1-21-2023

The linkages between climate change and foot & mouth disease: A One health perspective from nomadic herders in Mongolia

Alessandra DiPietro
Institute for Integrative Conservation

The Journal of Climate Change and Health 10 (2023) 100208

Contents lists available at ScienceDirect

The Journal of Climate Change and Health

journal homepage: www.elsevier.com/joclim

Research article

The linkages between climate change and foot & mouth disease: A One health perspective from nomadic herders in Mongolia

Alessandra DiPietro[a], Erdene Tserenochir[b], Erica Garroutte[a], Rentsen Oyunbat[c], Iyabo Obasanjo[a,*]

[a] Institute for Integrative Conservation (IIC), William & Mary, 221N Boundary, Williamsburg, Virginia, USA
[b] Mongolian University of Life Sciences, Department of Infectious Disease and Microbiology, Ulaanbaatar, Mongolia
[c] Mongolian Conservation Initiative, Ulaanbaatar, Mongolia

A R T I C L E   I N F O

Article History:
Received 30 August 2022
Accepted 16 January 2023
Available online 21 January 2023

Keywords:
Nomadic herders
Climate change
Foot & mouth disease
One Health
Mongolia

A B S T R A C T

Introduction: One Health is a multifaceted approach increasingly used to explore climate-driven public health challenges; however, it is often lacking the expertise of local people who are most connected to and affected by these challenges. Our goal was to explore how nomadic herders in a conservation area (Ikh Nart Nature Reserve in Mongolia) understand the issues of interconnectedness of environmental, animal, and human health through Foot-and-Mouth Disease of ungulates and climate change.
Materials and Methods: We carried out a cross-sectional study of 104 nomadic herders in Dornogobi, Mongolia, using a questionnaire with 11 open-ended questions which were translated into English for analyses and coding using NVivo. The questions explored herders' perceptions and experiences on the linkages between human wellbeing, environmental factors, and outbreaks of Foot-and-Mouth Disease of ungulated animals, which is occurring more frequently in Mongolia.
Results: Pasture degradation was the factor herders most linked to animal, human, and environmental health and climate change. The herders displayed adept understanding of One Health concepts. The herders' responses throughout the survey revealed a cycle where climate change contributes to landscape degradation, declining animal health, and human socioeconomic consequences.
Discussion: Mongolia's rich tradition of herding and generational linkages to natural resources provide a unique, holistic approach to understanding the effects of climate change and landscape degradation on disease transmission and human well-being.
Conclusion: Indigenous Peoples and Local Communities should be actively engaged through leadership and input in formulating transdisciplinary strategies to combat climate change and its effects on animal and human health.

1. Introduction

Foot and Mouth Disease (FMD) virus is a highly contagious pathogen of ungulates that can spread between animals or by contact with animal products. FMD can have especially dramatic impacts on wildlife populations, the livestock industry, and the livelihoods of nomadic pastoralist communities globally [1]. As resource availability becomes unpredictable with climate change, increased interaction and competition over resources between wildlife, livestock, and nomadic herding communities creates the ideal conditions for aerosol transmission of this virus [2]. The nomadic herding lifestyle remains a cultural staple across Mongolia, where FMD outbreaks have become more frequent and more intense over the past 30 years, reaping socioeconomic consequences to herding communities. FMD affects pastoralist communities worldwide and they further suffer severe economic losses because of the disease [3]. Case numbers and existing literature have shown frequent epidemics of FMD in Mongolia in the twenty-first century, including 2001–2002, 2010–2011, 2013–2014, and 2017–2018 [1,4–7]. The first outbreak of FMD in Mongolia occurred in 1973 and all outbreaks until 2005 had less than 500 total cases in camels, sheep, goats and cattle [4,7]. Then there were no cases until 2010, which was the year with the highest number of cases with 27,842 cases reported [4]. There were 1287 cases in 2013, 3454 cases in 2014, 1024 cases in 2015, 173 cases in 2016, 10,843 cases in 2017, and 4269 cases in 2018 respectively [4]. This increasing frequency of FMD outbreaks coincides with increased drought and environmental degradation across Mongolia, making

* Corresponding author.
E-mail addresses: iobasanjo@wm.edu, iobas427@gmail.com (I. Obasanjo).

https://doi.org/10.1016/j.joclim.2023.100208

nomadic herding communities increasingly vulnerable to FMD outbreaks. Understanding the drivers of increased FMD transmission rates and their association to climate change across Mongolia is critical for both prevention and response management.

A One Health approach, which places equal consideration on human, animal and environmental factors and their linkages, is critical for understanding and mitigating the impacts of climate change and FMD on nomadic herder communities in Mongolia [5]. In the last decade, the vulnerability of herders to FMD has been exacerbated by the increasingly common droughts and overgrazing that are degrading Mongolia's rangelands, raising the cost of living, and increasing competition for resources between livestock herds [8,9]. According to a survey by Limon et al. [10], the 2017−2018 FMD outbreak in Mongolia had significant socioeconomic impacts and indirect effects on human health; because the sale and consumption of animal products from infected livestock is prohibited, the outbreak left herders with both financial struggles and food insecurity. Additionally, the rangeland in Mongolia is used communally, so the spread of this disease is difficult to regulate between livestock of different herds and between livestock and migratory wildlife. Climate change has exacerbated this issue, as natural resources like water sources are dwindling, causing domestic and wild animals to be forced into proximity [10,11]. To combat the multitude of consequences FMD brings to Mongolia and ensure all factors are considered, a One Health approach is essential.

