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Kibona, Tito

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Article

Taenia multiceps in Northern Tanzania: An Important but Preventable Disease Problem in Pastoral and Agropastoral Farming Systems

Tito Kibona [1,2,*], Joram Buza [1], Gabriel Shirima [1], Felix Lankester [2,3], Jahashi Nzalawahe [4], Abdul-Hamid Lukambagire [4], Katharina Kreppel [1,5], Ellen Hughes [6], Kathryn J. Allan [6,7] and Sarah Cleaveland [6]

1 Nelson Mandela African Institution of Science and Technology, Arusha, Tengeru P.O. Box 447, Tanzania
2 Global Animal Health Tanzania, Arusha P.O. Box 1642, Tanzania
3 Paul G. Allen School for Global Health, Washington State University, Pullman, WA 99164, USA
4 College of Veterinary Medicine and Biomedical Sciences, Sokoine University of Agriculture, Morogoro P.O. Box 3015, Tanzania
5 Department of Public Health, Institute of Tropical Medicine, 2000 Antwerp, Belgium
6 Institute of Biodiversity, Animal Health & Comparative Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow G12 8QQ, UK
7 School of Veterinary Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow G12 8QQ, UK
* Correspondence: kibonat@nm-aist.ac.tz; Tel.: +255-763717678

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Abstract: Coenurosis due to *Taenia multiceps* has emerged as a major concern to small ruminant-owning communities in northern Tanzania. Although a high incidence of disease has been reported, gaps still remain in our knowledge of the disease problem across different agro-ecological settings. The study aimed to determine the prevalence of coenurosis in small ruminants and taeniid infection in dogs and identify risk factors for infection. Questionnaire surveys, postmortem examination of small ruminants, and coproscopic examination of dog faeces were used to collect data on reported coenurosis cases and taeniid infections, respectively. The twelve-month period prevalence of coenurosis in small ruminants was 8.4% (95% CI 8.2–8.6). The prevalence of taeniid infection in dogs was 12.5% (95% CI 9.1–17.4). The village-level prevalence of coenurosis in sheep and goats was significantly correlated with taeniid infection prevalence in dogs (r = 0.51, $p = 0.029$). Multivariable analysis indicated that home slaughter was significantly associated with the livestock owner-reported neurological syndrome due to coenurosis in sheep and goats (OR = 13.3, 95% CI 4.2–42.0, $p < 0.001$) and the practice of offering discarded brains to dogs was significantly associated with taeniid infection prevalence in dogs (OR = 2.80, 95% CI 0.98–7.98, $p = 0.05$). Coenurosis is a major disease problem in livestock-keeping communities of northern Tanzania, but there is little awareness of transmission risks associated with home slaughter and dog feeding practices. There is a need for veterinary and animal health services to engage more actively with communities to increase awareness of the transmission cycle of *T. multiceps* and the preventive measures that can be taken to reduce the impact of disease in livestock-dependent communities.

Keywords: *Taenia multiceps*; small ruminants; risk factors; dog management; coenurosis; Tanzania

1. Introduction

Taeniid tapeworms represent an important group of parasites that threaten the health of both livestock and humans. The impact of taeniids in both veterinary and public health is primarily confined to the metacestode stage of the parasite in the intermediate host [1]. One important taeniid species is *T. multiceps*, a cestode of dogs and wild canids, which is the cause of a fatal disease called cerebral coenurosis in small ruminants [2–5]. The parasite has zoonotic potential, with occasional cases of coenurosis in humans reported in different parts of the world including Italy, Israel, North America, Uganda, and Egypt [6–8]. Human teniid infection, such as cerebral coenurosis (*T. multiceps*), occurs with the ingestion of parasite eggs from contaminated environment, food, or water [1]. However, human infections are not involved in the complete life cycle of these parasites making human a dead-end host. Small ruminants become infected with *T. multiceps* following ingestion of eggs from contaminated pastures and water. Following ingestion (in both human and livestock hosts), the hatched oncosphere penetrates the intestinal wall and enters the blood stream and finally makes its way to the brain and spinal cord [3,9,10]. Metacestode larvae have a high affinity to cerebrospinal fluid (CSF), which stimulates differentiation and development into cysts [11].

