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A simple, collaborative prioritization process for wildlife-associated zoonotic diseases in northern Tanzania

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Abstract

Background and Aim: Zoonotic diseases are naturally transmissible infections between animals and humans. To address these cross-sectoral health issues holistic, transdisciplinary health approaches are required. The legalization of the game meat trade in Tanzania in 2020 has created a new value chain from wild habitats to registered game meat selling facilities in human settlements, thus creating new human–animal interfaces associated with potential risks of zoonotic disease transmission among wildlife, livestock, and human populations. This study aimed to apply a simple, collaborative prioritization process to identify important zoonotic pathogens associated with wild animal taxa harvested and traded for game meat consumption in northern Tanzania.

Materials and Methods: A prioritization process was conducted to identify and rank zoonotic diseases associated with wildlife in the Arusha, Kilimanjaro, and Manyara regions of northern Tanzania to help determine the zoonotic disease risks associated with the game meat value chain. Two districts from each region were selected for this study. The prioritization process was conducted through an expert workshop that involved 41 participants, including a District Veterinary Officer, Public Health Officer, and District Game Officer from each district, as well as national One Health focal persons, zonal Veterinary and Laboratory Officers, scientific researchers, and a representative from the national Game Meat Selling Advisory Committee.

Results: Experts identified 11 common zoonotic diseases reported in these regions, of which anthrax, rabies, brucellosis, Rift Valley fever, and bovine tuberculosis were considered the most important. This finding is broadly consistent with the national priority list for zoonotic diseases.

Conclusions: This approach was time-efficient and cost-effective. In Tanzania, multi-sectoral planning, communication, and cooperation among human health, domestic animal health, wildlife health, and environmental protection have been strengthened. In the future, we recommend regular exercises using such an approach to update the information on important diseases and promote information sharing for epidemic and pandemic preparedness associated with the wild animal trade.

Keywords: epidemic and pandemic, expert opinion, game meat, one health, wildlife, zoonoses.

Introduction

Infectious diseases naturally transmitted between animals and humans are usually referred to as zoonotic diseases. Emerging infectious diseases (EID) that cross species boundaries have garnered increased attention recently due to their potential impact on public health and are of major concern globally [1]. Out of all EID events, 60.3% are primarily associated with zoonotic transmission, with 71.8% of those events having a source in wildlife. Emerging and re-emerging human zoonotic diseases have resulted in approximately 2.7 million human deaths every year since the 1970s [2]. In Tanzania, zoonotic diseases such as bovine tuberculosis, rabies, brucellosis, anthrax, and Rift Valley fever have been demonstrated to compromise human health, livestock productivity, and food security [3–5].

Trade in wildlife and wild meat increases the possibility of transmission of viral and bacterial pathogens from wildlife to humans and of associated zoonotic diseases [6]. Following the publication of the Game Meat Selling Regulations in Government Gazette

no. 84 of February 7, 2020, the rapidly expanding game meat trade in Tanzania raised concerns about the potential for known and novel pathogens of a zoonotic nature to spread from wildlife through various human–animal interfaces (including hunting, slaughter, preparation, transport, and sale of wild meat) to infect humans and livestock. This concern occurred at the same time as the increase in public health concerns related to severe acute respiratory syndrome-related coronavirus and other zoonotic diseases at a global level. Multiple studies have highlighted risks of pathogen transmission and zoonotic disease from wild animal trade [7–9].

Global health problems require interdisciplinary, intersectoral expertise and close cooperation between government, non-government, and educational agencies to achieve optimal health for people, animals, and the environment. Given the increasing emphasis on global health, food, water, energy, and environmental issues, the benefits of cross-sectoral and transdisciplinary cooperation are becoming increasingly recognized. The One Health approach is an integrated and unifying approach that aims to balance and optimize the health of people, animals, and ecosystems sustainably [10]. It has the potential to protect health, address health challenges such as the emergence of infectious diseases, antimicrobial resistance, food safety, and promote the health and integrity of our ecosystems. It recognizes the interdependencies between human, domestic, and wild animal health. It helps to address the full spectrum of disease control from prevention and preparedness to detection, response, and management, thus contributing to global health security [11, 12]. This approach can be applied at community, subnational, national, and international levels but depends on shared and effective governance, communication, collaboration, and coordination. The cooperation achieved through this approach can make it easier for people to better understand the co-benefits, risks, trade-offs, and opportunities to develop equitable and holistic health solutions.

