature of the environment around the infrastructure. Four transect lines of 100m long were set in each recreational infrastructure, the distance between transects was 10m. In each transect line Sherman traps of size (8×9×23 cm) were set 10 meters apart, making a total of 10 traps per line, and 40 traps per site, these traps were baited with peanut butter mixed with maize flour. Traps were set early morning and in the evening due to most rodents being nocturnal, and the traps were re- baited after capture was done and data was recorded. The traps were camouflaged by being hidden in bushes or being covered up by grass so as to avoid being taken by other animals in the park.

3.4 Data Collection

3.4.1 Rodent capture and handling

The captured rodents were marked by shaving their fur using a pair of scissors on their backs near the tail for easy visibility of the mark. Data recorded included, sex, body weight and length, tail length, hind foot and ear length were measured using digital calliper, to help in specie identification with the help of guide books (Happold *et al.*, 2013; Kingdon, 2015), the age categorised as juveniles (<20g), sub-adults/immature (21g-23g), Adults (>24g) (Leirs and Verheyen, 1995) and sex (female and male) of the individuals, to help in knowing the population structure respectively. The distribution of the rodent species was recorded by considering the presence or absence of the captured rodents in the particular habitat.

3.4.2 Removal and handling of haemoparasites from captured rodents

Blood samples were collected from the captured rodents. This was done by placing a capillary tube at the corner of the eye, where blood would be drawn into the tube and thereafter the rodent's eye was wiped using cotton to avoid the blood affecting the eye. Thick and thin smears were made on glass slides, for each blood sample drawn from the rodents and labelled. The blood smear was fixed using 100% methanol concentration for two minutes, then left to air dry and preserved in a slide box.

3.4.3 Processing and identification of haemoparasites

The preserved dry smears were stained with 10% Giemsa for 30 minutes at the laboratory, where they turned from red to purple colour, and the stained samples were examined using 100 × objectives under ordinary light microscope. Examining the stained smear helped in identifying different haemoparasites that were carried within the captured rodents' blood.

3.5 Data Analysis

3.5.1 Rodents' abundance and species diversity

Rodents' abundance was calculated as the minimum number alive (MNA) index in each capture. MNA in Capture-Mark-Recapture is defined as the number of individuals caught in that capture session in each habitat and those that were caught both previously and subsequently (Krebs, 1966).

Species diversity (number of species and numerical contribution of each to the community) were calculated using the Shannon-Wiener diversity index (Krebs, 1999), as it also accounts for species evenness and richness in distribution of a sample in a number of sites.

$H_i = -\sum_{i=1}^{s} Pi\, Lnp_i$…………………………………….…………………………….. (1)

Where pi = S / N

H_i = species diversity index,

S = number of individuals of one species,

N = total number of individuals in the sample,

Pi = is the relative abundance (proportion) of the i^{th} species in the community,

Ln Pi = natural logarithm of Pi.

Kruskal Wallis test was used for comparing species richness and abundance between the recreational infrastructures.

3.5.2 Rodents' population structure

Sex ratio was calculated in each recreational infrastructure as the number of female divides by the number of females plus the number of males i.e., $\frac{F}{F+M}$.

Breeding pattern was grouped as active and inactive individuals, where active females were perforated or pregnant and active males had visible scrotum, while inactive females had small nipples and not perforated and inactive males had no visible scrotum. In each recreational infrastructure age of *Mastomys Natalensis* was categorised as the age of juvenile and adults. To test the significant difference of recreation infrastructure on sex, breeding Pattern, Kruskal Wallis test was used while in age ANOVA test was used.

3.5.3 Haemoparasites

The prevalence of haemoparasites in rodents was estimated between species, and the recreational infrastructures. The prevalence of the haemoparasites was tested and expressed in percentage (Okeke *et al.*, 2013). Prevalence (N) =N1/N2*100, where N=percentage prevalence, N1=Number of rodents infected, N2=Total number of rodents examined for the blood parasites. In testing for significant difference between recreational infrastructures, ANOVA test was used.

