

RESEARCH ARTICLE



Identifying relationships between multi-scale social-ecological factors to explore ungulate health in a Western Kazakhstan rangeland

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Abstract

1. Rangelands are multi-use landscapes which are socially and ecologically important in different ways. Among other interactions, shared use of rangelands by wildlife and livestock can lead to disease transmission. Understanding wildlife and livestock health and managing disease transmission in rangelands requires an integration of social and ecological knowledge.
2. Using the example of Western Kazakhstan, home to two types of ungulate hosts, the critically endangered saiga antelopes, *Saiga tatarica*, and livestock, we conducted a cross-scale analysis of social-economic, ecological and climatic factors that contribute to transmission of diseases. We focused on gastrointestinal nematodes (GINs) because they are transmitted between hosts that share pasture and they affect ungulate fitness. We used an interdisciplinary social-ecological methods approach which included conducting faecal egg counts of GINs in saigas and livestock, semi-structured interviews and focus group discussions with livestock owners and herders in the region, and triangulation of information through secondary sources.
3. Livestock rearing was done in two ways: (a) village-based livestock and (b) outlying farms. The latter overlapped more with saigas. Village-based livestock had significantly higher worm burdens than those on outlying farms, which had comparable burdens to saigas. Various factors exacerbate GIN prevalence and transmission: Veterinary services are minimal; both saiga and livestock numbers are increasing; and changing climate is increasing farmers' dependence on shared pastures for hay production. It will be crucial for saiga conservationists to engage in multi-pronged conservation interventions, which are evaluated and adapted through the lens of rural livelihoods and the livestock health on which they depend.
4. Our work provides researchers and practitioners with an avenue to better understand complex inter-relationships and plan interventions within rangelands,

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while viewing host health from an interdisciplinary perspective—ultimately working towards wildlife conservation while safeguarding livelihoods across the world's rangelands.

KEYWORDS

disease, gastrointestinal nematode, goat, pasture, saiga, sheep, social–ecological system, ungulate

1 | INTRODUCTION

1.1 | Background

Rangelands, comprising grasslands, shrub-lands, savannas and marshes grazed by livestock and wildlife (Allen et al., 2011), cover c. 40% of all land, and provide habitats for multiple species (Reid et al., 2008). Rangelands provide ecosystem services like carbon sequestration, contribute to satisfying the growing demand for livestock products and hold important biodiversity (Hobbs et al., 2008; Thornton, 2010). Much wildlife, including the critically endangered Saiga antelopes *Saiga tatarica* and various declining populations of reindeer *Rangifer tarandus*, call rangelands their home. Most of these species live outside Protected Areas, sharing rangelands with millions of people and their livestock (Reid et al., 2008).

Worldwide, there are >200 million pastoralists. Their livelihoods depend on livestock raised either on communal or private pastures, with varying mobility (Niamir-Fuller et al., 2012). Around 550 million of the world's poor people (living on less than \$1.25/day) depend on livestock as one of their few or only assets. c. 58 million of them live in rangelands (Robinson et al., 2011). Rising global demand for livestock products (Otte et al., 2012) may increase human impact on both wildlife management and pastoralism in rangelands. Alongside, poverty and vulnerability are high in rangelands in developing countries, with climate change set to increase weather volatility and impact already-vulnerable pastoralists (Thornton et al., 2014). While the links between climate change, food security and vulnerability are complex, increased understanding of these interactions can enhance interventions to support adaptive capacity of rangelands (Boone et al., 2018).

The sharing of pasture by multiple species of domestic and wild ungulate can lead to interactions which may be positive, for example, facilitation (e.g. Odadi et al., 2011), neutral, that is, coexistence with limited interaction (e.g. Mori et al., 2020) or negative, for example, competition (e.g. Bagchi et al., 2004). Pasture sharing can also lead to disease transmission, which can impact livestock-based economies (Reid et al., 2008) and wild ungulate health (Smith et al., 2009). This is particularly relevant for wild ungulates as pathogen assemblages are associated with host phylogeny (e.g. Walker & Morgan, 2014). Pozo et al. (2021) identified four social–ecological challenges underlying conflict between livestock production and wild herbivore conservation, of which disease transmission is one. The interplay

between factors such as resource availability, climate and disease, nestled within complex interactions with livestock in pastoral systems, produce a net effect on wild species (Sæther, 1997). For instance, climate change influences forage availability for ungulate hosts, parasite–host assemblages and also interactions between the two through host nutritional status (Brooks & Hoberg, 2007).