The Tripartite Zoonoses Guide (2019), developed jointly by the World Health Organization, Food and Agriculture Organization of the United Nations and World Organization for Animal Health (WOAH, formerly OIE) to support countries in addressing zoonotic diseases, and the WOAH and International Union for Conservation of Nature (IUCN)'s Guidelines for Wildlife Disease Risk Analysis (2014), are evidence of systematic approaches and global commitment to collaboratively handling health issues [13, 14].

In Tanzania, a One Health Zoonotic Disease Prioritization Workshop coordinated by the USA was held in March 2017, connecting Centers for Disease Control and Prevention (CDC) with input from representatives of human health, livestock, agriculture, wildlife, environment, research, and higher education sectors [15]. This two-day workshop used a five-step semi-quantitative One Health Zoonotic Diseases Prioritization Tool [16] to prioritize zoonotic diseases of greatest national concern for Tanzania. The workshop participants identified rabies, Rift Valley fever, and other viral hemorrhagic fevers (Marburg, Ebola), zoonotic influenza, anthrax, human African trypanosomiasis, and brucellosis [15] as priority zoonotic diseases in decreasing order of importance.

TRAFFIC, a global non-governmental organization specialized in research, analysis and developing solutions to improve legality, sustainability, and safety of the trade in wild plants and animals, commenced a project titled "Reducing Risks in Tanzania's Game Meat Industry: Developing a Model for Safe, Sustainable, and Legal Supply" with the support of United States Agency for International Development (USAID) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), in 2020. The project was developed to increase understanding of potential zoonotic disease risks from the newly established game meat trade in Tanzania, and in turn propose practical interventions for risk reduction including application of a One Health approach to mitigate potential zoonotic disease risks associated with the wild meat trade in northern Tanzania. As part of an overarching disease risk analysis framework, a key step in the project was to identify and prioritize zoonotic diseases (disease 'hazards') associated with the trade, as well as to identify critical control points in the value chain of wild meat at which to target risk mitigation measures and to build capacity for their implementation.

This disease prioritization process needed to acknowledge the geographic, socio-economic, cultural, and environmental contexts of human–animal interaction, including wildlife, livestock, and peri-domestic species in northern Tanzania. We developed a straightforward workshop-based methodology to prioritize zoonotic diseases of wildlife that were of greatest concern to human health and well-being in association with the wild meat value chain (where wild meat is inclusive of game meat [legal] or bushmeat [illegal]), while also gathering additional, related epidemiological information about these diseases. This prioritization process brought together representatives of human health, animal health, and wildlife management sectors.

This study provides a detailed description of this prioritization process for wildlife-associated zoonotic diseases. This simple approach has the potential to be replicated and adapted to other contexts of One Health prioritization and risk analysis, in particular with regard to trade and consumption of wild animals. This process elicited and analyzed experts' perceptions of the importance and epidemiological features of zoonotic diseases associated with the game meat value chain in northern Tanzania.

Materials and Methods

Ethical approval

Ethical approval was obtained from the Tanzania Commission for Science and Technology (COSTEC)

permit No. 2022-811-NA-2022-0256 and Tanzania Wildlife Research Institute (TAWIRI) Permit No. AB. 235/325/01/84.