CHAPTER FOUR

4.0 RESULTS

4.1 Rodents' Specie's Richness, Diversity and Abundance

4.1.1 Species' richness

A total of 128 (60 males: 68 females) rodents were captured between July 2020 and October 2020, belonging to 9 different species (Table 1). However, the number of species captured between infrastructures were found to be significantly different using Kruskal Wallis test ($\chi 2 = 34.0$, df = 5, p = 0.003). Generally species richness was higher in areas which had been less disturbed by development of infrastructures than those with such disturbances. Between Infrastructures, less busy (pimbi campsite and wildlife lodge) recreational infrastructures had higher species richness as compared to the busiest recreational infrastructures (Table 1).

4.1.2 Abundance

Generally, rodents were more abundant at the youth hostel which is among busiest in recreational infrastructure, and were less abundant at the airstrip road which was another busy recreational infrastructure (Table 1); however the number of rodents was relatively similar in less busy recreation infrastructures (Table 1). At the control site however, there were no rodent species captured (n= 0), only *crocidura spp* were captured. Kruskal Wallis was used to find significant difference in rodent's abundance ($\chi 2 = 3.91$, df = 5, p = 0.03084) in the infrastructures. With the relative abundance of 53%, *Mastomys natalensis* were dominant species in the study areas, while *Rhabdomys spp* was the least abundant of all the species in all habitats (Table 1). Further analysis, indicated that there was a significant difference on species abundance between recreational infrastructures.

Table 1: Rodent's species abundance and richness in the study sites

	Recreational Infrastructures						
	Busiest Sites		Less Busy Sites			Control Site	
Species	**Youth hostel**	**Airstrip road**	**Wildlife Lodge**	**Pimbi Camp**	**Nyani Camp**	**Open Area**	**Total**
M.natalensis	25	10	16	5	12	0	68
A.niloticus	7	5	5	1	4	0	22
Sacostomys spp	2	0	1	2	0	0	5
Aethomys spp	0	1	1	5	2	0	9
Mus spp	0	1	1	4	6	0	12
Acomys spp	0	0	0	5	0	0	5
Rhabdomys spp	0	0	0	1	0	0	1
Tatera/gb spp	0	0	0	2	0	0	2
Graphiurus spp	0	0	4	0	0	0	4
Total	34	17	28	25	24	0	128
Richness	3	4	6	8	4	0	

4.1.3 Species diversity

Generally, areas that were less busy or active had a more diverse community as compared to the busy sites and the control area. Across trapping sites; Pimbi campsite had the highest diversity of species, while the busiest (youth hostel) had the least with 1.921 and 0.718 respectively (Figure 2).