From this point of view, endoparasites, particularly gastrointestinal nematodes (GINs), are of particular interest in rangelands as they are determinants of fitness for wild and domestic ungulates (Gulland, 1992; Perry & Randolph, 1999). Indirect contact, particularly via pasture sharing, can enable cross-transmission of trophically acquired GINs, whose development on pasture generates a lag time between pasture occupation and infectivity (Morgan et al., 2006). Because part of GIN's life history is affected by environmental conditions, changes in climate are likely to impact them profoundly (Brooks & Hoberg, 2007). In rangelands, human intervention to reduce or mitigate the impacts of GINs can strongly influence their presence in livestock and consequently co-transmission with wild ungulates (Weinstein & Lafferty, 2015). To ensure effective GIN management, it is critical to incorporate these social determinants of livestock health to fully understand the disease transmission dynamics. For instance, broad-spectrum anthelmintic use in livestock is common, often either strongly suppressing GINs or causing resistant strains to persist (Weinstein & Lafferty, 2015). Van Veen (1997) summarized activities by transhumant livestock owners across Central Asia and Africa to evade disease transmission (including GINs), showcasing local understanding of disease epidemiology. Yet, understanding of disease mechanisms and management at the livestock–wildlife interface remains limited, particularly with respect to GINs (Rhyen & Spraker, 2010).

Moreover, while many studies consider a number of ecological and social factors influencing rangelands, advances in integrating these components to reconcile potentially competing goals (e.g. livelihood and wildlife conservation) have been limited (Hruska et al., 2017). For instance, ecological research has seen considerable focus on grazing regimes and ecological indicators with limited consideration of the goals of livestock owners. Similarly, social science has provided a lot of information on rangeland users, but has focused less on how social and ecological factors combine to produce ecological outcomes (Brunson, 2012). Rangeland research and management, particularly concerning host health, cannot overlook the human dimension if it aims to be applied.

Given the intricate interconnections between people, their livestock, wildlife and the collective social, political and ecological surroundings of wildlife and livestock, it is clear that rangelands are intertwined social–ecological systems (Hruska et al., 2017; Reid et al., 2014). Consequently, host health and disease management in rangelands is also a social–ecological concern (Valente et al., 2020).

1.2 | Research questions and aims

We aimed to understand the inter-relationships between ecological, social, economic (market related), political and climatic factors affecting host health in rangelands (Figure 1). We look for evidence of links between different factors by mapping their directionality and strength, while considering uncertainties and discuss the likelihood that these links might change in the future. We illustrate this approach using a case study from the Western Kazakh rangelands, where saiga antelope, *Saiga tatarica*, shares pastures with livestock.

While various pathogens of concern exist, we focused our work on GINs (hereafter 'health' and 'disease' is in reference to GINs unless stated otherwise) because indirect contact, particularly via pasture sharing, can facilitate cross-transmission of trophically acquired GINs. We restricted our work to wild ungulates (saigas) and small-bodied domestic ungulates (sheep and goats) for two main reasons: (a) these are the main grazers in this system and (b) because phylogenetic relatedness is a good predictor of resource competition and disease transmission. Saigas in Kazakhstan are known to share the majority of their GIN species with sheep and goats (Morgan et al., 2005; Appendix S1).

Research questions used to explore each type of inter-relationship are illustrated in Figure 1 and defined in Table 1, which also highlights key uncertainties based on literature. Our overarching research question was to investigate how ecological, social, economic, political and climatic factors interact with each other

across spatial scales to affect host health in a multi-use rangeland system. Given the social–ecological complexities of rangelands, we expected that various factors would interact to affect disease prevalence and transmission. To investigate this, we used mixed methods within a social–ecological approach. This included conducting faecal egg counts of GINs in wild and domestic hosts, semi-structured interviews and focus group discussions with livestock owners and herders in our study area and triangulation of information through secondary sources.