Study period and location

The expert workshop was held at Sokoine University of Agriculture (SUA) for five days (November 21–25, 2022). During this period, the co-organizers convened for two days for preparation and planning, followed by a three-day meeting with the invited experts. The workshop gathered experts from six districts of northern Tanzania: Monduli and Arusha districts of the Arusha region, Moshi and Siha districts of the Kilimanjaro region, and Babati and Simanjiro districts of the Manyara region. The districts were selected specifically because they are focal geographic areas for the trade in wild meat, as previously identified by TRAFFIC field research (unpublished data). A District Game Officer (DGO), District Veterinary Officer (DVO), and Public Health Officer (PHO) were invited to constitute a multi-sectoral expert team from each selected location. One Health focal points were invited from Tanzania's Ministry of Health, Ministry of Livestock and Fisheries, and Ministry of Natural Resources and Tourism. In addition, zonal Veterinary Officers and a zonal Veterinary Laboratory Officer from the northern zone of Tanzania attended the workshop. Researchers from the National Medical Research Institute (NIMR), Tanzania Livestock Research Institute (TALIRI), TAWIRI, and SUA also participated, together with the chair of Tanzania's Game Meat Selling Advisory Committee (GMSAC). A total of 41 participants contributed to the workshop, thus informing the prioritization process.

Data collection and analysis

Six groups corresponding to the study districts were formed, each of which comprised experts from the different professional fields represented in the workshop. The responsibilities of the experts were to share their opinions and experience based on their field of expertise and experience in their respective districts. They were asked to list the zoonotic diseases observed in their respective districts and rank them according to their importance based on stipulated criteria, while epidemiological information related to these diseases was discussed and documented, as described below. The list of observed diseases represented those of particular concern or note to the invited experts, as opposed to commonplace diseases that would be less commonly investigated by, or reported to, health authorities.

Prioritizing zoonotic diseases

Each group was asked to discuss and come up with a list of the most common zoonotic diseases observed in humans in their respective districts in the past 10 years.

These diseases were then ranked under each of the following categories:

- Prevalence in that district
- Socio-economic impact
- Availability of effective medical interventions
- Likelihood of potential transmission (epidemic potential) from one person to another
- Severity of disease in people according to the criteria used in the 2017 CDC workshop described above [15].

However, unlike the 2017 CDC workshop, only zoonotic diseases observed over the past 10 years in the respective districts were considered by this group of experts (as opposed to the prioritization of diseases that had not yet been detected in Tanzania). Another difference was that our prioritization process purely used rankings (1st, 2nd, 3rd, etc.) and drew on expert judgment through elicitation of group opinion in the manner of participatory disease surveillance [17], making this method distinct, time-efficient, and more cost-effective than the 2017 CDC process.

For ranking, groups generated ranks ranging from 1 to 9 for the highest- to lowest-priority diseases respectively. The ranks across the five criteria were summed, and the disease with the lowest rank was considered the top-priority zoonotic disease for that particular district (Tables-1–6). Group discussions were followed by a plenary session in which each group presented their findings to a larger audience of experts. This was followed by a wide-ranging discussion, which allowed the groups, where appropriate, to revise their list and rankings based on experience and feedback from other experts.

All information gathered during the discussions was captured in a simple table on a flip chart and then entered into a Microsoft Excel spreadsheet. A copy of the Excel sheet was then created where the diseases' final ranks were reversed to create scores, such that a disease with a rank of one out of five listed diseases was assigned a score of 5; a disease ranked five out

Table-1: Results of ranking of the listed wildlife-associated zoonotic diseases for Arusha district.

Zoonotic disease	Ranking criteria, where 1 = highest rank and 5 = lowest rank						Overall ranking
	Prevalence	Socioeconomic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Rabies	1	3	5	1	1	11	1.5
Anthrax	2	1	4	2	2	11	1.5
Brucellosis	3	2	3	4	4	16	3.5
Bovine tuberculosis	4	5	1	3	3	16	3.5
Porcine taeniasis	5	4	2	5	5	21	5

Table-2: Results of ranking of the listed wildlife-associated zoonotic diseases for Babati district.