Transmission to dogs and other canids, the definitive hosts, occurs when metacestodes in the brain or spinal cord of coenurosis-affected goats or sheep are eaten and develop into mature *T. multiceps* worms in the intestines [2]. The adult worms shed proglottids into the host's faeces with each mature proglottid containing up to 37,000 eggs, allowing canid hosts to amplify infection within an ecosystem [3,12,13]. In dogs, *T. multiceps* infection is typically subclinical with few health impacts; however, under heavy infestation dogs can demonstrate non-specific gastrointestinal syndrome such as abdominal pain, diarrhea, and constipation [14]. Although there is limited clinical impact in dogs, treatment of *T. multiceps* and related cestodes (such as *Echinococcus granulosus*) in dogs is recommended to safeguard ruminant hosts [14,15]. Deworming treatment of dogs using praziquantel and other preventive strategies such as avoidance of feeding raw offal from animal carcasses to dogs, can be highly effective in the control of these taeniids [5,16].

The parasite is distributed worldwide and is well-recognised as a cause of small ruminant disease [2]. However, there is evidence to suggest that coenurosis due to *T. multiceps* has become a growing threat to the health of small ruminants in eastern and other parts of Africa [17–24]. However, despite the availability of preventive measures, very little attention is being given to address the disease. In Tanzania, cerebral coenurosis appears to be emerging as a major health problem in small ruminants in pastoral communities [20,24–26]. In a recent small-scale study in northern Tanzania [24], over 80% of cases of neurological syndrome in sheep and goats were caused by the *T. multiceps* metacestode. *Coenurus cerebralis* and coenurosis was identified as the cause of very high mortality in small ruminants [24]. In another study, farmers ranked neurological syndromes, locally known as *Ormilo*, as the most important health problem in sheep and goats in pastoral communities of northern Tanzania [26]. Although canids are known to be the definitive host of *T. multiceps*, little is known about the prevalence and determinants of taeniid infection in dogs in these areas. The aim of this study was to: (a) determine the prevalence of coenurosis in small ruminants and taeniid infection in dogs across a range of agro-ecological systems in northern Tanzania: (b) identify risk factors for coenurosis in small ruminants and taeniid infection in dogs.

2. Results

2.1. Prevalence

The prevalence of reported cases of coenurosis across a period of twelve-months in small ruminants was 8.4% (95% CI 8.2–8.6) with a prevalence of 9.4% (95% CI 9.2–10.0) in pastoral and 7.3% (95% CI 6.5–8.2) in agro-pastoral systems. The difference in farmer-reported coenurosis prevalence between two livestock systems was statistically significant ($\chi^2 = 18.9$, df = 1, $p < 0.0001$). Postmortem examinations were conducted in 139 small ruminants, 90.6% (126/139) from local abattoirs and 9.4% (13/139) were conducted from home-slaughtered animals. Results from postmortem surveys at slaughter points revealed a coenurosis prevalence of 15.1% (95% CI 9.5–22.8) among small ruminants brought to slaughter. The prevalence of coenurosis cysts in home-slaughtered animals, which were all slaughtered due to suspected coenurosis, was 69.3% (95% CI 38.9–89.9). Analysis of faecal samples for Taeniid in dogs revealed an overall prevalence of 12.5% (95% CI 9.1–17.4) with a prevalence of 15.6% (95% CI 9.7–24.2) in pastoral and 10.9% (95% CI 6.9–16.8) in agro-pastoral but, these were not statistically significant across livestock systems (χ^2 = 0.8096, df = 1, *p* = 0.3682). Overall, the interquartile range egg count per gram (g) of faeces was 100 (range 50 to 250) eggs/g (Table 1).

Table 1. Taeniid counts among positive tested dogs in livestock keeping communities in rural northern Tanzania.

Category Reference	Eggs Count		Egg Count Range		95% CI	
	Median	Mean ± SD	Min	Max	Lower	Upper
Overall (*n* = 32)	100	97 ± 55	50	250	77	116
Pastoral (*n* = 15)	50	83 ± 41	50	150	61	106
Agro-pastoral (*n* = 17)	100	109 ± 64	50	250	76	142

2.2. Correlation Results

There was a positive correlation between village-level prevalence of taeniid infection in dogs and reported coenurosis in small ruminants r = 0.51, *p* = 0.029 (Figure 1).