Inter-relationships between different factors affecting host health within rangelands are scale dependent (Cash et al., 2006). Each scale may have different social and ecological patterns and processes at different hierarchical levels (Hruska et al., 2017). For instance, in the case of rangeland sustainability, the grazing distribution of wild and domestic animals may be critical at the level of a rangeland ecological site. This is driven by ecological processes determining resource availability and social management systems that determine livestock location (Western et al., 2009). However, at the regional level, market prices and legislation governing land access and use may be important (Hruska et al., 2017). Due to financial and logistical constraints, it is most feasible to concentrate analysis at one or few spatial scales. Therefore, for simplicity and applicability to real-world management decisions, we distinguish in our work between two scales: (a) the 'local' scale, which refers to factors affecting host health at a pre-defined location, in our case the calving and summer range of saigas in 2019 in Ural (see Section 2.1 below) and (b) the 'regional' scale, which refers to broader factors that affect host health.

Thus, at the local scale, we aim to compare spatial distributions of livestock and saiga to determine whether these result in contact patterns enabling disease transmission. We also compare the abundance and diversity of GINs across species and investigate local disease control efforts among livestock owners. More broadly, we look at the mandate and coverage of veterinary services in our study area, investigate the impact of land access arrangements and market

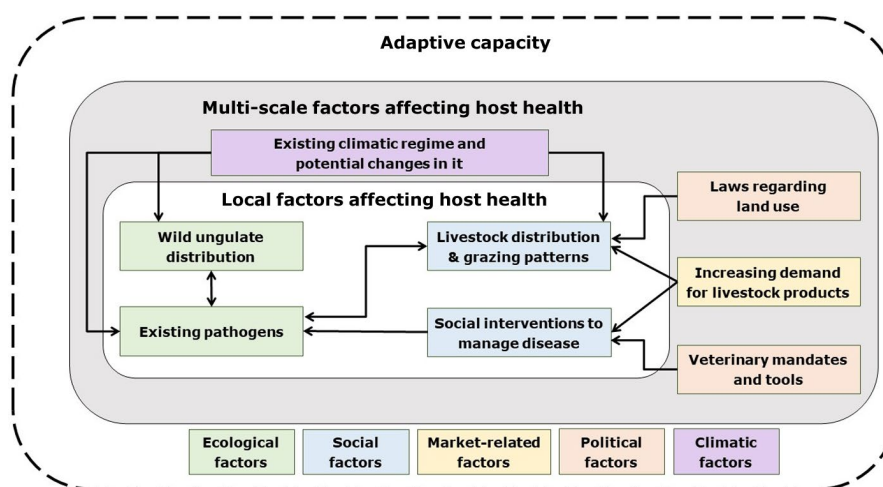


FIGURE 1 A schematic representation of the various factors affecting host health within a rangeland system. Each box represents a component (Table 1). Adapted from Reid et al. (2014) and Hruska et al. (2017)

access on livestock grazing, and the implications of climate change for the study system.

Given the complexities involved in these systems, our approach is primarily descriptive, at least initially. Through our work, we hope to highlight and map the interdisciplinary and cross-scale nature of the research required to better understand and manage livestock–wildlife interactions through GIN disease and shared resource use.

2 | METHODS AND MATERIALS

2.1 | Study area

Kazakhstan's rangelands are home to >80% of the global population of critically endangered saiga antelope (CMS Saiga MoU, 2015). Saiga habitat is a predominantly flat, treeless landscape characterized by hot, dry summers and severe winters. Annual rainfall is low, varying from an average c. 300 mm in the steppe to c. 250 mm in semi-desert and c. <250 mm in desert zones. Migrating saigas use all these zones seasonally, spending summer in the north and winter in the south (Bekenov et al., 1998). Saigas congregate in dense aggregations in early to mid-May. Calving grounds usually cover around 150–900 km² (Bekenov et al., 1998) with site selection increasingly driven by human disturbance (Singh et al., 2010). Calving is a critical life-history period for saiga (Singh et al., 2010); for example, a recent mass mortality event during calving, though driven by a temperature and humidity anomaly, was probably exacerbated by calving-related stresses (Kock et al., 2018).