Zoonotic disease	Ranking criteria, where 1 = highest rank and 5 = lowest rank						Overall ranking
	Prevalence	Socioeconomic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Anthrax	1	1	5	1	2	10	1
Rabies	2	3	4	3	1	13	2
Yersiniosis	5	4	1	2	3	15	3
Brucellosis	3	2	3	4	5	17	4
Bovine tuberculosis	4	5	2	5	4	20	5

Table-3: Results of ranking of the listed wildlife-associated zoonotic diseases for Monduli district.

Zoonotic disease	Ranking criteria, where 1 = highest rank and 9 = lowest rank						Overall ranking
	Prevalence	Socioeconomic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Rabies	1	4	2	3	1	11	1
Anthrax	2	1	1	2	6	12	2
Rift Valley fever	8	2	8	1	2	21	3
Brucellosis	3	3	7	4	5	22	4
Human African trypanosomiasis	4	7	3	5	7	26	5
Bovine tuberculosis	5	5	6	7	4	27	6.5
Porcine taeniasis	7	6	5	6	3	27	6.5
Sparganosis	9	9	4	9	8	39	8
Leptospirosis	6	8	9	8	9	40	9

Table-4: Results of ranking of the listed wildlife-associated zoonotic diseases for Moshi district.

Zoonotic disease	Ranking criteria, where 1=highest rank and 5=lowest rank						Overall ranking
	Prevalence	Socio economic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Anthrax	1	1	5	1	1	9	1
Rabies	2	5	4	2	2	15	2
Salmonellosis	3	2	2	5	4	16	3.5
Leptospirosis	4	4	1	4	3	16	3.5
Brucellosis	5	3	3	3	5	19	5

Table-5: Results of ranking of the listed wildlife-associated zoonotic diseases for Siha district.

Zoonotic disease	Ranking criteria, where 1=highest rank and 4=lowest rank						Overall ranking
	Prevalence	Socioeconomic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Anthrax	1	1	4	1	1	8	1
Rabies	2	3	3	2	2	12	2
Brucellosis	4	2	2	3	3	14	3
Bovine tuberculosis	3	4	1	4	4	16	4

Table-6: Results of ranking of the listed wildlife-associated zoonotic diseases for Simanjiro district.

Zoonotic disease	Ranking criteria, where 1=highest rank and 5=lowest rank						Overall ranking
	Prevalent	Socioeconomic impact	Availability of intervention	Epidemic potential	Severity	Overall sum	
Anthrax	2	2	3	2	2	11	1
Brucellosis	1	4	2	3	5	15	3
Rabies	3	3	4	4	1	15	3
Rift valley fever	5	1	5	1	3	15	3
Bovine tuberculosis	4	5	1	5	4	19	5

of five was assigned a score of 1; and so on [17]. The purpose of reversing the ranks to create scores was to give equal weight to diseases that were not recorded in a particular district, that is, a zero score (Table-7). Thereafter, another sheet was prepared to collate the results from all districts: the districts were added in the columns and all diseases were listed in the rows. Scores were added for each disease in each district. If

Table-7: Combined scores for identified wildlife-associated zoonotic diseases for all the six study districts.

Diseases	Overall scores (reversed ranks) for each district							Overall importance (rank)
	Arusha	Siha	Babati	Monduli	Moshi	Simanjiro	Overall sum	
Anthrax	4.5	4	5	8	5	5	31.5	1
Rabies	4.5	3	4	9	4	3	27.5	2
Brucellosis	2.5	2	2	6	1	3	16.5	3
Rift Valley fever	0	0	0	7	0	3	10	4
Bovine tuberculosis	2.5	1	1	3.5	0	1	9	5
Human African trypanosomiasis	0	0	0	5	0	0	5	6
Porcine taeniasis	1	0	0	3.5	0	0	4.5	7
Leptospirosis	0	0	0	1	2.5	0	3.5	8
Yersiniosis	0	0	3	0	0	0	3	9
Salmonellosis	0	0	0	0	2.5	0	2.5	10
Sparganosis	0	0	0	2	0	0	2	11

For each district, the ranks in Tables-1–6 are reversed such that a disease with the lowest rank in Tables-1–6 is assigned the highest score for that region. The disease with the highest score across districts is then given an overall rank of number one, the disease with the lowest score is given the lowest overall rank, and so on.

a disease was not included in the district, it was given a zero score. Finally, the scores for each disease were summed, and the diseases with the highest scores were considered as the greatest priority diseases (Table-7).