With its interdisciplinary nature, One Health research utilizes the perspectives of a diverse range of experts; however, the perspectives of the people and other actors in society (i.e., transdisciplinary approaches) often get overlooked. Mongolia is unique globally because it is one of the last places where nomadic herding at this scale still can be practiced Mongolians are known for their rich cultural heritage around herding. As of 2019, approximately 26% of Mongolians lived a pastoral lifestyle, a trade often passed down through generations [12]. Previous efforts to include herders in decision-making have come with great success in Mongolia. A study documented the impressive understanding of local flora and pasture management that herders possessed, combating existing stereotypes [13]. By consulting the social and cultural norms held by the people of the Dornogobi province, Reading et al. [14] were able to aid in the geographical expansion of the Ikh Nart Nature Reserve boundaries. Considering their knowledge of and dependence on free-range pastureland, lived experience with climate change effects, and socioeconomic vulnerabilities, integrating the deeply rooted knowledge of herders into a One Health perspective is entirely compatible and necessary to effectively manage FMD in Mongolia.

The Dornogobi province where Ikh Nart Natue Reserve is located is in Eastern Mongolia, which has had more FMD outbreaks than other regions of Mongolia. Dornogobi had a total of 2577 cases from 2010 to the end of 2019 and it is located next to Sukhbaatar province, which had the highest number of cases of FMD with 27,052 cases during the same period; the 10 provinces mostly in the center and north of the country had no outbreaks during this period [4]. Our study is centered in Ikh Nart Nature Reserve. This study was designed to explore nomadic herders' perspectives of One Health concepts, how they perceive FMD to relate to One Health, and what policies they believe are and would be effective in preventing and managing the spread of FMD outbreaks in the future. Further, this study aims to provide one example of the importance of engaging local communities and Indigenous Peoples in the design, implementation, and evaluation of One Health approaches to climate change and disease mitigation.

2. Methods

2.1. Study area

Ikh Nart Nature Reserve (Hereafter Ikh Nart) is in the Dornogobi province of southeastern Mongolia (Fig. 1). Situated along the transition between Gobi-Steppe ecosystem and the Gobi Desert, the reserve protects 66 ha of rocky outcroppings and grasslands that provide habitat for unique assemblages of wildlife species, including several threatened species like the Argali sheep, and provides protection of nearly 150 nomadic herding families who move across the grasslands seasonally with their livestock herds [14]. Nomadic herders follow available pastureland according to seasonal and climatic conditions to support their livestock herds consisting of sheep, goat, cattle, camels, and horses. Animal products are either consumed or

Fig. 1. Map of Ikh Nart Nature Reserve, Mongolia.A survey was distributed to 150 nomadic herding families that live in and graze their livestock seasonally in Ikh Nart Nature Reserve, in the Dornogobi Province of Mongolia.

Table 1
Survey Questions Categorized by Topic. A paper survey was distributed to 150 households in Ikh Nart Nature Reserve, Mongolia. The questions were translated into Mongolian and were answered in Mongolian and translated to English for analysis.

Category	Questions
1. Perspectives on One Health	1. What is the relationship between environmental health, livestock health, wildlife health, and human health in Mongolia? 2. What sort of changes have you seen to the environment where your livestock graze over the past 20 years? 3. How have changes to the environment impacted the health of your livestock? 4. How have changes to the environment influenced how you manage your livestock? 5. How have changes to the environment impacted the health and livelihoods of your family and the broader community?
2. Impacts and drivers of Foot & Mouth disease	6. How has FMD impacted the livestock, wildlife, and the livelihoods of the people who live in the Ikh Nart region? 7. How have diseases such as FMD impacted livestock herds in your community? 8. What do you think are the primary drivers of FMD in Ikh Nart over the last 20 years?
3. One Health approaches to FMD prevention and management	9. How have diseases such as FMD been addressed by governmental policies? 10. What resources do you use to prevent or respond to livestock diseases such as FMD? 11. What strategies do you think would be most effective in preventing livestock disease transmission and for the promotion of livestock health in the future?

sold at local markets and constitute almost the entirety of a herding family's livelihood.

2.2. Exploring herder perspectives

This study was designed as a cross-sectional study to be part of an ongoing effort led by the Mongolian Conservation Initiative, Denver Zoo, Ikh Nart Park Administration, local government, and other partners to support a community management plan for Ikh Nart. The Mongolian Conservation Initiative (MCI) and partners have been working with herder families that live permanently or seasonally in Ikh Nart for nearly 20 years. A questionnaire with 11 open-ended questions was developed to survey herder families in Ikh Nart (Table 1). The Mongolian Conservation Initiative team visited 150 families that live in or around Ikh Nart to distribute a paper survey in July 2021. Some families were not home and/or not interested in participating, or they did not return their questionnaire. Of the 150 targeted families, we received 104 completed surveys. The survey questionnaire was reviewed by the William & Mary Protection of Human Subjects Committee and approved before the start of the distribution (StudentIRB-2021−04−20−14,919), and informed consent was obtained from each respondent. The survey was completed by one adult per household, and it asked about their perspectives on the linkages between human, animal, and environmental health, their experiences with FMD, and their perspectives on a One Health approach to managing outbreaks (Table 1). The questionnaires were developed in English and translated into Mongolian and the herder answers were translated back to English by the same translator before coding.