We focused on the calving and summer distribution of the Ural population in Western Kazakhstan Province (Figure 2). We chose to work in this area as livestock and saiga population densities and overlap are particularly high, both seasonally and annually, compared to other saiga populations (Dara et al., 2020). Hunting following the collapse of the Soviet Union caused major declines in saiga numbers range wide and remains a threat (CMS Saiga MoU, 2015). However, although the Ural saiga population fell from 236,000 in 1991 to 26,400 in 2013, it had recovered to around 217,000 by 2019 (Zuther, 2020). Livestock numbers across Kazakhstan are also currently recovering from their post-Soviet Union decline (Kerven et al., 2016), providing a renewed threat of disease transmission to saigas. There is even a perception that in Ural, exploitative resource competition between saigas and livestock might be occurring (Satke, 2020). Given this background and that livestock densities are currently low in the other populations (Dara et al., 2020; Khanyari, Robinson, Morgan, Brown, et al., 2021), saigas are more likely to come in contact with livestock in this population than the others, making it a relevant case study site.

Historically, Kazakh pastoralists followed long-distance seasonal migratory routes. This remained so during the Soviet period as a result of support for State Farms. However, after the Soviet collapse, State Farms were broken up and herds fragmented among thousands of small private households and farms. Many people were constrained to graze their animals around villages, as they could not

afford seasonal migration (Kerven et al., 2016, 2021). Nonetheless, those with larger livestock holdings increasingly leased pasture further from villages, out in the steppe (Kerven et al., 2021). Therefore, we divide livestock holdings into two types: village based and outlying. Most village-based livestock are held by private households which are not registered as farmers and cannot lease land. Their animals thus usually graze on village lands (usually up to a 3km radius around the village) physically demarcated and legally designated for common use, although some types of livestock (e.g. horses) may roam much further. Outlying holdings belong to registered farms and utilize land parcels leased privately, beyond the village lands. Villages employ the *khyzyk* system, where all the sheep and goats owned in the village are grazed together as one herd, with herding duties rotating among owner households daily. Animals at outlying stations are grazed in single-owner herds.

2.2 | Data collection and analysis

2.2.1 | Social factors affecting host health

Given the logistical issue of covering all farms in vast and remote areas, we used a snowball sampling strategy (Noy, 2008) to obtain a representative sample of outlying farm owners to interview, as well as one key informant per village. We considered our sample to be adequate when all additional respondents provided similar responses to previous ones.

We conducted 46 semi-structured interviews with livestock owners and professional shepherds; 11 in villages and 35 on outlying farms. Answers for village-based livestock were obtained at the level of each *khyzyk* (as these animals are managed as single flocks), while answers for outlying livestock were obtained at the level of each outlying farm. From each village, we interviewed a member of the *khyzyk* who served as the key informant for the village—all villages we visited had one *khyzyk*. These informants were identified by the *khyzyk* members and chosen based on their knowledge about livestock management.

We also conducted key-informant interviews with veterinary officials where possible, particularly to validate livestock health information ($n = 5$). The aim was to understand livestock rangeland use, livestock composition and distribution and livestock health and its management (Table 1). We also collected information on livestock numbers at each village and outlying farm, and calculated stocking densities by dividing the number of animals (individual stocks of sheep and goat) by the area grazed (demarcated by interviewees and key informants as circles, with radius equal to the furthest distance routinely grazed from the central point). Quantitative and semi-quantitative answers to these questions were analysed using descriptive statistics and bootstrapped with replacement (10,000 iterations) to estimate means and 95% confidence intervals. Where applicable, bootstrapped *t* tests were used to compare significance. The questionnaire is shown in Appendix S2. The survey was approved by the University of Bristol's Ethical committee (Ref: 85482).

Consent was established orally before the surveys. Written consent was not obtained as most respondents were not literate. All the responses were coded, and respondents' names or other identifying features were not used or shared to ensure anonymity.

