Journal of
Infectious Diseases and Epidemiology

REVIEW ARTICLE

Influence of Land Cover and Host Species on Trypanosome Infection in Cattle and its Socio-Economic Impacts to Pastoralists of the Maasai Steppe, Tanzania

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Abstract

Introduction: Trypanosome infections result into trypanosomosis in cattle and this is an infection detrimental to pastoralist income. The patterns of transmission are thought to be influenced by ecological factors including wildlife and land cover. We assessed the influence of the relative abundance of wildlife and land cover (cultivation and habitat type) on the presence of trypanosome infections in replicated cattle herds of the Maasai Steppe.

Methodology: We undertook a cohort field study in three villages of the Maasai Steppe: Sukuro, Kimotorok and Oltukai. The study took place in July 2017 and October 2017 and utilized 50 cattle from each village. Pastoralists were asked questions during each visit when blood sampled were taken to seek their viewpoint on the relative abundance of wildlife, habitat types and cultivation observed in the areas their cattle grazed. In addition, the percentage cover of cultivated land and habitat types in the grazing areas were determined during field visits and participatory mapping with pastoralists. A systematic review was used to understand the socio-economic importance of trypanosomosis. The species of trypanosomes in cattle were identified using nested Polymerase chain reaction (n-PCR).

Results: There was a significant and positive association between the presence of trypanosome infection and the abundance of wildlife within grazing areas, in particular the abundance of buffaloes (Odd Ratio > 1, P = 0.038, 95% CI 1.26 to 1.38) when cattle grazed in woodland habitats. Cultivation on grazing areas had a negative association with the presence of trypanosome infections (R < 1, P = 0.001, 95% CI 0.0614 to 0.0986) in cattle but this varied between villages. A systematic review showed that trypanosomosis had socio-economic impacts such as loss of income, reduced quality, and quantity of livestock products, management cost, and inadequate provisions of socio-services and potential zoonotic transmission to humans.

Conclusion & recommendations: The socio-economic impacts of trypanosomosis will continue to be a challenge to pastoralists when cattle are grazed close to wildlife areas which are infested with tsetse fly habitats. Control strategies for trypanosome infection in cattle on the Maasai Steppe should consider the interaction of cattle with ecological factors.

Keywords

Ecological factors, Cultivation, Trypanosome infections, Cattle, Maasai Steppe Tanzania

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Abbreviations

AAT: Animal African Trypanosomosis; DNA: Deoxyribonucleic Acid; QGIS: Quantum Geographical Information System; PCR: Polymerase Chain Reaction; NM-AIST: Nelson Mandela African Institution of Science and Technology; SUA: Sokoine University of Agriculture, PEHPL: Programme for Enhancing the Health and Productivity of Livestock

Introduction

High risk of trypanosomosis is anticipated in the Maasai Steppe ecosystems due to the proximity of cattle to protected areas. Protected areas in the Maasai steppe such as Tarangire and Lake Manyara National Parks harbor diverse species of wildlife that can act as reservoirs of trypanosome infections [1,2]. Different habitat types support a variety of wildlife reservoirs and suitable conditions for tsetse flies, the vector for trypanosomes, to develop and persist [2]. Among the common wildlife species observed in the Maasai steppe are African buffalo or cape buffalo (*Syncerus caffer*), blue wildebeest (*Connochaetes taurinus*), common eland (*Taurotragus oryx*), plains zebra (*Equus quagga*), African bush elephant (*Loxodonta africana*), impala (*Aepyceros melampus*), lion (*Panthera leo*), cheetah (*Acinonyx jubatus*) and warthog (*Lycaon pictus*) [3]. Wildlife species like wildebeest migrate seasonally through the Tarangire National Park while other wildlife species such as buffaloes are relatively sedentary. The movement of wildlife have been reported as important disease reservoirs of infection that spillover into cattle, including trypanosomosis [4]. In the Maasai steppe, the interaction of wildlife with livestock is common with seasonal fluctuation in wildlife abundance associated with the migration of some species [5]. This commingling brings the infected wildlife reservoir and vectors close to the cattle and is thought to be a driver for the transmission of trypanosome infections both from wildlife and among cattle [4].

Habitat type influences both the abundance and distribution of wildlife reservoirs and tsetse flies in the ecosystem [2]. For instance, riverine, swampy, open woodland and ecotone habitat types in the Maasai steppe have been reported to have a significant effect on the distribution and abundance of wildlife and tsetse flies [2]. Among the tsetse fly species reported in these habitat types are: *G. swynnertoni, G. m. morsitans, G. pallidipes* which are competent vectors in the transmission of trypanosome infections between cattle, wildlife and humans [1,6,7]. Regardless of the relationship between tsetse fly species and habitats in the Maasai steppe, little has been done to determine the influence of wildlife and habitat on the trypanosome infection in cattle.

Cultivation of crops in the Maasai steppe ecosystem has increased substantially in recent years [8,9] and is now considered as a form of economic diversification for pastoralists in the Maasai Steppe [3,10].

However, the practices of cultivation are anticipated to alter ecological components of habitats through the clearing of vegetation during farm preparation. The alteration of habitats for cultivation, significantly impacts the abundance and distribution of tsetse flies which serves as the vector for trypanosome parasites. This impact could either be positive or negative in the altered habitats. In this case, understanding the direction of impacts on trypanosome infection is important for trypanosomosis control.

Trypanosomosis has socio-economic impacts on pastoral communities. Economic costs of Trypanosomosis intervention in Ethiopia were estimated at US$28.23 for prevention of infection while it cost US$18.2 for treatment per household [11]. The current study investigated the influence of ecological factors on trypanosome infections in cattle in the Maasai steppe ecosystem and assessed the socio-economic implications of the disease to pastoralists so as to understand its negative impacts on pastoral communities.