Related epidemiological data

In addition, expert opinions concerning the epidemiological parameters of these zoonotic diseases in wildlife were collected, including the following:

- Seasonality of diseases in wildlife for the past decade (2013–2022);
- Species of domestic animals and wildlife affected;
- Routes of transmission between humans, domestic animals, and wildlife;
- Perceived origins of human, domestic animal, and wildlife disease outbreaks; and
- Morbidity and mortality rates among humans, domestic animals, and wildlife.

This information was collected using the same process and at the same time, as described above.

Results

Zoonotic diseases identified

A total of 11 zoonotic diseases were identified by different groups across the six districts, with four to nine zoonotic diseases identified per district. Of these, there were three diseases, rabies, anthrax, and brucellosis in the lists of all six groups. Some diseases, such as yersiniosis (bubonic plague) (Babati), human African trypanosomiasis (Monduli), sparganosis (Monduli), and salmonellosis (Moshi), occurred in only one district. Tables-1–6 show the results of ranking the listed zoonotic diseases based on the set criteria for the six study districts. Table-7 presents a summary of scores (reversed ranks) for all diseases in all the study districts. For each district, the overall ranks in Tables-1–6 are reversed such that a disease with the lowest score is assigned the highest score. The disease with the highest score across districts is then considered most important, the disease with the lowest score is given the lowest importance (lowest overall rank), and so on.

Related epidemiological data

Table-8 presents the combined results from the six study districts concerning the seasonal occurrence of these wildlife-derived zoonoses. In general, experts from a majority of districts indicated that rabies has no seasonal predisposition. However, in the Arusha and Babati districts, anthrax was most common during dry spells, whereas in Moshi and Simanjiro districts, it was most common during wet seasons. For Monduli and Siha, it was noted that it was common all the time. Experts from all districts agreed that brucellosis and bovine tuberculosis may occur at any time throughout the year. Seasonal variation in other diseases was considered to be limited.

Table-9 presents responses regarding the host ranges of these diseases across the study districts. Anthrax, brucellosis, porcine taeniasis, and bovine tuberculosis predominantly affect wild ungulates in northern Tanzania, which are the taxa most commonly associated with the wild meat value chain [18–22]. It was considered that rabies was mainly affecting animal species that were not targeted or traded for the purposes of game meat. Rift Valley fever is known to affect wildlife; however, experts do not consider it possible to describe the wild species affected due to the lack of available data.

Table-10 provides information on perceived transmission routes and Table-11 provides information on perceived sources of zoonoses associated with wildlife. This information is provided separately for humans, domesticated animals, and wild animals. These findings indicate potential for zoonotic disease transmission both directly and indirectly along the wild meat value chain. Rabies cannot be transmitted through the consumption of game meat but can be transmitted during the acquisition (hunting) of wild animals, which can be regarded as an initial step in the wild meat value chain.

Table-12 presents expert opinions on rates of morbidity (i.e., illness) and mortality as a consequence of these zoonoses in human, wildlife, or domestic animal populations across the study districts. Overall, the mortality and morbidity rates due to these diseases were low for most human and wildlife diseases.

Table-8: Expert opinion on seasonality in occurrence of wildlife-associated zoonotic diseases in the northern Tanzania for the past 10 years (2013-2022).