2.2.2 | Local ecological factors affecting host health

The Association for Conservation of Biodiversity of Kazakhstan (ACBK, an NGO) has been monitoring saigas for several years. They record exact GPS locations of saiga calving sites, rough maps of saiga locations in other seasons and a saiga population count. These include historic saiga locations (Singh et al., 2010), and updated locations since. We delimited the calving and summer distributions of the Ural saiga population through a combination of field surveys and expert opinion of researchers within ACBK. As fine-scale calving location can change annually (Singh et al., 2010), we identified specific calving locations in 2019 (the year of the study) from aerial and ground surveys conducted by ACBK (see Singh et al., 2010 for survey methods).

Within the calving and summer areas, fresh faecal samples were collected from sheep, goats and saigas. At least one pooled faecal sample was collected from each village and outlying farm interviewed. Because sheep and goats are herded together and kept in enclosures at night, these samples were collected from the ground of enclosures or pasture, and comprised faeces from multiple individuals (i.e. pooled samples of at least 15 individuals), which could include sheep and/or goats. Results are therefore presented for small ruminants in aggregate, and it was not possible to separate parasitological results by livestock species. Between 5th May and 2nd June 2019, we collected and analysed 155 pooled faecal samples: 79 from saigas and 76 from livestock (split equally between outlying farms and village-based livestock). Livestock samples were pooled for each village or outlying farm and saiga samples were pooled at the level of the study population (following Morgan et al., 2005).

Faecal samples were analysed for helminths using the mini-FLOTAC technique (Cringoli et al., 2017), which uses flotation-dilution to quantify parasite egg density, expressed as Faecal Egg Counts (FEC). FEC in an aliquot of pooled faecal sample should be a good reflection of the average individual FEC (Morgan, Cavill, et al., 2005). While FEC do not correspond precisely to counts of adult helminth worms within the animal, there is a correlation between the two, including in ungulates in this system (Morgan, Shaikenov, et al., 2005). FEC provide a direct measure of the relative contribution of different hosts to pasture contamination. Given their adverse impact on wild and domestic ungulate health and fitness, we were particularly keen to investigate the existence of strongyle helminths in both hosts.

Following the protocol described in Cringoli et al., (2017), 5 g of faeces was analysed per sample in 45 ml of saturated salt solution. The number of eggs found for each parasite was recorded for each sample and multiplied by a factor of 5 to obtain the total faecal egg count (FEC) in eggs per gram (EPG) of faeces. Thus, the sensitivity

of the mini-FLOTAC technique is 5 EPG. Parasites were identified to morphologically distinguishable egg types, since overlap in egg appearance limits species-level identification.

As our sample sizes were small, we bootstrapped our data with replacement 10,000 times to obtain means and 95% confidence intervals (0.025 and 0.975 quantiles) of faecal egg counts for livestock and saigas. We used the bootstrap *t* test to compare mean abundance of endoparasites between saigas and livestock.

To supplement the livestock FEC data, we developed impact scores to assess the effect of endoparasites on livestock health. This was done by direct questioning of the livestock caretakers, who adjudged the impact of endoparasites (particularly GINs) on a scale of 0–5 (5—animal dies; 4—alive but useless, in terms of what they define productivity to be; 3—severely impacted; 2—impacted but not so severely; 1—little impact; 0—barely noticeable). A Mann–Whitney *U*-test and a frequency analysis using Fisher's exact test were used to assess differences in impact scores across village-based and outlying livestock.

2.2.3 | Regional factors affecting host health

The same interviewees and key informants described in Section 2.2.1 were used to gain information on the market, policy and climate-related factors affecting host health. The questions revolved around the components affecting livestock production (Figure 1): market demand, land tenure laws, veterinary regimes and the impact of climate and climate change on host health (see Appendix S2). Where possible, information from interviews was cross-validated with information in published literature and public datasets: We cross-verified claims about changes in livestock numbers by looking at livestock data from the Kazakh Bureau of National Statistics (stat.gov.kz, 2020). Livestock numbers were available by province and district from 2014 to 2020. Our study falls primarily in the Zhanybek district of Western Kazakhstan province; hence, we extracted data for both and analysed the trend in numbers of sheep and goats, which are recorded in aggregate as small ruminants, and all livestock (sheep/goats, cattle and horses) over time using Pearson's correlation against year. We cross-verified claims about climate change by referring to literature and online climate data. Daily temperatures and precipitation were obtained from the POWER Data Access Viewer (DAV) (POWER, 2020). We used the POWER Single Point Data Access widget which provides access to near real-time 0.5 × 0.5 degree datasets, obtained for the years 2000–2019 and averaged across the calving and summer saiga range. We generated a scatter plot of the time-series data and checked for trends over time using Pearson's correlation, after plotting the residuals of the original data to rule out auto-correlation.