2.3. Data analysis

Responses were written by herders in their native Mongolian language, then translated to English. Qualitative analyses and coding were carried out using NVivo qualitative data analysis software (QRS International Pty Ltd, Australia, Version 12, 2018). Responses remained grouped under the specific question they answered on the distributed survey. The most common phrases or concepts that appeared in response to each question formed the foundational first-order codes for each survey question, never more than 12 codes to start. First-order codes were then examined and consolidated into second-order codes based on larger common themes identified within first-order codes. If a first-order code was large enough (usually over 5 responses), the concept was kept as a sub-code under the larger umbrella of the second-order code. Note that the number of responses to sub-codes also contributes to the overall quantity of responses to second-order codes. This is displayed via the color schemes and legends used in the tree-map figures in the Results section. After second-order codes were established, it became apparent that many questions across the survey had similar codes, prompting a third and final re-examination of the greater themes at hand. This led to a conclusive understanding of a cyclical and interdependent nature to the experiences of herders that spanned multiple questions and all three survey sections.

3. Results

A total of 104 questionnaires were completed by 67 male and 35 female herders; each question thus returned 104 responses which was a response rate of 69.3% from the 150 targeted families. The total average age of respondents was 39 years old. The average age for female respondents was 33 years, while the average age of male respondents was 41 years. Two questionnaires did not have the gender indicated.

3.1. A cyclical relationship between people, animals, and the environment

Ninety-eight respondents (94%) agreed or strongly agreed that there was a relationship between the environment, animal health, and human health and wellbeing. Their answers across survey categories demonstrated a cyclical relationship between the environment, animal, and human health, and the challenges herders face because of climate change, which was revealed through the direct and indirect links between their livelihoods and pasture resources (Fig. 2). In their answers to several of the questions, respondents mentioned human reliance on livestock, the linkage between reliance of livestock on pastureland and natural resources, and linkages between pasture, livestock, and human livelihoods and health. Wildlife was mentioned in several responses, highlighting the linkage between herders and wildlife and their shared linkage to pasture and water resources. Further, respondents indicated a relatedness or a cyclical link to the environment, highlighting the way that they see the role of humans in the environment and the ways that humans influence and are influenced by the environment. One response articulates, “We use our livestock which also feed on grasses that are produced by nature. So, we are all related.”

Herder respondents almost unanimously noted pasture degradation linked to climate change and mining, and the cascading impacts on animal and human health. This is indicated by their responses to Question 3, “How have changes to the environment impacted the health of your livestock?” shown in Table 2. The respondents noted

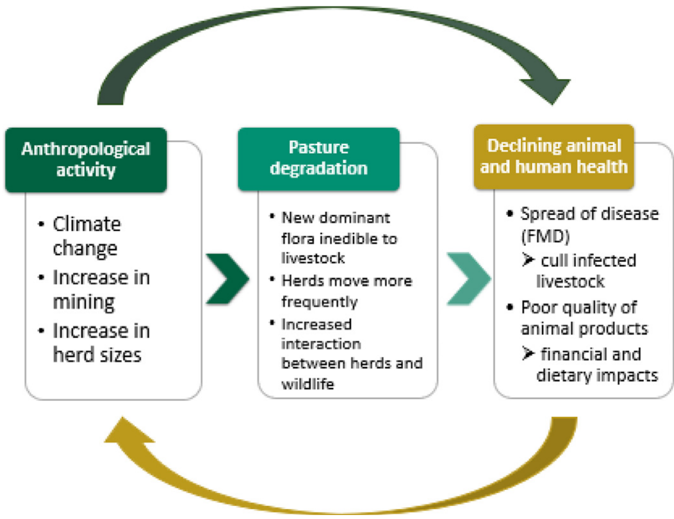

Fig. 2. Diagram of herders' perspective on cyclical linkage between climate change and cascading impacts of FMD. A conceptual diagram summarizing the respondents' perspectives on the cyclical linkage between climate change and environment, pasture degradation, and human and animal health.

changes in climate resulting in pasture degradation, with many noting less rain, more dust, harsher dzuds (extreme cold events), increasing winds, and rising temperatures having a noticeable impact on pastureland, with some mentioning desertification by name. Combined with increasing mining of pastureland and growing herd sizes, herders noted that climate change has impacted resource availability, a shift in palatable forage, and declining quality of forage, which has led to declining livestock health and profitability. Herders then described that they increase their herd sizes and move more frequently to follow good pasture to combat these loses, which results in competition for limited natural resources between each other and wild animals. The resources now in high demand include pasture and sources of fresh drinking water. Herders are generally aware of these interactions, explaining, "There are many changes for our pasture, such as, the number of plant species has decreased, and herders use the same area for a long time, thus pasture is getting degraded." Specifically addressing these effects on livestock health, one herder said, "Due to the lack of pastures and water, livestock fattening is deteriorating, and they are becoming more vulnerable. In addition, desertification and high levels of dust have a significant impact on the lungs of livestock." The byproducts of mining are also implicated in livestock health in this response that says, "Mining actions are changing natural landscape of our motherland. Mining sites are negatively affecting our livestock health." Dust and sandstorms were noted to have direct impacts on human health, with herders responding, "Because of dry air and droughts, our kids [are] having allergies" and, "Due to dust & dry air, many herders had issues in their lungs." Herders also noted the same issues with the lungs of their livestock.