Material and Methods

Study area

A cohort field study was conducted in the Maasai steppe in three selected villages: Sukuro, Kimotorok, and Oltukai. Sukuro and Kimotorok villages are in the Simanjiro District while Oltukai village is in the Monduli district. These villages were selected because of the human-livestock-wildlife interactions and the presence of trypanosome infections in cattle [12]. The villages are located close to the protected areas of Tarangire National Park and Lake Manyara National Park which are inhabited with abundant wildlife species that act as trypanosome reservoirs (Figure 1). The community in the Maasai Steppe consists mainly of Maasai people who are well known as pastoralists. The Maasai steppe, like other tsetse flies dominated areas, is surrounded by protected areas which are suitable habitats for wildlife and tsetse flies and so threaten cattle with infection of trypanosome infections [13,14].

Study design: Two approaches were used in this study. First, a systematic literature review and second a cohort study for field data collection. The systematic review was performed to assess the socio-economic implications of trypanosomosis on pastoral communities. The cohort study for field data collection was undertaken to assess the influence of ecological factors (wildlife, land, cover and habitats) on trypanosome infections in cattle.

Socio-economic impact of Trypanosomosis in pastoral communities: A literature search through PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was undertaken for both printed and internet-based information without bias of language. Key words searched in both internet and
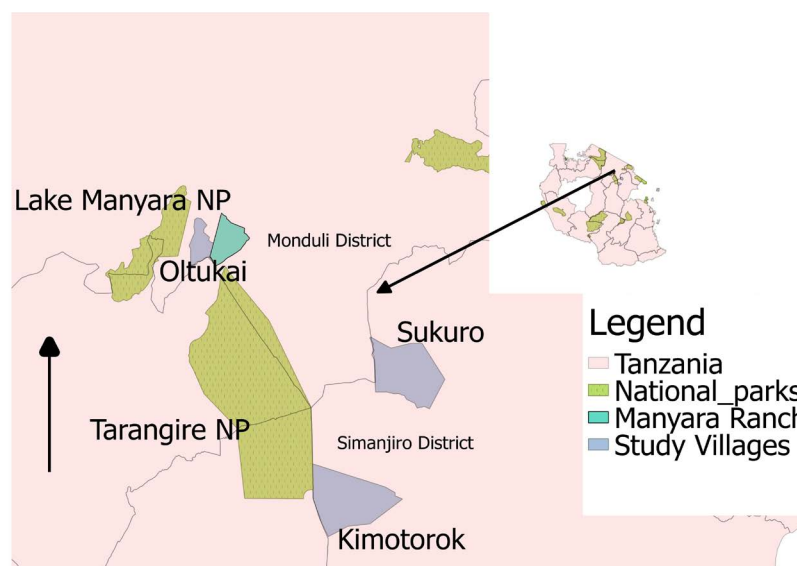
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Figure 1: Map showing the location of the three study villages; Sukuro and Kimotorok in Simanjiro District and Oltukai in Monduli district [30].

printed documents were; trypanosome infection and socio-economic impacts, trypanosomosis effect to pastoralists, effects of trypanosomosis to pastoralists, cost of treating trypanosomosis, and impact of trypanosomosis to pastoralist. Inclusion criteria for documents to include in analysis were those pater/documents which show economic or social data in relation to trypanosomosis while exclusion criteria were those that did not mention the association between trypanosome infection/trypanosomosis and socio-economic impact.

Google Scholar (https://scholar.google.com/) and PubMed search engines were used to search the internet while other documents were searched from printed government reports, posters, and proceedings. Data available at the Simanjiro district livestock office for 3 years, 2011-2013, was used as a case study, whereby records of cattle diseases and number of cattle that died due to trypanosomosis were sought from the published reports. Monetary costs through treatment and control strategies, like spraying, were calculated based on a previous study by Muhanguzi, et al. [15]. This showed costs of treatment and control (like spraying) of one cow per year to be $5.5USD and $3.5USD, respectively. The economic losses caused by mortality due to trypanosomosis in each year was calculated based on the Pugu market prices for the year 2018 which was 350USD per cow [16].

Association between ecological factors (wildlife, land cover and habitats) and trypanosome infections in cattle: In each village, blood samples were collected from cattle in selected bomas (Maasai homesteads) and stored for detection of trypanosomes. In each village, five smallholder livestock keepers were selected to be included in the cohort study. In each boma, 10 cattle were tagged for blood sampling in each boma, 10 cattle were tagged which were sampled consecutively in

July, October 2017 and in January 2018. During each sampling session, the cattle were given a prophylactic dose of diminazene aceturate in order to clear any trypanosome infections just prior to blood collection and to monitor newly-acquired infections. Diminazene aceturate is known to be effective for 20-21 days in cattle [17,18] and therefore the cattle could only acquire new infections beginning 21 days after the drug administration.

Three milliliters of blood were collected from the jugular vein by venipuncture into an EDTA-containing Vacutainer tube from 150 cattle in each sampling session (50 blood samples from each village). The blood was stored, kept in ice boxes and transported to the laboratory at the Nelson Mandela African Institution of Science and Technology (NM-AIST), in Arusha Tanzania and then stored at -20 °C until DNA extraction.

Questionnaires were presented to the cattle owners each time their cattle were sampled. The cattle owners were asked to provide information on availability of farms for cultivation, habitats and the wildlife species observed in cattle grazing fields.