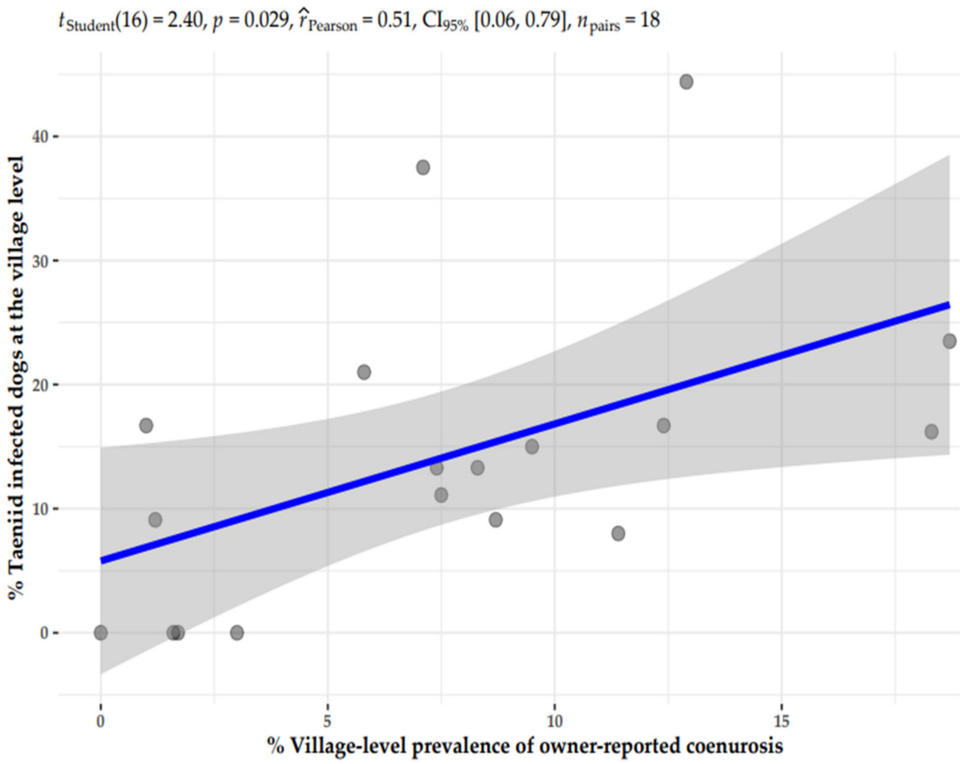

Figure 1. Pearson's correlation analysis between taeniid infection in dogs and the village-level prevalence of owner-reported neurological syndrome (*Ormilo*) in small ruminants in northern Tanzania.

2.3. Descriptive Results on Risk Determinants of Coenurosis Prevalence and Taeniid Infections in Dogs

A detailed risk factor survey was conducted in 111 pastoral and 137 agropastoral households randomly selected from 18 villages. Out of 111 households interviewed through a questionnaire survey in pastoral communities, 82 (73.9%) households practiced home-slaughter in the last twelve months, while in agro-pastoralist households only 19.0% (26/137) reported home-slaughter during the same period. There were notable variations in practices for the management of brain materials from slaughtered, affected animals in these two livestock systems. In pastoralist households, 75.9% (95% CI 66.9–83.15) of the brains from coenurosis affected small ruminants were given to dogs directly while only 31.6% (95% CI 22.2–42.7) respondents did the same in agro-pastoral systems. While burning infected brains is considered an effective management option, it was rarely practiced in either pastoral or agropastoral communities (Table 2).

Table 2. Brain management and disposal practices reported by small ruminant keepers in rural northern Tanzania.

Disposal Practice	Livestock System	Frequency	Mean Percentage	95% CI	
				Lower	Upper
Buried	Agro-pastoral	2	2.63	0.72	9.10
Burnt	Agro-pastoral	5	6.58	2.84	14.49
Consumed	Agro-pastoral	6	7.89	3.67	16.17
Given to dogs	Agro-pastoral	24	31.58	22.23	42.70
Thrown away	Agro-pastoral	39	51.32	40.29	62.22
Burnt	Pastoral	2	1.92	0.53	6.74
Given to dogs	Pastoral	79	75.96	66.92	83.15
Thrown away	Pastoral	23	22.12	15.21	31.00

Across both agro-pastoral and pastoral (98.4%, 248/252) systems, nearly all dog-owning households left their dogs to roam freely throughout day and night. Overall, 40% (102/252) of households across both pastoral and agro-pastoral areas reported feeding dogs with household left-overs while offal was the second popular feeding option (27%, 70/252) (Table 3). Fifteen percent of households reported deworming their dogs. For those that did not deworm dogs, several reasons were given including: "no need for deworming dogs" 56% (n = 120), followed by lack of knowledge on appropriate deworming drugs for dogs 39% (n = 84). The cost of dewormers was the least mentioned reason given for not deworming dogs. A few households (n = 13) used non-taeniid target deworming agents, whereas only 13.3% (n = 2) dewormed their dogs using the correct treatment (praziquantel).

Table 3. Different dog feeding options mentioned by dog owners in the study on major determinants of taeniid prevalence in dogs in rural Arusha and Manyara regions in northern Tanzania.