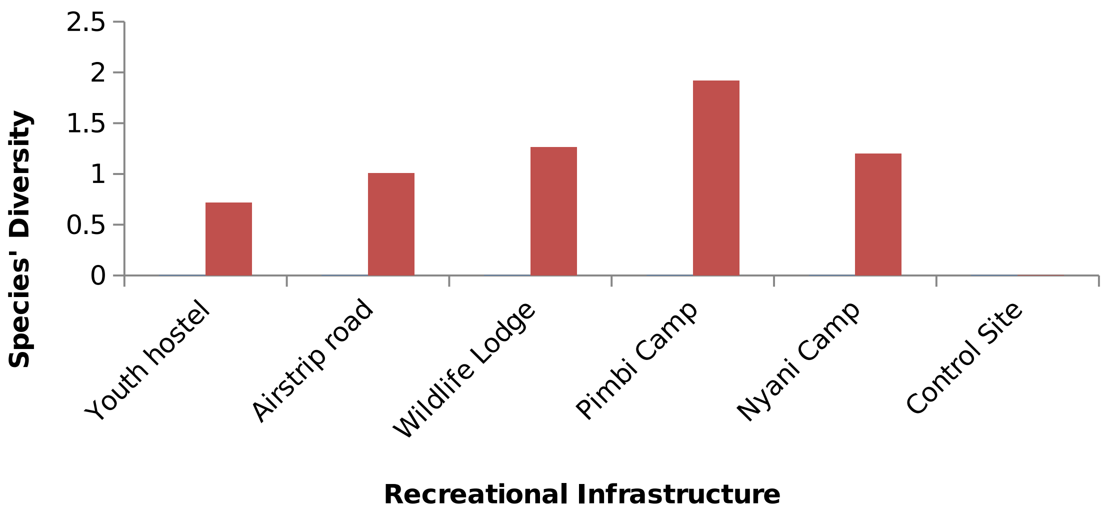

Figure 2: Rodent's species diversity across Infrastructure.

4.2 Rodent Species' Population Structure and Distribution

4.2.1 Sex ratio

Regardless of the level of activeness, sex ratio varied between recreational infrastructures, where the sex ratio was 0.53 for all individuals caught throughout the infrastructures. Sex ratio was higher at the youth hostel (Figure 3) and at wildlife lodge (which is among the less busy sites), the ration was observed to be lower at Pimbi camp which is among the less busy sites, statistically, this variation was found to be highly significant (χ^2 = 1.317, df = 5, p = 0.02162). The percentage of females was particularly high in youth hostel for both *M. natalensis* and *A. niloticus*, followed by wildlife lodge for *M. natalensis* and *Graphiurus spp*, where the least was Pimbi campsite for all species (Figure 3). Whereas, the percentage of females between species was particularly high for the *M. natalensis* species throughout the infrastructures, while the species with the least percent of female throughout the infrastructures was *Acomys spp* (Appendix 4).

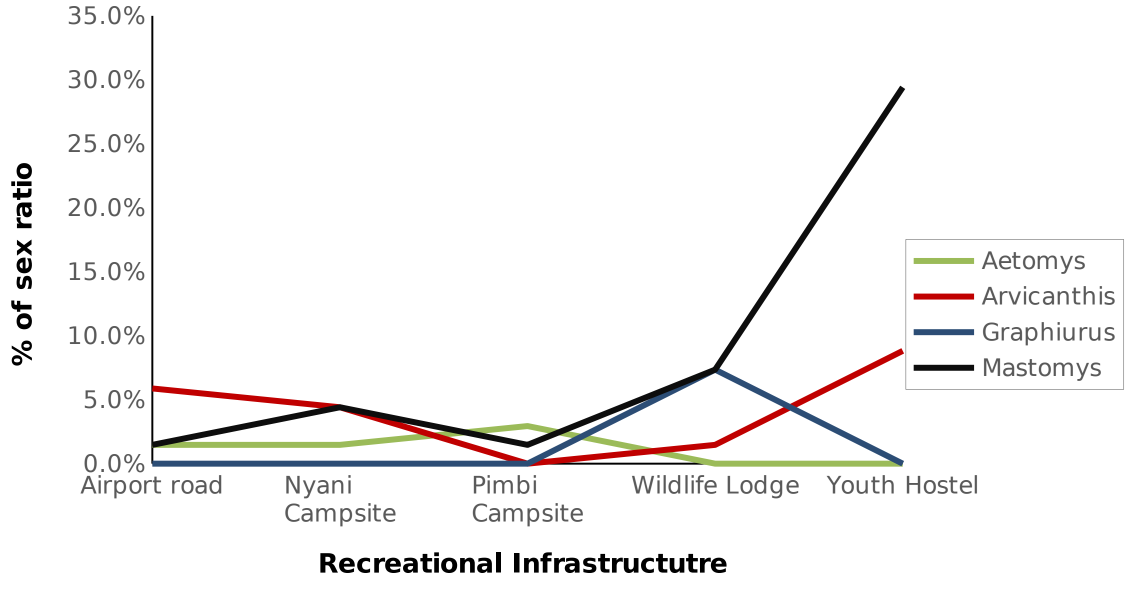

Figure 3: Rodent's species sex ratio across Infrastructure

4.2.2 Breeding patterns

Breeding pattern was categorized into active and inactive individuals. The less busy sites had high occurrence of inactive individuals i.e., Wildlife lodge had a high number of inactive individuals, followed by Nyani campsite and least was Pimbi campsite (Fig. 4). The number of active individual rodents in the busy site (youth hostel) was higher than in all infrastructures. There was a significant difference in number of active individuals across infrastructures with (χ^2 =58.6487, df = 5, p = 0.018).