Estimation of the relative abundance of wildlife in cattle grazing areas: Information was gathered from cattle owners on wildlife species observed in the grazing areas 2 months prior to each blood sampling session. Specific information sought from the questionnaire respondents included the area where cattle grazed in the past two months prior to blood sampling and abundance (number) of wildlife and their species sighted in grazing areas. When more than one sighting was reported for the same wildlife species, then the average number of wildlife species was estimated. Information obtained from cattle owners through questionnaires was validated for selected grazing areas through follow-up site visits.

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Ten wildlife species were most dominant in the study area and these were: African or Cape buffalo (*Syncerus caffer*), blue wildebeest (*Connochaetes taurinus*), common eland (*Taurotragus oryx*), plains zebra (*Equus quagga*), African bush elephant (*Loxodonta africana*), impala (*Aepyceros melampus*), the common ostrich (*Struthio camelus*), Giraffe (*Giraffa camelopardalis*), spotted hyena (*Crocuta crocuta*) and warthog (*Phacochoerus africanus*) [2,19].

Cultivation and habitat types in the grazing areas: The pastoralists were asked to identify the areas where they had been grazing their cattle during each of the two-time intervals. The two-time intervals considered were; July 2017 to October 2017 (t1) and then November 2017 to January 2018 (t2). The observed farms/cultivated areas in the grazing areas categorized as cultivated area, while those areas without farms or cultivation were classified as uncultivated areas. In addition, polygons for grazing areas were estimated using Google Earth Pro on an Apple Ipad, Version 9.3.5 (13G36). Proper visualization during polygon creation and care was done by zooming in and out to identify recognizable features. This was done in collaboration with the pastoralists and livestock keepers where the pastoralists were requested to show the farmed/cultivated areas utilized in the past 2 months prior to blood collection. Percentage cover of cultivated areas and habitat types within each polygon were calculated in relation to the identified grazing areas using formula below;

Percentage of cultivated area or Habitat type = [size of the cultivated area or habitat type (Km2) within grazing area polygon/Size of Grazing area Polygon (Km2)] x100%.

DNA extraction and Nested PCR for detecting trypanosome species: Quick-gDNA blood mini prep kit (D3017, Zymo Research, USA) was used to extract DNA from cattle blood which and kept at 4 °C until Polymerase chain reaction (PCR). The nested ITS-PCR was used for detecting trypanosome infections by using ProFlex™ PCR System Thermocycler (Applied Biosystems®, Life technologies). There were two rounds for each reaction during n-PCR procedure to detect trypanosome.

During the first round, 2.5 μL (microlitre) of the extracted DNA was added to 6.25 μl of PCR master mix (Quick-load® Taq 2 × Master mix, BioLabs, New England, USA) containing 3.25 μl of nuclease-free water with the outer ITS primers ITS1 (5' - GAT TAC GTC CCT GCC ATT TG - 3') and ITS2 (5' - TTG TTC GCT ATC GGT CTT CC - 3') each with 0.25 μl. Post PCR product of 0.5 μl DNA template from the first round was used in second round PCR which contained the inner ITS primers ITS3 (5' - GGA AGC AAA AGT CGT AAC AAG G - 3') and ITS4 (5' - TGT TTT CTT TTC CTC CGC TG - 3'). The conditions applied in each round was 95 °C heating for 7 minutes followed by 35 cycles of denaturation at 94 °C for 1 min, then annealing at 55 °C for 1 min and finally extension at 72 °C for 2 minutes.

The 1.5% GR green stained agarose gels were used to separate the PCR products using the known DNA of *T. vivax/T. congolense* as a positive control. The positivity or negativity of the sample was determined based on definite DNA fragment size seen on gels as specified in previous studies [20,21]. During detection of trypanosome species, E-Box imaging system (E-Box CX5 Vilber Lourmart) was used to visualize the Gel images (Figure 2).