Feeding Option	Frequency (%)	95% Confidence Intervals	
		Lower	Upper
Leftovers	102 (40.5)	34.6	46.6
Offal	70 (27.8)	22.6	33.6
Porridge	25 (9.9)	6.8	14.2
Left to scavenge	55 (21.8)	17.2	27.3

2.4. Analysis of Risk Determinants for Coenurosis and Taeniid Infections

Univariate logistic regression was used to determine how factors are linked to the prevalence of coenurosis in small ruminants (Table 4). This involved 248 households that participated in a detailed survey of risk determinants for the coenurosis prevalence in small ruminants.

A detailed survey on risk determinants of taeniid infections in dogs was carried out in 252 households and at least one fecal sample was collected from each household for taeniid prevalence in dogs. To determine how these risk determinants are linked to the prevalence taeniids in dogs, a univariate regression analysis was performed for each variable (Table 5).

Table 4. Results of univariate analysis of individual risk determinants and their relationship to farmers' reported cases of coenurosis in small ruminants in rural northern Tanzania.

Variables	Variable Category	Responses	*n*/N (%) ‡	Univariate Analysis	
				OR (95% CI)	*p*-Value *
Flock management	Livestock systems	Agropastoral	137/248 (55.2)	(Intercept)	
		Pastoral	111/248 (44.8)	17.02 (7.69–37.69)	<0.001
	Introduced animals	No	183/248 (73.8)	(Intercept)	
		Yes	65/248 (26.2)	2.36 (1.22–4.58)	0.011
	Home-slaughter	No	140/248 (56.4)	(Intercept)	
		Yes	108/248 (43.6)	22.67 (9.32–55.13)	<0.001
Water source	River (dry season)	No	160/248 (64.5)	(Intercept)	
		Yes	88/248 (35.5)	2.62 (1.44–4.75)	0.002
	River (wet season)	No	132/248 (53.2)	(Intercept)	
		Yes	116/248 (46.8)	2.00 (1.17–3.44)	0.011
	Dam (dry season)	No	120/248 (48.4)	(Intercept)	
		Yes	128/248 (51.6)	5.04 (2.83–8.98)	<0.001
	Dam (wet season)	No	67/248 (27.0)	(Intercept)	
		Yes	181/248 (73.0)	2.55 (1.43–4.55)	0.001
Grazing options	Transhumance	No	197/248 (79.4)	(Intercept)	
		Yes	51/248 (20.6)	8.38 (2.90–24.17)	<0.001
	Communal grazing	No	112/248 (45.2)	(Intercept)	
		Yes	136/248 (54.8)	6.32 (3.52–11.32)	<0.001

* Variable with $p < 0.25$ were included in the multivariate analysis, ‡ Proportion of households which reported risk practices to coenurosis in small ruminants in the last twelve months (*n* = number small ruminant keeping households which reported a particular risk practice to coenurosis in their flocks, N = total number small ruminant keeping households visited during the study).

Table 5. Summary of the univariate analysis on individual determinants and their relationship to copro-positivity of taeniids in dogs in rural northern Tanzania.

Variables	Variable Category	*n*/N (%) ‡	Univariate Regression	
			OR (95% CI)	*p*-Value
Livestock systems	Agro-pastoral	156/252 (62)	Ref	
	Pastoral	96/252 (38)	1.51 (0.72–3.19)	0.28
Herding dogs	Yes	95/252 (38)	3.74 (1.39–10.07)	<0.01 *
	No	157/252 (62)	Ref	
Deworming	Yes	38/252 (15)	0.78 (0.26–2.37)	0.66
	No	214/252 (85)	Ref	
Feeding brains	Yes	180/252 (71)	3.13 (1.06–9.28)	0.04 *
	No	72/252 (29)	Ref	
Feeding options	Leftovers	102/252 (40)	Ref	
	Offal	70/252 (28)	1.30 (0.56–3.01)	0.54
	Porridge	25/252 (10)	0.55 (0.12–2.58)	0.44
	Scavenge	55/252 (22)	0.49 (0.15–1.58)	0.23
Sex	Female	93/252 (37)	Ref	
	Male	159/252 (63)	0.83 (0.39–1.78)	0.64
Age †	Mature juveniles (0.5 ≥ years < 1)	13/252 (5)	2.22 (0.81–6.11)	0.122
	Early adulthood (1 ≥ years < 3)	107/252 (43)	Ref	
	Middle aged (3 ≥ years < 6)	99/252 (39)	0.62 (0.20–1.86)	0.393
	Late adulthood (6 ≥ years < 9)	26/252 (10)	1.94 (0.55–6.78)	0.300
	Senior (9 ≥ years)	7/252 (3)	1.36 (0.14–12.98)	0.791

† No puppies were involved in the study, only dogs ≥6 months of age were sampled, the age grouping criteria were as described by Wallis et al., 2020 but with modification for Mongrel dogs. * Variable with $p < 0.25$ were included in the multivariate analysis. ‡ Proportion of dog-keeping households which reported different dog management practices (*n* = number dog-keeping households which reported a particular practice, N = total number of dog-keeping households visited during the study).