Financial impacts were a recurring theme, as livestock health was reportedly declining, and the quality of animal products has been reduced because of climate-driven environmental degradation. One herder describes the situation, "Living as a herder is becoming more difficult, especially for our finance. We could not produce good milk and meat products and supply them to the market. Many livestock are not fat enough to survive the harsh winters, which also has financial implications. Our livestock do not get enough fat to survive, and wool and cashmere yield is decreasing." One herder even implicated the mental health effects of socioeconomic loss, saying, "I think that it's impacted negatively for our psychology and physical health."

3.2. Foot & mouth disease has cascading impacts on human, animal, and environmental health

Despite documented increasing frequency of FMD outbreaks in the Dornogobi Province in the last 20 years [4–6], twenty-four respondents were unsure of the impacts or did not indicate that FMD is a current challenge for herders. A few of the respondents said that it was a problem in the past: "In the past, foot and mouth disease only occurs in the eastern Mongolia, but now, it's also occurring in the central Mongolia including Gobi region. I think we will [be] safe when we vaccinate our livestock. Foot and mouth disease is a dangerous disease." Of the respondents who were unsure about its impacts, 12 (50%) also mentioned the impacts of FMD on wildlife, with one saying, "Foot and mouth disease spreads in populations of wild animals; with time we will have real risk. We could not vaccinate them like livestock. If we protect our livestock, wild animals are also protected." Others claim wild animal populations are declining because of the disease, especially the Mongolian gazelle. Several respondents mentioned a risk of wildlife spreading the disease at common water sources and a few mentioned a risk of animal-to-human transmission of the disease, although FMD is not generally zoonotic and human cases are rare. The few cases that have been recorded indicate that human cases are characterized by fever, malaise, nausea, muscle and joint pain as well as mucous membrane lesions of the mouth and pharynx and on the hands and feet [15]. The only common impact from FMD was a dislike of the restrictions of movement during outbreaks; herders lament the restriction of movement during

Table 2
Coding of Answers for Question 3. How have changes to the environment impacted the health of your livestock? Note that some herder responses were coded to more than one answer.

Q3	How have changes to the environment impacted the health of your livestock?	
agree	agree there are impacts, impacts unspecified	16
climate change	changes to weather patterns, especially across seasons	7
rain	changes to rain patterns, especially raining less	3
summer	mention changes to summer weather patterns, especially a "late summer"	2
winter	mention changes to winter weather patterns including less snow or harsh storms	4
dust and droughts	mention changes to the landscape in terms of desertification and more dust/dust storms having negative impacts on general livestock health	8
less impact	does not acknowledge a current impact on livestock health, may note a previous one or an impact seen in other regions	30
unsure		4
mining	mining has generally negative impacts on livestock, sometimes via pasture degradation, sometimes via unnatural by-products like toxins or trash left in the area	16
not enough for livestock to eat	pasture degradation, availability, quality of flora are concerns, as they lead to livestock not getting fat enough, decreased quality of animal products like cashmere, and vulnerability to illnesses	32
organs impacted	mention inner organs (especially the lungs) being harmed, usually by the increased dust and desertification and/or by increased mining	7

outbreaks, as they are not allowed to migrate with herds during isolation efforts. While this poses an issue for feeding herds, herders seem to recognize that it is necessary to stop the spread of FMD.

Despite a consensus that FMD was not a current concern, many respondents noted the socioeconomic impacts of environmental degradation and FMD. A frequent response among respondents was that "Herder livelihoods are deteriorating," and one respondent connected all three aspects of One Health to FMD outbreaks, stating, "If our livestock die due to any disease or climate challenge, it is big pressure on our finances." A few respondents mentioned the detrimental impacts of restricted movement on finances, with one saying, "Foot and mouth disease, if spread to many different regions in Mongolia, it's very bad for finance and economy," and, "Livestock could not get enough fat. So, we are not able to sell our meat and milk products."

When asked about the drivers of FMD transmission, respondents noted shifts in herder movement because of variable or limited resources driven by climate change and mining. Some respondents mentioned the struggles of climate change and pasture availability; the consequences of mining on pasture were again raised by a herder who disclosed, "Pasture degradation maybe resulted from mining action; we moved many times looking for good pasture over the course of the year." Many couple their response of increased and/or unregulated movement with a nod to the increasing size of herds, an increase specifically in sheep and goats. Many responses point out the lack of vaccination in some herds, which then travel from areas of outbreak to uninfected areas, bringing FMD with them. One herder explained, "I think it's due to herders' movements. When there is poor pasture and water, herders move to another place that is better than previous one, with some disease. Sometimes, their livestock did not get the vaccine." All three areas of One Health are exemplified in this response (Fig. 2). As Fig. 2 describes, herders mentioned that to find what good pasture is left, they must move more often, which increases interactions with other herds and with wild animals, both of which can be sources of disease transmission. FMD is highly contagious and because animals must quarantine or be culled if they have contracted FMD, herders combat the loss of livestock from disease by increasing how many animals they own; larger herds mean more overgrazing and pasture degradation, which is already a declining resource due to more mining and climate change/desertification, so the cycle continues.

3.3. Improved One Health approach to FMD

Tree-maps in Figs. 3, 4, and 5 are used to show the participant's answers to the One Health approach. When asked how diseases such as FMD have been addressed by governmental policies (Question 9), 42 respondents (40%) indicated vaccination, 29 were unsure (5 of those denying any government interaction has occurred), and 24 agreed that the government had policies but did not specify (Fig. 3). Isolation of infected animals and vaccination were the two methods indicated by respondents that they used most for controlling FMD in their herds (Fig. 4).