To better contextualize the information from the semi-structured interviews, we conducted 15 focus group discussions (FGDs; Nyumba et al., 2018). Group size was 3–11 people (average = 6). As grazing is mostly managed by men, most participants were males (32–68 years old) and included farmers and government employees. However, where possible, we tried to include female respondents

TABLE 1 Components of the conceptual model in Figure 1 that aims to map factors and their interactions affecting host health in multi-use systems. Although shared pathogens can, in principle, impact both livestock and wildlife, we are most concerned with the conservation implications of transmission from livestock to wild ungulates. GIN, gastrointestinal nematode

Component*	Potential interactions with and implication for host health	Key uncertainties when considering impact of factors on host health	Research question
Wild ungulate distribution	Cross-species disease transmission depends on contact patterns, governed by host distribution and movement (Vosloo et al., 2002)	Distributions may cover vast areas and be highly dynamic in a changing environment (e.g. Singh & Milner-Gulland, 2011)	<i>Does saiga distribution result in contact patterns which can enable disease transmission from livestock?</i>
Existing prevalence and diversity of pathogens	Depending on species and abundance, GINs may cross-transmit and are determinants of fitness in wild and domestic ungulates (Gulland, 1992; Perry & Randolph, 1999)	Identification of pathogens can be resource intensive (Avramenko et al., 2019). GIN eggs are deposited in the environment in faeces, where they develop to infective larvae, which then move onto herbage. Larvae are ingested by hosts during grazing. Climate/weather and availability of forage impact this process and if not accounted for, leads to uncertainty (Rose et al., 2015)	<i>What is the abundance and diversity of GINs, and how do helminth burdens compare between saiga and livestock (across different livestock grazing practices)?</i>
Livestock distribution and grazing patterns	Cross-species disease transmission depends on contact patterns, governed by host distribution and movement (Vosloo et al., 2002)	Micro-scale grazing patterns/movement can facilitate transmission (Wilcox and Colwell, 2005). Stocking densities and livestock herd composition can determine magnitude of impact on livestock health and transmission to wildlife (Macpherson, 1995)	<i>Do livestock distributions and grazing patterns result in pasture sharing with saiga? How does this differ between different livestock grazing practices?</i>
Human interventions to manage disease	Human (herder/owner) interventions can improve livestock health by reducing pathogen burdens—but interventions may lead to adverse effects, for example, drug resistance (Charlier et al., 2014)	Changes in diseases targeted by treatment may in fact, reflect net effects of other factors (Brock et al., 2014). Human interventions, especially in resource-poor environments, tend to be dynamic and erratic (Van Veen, 1997)	<i>Are there prevalent antiparasite interventions that can influence GIN burdens in livestock and potentially in saigas?</i>
Veterinary mandates and tools	In many countries, disease mitigation programmes (e.g. vaccination/use of anthelmintics) are determined at specific levels of government. Their implementation, and alternative private provision of health care, can directly alter livestock health, with the potential to affect wild host health	Veterinary services are set at varying levels of government (e.g. national), but can differ between spatial scales within a country (e.g. states/provinces) Additionally, sometimes, this information is not always publicly disclosed	<i>What is the state of veterinary services in our area of interest? Are there services that can deal with suppression of GINs?</i>

(Continues)

TABLE 1 (Continued)