Finally, a multivariate model for the determinants of prevalence of coenurosis in small ruminants and presence of taeniid infection in dogs was developed. Home-slaughter was the only variable significantly associated with neurological syndrome related to coenurosis prevalence (OR = 13.3, 95% CI 4.2–42.0, $p < 0.001$). Home-slaughtering households reported thirteen times more cases of coenurosis than those who did not slaughter in the same period. Home-slaughter practices were directly linked to taeniid infection in dogs. The final model indicated that dogs in the household which were fed brains in the last twelve months were just under three times more likely to test positive for taeniids than those not fed on brains in the same period (OR = 2.80, 95% CI 0.98–7.98, $p = 0.05$: Table 6).

Table 6. Multivariate analysis of household practices and individual dog attributes in relation to copro-positivity of taeniids in dogs and coenurosis in small ruminants in rural northern Tanzania.

Infection	Risk Factor	Response	*n*/N (%) ‡	OR (95% CI)	*p*-Value
Taeniid	Feeding brains	No	72/252 (29)	Ref	0.05
		Yes	180/252 (71)	2.80 (0.98–7.98)	
Coenurosis	Home-slaughter	No	29/111 (26)	Ref	<0.001
		Yes	82/111 (74)	13.3 (4.2–42.0)	

‡ Proportion of households which reported risk practices (*n* = number of households which reported a particular risk practice, N = total number of households visited during the study).

3. Discussion

The current study assessed the prevalence of owner-reported neurological syndrome, known locally as *Ormilo*, and associated risk factors in small ruminants in agro-pastoral and pastoral livestock systems in northern Tanzania. Furthermore, the study investigated the determinants of taeniid prevalence in dogs and the farmers' knowledge and practices in relation to coenurosis prevention established. The study confirmed coenurosis in a high proportion (69%) of animals slaughtered at home due to suspected *Ormilo*, somewhat lower than previous studies (82%) [24] but consistent with the interpretation that a large proportion of neurological cases in small ruminants in these communities is caused by *T. multiceps*. This interpretation is supported by the risk factor analysis showing that households practicing home (backyard) slaughter of small ruminants were thirteen times more likely to report cases of neurological disease in sheep and goats than those that did not. Since *T. multiceps* is known to be transmitted by consumption of cysts by definitive hosts (canids), our conclusion that the neurological condition, *Ormilo*, is caused primarily by *T. multiceps* is also strengthened by the observation of a higher prevalence of the neurological condition in pastoralist villages where risk behaviours such as feeding brains of small ruminants to dogs as described by Hughes et al., 2018 are reported more often.

The study adds to earlier studies [20,24–26], confirming that cerebral coenurosis is a major disease problem in pastoral farming systems in Tanzania, but additionally demonstrates a high disease prevalence (7.3%) in agro-pastoral flocks. The impact on productivity, food security and rural livelihoods in Tanzania is likely to be profound, given that these sectors comprise a very large proportion (35%) of livestock-owning households in the country, and provide more than 50% of milk and 90% of meat consumed in Tanzania [27].

Backyard slaughter practices can be linked to poor management of offal including brain material from infected small ruminants, which are often either fed to dogs or thrown away. Community social events and celebrations such as circumcision festivals and traditional wedding ceremonies, traditional medication retreat for Maasai (orpul) often involve massive, unsupervised backyard slaughter. Similarly, backyard slaughter has been reported commonly during festivals in Egypt [28]. Unsupervised backyard slaughter might be due to a shortage of human capacity to carry out extension services and meat inspection and is likely to be common in most rural settings in Tanzania [29]. Furthermore, Amer et al., 2017 stated that backyard slaughter was characterised by limited infrastructure for meat inspection leading to unsupervised disposal of brains rendering them accessible to dogs. Factors associated with backyard slaughter are likely be an important reason for the high prevalence of cerebral coenurosis in goats and sheep reported in many African countries [18,20,24,30].