The most common recommendations from herders to prevent the spread of FMD in the future included continued or more regular vaccination of livestock (35 responses), improved veterinary efforts (24), improved pasture management (19 responses), and increased communication and education about FMD prevention (16 responses) as indicated in Fig. 5. Ten (10) respondents noted a need to adhere to current protocols in place, specifically the vaccination and isolation efforts. Many herders noted the importance of pasture management in the efforts of disease prevention, demonstrating a thorough understanding of how environmental and animal health are linked with their desire to improve the quality over the quantity of livestock, as well as a desire for stricter regulations for herder movement. One respondent asserted "We need to reduce movement of herders. And we need to improve our pasture's quality and rehabilitation."

4. Discussion

The relatively young age of the herders responding to our questionnaire probably is due to the age group between 30 and 45 being the largest percentage in the population, because the 1970s to the 1980′s was the period of highest birth rate in Mongolia due to generous birth and child benefits during the Communist period. Birth rates have declined significantly since the end of the Communist period at the end of the 1990′s [16–18].

The results from this study demonstrated that herders provided a unique understanding of the cyclical nature and relatedness between environmental, animal, and human health needed to improve One Health approaches to FMD. Focusing on relatedness is a spiritual and cultural viewpoint on the role that humans play in a connected

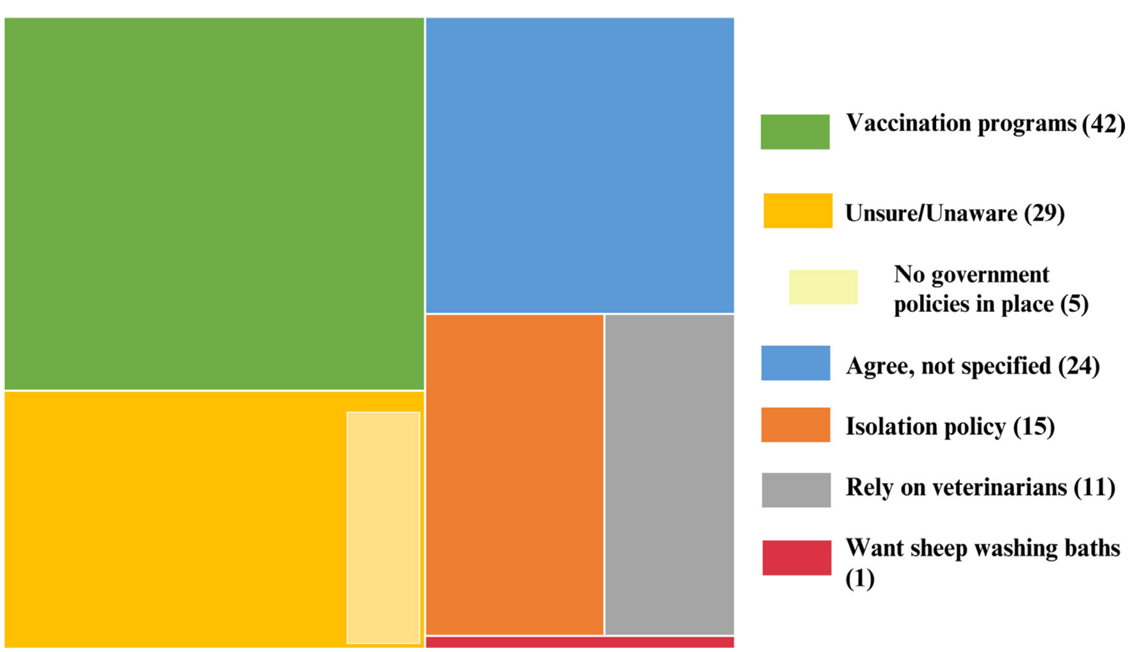

Fig. 3. Tree-map of the frequency of responses to Question 9, How have diseases such as FMD been addressed by governmental policies?.