Data analysis: To test for significant differences in wildlife abundance and land covers related to infection of trypanosomes in cattle, Kruskal Wallis and Mann-Whitney U test were used since the data showed
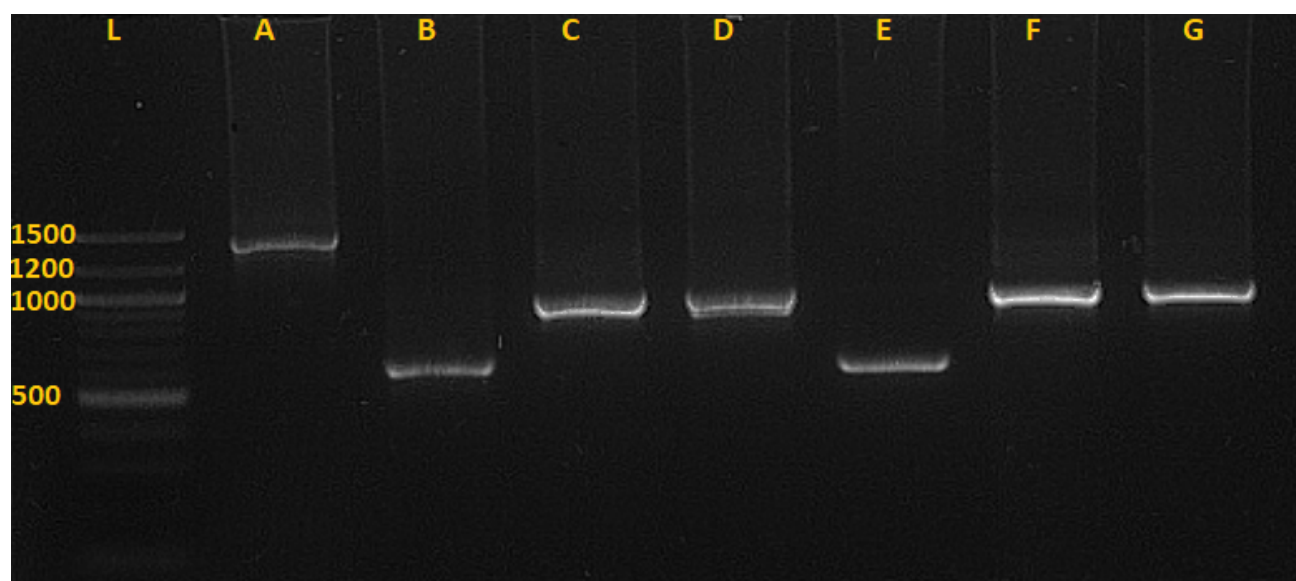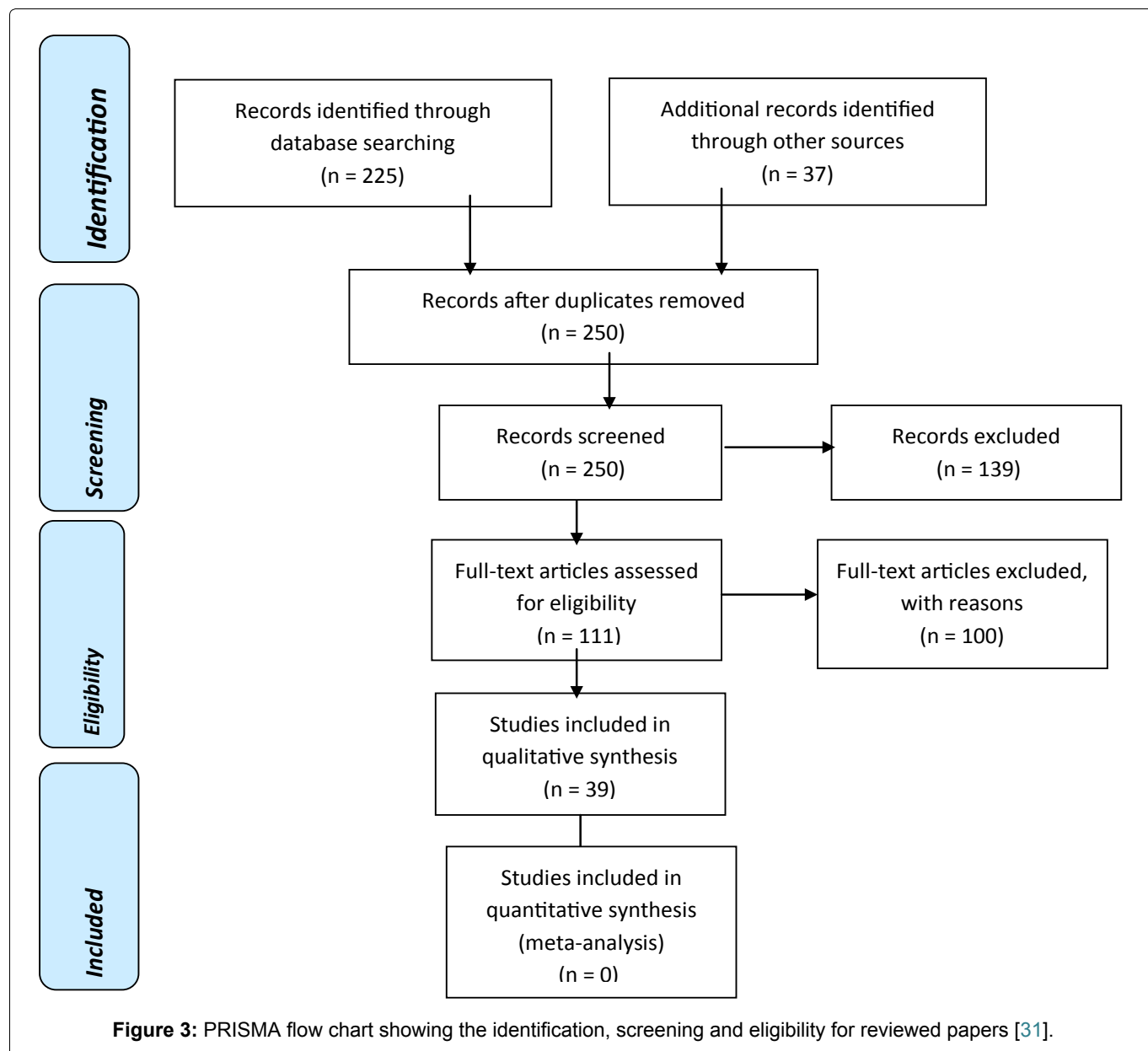

Figure 2: Agarose gel image of the DNA showing the species of trypanosomes after amplification. A is *T .c. savannah* (1403bp), B and E are *T. vivax* (620bp), C and G are *T. theileri* (981bp), D and F are *T. simiae tsavo* (954bp) and L is a ladder.

Figure 3: PRISMA flow chart showing the identification, screening and eligibility for reviewed papers [31].

non-parametric patterns. Analyses were performed in R statistical software (R Development Core Team 2011). Generalized Linear mixed model (GLMM) was used to determine the association existing between independent variables (wildlife and land cover) with the prevalence of trypanosome infection (dependent variable) in the Maasai Steppe while considering maximum likelihood with binomial as family. ODD Ratio (OR) was calculated using the coefficient from GLMM model. Results for socio-economic impact from the literature were synthesized and summarized in a table form.