Using faecal egg counts, we demonstrated a high prevalence of taeniid eggs in dog faeces in the study area. Morphologically, it is not possible to differentiate these eggs to species level using microscopic examination, so these results are not a definitive diagnosis of *T. multiceps* infection in these hosts. Despite this limitation, these results provide new insights into the epidemiology of dog-associated parasite infections in Tanzania. There is little information available on taeniid infections in local dogs, with previous work limited to a single study in Ngorongoro Conservation Area [31]. Our results demonstrate that taeniid infections are widespread in our study area and consistent with questionnaire results reporting a lack of worming practices in local households. Although the current study did not type taeniid eggs to the species level, the high prevalence of coenurosis provides circumstantial evidence that *T. multiceps* is likely to be present, potentially alongside other taeniids of zoonotic or animal health importance such as *Taenia hydatigena*, *Taenia ovis*, *Echinococcus granulosus*. Similarly, this study revealed a higher prevalence of taeniid infection in pastoral as compared with agropastoral systems, consistent with the higher prevalence of the coenurosis-related neurological syndrome reported in small ruminants in these pastoral livestock keeping communities.

Despite a high reported prevalence of coenurosis in small ruminants, this study demonstrated a lack of awareness among livestock keepers around the value of deworming dogs. For those that reportedly dewormed their dogs, only very few reported using an appropriate deworming drug for taeniids such as praziquantel. The common deworming agents used were those that treat round worm infections in ruminants (levamisole and albendazole), none of which were formulated to treat tapeworm infection in dogs. In Europe, deworming has been effective in controlling taeniids in dogs [32]. However, this approach is likely to be challenging in Tanzania, although cost was not commonly given as a reason for not deworming dogs, there may be little awareness of the costs involved in sustaining a high-frequency (approximately every 2 months) dosing regimen needed to control taeniid infections. Opportunities may arise for embedding control of Taenia with other dog-related interventions for public health, such as rabies vaccinations as proposed in a case study on the control of echinococcus in Morocco [33].

Despite uncertainties around the feasibility of de-worming dogs as a method of control, this study clearly highlights that feeding small ruminant brains to dogs poses a significant risk for taeniid infections. This provides an opportunity for potential low-cost behavioural interventions for disease control and prevention. These might include, for example, the cessation of feeding brains of slaughtered small ruminants to dogs and/or throwing the brains away in places where they may be scavenged by dogs from other households or by wild carnivores. Instead, brains should be burnt. Although these interventions are not costly, there may be constraints in relation to the lack of availability of other food for dogs, particularly at times when household food (which comprises a major part of dogs' diets) is in short supply. Nonetheless, dissemination of information about the life cycle of *T. multiceps* and the value of behavioural changes for prevention of coenurosis should be considered a high priority for animal health professionals working in communities suffering from a high disease burden.

4. Materials and Methods

4.1. Study Design

This study was conducted in northern Tanzania between January and December 2019. The study area included Longido, Karatu, Monduli and Ngorongoro districts in Arusha region; and Mbulu and Babati districts in Manyara region (Figure 2). The study villages were characterised by two predominant agro-ecological settings; pastoral and agro-pastoral. This study comprised multi-stage sampling consisting of three major stages:

Stage One: From purposively selected districts, a list was compiled of villages that had previously been selected at random from villages in northern Tanzania for a research study on zoonoses and emerging livestock system (ZELS) and subsequently classified as pastoral or agro-pastoral [34]. From this list, 18 villages were randomly selected comprising nine pastoral and nine agropastoral villages. Three additional villages were also selected in agropastoral livestock system for replacement of the originally selected villages in case of inaccessibility during the study due to weather and road infrastructure. For each village, a list of sub villages was provided by village leaders and at least two sub villages were randomly selected, and a questionnaire survey administered to all households in the sub-village owning dogs and/or small ruminants to collect information on self-reported cases of coenurosis in sheep and goats and potential determinants of *T. multiceps* and other taeniid infection. During the coenurosis survey a question was asked "Have any of your sheep or goats experienced a disease with persistent neurological syndrome (circling, ataxia, confusion and/or paralysis in the past twelve-months?" In addition, "What is the local name for the diseases you have described". To determine the validity of using farmer-reported cases of coenurosis, with the livestock owner's consent, the post-mortem examinations of brains were carried out on home-slaughtered animals with suspected coenurosis. Such post-mortem (PM) evaluation was conducted by the qualified study veterinarian to determine presence or absence of the cyst in the brain.