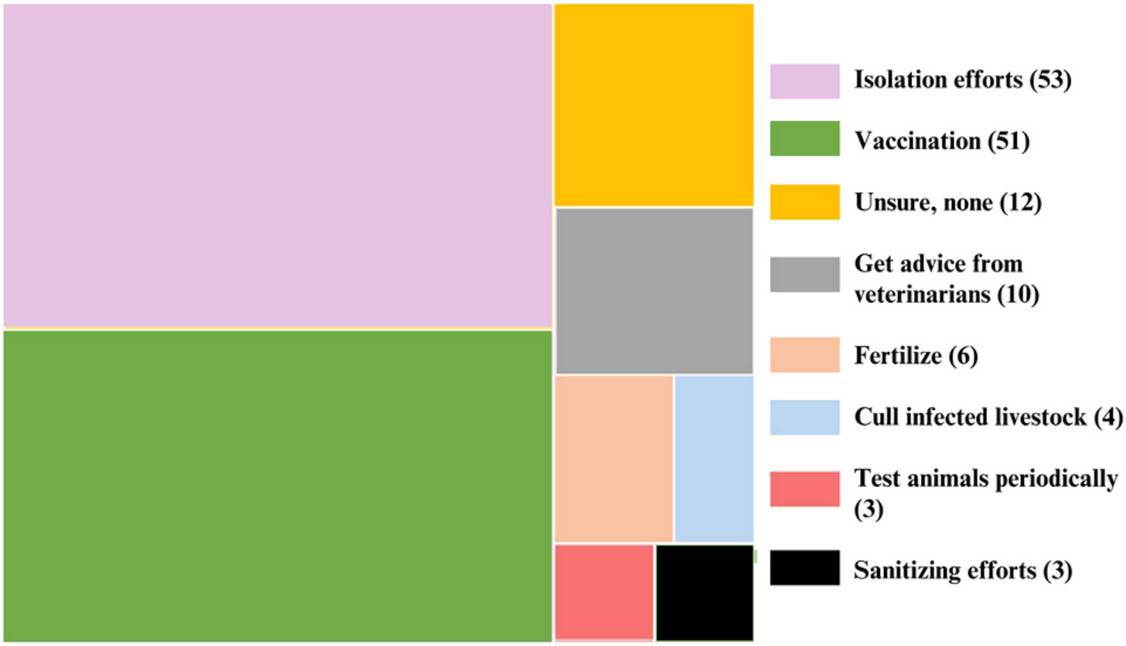

Fig. 4. Tree-map of the frequency of responses for Question 10, What resources do you use to prevent or respond to livestock diseases such as FMD? Note that some herder responses were coded to more than one answer.

system, which may provide a unique perspective on how to understand One Health and its goals in a transdisciplinary environment. If relationships are built, we see an opportunity for One Health practitioners to collaborate with nomadic herder communities to further explore this idea of relatedness and how it can be embedded into education and management of FMD.

Herders almost unanimously noted evidence for environmental degradation due to climate and mining, which has negatively impacted livestock and herder health. Mining is a rapidly expanding industry in Mongolia, and while it provides new jobs in rural areas, mining processes increase dust, deplete and likely contaminate the water sources and decrease pastureland used by herders [10,19]. The same dust that herders associated with lung damage in both humans and animals in this survey is also known to ruin milk curds and cashmere before these animal products can be sent to the market [19]. While climate and ecological data can provide clear trends in data, this firsthand knowledge of the current cascading impacts of climate change on animal and human well-being provides predictions and knowledge that are critical for prevention of FMD and climate mitigation.

Aligned with One Health theory, herders demonstrated how degradation of pastureland due to climate and mining is correlated with human and animal health. Herders were acutely aware of this, as they further described the socioeconomic impacts of climate change

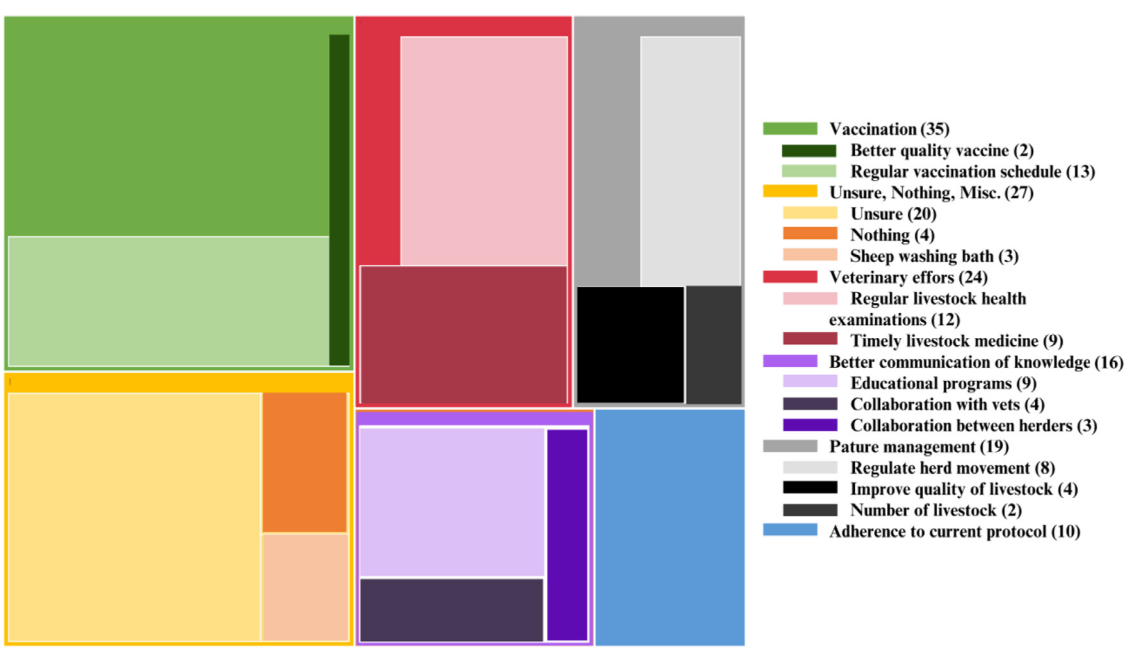

Fig. 5. Tree-map of Herder Responses to Question 11. What strategies do you think would be most effective in preventing livestock disease transmission and the promotion of livestock health in the future? Answers were sub-coded as indicated on the right label. Note that some herder responses had more than one answer code.

and FMD, visualizable as a cycle. Because animal products are either sold at the market or consumed by the herders, laws prohibiting the sale of meat of infected animals ensure that sickly livestock directly correlate with less income and greater food insecurity. In 2020, Limon et al. [10] quantified that approximately 50% of their surveyed herders were forced to borrow money to pay for necessities like food, medicines, or loans because of the 2017−2018 FMD outbreak. Survey responses from questions 5 and 6 explicitly agree with Limon et al. [10], that socioeconomic difficulties like unsteady income and food insecurity were intensified by FMD. Other major themes included herd sizes and increased movement of herds, with livestock numbers increasing from 1,036,590 in 2000 to 2,551,545 in 2020 [20]. Combined with reports of pasture shortages due to climate change and mining, it is no wonder herders must move more often to keep these larger herds fed. This, however, puts strain on the shared natural resources of pastureland, according to Dangal et al., contributing to the aforementioned cycle [11].