Results

Socio-economic implication of Trypanosomosis to pastoral communities

Out of 250 records identified during systematic review, only 25.6% were included in the descriptive analysis (Figure 3). The literature showed that zoonotic risk and the socio-economic impact of trypanosomosis to pastoral communities were able reduce

the basic social provision, increase human/wildlife/ livestock conflict and increase management costs (Table 1). In this study, it was clear that most of the costs were spent on treating animals rather than other control strategies such as spraying. For instance, in 2011 a total of $40,689USD was used to treat sick animals while $25,949USD for spraying in Simanjiro (Table 2).

Wildlife Abundance and prevalence of trypanosome infections in cattle

A total of 14 wildlife species were observed by pastoralists in their grazing areas. All 14 species were observed in grazing areas in Kimotorok, 13 species in Sukuro, and only 6 species were observed in Oltukai. Ten species of wildlife were considered for analysis since they were regularly recorded by pastoralists and researchers and are known to be reservoirs of trypanosomes and can host tsetse flies [2,7,22]. Overall, the highest abundance was reported for wildebeest followed by zebra and buffalo while wart-

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Table 1: The socio-economic implication in term of Zoonotic diseases, family happiness, risk zone, management cost and quality of cattle products of trypanosomosis in Tanzania.

c/n	Measuring implication	Comments	Reference
1	Potential for zoonotic infection to man	- Showed the human infective parasite species such as *T. brucei* - Host : Domestic animals such as cattle, sheep, pig and goats, tsetse flies, wildlife such as wildebeest (*Connochaetes*), chimpanzees - Studies from Tanzania mainland were considered - The studies focused on those areas where there is human/wildlife/livestock interface	[1,6,7,12,22,27,30-36]
2	Reduce family happiness due to the hindrance of social provision caused by trypanosomosis	- Fear of losing diseased animal and human - Much time spent to search for the solution of the diseased animals and sometimes disconnect the family - More financial resources used for treatment instead of other social activities like food, shelter, health, and education. - The pastoralists have a generally negative attitude towards trypanosomosis due to loss caused to livestock	[15,29,31,34,37-39]
3	Pushes the herders with their cattle in proximity to dangerous (predators) Wildlife, more risk zone as they practice diseases avoidance	- In avoiding areas with Trypanosomosis and other diseases the herder move crosser to protect which are riskier. - The risk areas having high interaction of wildlife-livestock - The risk areas have more vectors and prone to other diseases infection - The risk area has a high chance of predation to livestock - Increase of Human/livestock/wildlife conflicts	[1-3,5,7,12,21,23,27,30-32,35,36,40-45]
4	Reduced quality and productivity	- Low Milk production - Death of livestock - Reduced meat off take - Increase calving rate, - Increase in calf mortality - Reduced quality for meat, milk, hide, draught power - Reduced income to pastoralists	[11,41-44]
5	Increased management cost	- Treatment diseased animal - Controlling such as Spraying - Diagnosis cost	[11,15,23,24,29,40,42]

Note: The literatures focused more findings for the studies done in Tanzania particularly those areas proximal to protected areas except for few cases. The areas was considered proximal if it is located around protected areas such as National park, game reserves and receives wildlife from protected areas.

Table 2: The economic loss in terms of cattle died, treated, diseases management caused by trypanosomosis in cattle costs for the year 2011-2013.

Year	Diseased	Treated	Recovered	Died	Loss by Death (USD)	Loss by Treatment (USD)	Loss by spray and control (USD)	Total cost (USD)
2011	7,414	7,398	6,843	762	266,700	40,689	25,949	333,338
2012	9,431	8,582	8,612	916	320,600	47,201	33,009	400,810
2013	73,99	7,287	6,539	871	304,850	40,079	25,897	370,826
Total	24,244	23,267	21,994	2,549	892,150	127,969	84,855	1,104,974
Cattle purchasing price was 350USD, treatment and spray cost per cattle per year 5.5 USD and 3.5 USD respectively								

Table Source: (Modified from Ngongolo, Mtoka, & Rubanza [31]).

Note: The monetary value in terms of cattle price and costs for treatment and spray was estimated as suggested by Muhanguzi et al. and Reporter [15,16].
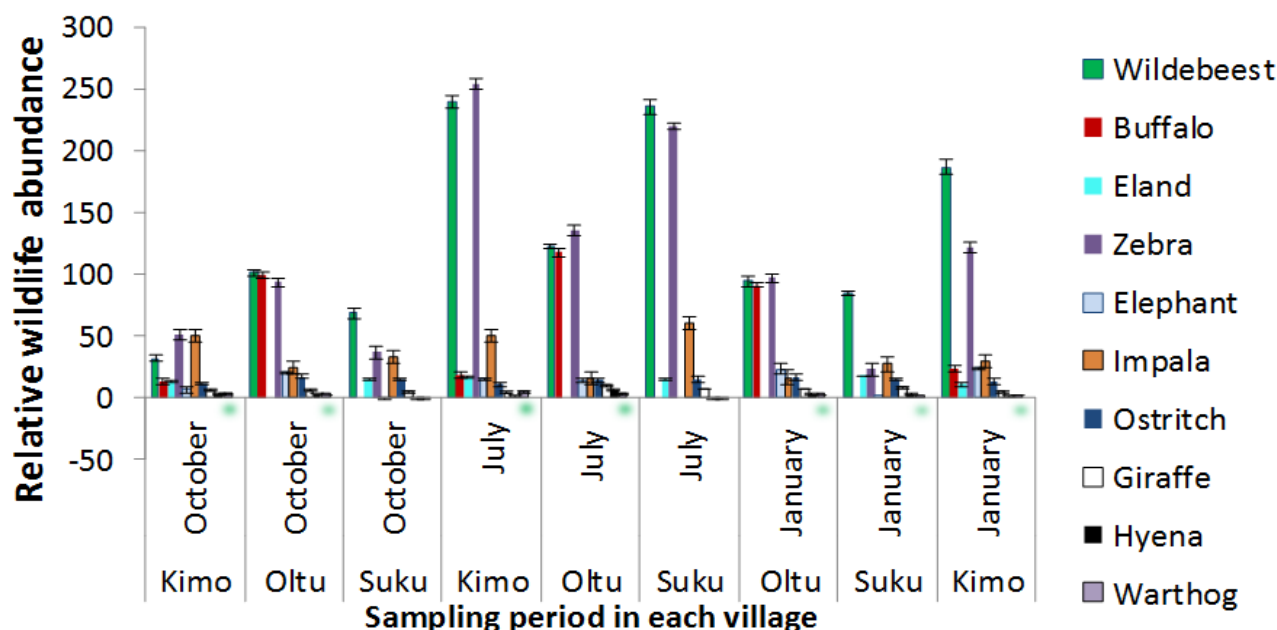
Figure 4: The relative abundance of wildlife for the three sampling period of July 2017, October 2017 and January 2018 for each of the three study villages Kimtorok (Kimo), Sukuro (Suku) and Oltukai (Oltu).