Disease	Arusha	Siha	Babati	Monduli	Moshi	Simanjiro
Rabies	All times	All times	All times	All times	Dry	All times
Anthrax	Dry	All times	Dry	All times	Wet	Wet
Brucellosis	All times	Dry	All times	All times	All times	All times
Porcine taeniasis*	N/A	N/A	N/A	N/A	N/A	N/A
Bovine tuberculosis	All times	All times	All times	All times	N/A	All times
Yersiniosis	N/A	N/A	Wet	N/A	N/A	N/A
Human African trypanosomiasis*	N/A	N/A	N/A	N/A	N/A	N/A
Sparganosis	N/A	N/A	N/A	Wet	N/A	N/A
Rift Valley fever*	N/A	N/A	N/A	N/A	N/A	N/A
Leptospirosis	N/A	N/A	N/A	N/A	All times	N/A
Salmonellosis	N/A	N/A	N/A	N/A	All times	N/A

*Experts were unable to state the seasonality due to insufficient data.

Table-9: Expert opinion on host species affected with wildlife-associated zoonotic diseases in the northern Tanzania.

Disease condition	Affected hosts		
	Human	Wildlife	Domestic animals
Rabies	All	Jackals (*Canis* sp.), hyena (*Hyaenidae*), wild dog (*Lycaon pictus*), monkey (*Cercopithecidae*), Bat-eared Fox (*Otocyon megalotis*), zebra (*Equus* spp.)	dogs, goats, sheep, cattle, cats, donkeys
Anthrax	Mostly men	Zebra, eland (*Taurotragus oryx*), wild pig (*Sus scrofa*), impala (*Aepyceros melampus*), buffalo (*Syncerus caffer*), Lesser kudu (*Tragelaphus imberbis*), elephant (*Loxodonta africana*), gazelle (*Antilopini*), and wildebeest (*Connochaetes* spp.)	cattle, pigs, goats, sheep
Brucellosis	Mostly women	Buffalo (majority), wildebeest	cattle, pigs, sheep
Porcine taeniasis	Mostly men	Warthog (*Phacochoerus africanus*), bush pig	goats, cattle, pigs, sheep
Bovine tuberculosis	Yes	Wildebeest	cattle, sheep, goats
Yersiniosis*	Yes	N/A	N/A
Human African trypanosomiasis*	Yes	N/A	N/A
Sparganosis*	Yes	Grant's Gazelle	N/A
Rift Valley fever	Yes	Yes	cattle, goats, sheep
Leptospirosis*	Yes	N/A	dogs
Salmonellosis*	Yes	N/A	poultry, pigs, calves

*Experts were unable to state the wild and/or domestic species affected due to insufficient data.

Table-10: Expert opinion on probable transmission routes of wildlife-associated zoonoses among different hosts in northern Tanzania*.

Zoonotic disease	Probable routes of transmission		
	Wild-Human	Domestic-Human	Wild-Domestic
Rabies	Bites, contact with saliva on bruised skin	Bites, contact with saliva on bruised skin	Bites
Anthrax	Ingestion (meat), direct contact, inhalation	Ingestion, direct contact, inhalation	Ingestion through contaminated pasture (herbivorous) and carcass
Brucellosis*	N/A	Ingestion of undercooked meat and milk	Ingestion through contaminated pasture (herbivorous)
Bovine tuberculosis*	N/A	Ingestion of undercooked meat and milk	N/A

*Experts felt unable to state some transmission routes for brucellosis and bovine tuberculosis, and did not give any transmission routes for remaining diseases (porcine taeniasis, yersiniosis, human African trypanosomiasis, sparganosis, Rift Valley fever, leptospirosis, and salmonellosis), in light of insufficient information.

Anthrax and Rift Valley fever are considered to cause a moderate amount of morbidity and mortality in domestic animals (livestock).

Discussion

One Health approaches, which recognize the interconnectedness of human, animal, and environmental health, are crucial for effective zoonotic disease surveillance, prevention, and control [23]. We identified 11 priority wildlife-associated zoonotic diseases in northern Tanzania using a consultative, multi-sectoral approach based on One Health principles. This collaborative prioritization process promoted, enhanced, and facilitated communication

Table-11: Expert opinion on probable origins of outbreaks of wildlife-associated zoonoses among different hosts in the northern Tanzania*.