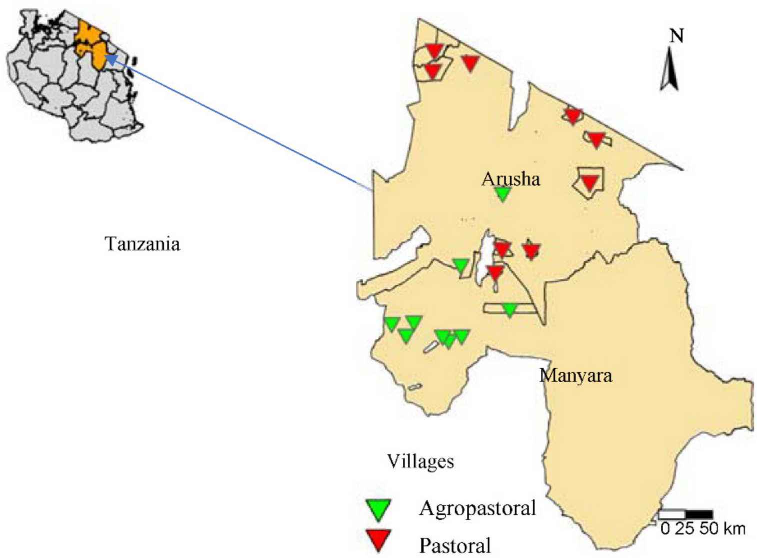

Figure 2. Map showing the position of the Arusha and Manyara regions in northern Tanzania with agro-pastoral (green triangles) and pastoral study villages (red triangles). Map created using using R statistical environment version 4.0.3 R Core Team (2021), Thematic Map R package [35]. Shape files for administrative boundaries from the 2012 census were sourced from the Tanzania National Bureau of Statistics (NBS).

4.2. Household Questionnaire Survey

Data were initially collected from all households in selected sub-villages to determine dog and small ruminant ownership, as well as slaughter and feeding brains of small ruminants during slaughter practices. For up to ten small ruminant owning households in selected villages, a more detailed second survey was carried out to collect information on reported cases of neurological disease in small ruminants that was consistent with coenurosis, using local terms as described above. Further, up to ten dog-owning households were randomly selected from each sub-village to collect data on the number of dogs grouped by age with dogs considered adult if they had reached reproductive age (approximately 9 months of age) and juveniles classified as dogs of 3–9 months of age. Puppies (under 3 months of age) were not included in this study since they are not fed meat or offal and hence are at low risk of taeniid infection. Dog owners were also asked about detailed practices relating to feeding of dogs, dog movement and confinement patterns, and deworming practices.

4.3. Postmortem Survey for Coenurosis in Small Ruminants

A further cross-sectional visit was conducted to slaughter points for at least two days during the data collection period at the study site. Slaughter points were identified through local experts (livestock field officers and meet inspectors) in their respective areas of jurisdiction. Postmortem inspection of the brains was performed in each small ruminant slaughtered with or without history of neurological syndrome. Individual animal data were collected, these included village name/livestock system at the slaughter point, age (by dentition), and sex. Preparation of the head and brain for inspection of *Coenurus* cysts was performed by the qualified veterinarian from the study team as described elsewhere [36]. All animals found with brain cysts, which is widely accepted as being diagnostic for coenurosis, were considered positive. Animals that had no brain cysts during inspection were considered free of the disease. Home (backyard slaughter) under supervision of the veterinarian was used to validate farmer reported cases, where presence of cyst in the brain was strong evidence for *T. multiceps* infection in small ruminants.

4.4. Coproscopic Examination of Taeniid in Dogs

To investigate taeniid infection prevalence in dogs, as many dogs as possible were restrained at each selected dog-owning household for collection of faecal samples. Up to 10 g of fresh faecal material was collected from each dog for coproscopic examination to identify and quantify taeniid worm burden. During sample collection dogs were humanely restrained and faecal samples were collected per-rectum with well-gloved fingers. In an event where dogs were difficult to handle, households were re-visited after advising dog owners to feed the dog a well-cooked meal in the morning, after which most dogs would defecate. Faecal samples were stored at refrigeration temperature (4 °C) in a mobile fridge before laboratory examination. At the end of the visit, all participants received advice on dog care and were taught how to treat their dogs for worms. All dogs received a single dose of praziquantel at the time of this visit (25 mg per 5 kg body weight). During laboratory examination, faecal taeniid egg counts were determined using a modified McMaster technique as described previously [37–39]. The technique is based on the concentration by centrifugation and flotation using Sheather's sucrose solution specific gravity of 1.27 [39].

5. Data Management and Analysis

5.1. Data Analysis Plan

Data from both surveys were entered into Microsoft Excel® (Microsoft Corporation, Washington, WA, USA) before analysis using R statistical environment version 4.0.3 R Core Team (2021). Descriptive statistics on village data were summarised as: percentage of responses on risk determinants of coenurosis in small ruminants and various management options for dogs across livestock systems in rural northern Tanzania. A chi-square analysis was carried out to examine differences in household risk practices in each management option for dogs and small ruminants in different agro-ecological settings. In each chi-square analysis, a p-value of $\leq$0.05 was considered statistically significant. Determinants of risk factors for coenurosis in small ruminants and taeniid infection in dogs were identified through univariate and multivariate mixed logistic regressions.