Table 3: Generalized linear mixed model on the overall association between the prevalence of Trypanosome infections in cattle and abundance of wildlife species.

Variables		Estimate	Std. Error	OR	p
	(Intercept)	-1.647	2.051		0.6096
Wildebeest	Moderate	-1.145	5.958e-01	0.41	0.0546
	Low	-1.522	7.702e-01	0.86	0.0481*
Buffalo	Moderate	-1.145	7.385e-01	1.04	0.4438
	Low	1.319	6.344e-01	2.93	0.0375*
Zebra	Moderate	3.0038	1.2857	0.33	0.019478*
	Low	-1.871	8.369e-01	0.91	0.0253*
AIC = 302.1, logLik = -138.0					
Interaction of wildlife species which showed significant association with trypanosome infection					
Interacting species		**Estimate**	**Std. Error**	**OR**	**p**
	(Intercept)	-5.43	1.65		0.000976***
Bufallo*Zebra	Moderate	-3.70	1.52	2.1	0.014826*
	Low	-1.21	4676.88	1.3	0.999793
AIC = 297.3, logLik = -130.7					

* = Significant; ** = High significant, *** = Highly significant.

Only those wildlife which showed significant association effects were presented in this table. Model used binomial errors where p = probability value, intercept represent high abundance. OR = Odd ration where OR > 1 shows positive association while OR < 1 shows negative association.

hogs exhibited the least abundance (Figure 4). High peaks of relative wildlife abundance were observed in July 2017 and January 2018 with clear distinction for wildebeests, zebra, and buffalo in Kimotorok village (Figure 4).

The likelihood of cattle being infected with trypanosome infection was observed in the low and moderated abundance of wildebeest, zebra, and buffaloes (Table 3). There is more infection of trypanosomes in cattle when zebra and buffalo are present at the same time

(Table 3).

Land cover and prevalence of trypanosome infections

Influence of habitat types: The overall estimated size of the grazing area using Google earth Pro was 1102 Km². The villages varied in their sizes of grazing areas where Sukuro had 667 Km², Kimotorok 227 Km² and Oltukai at 208 Km². Five habitat types were identified within the grazing areas for the three study villag-
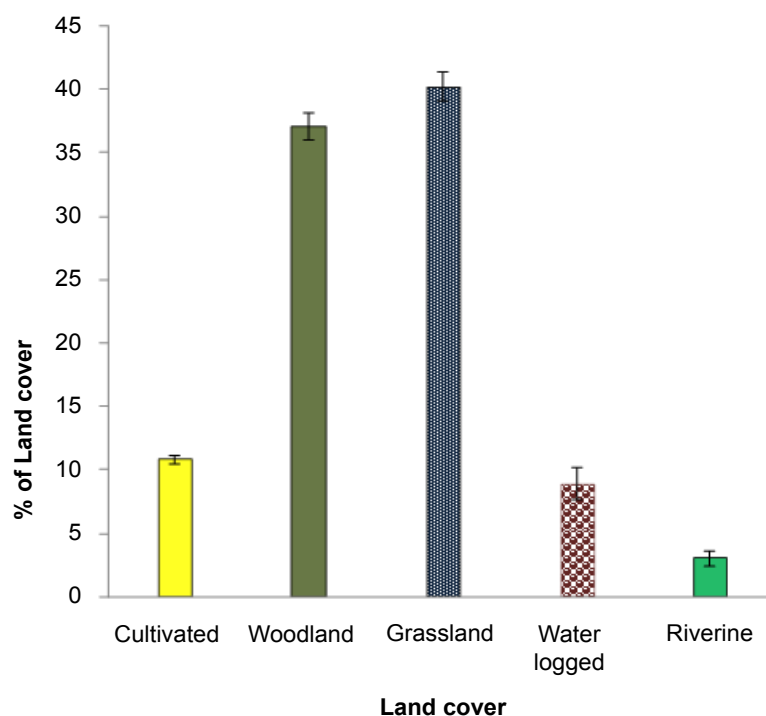
Figure 5: The overall percentages of land cover (habitats and cultivated area) in grazing areas in the study areas.
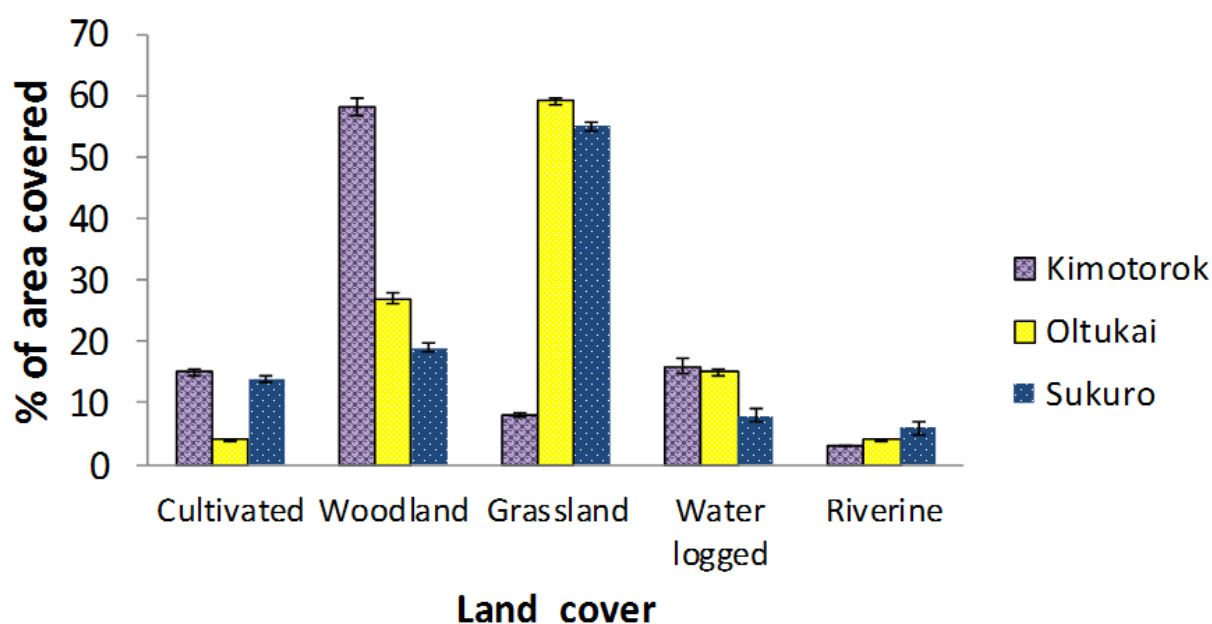