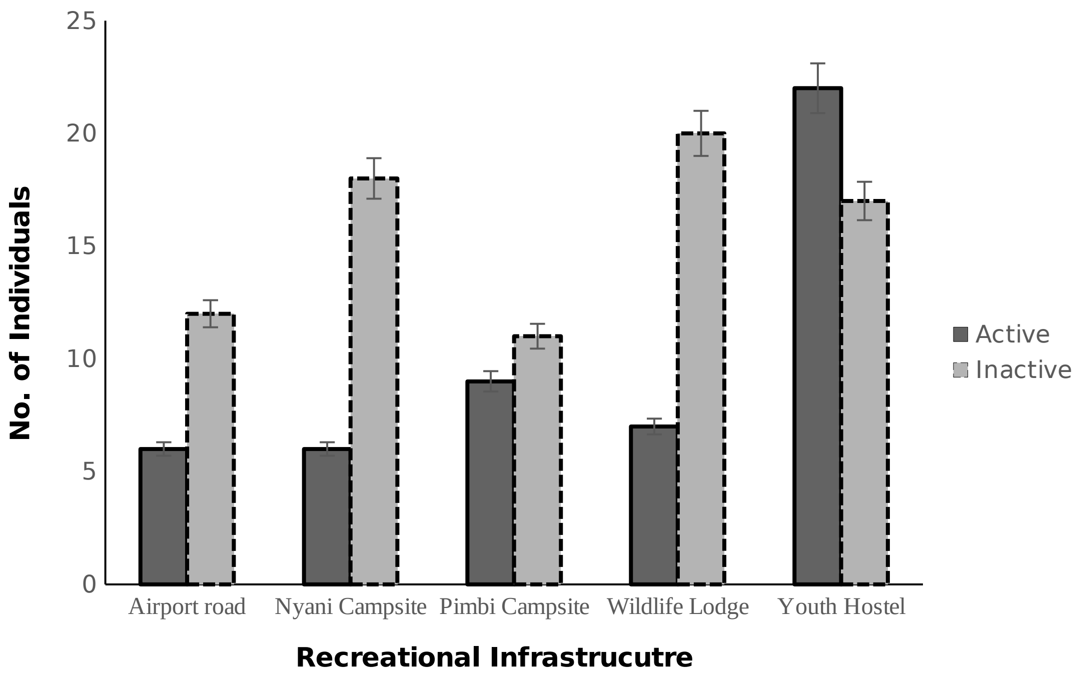

Figure 4: Breeding patterns of captured rodents across infrastructure.

4.2.3 Age structure

Generally *M. natalensis* population in the study area (Serengeti National Park) is slightly dominated by juveniles (55% of the total captured population). However, there was variation in age structure between the disturbed areas (with infrastructures).

Similarly, there was variation in age structure within infrastructure facilities/sites. Population of M. *natalensis* at Youth hostel comprised more with adults than juvenile, while that at Wildlife lodge and Nyani campsite were comprised more with juveniles, whereas the population at Pimbi camp had relatively similar composition of adults and juveniles (Figure 5). The abundance of adults and juvenile was not significantly different across and within the infrastructure ($F_5 = 1.92$, $p = 0.070$).