Herders primarily use isolation efforts and vaccination to prevent the spread of FMD, highlighting a need for improved communication and adherence to movement and vaccination protocols. While isolation may be necessary to stop disease spread, keeping herds in one location on a prolonged basis poses additional strain on an already taxed landscape and endangers animal nutrition, contributing to the overgrazing component of the Fig. 2 cycle. In the future, herders want to continue these isolation protocols and vaccination efforts; however, some mention slight alterations to the current regimen. For instance, a regular vaccination schedule twice a year would make it easier to keep track of which herds have been vaccinated and when the animals are next due. Some herders proposed that knowledge of FMD be communicated through more frequent educational workshops taught by veterinarians. Being able to thoroughly understand the warning signs and symptoms of newly infected livestock may enable herders to separate infected livestock without having to wait for the veterinarians, saving many animals from infection and culling, and thus protecting herder incomes. Culling of livestock also results in public despair, loss of trust in authority, and even health impacts amongst livestock owners [21], which is consistent with the physiological despair one respondent conveyed.

Mongolia's rich tradition of herding and generational connection to natural resources gives herders a unique perspective on the effects of climate change and landscape degradation on animal health and human wellbeing. Metrics like the ones used in Dangal et al., which considers daily observations of people of the land and weather, are far more reliable for understanding the big picture effects of climate change on animal and human health [11]. A One Health perspective excels at finding these big picture effects by considering multiple angles of a single problem and has been increasingly utilized for infectious disease outbreaks. In this case, herders from Ikh Nart demonstrated their knowledge of the cycle of climate change, pasture degradation, declining livestock health, and subsequent income loss and the way FMD exacerbates this cycle. Herders also provided a unique perspective on the relatedness between people and nature, and demonstrated an opportunity to include cultural and spiritual dimensions into a One Health approach. There needs to be a transdisciplinary framework for engaging local communities in the design, implementation, and evaluation of all One Health approaches to mitigate the impacts of climate change and disease transmission. The herder answers also indicate that many were unsure of which policies were in place to help them manage FMD (Fig 3). Although there are international policy guidelines and national policies that the Mongolian government initiates to manage FMD [10, 22], these policies do not seem to be understood by herders as preventive measures against FMD spread. There is a need for more direct education on how the preventive measures are supposed to help contain spread. Limon et al. [10] found that the containment policies also led to negative socioeconomic consequences for herders. In our study vaccination was the control measure most favored by herders and this is probably because it causes the least economic impact for them, as it prevents both culling and death of animals when an outbreak occurs.

Our results may not be generalizable to the whole of Mongolia since we only surveyed herders in a specific area being managed for conservation, and herders in the area already may be primed to understand how climate change and its environmental effects affect their health and the health of their livestock. Another limitation of our work is that we relied on translation of herder answers and the filling out of the questionnaires by herders did not allow for follow-up questions, which may have further elucidated information that their answers on paper did not allow us to decipher. Many survey responses were brief and contained phrases without explanation of their greater context, which often had to be extrapolated based on deductions from similar answers with more context given by other herder respondents.

Author contribution statement

Alli DiPietro: Investigation, Formal analysis, Visualization, Original Draft

Erdene Tseren Ochir: Proposal review, Results validation based on local knowledge, Writing review

Erica Garroutte: Conceptualization, Methodology, Project Administration, Writing review and editing

Rentsen Oyunbat: Methodology, Field data collection, translation

Iyabo Obasanjo: Funding acquisition, Supervision, Writing review and editing

Declaration of interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Iyabo Obasanjo reports financial support was provided by Dr. Thomas Hall Grant of the Consortium of Universities of Global Health.

Acknowledgements

Dr. Alexandra Sabo for help with NVivo, William Mun for support with the research, Tate Stevens for aiding in the visual display of data, Charles Center of William and Mary for summer research funding, Mongolian Conservation Initiative, the Institute for Integrative Conservation at William and Mary and undergraduate students in the 2019 One Health course at W&M. Funding was provided by the 2021 Dr Thomas Hall Global Education Grant of the Consortium of Universities for Global Health.

References

[1] McFadden AM, Tsedenkhuu P, Bold B, Purevsuren B, Bold D, Morris R. Epidemiology of the 2010 Outbreak of Foot-and-Mouth Disease in Mongolia. Transbound Emerg Dis 2015;62(5):e45–51 OctEpub 2014 Jan 29. PMID: 24472307. doi: 10.1111/tbed.12208.

[2] Prempeh H, Smith R, Müller B. Foot and mouth disease: the human consequences. The health consequences are slight, the economic ones huge. BMJ 2001;322 (7286):565–6 Mar 10PMID: 11238137; PMCID: PMC1119772. doi: 10.1136/bmj.322.7286.565.

[3] Knight-Jones TJD, McLaws M, Rushton J. Foot-and-Mouth Disease Impact on Smallholders - What Do We Know, What Don't We Know and How Can We Find Out More? Transbound Emerg Dis 2017;64(4):1079–94 AugEpub 2016 May 11. PMID: 27167976; PMCID: PMC5516236. doi: 10.1111/tbed.12507.