Figure 6: Land covers for habitats and cultivated area in grazing areas in each of the three village (Kimotorok, Oltukai and Sukuro) during the study period.

es: Woodland, grassland, waterlogged areas and riverine. The grazing areas were dominated with grassland and woodland while being least for riverine (Figure 5). The percentage cover of different types of habitats varied among the three villages whereby woodland dominated in Kimotorok, grassland dominated in Sukuro and Oltukai while least percentage cover of riverine in all the three villages (Figure 6).

The likelihood of cattle being positively infected with trypanosome infection was greater when cattle grazed in woodland, as opposed to grassland which showed a negative association with trypanosome infection (Table 4). However, variation in infection was observed when considering the three villages separately. For instance, both percentage cover of grassland and woodland revealed positive associations with trypanosome infection in Kimotorok (Table 5).

Association between Agricultural human activities and trypanosome infection in cattle: Highest percent of cultivation in grazing areas was observed in Sukuro and Kimotorok villages while Oltukai had the least (Figure 5). The difference in the percentage

Table 4: The association of land covers (habitat type and cultivation) with the prevalence of trypanosome infections in cattle of the Maasai Steppe. Season of sampling was considered as a random effect. The effects of the habitats were compared to the intercepts.

	Fixed Effect	Estimate	Std. Error	OR	p
	(Intercept)	-1.51	0.58		0.08
1	Cultivation	-12.02	0.04	0.92	< 0.001**
2	Woodland	-0.08	0.03	1.02	0.01*
3	Grassland	-0.08	0.03	0.98	0.009**
4	Water logged	-0.04	0.03	0.93	0.16
5	Riverine	0.07	0.09	0.92	0.47
6	Random effects (Villages)	Variance = 0.73			
7	AIC	277.4			
8	logLik	-131.7			

* = Significant; ** = High significant, *** = Highly significant.

Table 5: The association of land covers (habitat type and cultivation) with trypanosome infection in cattle of the Maasai Steppe for each of the three villages (Kimotorok, Sukuro and Oltukai).

	Kimotorok			Sukuro			Oltukai		
Variables	Coeff	OR	P	Coeff	OR	P	Coeff	OR	P
Intercept	-0.29		< 2e-16	12.43		0.03	28.70		0.051
Cultivation	0.03	1.04	< 2e-16	-0.12	0.88	0.02	0.27	1.31	0.6
Woodland	-0.01	1.01	< 0.001	-0.13	0.86	0.09	-0.27	0.76	0.09
Grassland	-0.012	1.02	0.002	-0.14	1.01	0.01	-0.40	0.66	0.01
Water logged	-0.03	1.05	0.533	0.005	0.87	0.9	-0.03	0.71	0.81
Riverine	-0.85	1.10	< 2e-16	-0.17	0.84	0.52	-0.18	0.84	0.56
Random effects; Months	Variance = 2.54			-			0.03411		
	Std = 1.594			-			0.1847		
AIC	88.3			104.6			71.8		
log Lik	-37.1			-45.3			-45.0		

Months of sampling were considered as random effect. The effects of the habitats were compared to the intercepts. Family = Binomial. OR = Odd ration where OR > 1 shows positive association while OR < 1 shows negative association.

of cultivated areas in the grazing areas between the three villages varied significantly (KWS = 243.788, P < 0.001, df = 2).

In addition, cultivation was observed to be associated with the trypanosome infection. Overall, the impact was negative with OR < 1 (Table 4). In considering each study village, a significant positive association was observed in Kimotorok (Table 5).