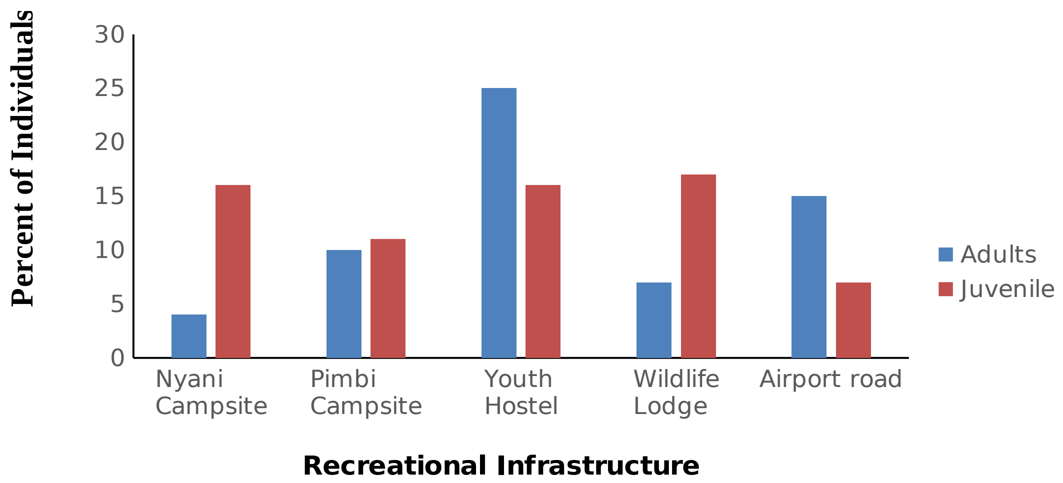

Figure 5: Age structure of captured *M. natalensis* across infrastructure

4.3 Potential Haemoparasites

The rodents species captured were tested for haemoparasites and 31 individuals, which accounts for 24% of the total captured rodents examined, showed pleomorphic rods of *Bacillus spp*. The prevalence between infrastructure was significantly different ($F_5 = 4.937$, $p = 0.00014$). It was observed that 57.14% of all rodents that examined observed to have Bacillus haemoparasites were captured at Pimbi campsite, while 7.14% of the rodents were from Wildlife Lodge, while Youth hostel had no rodents that had haemoparasites (Table 2).

Table 2: Percent of haemoparasites positive individuals in specific infrastructure.

	Airstrip road	Nyani Camp	Pimbi Camp	Wildlife Lodge	Total
F	**0**	**7.14**	**35.71**	**0**	**42.85**
Acomys spp	0	0	7.14	0	7.14
Aetomys spp	0	0	14.29	0	14.29
Mus spp	0	7.14	7.14	0	14.28
Sacostomys spp	0	0	7.14	0	7.14
M	**14.29**	**14.29**	**21.43**	**7.14**	**57.15**
Aetomys spp	7.14	0	0	0	7.14
Mastomys spp	7.14	7.14	14.29	7.14	35.71
Mus spp	0	7.14	0	0	7.14
Sacostomys spp	0	0	7.14	0	7.14
Total	14.29	21.43	57.14	7.14	

CHAPTER FIVE

5.0 DISCUSSION

5.1 Rodent Species Abundance and Diversity across Trapping Sites

This study aimed at assessing the impacts that recreational infrastructure poses on rodents communities and their associated haemoparasites. The study found a variation in rodent composition between infrastructures i.e., sites where there was no infrastructure built, sites where the infrastructure was barely in use and sites where the infrastructure was occupied by visitors, but the areas also had a variation in their surrounding environments including vegetation cover.

During the study, nine rodent species were captured, (*Mastomys natalensis, Arvicanthis niloticus, Sacostomys spp*, *Mus musculus, Aetomys spp, Acomys spp, Rhabdomys spp, Tatera spp, Graphiurus spp)* (Appendix 3). The most dominant species among these was the *M. natalensis* which was found in five out of the six sites; i.e. youth hostel, wildlife lodge, airstrip- seronera road, pimbi campsite and Nyani campsite. The least dominant species was the *Rhabdomys spp,* this species was only captured at the Pimbi campsite.