Zoonotic disease	Probable source of outbreak		
	Human	Domestic animals	Wild animals
Rabies*	Dog bite	Dog bite	N/A
Anthrax	Direct contact, meat consumption	Direct contact	Direct contact
Brucellosis*	Consumption of unpasteurized milk and undercooked meat	Direct contact, contaminated feeding utensils, carcasses, and feeds	N/A
Porcine taeniasis*	Consumption of undercooked meat	Contaminated feeds/grazing	N/A
Bovine tuberculosis*	Consumption of unpasteurized milk and undercooked meat	Inhalation	N/A

*Experts felt unable to state the origin of outbreaks of these diseases in wild animals and were unable to give any information regarding outbreaks of remaining diseases (yersiniosis, human African trypanosomiasis, sparganosis, Rift Valley fever, leptospirosis, and salmonellosis), in light of insufficient information.

Table-12: Expert opinion on the rate of morbidity and mortality in relation to wildlife-associated zoonotic diseases in northern Tanzania.

Disease condition	Morbidity			Mortality		
	Human	Wildlife	Domestic animals	Human	Wildlife	Domestic animals
Rabies	Low	Low	Low	Low	Low	Low
Anthrax	Low	Low	Moderate	Low	Low	Moderate
Brucellosis	Low	Low	Low	Low	Low	Low
Porcine taeniasis	Low	Low	Low	Low	Low	Low
Bovine tuberculosis	Low	Low	Low	Low	Low	Low
Yersiniosis*	Low	N/A	N/A	Low	N/A	N/A
Human African trypanosomiasis*	Low	N/A	N/A	Low	Low	Low
Sparganosis*	Low	N/A	N/A	Low	Low	Low
Rift Valley fever	Low	Low	Moderate	Low	Low	Low
Leptospirosis	Low	Low	Low	Low	Low	Low
Salmonellosis	Low	Low	Low	Low	Low	Low

*Experts felt unable to provide complete information due to a lack of available data. Interpretation of qualitative ratings: Negligible=Occurrence is possible in exceptional circumstances; Low=Occurrence probable in some districts; Moderate=Occurrence is probable across districts; High=Occurrence is considered common .

between game officers and veterinary and public health officials regarding the occurrence and nature of zoonotic diseases associated with wild animals in northern Tanzania. This activity has contributed to capacity building for early detection and response to known or unknown zoonotic disease outbreaks in these districts. These One Health principles have been recommended for identifying potential outbreaks and hotspots of zoonotic diseases associated with wildlife trade [24], in line with Tanzania's One Health Strategic Plan for the period 2022-2027 [25], which recognizes the need for transdisciplinary efforts focusing on human, animal and environmental health to control and prevent disease. Agricultural intensification, human population growth, urbanization and human encroachment into wildlife habitats are evident in Tanzania as drivers for zoonotic disease transmission and emergence.

In this study, we documented 11 wildlife-associated zoonotic diseases normally experienced in the Monduli, Arusha, Moshi, Siha, Babati, and Simanjiro districts of northern Tanzania. The five most important diseases for public health and well-being were considered to be anthrax, rabies, brucellosis, Rift Valley fever, and bovine tuberculosis (in decreasing order of importance). Anthrax, brucellosis, Rift Valley fever, and bovine tuberculosis are associated with wild ungulates and were, therefore, of most importance with respect to the wild meat trade, whether supplied through legal game meat or illegal bushmeat value chains, both of which have been associated with transmission of zoonotic and other pathogens worldwide [26]. The diseases identified and prioritized in this study have also been reported in various Tanzanian studies [e.g. 3–5, 7, 15]. However, the results contrasted with a study that covered multiple East African countries, including Burundi, Ethiopia, Kenya, Tanzania, Rwanda, and Uganda, from 1920 to 2017, which reported 21 zoonotic diseases prevalent in the region [27]. Our approach highlights the need to expand the scope, focus, and quality of such studies to adequately address the public health, animal health, and social and economic threats posed by zoonoses.