[4] World Animal Health Information Database WAHID-OIE. 2020 http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/Immsummary

[5] Nyamsuren D, Joly DO, Enkhtuvshin S, Odonkhuu D, Olson KA, Draisma M, Karesh WB. Exposure of Mongolian gazelles (Procapra gutturosa) to foot and mouth disease virus. J Wildl Dis 2006;42(1):154–8 JanPMID: 16699158. doi: 10.7589/0090-3558-42.1.154.

[6] Narmandakh D, Sakurai T. The impact of quarantine against Foot-and-Mouth Disease in Mongolia on pastoralists' farming performance and welfare. Japanese Journal of Agricultural Economics 2021;23:137–42. doi: 10.18480/jjae.23.0_137.

[7] Shiilegdamba E, Carpenter T, Perez A, Thurmond M. Temporal-spatial epidemiology of foot-and-mouth disease outbreaks in Mongolia, 2000 −2002. Vet Res Commun 2008;32:201–7. doi: 10.1007/s11259-007-9018-6.

[8] Mackenzie JS, Jeggo M. The One Health Approach-Why Is It So Important? Trop Med Infect Dis 2019;4(2):88. May 31PMID: 31159338; PMCID: PMC6630404. doi: 10.3390/tropicalmed4020088.

[9] Suzuki Y. Conflict Between Mining Development and Nomadism in Mongolia. In: Yamamura N, Fujita N, Maekawa A., editors. The Mongolian ecosystem network, ecological research monographs. Tokyo: Springer Japan. https://doi.org/10.1007/978-4-431-54052-6_20.

[10] Limon G, Ulziibat G, Sandag B, Dorj S, Purevtseren D, Khishgee B, Basan G, et al. Socio-economic impact of Foot-and-Mouth Disease outbreaks and control measures: an analysis of Mongolian outbreaks in 2017. Transbound Emerg Dis 2020 Mar 17Epub ahead of print. PMID: 32181584. doi: 10.1111/tbed.13547.

[11] Dangal SRS, Tian H, Lu C, Pan S, Pederson N, Hessl A. Ecosphere 2016;7(5). doi: 10.1002/ecs2.1274.

[12] Lkhagvatseren S, Hogan KM, Boldbaatar B, von Fricken ME, Anderson BD, Pulscher LA, Caddell L, et al. Discrepancies between self-reported tick bites and evidence of tick-borne disease exposure among nomadic Mongolian herders. Zoonoses Public Health 2019;66(5):480–6 AugEpub 2019 Apr 10. PMID: 30969028; PMCID: PMC6629472. doi: 10.1111/zph.12579.

[13] Jamsranjav C, Fernández-Giménez ME, Reid RS, Adya B. Opportunities to integrate herders' indicators into formal rangeland monitoring: an example from Mongolia. Ecol Appl 2019;29(5):e01899. JulEpub 2019 May 17. PMID: 31020715; PMCID: PMC6851969. doi: 10.1002/eap.1899.

[14] Reading RP, Murdoch JD, Amgalanbaatar S, Buyandelger S, Davie H, Jorgensen M, et al. From 'Paper Park' to Model Protected Area: the transformation of Ikh Nart Nature Reserve, Mongolia. PARKS 2016;22(2):41–54. doi: 10.2305/IUCN.CH.2016.PARKS-22-2RR.en.

[15] Bauerfeind R, von Graevenitz A, Kimming P, Schiefer HG, Schwarz T, Slenczka W, Zahner H. Zoonoses: infectious diseases transmissible between animals and humans. Washington, DC: ASM Press; 2016.

[16] Gereltuya A. Dramatic fertility transition in Mongolia and its determinants: the demise of the pronatalist state. Asia-Pacific Population Journal 2009;23(2):81–99 Aug.

[17] Judger M, Baffour B, Zhao Z. Recent fertility changes in Mongolia: what can we learn from examining tempo-adjusted fertility? Asian Popul Stud 2021;17(2):162–80.

[18] Spoorenberg T. Reconstructing historical fertility change in Mongolia: impressive fertility rise before continued fertility decline. Demogr Res 2015;33(29):841–70. doi: 10.4054/DemRes.2015.33.29.

[19] Moses E. Mongolia Shows How to Fight for Environmental Justice. World Resources Institute 2020 October 15, https://www.wri.org/insights/mongolia-shows-how-fight-environmental-justice.

[20] National Statistics Office of Mongolia. Animal Husbandry. Accessed July 30, 2022. http://www.1212.mn/Stat.aspx?LIST_ID=976_L10_1&type=description.

[21] Mort M, Convery I, Baxter J, Bailey C. Psychosocial effects of the 2001 UK foot and mouth disease epidemic in a rural population: qualitative diary based study. BMJ 2005;331(7527):1234. Nov 26Epub 2005 Oct 7. PMID: 16214809; PMCID: PMC1289318. doi: 10.1136/bmj.38603.375856.68.

[22] Ulziibat G, Maygmarsuren O, Khishgee B, Basan G, Sandag B, Ruuragc S, Limon G, et al. Immunogenicity of imported foot-and-mouth vaccines in different species in Mongolia. Vaccine 2020;38(7):1708–14 Feb 11Epub 2020 Jan 9. PMID: 31926753; PMCID: PMC7008245. doi: 10.1016/j.vaccine.2019.12.053.