The six trapping sites had a variation in the rodent communities found. In the control area, which was an open area and did not have any infrastructure built, there was no rodent species captured. These differences probably could be due to the difference on vegetation existing around infrastructures. For example only one species from Soricidae family, the *Crocidura spp* was trapped at the open area. According to Magige, 2013, open plain areas tend to have a lower number of rodents present due to possibility of predation and lack of immediate food sources.

In the pimbi campsite was found to be rocky in nature and had woodland vegetation cover this environment tend to favour a wide range of species as the site had highest diversity of rodent species.

The number of rodents in an area tends to change from time to time depending on several factors like food availability, environment factors and reproductive potential of rodents (Mulungu *et al.*, 2015). In the case of youth hostel, the high abundance of rodents might have been facilitated with the ease access of food products. The hostel is found near a shopping center that has two restaurants and three shops, but also human households are within a rodents' home range, i.e. 300 meters. Thus access to food from leftovers from the kitchens and dumpsters is a contributing factor to the high abundance. At the youth hostel the most dominant species was *M. natalensis* (74%), according to Bonwitt *et al.* (2017), areas with high human activity are associated with factors that draw the *M. natalensis* to the particular environment.

The Seronera Wildlife lodge was second in high diversity. The lodge is surrounded with woodland vegetation that helps in providing cover for the habitat and survival of the different rodent species. The lodge pits also provide access to easy food from the remains disposed from the lodge though it did not have high visitor occupancy at the time.

The seronera airstrip- seronera shopping centre roadway had low abundance and diversity possibly because it is associated with frequent movement of vehicles to and from the seronera shopping center and household area. This probably makes the rodents vulnerable to road mortality. It was also observed that the rodents were more abundant on the transect lines further away from the road as compared to the ones that were 10 meters from each side of the road. The road sides were also associated with grassland plains type of vegetation giving the rodents less cover.

5.2 Rodent Species' Population Structure and Distribution

The sex ratio was calculated in order to understand the population structure. It was calculated across the different infrastructure sites and among rodent species. The number of females both across infrastructure and among species in the sites was found to be slightly higher than that of males. The ratio of males to females having slight variations has demonstrated in other studies as well showing the differences in behaviour, immune and predation pressure as common characteristics in regulating the balance between sexes in different species of animals (Mulungu *et al.,* 2013; Borremans *et al.*, 2014).

In the case of breeding patterns, the youth hostel had the highest number of reproductively active individuals across species. According to Dantas *et al.* (2021), rodents can withhold from reproducing in case of harsh environment, therefore the ease in availability of food at the youth hostel might be associated with higher rates of reproductive activities because the rodents have food access and vegetation cover as it was surrounded by a rocky and woodland area, hence the freedom to reproduce.

In the case of age difference across the infrastructures which was based on the *Mastomys Natalensis* species; the youth hostel was found to have the highest number of adults and fairly high number of Juveniles as well. And generally across all infrastructures, the number of adults was higher than the juveniles. This can be associated with findings by, Assefa and Srinivasulu (2019) that showed adults have large home ranges, active movement, and higher social ranking within rodent communities.

The results show that in terms of population structure of the rodents across infrastructure, the Youth hostel had the highest activity in terms of age, breeding patterns and sex ratio. This is in line with Dantas *et al.* (2021) findings that showed higher reproductive activity of rodent species were found in areas where the rodents can have easy access to food materials for some species like *M. natalensis*, but mainly in an environment that is not too harsh for their survival including favorable vegetation type or environmental condition at large.

5.3 Potential Haemoparasites

The study included examining rodents' blood to look for potential haemoparasites that probably can causes diseases. The haemoparasites found were pleomorphic rods of *Bacillus spp*. According to Gratz (1994); Katakweba (2018), the presence of the *Bacillus spp* are not completely unexpected as rodents are carriers of various bacterial organisms, and may not impose potential risks of zoonosis in cases where the serological tests on blood sera from the same animals were found to be negative for antibodies against the antigens of potential pathogens (Katakweba *et al.,* 2012). This making it non conclusive to have a potential risk of a diseases in study site (Katakweba, 2018).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the results, recreational infrastructure do not highly influence rodent’s diversity and abundance within protected areas but rather the vegetation and environment surrounding such infrastructure. This is mainly because infrastructure development in PAs serves as a new environment to the rodent species but the rodents mainly come into contact with the surrounding habitat. But again, tourist seasonality can affect abundance of rodents (especially for *Mastomys natalensis*), as the study shows that areas with higher number of tourist activities had higher abundances of some species as well. In addition, a call for different mitigation measures that can facilitate tourism without imposing damage to the rodent communities.