The prioritization workshop was efficient, cost-effective, and time-efficient. It is important to note that information was shared between public health officials, veterinarians, and wildlife officers. The combination of these specializations offered wildlife officers (who normally move around protected areas) an opportunity to understand the importance of health issues related to wild animals, with which they regularly have contact during their work. The multi-sectoral approach is a model of cooperation and elicitation that supports One Health and the global health security agenda by

improving coordination, cooperation, and communication at the human–animal–environment interface, which is aimed at addressing common health threats in humans, domestic animals, and wildlife. This work has helped to strengthen communication channels for the prevention, detection, and response to disease outbreaks at this interface and to build capacity for improving health outcomes across systems. This cooperation can contribute to the early detection of animal diseases and to preparedness, resulting in economic savings. Reducing the time required to respond to disease outbreaks helps to prevent potentially costly and long-running outbreaks. Strengthening the capacities of public health officials, veterinarians, and game officers can improve the resilience to future epidemics or pandemic emergence.

The findings from the workshop compared well with those of the CDC's national zoonotic disease prioritization exercise in 2017 [15], which also determined anthrax, brucellosis, and Rift Valley fever to be among the highest priority threats. Rabies was the most highly ranked disease in the CDC workshop and the second most important disease in this exercise. Beyond the risks of rabies associated with sourcing (e.g., during hunting), there was less concern regarding rabies at the other nodal interfaces in the wild meat supply chain. Our approach was deliberately limited to common zoonotic diseases observed in this geographic area of northern Tanzania, unlike the CDC-led which considered all current and potential future zoonotic diseases, e.g. zoonotic influenza, which has never been reported in Tanzania. Nevertheless, having identification, treatment, and control strategies in place for existing zoonotic diseases improves the likelihood that anything novel that does not respond to existing diagnostic and management protocols can still be detected.

The prioritization method gave experts the opportunity to revise their scores following group discussion, thus developing a stronger consensus, similar to more structured expert elicitation methods, such as the Delphi process [28]. However, several caveats should be considered in future iterations of this process. As nine diseases were identified in Monduli and fewer in other districts, the overall scores were slightly weighted for this district. Our ranking criteria were considered to be equally important in the prioritization process, whereas in the CDC approach workshop, the criteria were weighted according to their perceived importance to experts. However, the simplicity of the process we have described in this current study makes it easy to replicate in other contexts.

Conclusions and Recommendations

A list of priority wildlife-associated zoonotic diseases affecting human and animal health that could also impact livestock productivity, food security, and biodiversity conservation in northern Tanzania was successfully established and realized using a multi-sectoral One Health prioritization approach. Our approach offers an opportunity to acknowledge shared interests, set common goals, and enhance teamwork to benefit overall health at local and national levels in Tanzania, linked to regional East African and global One Health contexts. It has improved multi-sectoral planning, communication, and collaboration for human, animal, and wildlife health in northern Tanzania, especially with reference to the management needs of the rapidly developing game meat industry. We recommend regularly holding such meetings in the future to promote information sharing to systematically embed a One Health approach to disease surveillance, understanding, and response, particularly associated with the wild animal trade where multiple government agencies need to co-ordinate their efforts across jurisdictions. These participatory approaches are highly recommended for zoonotic disease prioritization at subnational, national, and international scales and can also be applied in the prediction of novel pathogens and future preparedness for known zoonotic and other diseases.

Data availability

The supplementary data can be available from the corresponding author on a request.

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Authors' Contributions

DPM, QK, JC, JT, and KMB: Conceptualized and designed the study. DPM, EK, MS, EL, AC, and QK: Drafted the manuscript EK, MS, EL, and AC: Gathered and analyzed the data. JC, JT, and KMB: Edited the manuscript. All authors have read, reviewed, and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

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