5.2. Prevalence

In small ruminants, the farmer-reported twelve-month period prevalence for coenurosis was calculated as the number of cases of suspected coenurosis reported in the village flock over the last twelve months divided by the total number of small ruminants owned by the farmer over the past twelve months. In addition, postmortem examination surveys were conducted from identified slaughter points available within the village. Therefore, prevalence of coenurosis from postmortem surveys were determined as the total number of heads in which coenurus cysts were recovered divided by the total number of all heads inspected for coenurus cysts. However, home-slaughtered small ruminants inspected for coenurosis were not considered during estimation of the prevalence due to bias since were known to be sick and salvaged due to their health status.

The prevalence of taeniid infections was estimated as the proportion of taeniid positive dogs out of the total number of dogs tested in each agro-ecological setting. Finally, the preliminary analysis performed a Pearson's correlation analysis between taeniid infection in dogs and neurological syndrome prevalence at the village flock to establish a relationship between the two aspects involved in the *T. multiceps* cycles.

5.3. Logistic Regression Analysis for Risk Determinants for T. multiceps

A mixed effects logistic regression analysis was employed to identify and investigate potential determinants of coenurosis infections in small ruminants and taeniid infection in dogs.

(a) T. multiceps coenurosis infection in small ruminants

First, univariate regression analysis was performed for each predictor variable for coenurosis infection in small ruminants, The outcome variable was the "number of neurological cases" in the last twelve months and predictor variables were "backyard slaughter", "livestock system", "introduced animals", "water source (dry season and wet season)", "transhumance practices" and "communal grazing". Second, variables that were significant at a level of $p \leq 0.25$ in univariate analysis were included in the final multivariable model. The final model was arrived at by backward stepwise approach where non-significant predictors were iteratively removed while those with $p < 0.05$ retained and the Akaike information criterion (AIC) was used parsimoniously to select the best model. In multivariable analysis, mixed effect logistic regression was employed with households and villages included as random effects. Additionally, interactions and confounding effects between independent variables in the multivariable analysis were tested by adjusting for significant variables included in the model using Likelihood Ratio Tests (LRTs).

(b) Taeniid infection in dogs

To establish the key predictors for prevalence of taeniid infections in dogs, a univariate regression analysis of each predictor variable for taeniid infection in dogs was performed first. The outcome variable was taeniid positivity in a dog (yes/no) determined as either presence of eggs or recovery of segments of mature taeniid in the coproscopic examination. The predictor variables were: age, sex (male or female), livestock system (pastoral or agro-pastoral), and behavioural characteristics, including whether the dog was used for herding (yes or no), moved with the herders during grazing, and had been dewormed in the past twelve months (yes or no), and feeding practices, including whether brains were fed to dogs (yes or no), or the type of feeding practices (offal, porridge, leftovers, scavenging). The age as the only continuous variable for dogs, for the purpose of analysis the age groups (adult and juveniles) were categorized further by grouping as: mature juveniles ($0.5 \geq$ years < 1), early adulthood ($1 \geq$years < 3), middle aged ($3 \geq$ years < 6), later adulthood ($6 \geq$ years < 9), and seniors ($9 \geq$ years) as described by Wallis et al. [40]. Second, variables that were significant at a level of $p \leq 0.25$ in univariate analysis were included in the full multivariable models for taeniid infection in dogs. The final models were built by backwards elimination, dropping one variable at time from the full model based on (AIC). Likelihood ratio tests (LRTs) were used to check the significance of each variable in the final model. A p-value ≤ 0.05 of the LRT was considered significant and the variables were retained in the model. Interaction and confounding effects were tested using LRT and the significance of p-values on the presence or absence of the variable with respect to others.

6. Conclusions

Cerebral coenurosis is a major disease problem affecting sheep and goats in both pastoral and agropastoral settings in Tanzania. Dog feeding practices, specifically the practice of feeding sheep/goat brains to dogs, is a significant risk factor for taeniid infections in dogs, consistent with known transmission routes of *T. multiceps*. Deworming of dogs is not commonly practiced and when practiced, anthelminthics are mostly used inappropriately. In addition, there is little awareness of the value of deworming dogs, including in relation to prevention of coenurosis. Interventions to prevent and control coenurosis could include behavioural interventions around safe disposal of sheep/goat brains and deworming of dogs, however, the costs of maintaining a high-frequency deworming regime may make this harder to sustain than low-cost behavioural interventions.

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Informed Consent Statement: Written informed consent has been obtained from the small ruminants' owners on home-slaughtered animals with suspected coenurosis, dogs' faecal collection, and household questionnaire surveys on risk factors for coneurosis and taeniid infections in small ruminants and dogs respectively.

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