6.2 Recommendation

From the study, we recommend that more detailed studies should be done in relation to potential agents of diseases within PAs. This would help in knowing if there are potential risks to tourists and wildlife, and solving them before any outbreak occurs. But again we recommend that more studies related to rodent species communities be done, as more studies have been focused on large mammals, the impacts that faces the rodents and small mammals at large are not well known or accounted for; this could as well include park surveys. And lastly we recommend that proper planning of recreational infrastructure, as has been done thus far, to be followed in order not to disrupt or disturb the natural environment of the rodent communities; including proper disposal of garbage such as remains of food material from the tourist residing areas.

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APPENDICES

Appendix 1: Formula for Trap Success

Formula: (TS) = (Ni / TN) × 100

Where:

TS = Trap success

TN = total number of trap-nights (one trap set for one night)

Ni= number of rodents' species caught

Appendix 2: Formula for Shannon Wiener's Diversity Index

$$\mathbf{H_i} = -\sum_{i=1}^{s} Pi\, Lnp_i$$

Where pi = S / N

H_i = species diversity index**,**

S = number of individuals of one species,

N = total number of individuals in the sample**,**

Pi = is the relative abundance (proportion) of the i^{th} species in the community,

Ln Pi = natural logarithm of Pi.

Appendix 3: Rodent species captured at the study area

S/N	Genus	Species	Family	Order
1.	*Mastomys*	*Mastomys natalensis*	Muridae	Rodentia
2.	*Arvicanthis*	*Arvicanthis niloticus*	Muridae	Rodentia
3.	*Mus*	*Mus spp*	Muridae	Rodentia
4.	*Aethomys*	*Aethomys spp*	Muridae	Rodentia
5.	*Sacostomys*	*Sacostomys spp*	Nesomyidae	Rodentia
6.	*Acomys*	*Acomys spp*	Muridae	Rodentia
7.	*Rhabdomys*	*Rhabdomys spp*	Muridae	Rodentia
8.	*Tatera/ Gerbilliscus*	*Tatera spp*	Muridae	Rodentia
9.	*Graphiurus*	*Graphirius spp*	Gliridae	Rodentia

Appendix 4: **Rodent's species sex ratio across Infrastructure**

Recreational Infrastructures												
	Busiest Sites				**Less Busy Sites**						**Control site**	
Species	**Youth hostel**		**Airstrip road**		**Wildlife Lodge**		**Pimbi Camp**		**Nyani Camp**		**Open Area**	
	M	F	M	F	M	F	M	F	M	F	M	F
M.natalensis	4	21	8	2	6	10	4	1	8	4	0	0
A.niloticus	1	6	0	5	1	4	0	1	1	3	0	0
Sacostomys spp	2	0	0	0	1	0	0	2	0	0	0	0
Aethomys spp	0	0	0	1	1	0	3	2	1	1	0	0
Mus spp	0	0	0	1	0	1	3	1	4	2	0	0
Acomys spp	0	0	0	0	0	0	4	1	0	0	0	0
Rhabdomys spp	0	0	0	0	0	0	0	1	0	0	0	0
Tatera/gb spp	0	0	0	0	0	0	1	1	0	0	0	0
Graphiurus spp	0	0	0	0	0	4	0	0	0	0	0	0
Total	7	27	8	9	11	17	15	10	14	10	0	0
Sex ratio	**79%**		**53%**		**61%**		**40%**		**42%**		**0**	