Discussion

We examined the association of ecological factors with the level of trypanosome infection in cattle on the Maasai steppe ecosystem, in order to highlight the socio-economic effect of trypanosomosis on the pastoral communities. We observed that, some ecological factors particularly habitat (woodland and grasslands), wildlife (wildebeest, buffalo, and Zebra) and cultivation in grazing areas are significantly associated with the trypanosome infection in cattle of the Maasai steppe. This is in agreement with previous studies which showed that ecological factors (wildlife diversity and habitats) are either positively or negatively associated with the trypanosome infection and other livestock diseases such as bovine tuberculosis and East coast fever which have been reported in many other studies [2,7,21,23-25].

Wildlife abundance and prevalence of trypanosome infections in cattle

Overall wildlife abundance, regardless of species, revealed a positive association with cattle becoming infected with trypanosome infection in a wildlife-cattle system. Resident wildlife species such as buffaloes showed a positive association with the trypanosome infection in cattle. The positive association can be explained to either of these species being reservoirs of trypanosome parasite or other hosts such as other wildlife and domestic animals but does not demonstrate that this is indeed the causal effect. As such the presence of host species in the grazing areas did not show that wildlife promoted the circulation of trypanosome infection in cattle. However other studies done in Kenya which also indicated that, buffaloes

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are infected with *Trypanosoma congolense, T. brucei brucei* and *T. vivax* [26] Furthermore, it has been observed by studies from Serengeti in Tanzania and Luangwa Valley in Zambia that, the existence of wildlife species and tsetse flies in favorable habitat have facilitated the existence of trypanosome infection in these ecosystem [7,13] so this study is in line with these findings.

Although, buffaloes showed a positive association with trypanosome infection, still the presence of other wildlife species such as Impala, Eland, Giraffe, and Ostrich in the ecosystem and other factors should not be underestimated since they have been reported to harbor trypanosome parasites in other findings [7,13,22]. Seasonal and migratory behavior of wildlife between Tarangire National Park and the adjacent areas explain the importance of wildlife in trypanosomes transmissions. A study by Ngonyoka et al., (2017) showed that, host species like wildlife play a significant role in the abundance of tsetse flies with a greater impact during the dry season.

Land cover and the prevalence of trypanosome infections

Although five categories of habitats were identified in the study area, woodland showed a positive and significant association on trypanosome infection in cattle while grassland presented a negative association. The positive association of woodland on trypanosome infection can be tied to the vectors existing in this habitat type. Previous studies in this area have shown that the most abundant species for tsetse flies in this area that could utilize the woodland habitats are *Glossina morsitans, G. swynnertoni* and *G. pallidipes* [27] which are vectors for important trypanosome species in this area like *Trypanosoma brucei, Trypanosoma vivax* and *Trypanosoma congolense* [1]. In addition, the influence of habitats is tied with the season and dominated habitat type. The study area was dominated by woodland and physiognomy of habitats changes between the dry season and wet season. A study by Ngonyoka, et al. showed that, habitats type like ecotone zone between woodland and grassland play a significant role in the abundance of tsetse flies with greater impacts in the dry season.

Cultivation activities exhibited a negative association with the trypanosome infections in cattle with discrepancy among villages, with a larger positive association in Kimotorok. Human activities such as agriculture (cultivation) played a significant role on the abundance and distribution of tsetse flies vectors and wildlife hosts species for trypanosome infection. The negative association between the cultivation and prevalence of trypanosome infection can be explained by habitats being destroyed and driving wildlife reservoirs and tsetse flies away from this area. This is supported by findings in another study done

in Kenya which showed that, cultivation as a means of human development in a growing population destroys the habitats for tsetse flies [26,28].

In this study, while not conclusive, does suggest that, unless proper control strategies are undertaken, the socio-economic impact of trypanosomosis to pastoralists will continue to be a perplexing and challenging matter. Loss of income, reduced quality and quantity of livestock products, management cost, and little provisions of socio-services were highlighted to be among the socio-economic implication of trypanosomosis in cattle. Similar trends have also been observed in Ethiopia where trypanosomosis was observed to result in both reduced milk and meat uptake, decreasing calving rate and mortality, increase management costs a cost estimated in US$28.23 spent on preventive while US$18.2 spent on curative per house hold [11]. The findings from Zimbabwe showed that the direct economic cost of trypanosomosis was $1.8 million per year which is equivalent to $7.60 per cattle with estimated average indirect cost for controlling the diseases in 1991 to be $4.3 million [29].

Conclusion

Ecological factors in the Maasai steppe had a significant association with trypanosome infection in cattle. However the level of association on infection varied among villages, habitat types, and wildlife species involved. Woodland revealed a positive association while cultivation lowered the infection rate by destroying the habitats for wildlife and tsetse flies. Although cultivation showed a negative association with the infection, yet the observed positive associations particularly in Kimotorok need not to be underestimated. The positive association of cultivation is possibly due to cattle being driven to pristine habitat with high abundance of tsetse flies and wildlife. For instance, in this study the co-existence of cattle and wildlife like buffalo showed positive significant impact on the infection of trypanosome in cattle.

We recommend control strategies for trypanosomosis in the livestock-wildlife interaction ecosystem to consider some factors, among them: Habitats, wildlife, and cultivation. In addition, integrated trypanosome control strategies between wildlife conservation stakeholders and livestock keeper (pastoralists) in the Maasai steppe is essential to minimize associated socio-economic impacts to pastoralists. More public education to the pastoralists on the transmission, effect of wildlife and control strategies is imperative to be done.

Acknowledgements

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