Component ^a	Potential interactions with and implication for host health	Key uncertainties when considering impact of factors on host health	Research question
Legislation and institutions governing land access and use	Can directly or indirectly influence contact patterns between wild and domestic hosts (Robinson & Milner-Gulland, 2003; Weinstein & Lafferty, 2015)	While property rights legislation is determined at the national level, implementation can differ considerably between regions and other spatial scales within a country (e.g. states/provinces and districts). Presence of a law does not guarantee its enforcement, while many informal arrangements may exist. In many cases, economic factors may be more important in determining land-use decisions (Robinson et al., 2016)	<i>What are the laws regarding land use in our area of interest, and what are their implications for host health?</i>
Increasing demand for livestock products	This can alter livestock herding and health management practices, in turn potentially altering livestock and wild ungulate health in multi-use systems (Thornton, 2010)	Market drivers operate at various scales, with manifold impacts on livestock management practices. It is difficult to tease these apart (Thornton, 2010)	<i>What is the demand for livestock produce from our study area? How does this impact livestock management strategies with implications for host health?</i>
Existing climatic regime and potential future changes	Climate contributes to host contact patterns and availability of pathogens of concern (Rose et al., 2015; Vosloo et al., 2002)	It is difficult to decouple the impact of climate from the many confounding variables and interactions determining host health in rangelands (Pruvot et al., 2020). There is uncertainty in understanding future trajectories of climate and hence its implications for host-parasite assemblages—particularly in remote-data-poor regions (Rose et al., 2015)	<i>What impact is climate having on the interactions between the rangelands and hosts, and what is the implication of this for host health in our study area?</i>

^aColours of the column correspond to the legend represented in Figure 1.

in our discussions. To compare change over time, a reference point of the period just after the collapse of the Soviet Union in 1991 was used. This time brought sudden and remarkable social and economic change and was readily identified by participants.

3 | RESULTS

3.1 | General overview of results

At the local level, we found that livestock rearing was done in two ways: (a) village-based livestock and (b) outlying farms. The latter overlapped more with saigas. Village-based livestock had significantly higher worm burdens than those on outlying farms, which had comparable burdens to saigas. Treatment against worms was limited and spatially variable. Village-based livestock were primarily treated with anthelmintics, while outlying farms predominantly did nothing or consumed individuals showing signs of disease.

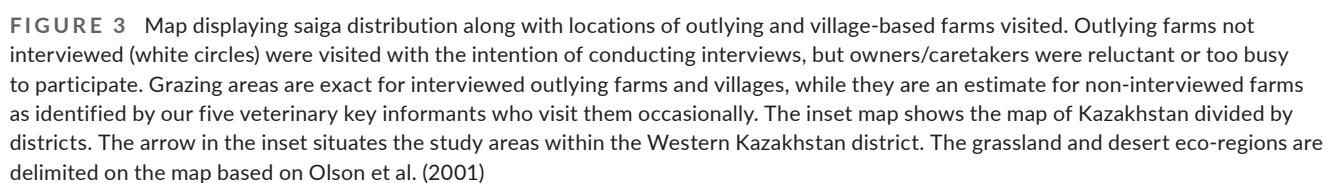
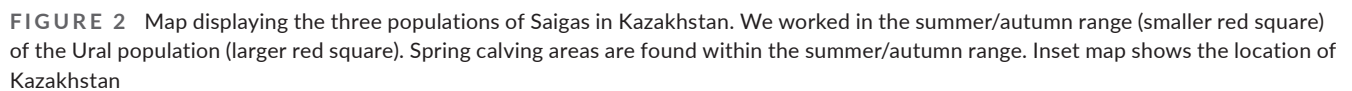
Zooming out to the regional scale, we found that increasing demand for livestock products is driving increases in livestock numbers. We also found that the traditional seasonal movement of livestock seldom occurs now, as most outlying farms are single sedentary

entities leased by single owners (usually a family) and used throughout the year. Reasons for this may include costs of movement and high transaction costs of obtaining a 49-year land lease, currently allocated by auction. Lastly, climatic alterations in the summer and winter are negatively affecting the quantity and quality of forage. This in turn is affecting livestock health, resulting in compromised productivity and even death. Moreover, climatic alterations are also resulting in pastoralists not being able to collect enough hay as there is less growth. Additionally, saiga numbers are growing rapidly and they are eating the grass that farmers normally harvest for hay.

Results are explained in detail in the following sub-sections. Overall, it is evident that various factors are exacerbating GIN prevalence and transmission: both saigas and livestock host GINs and both are increasing in number; veterinary services are minimal; livestock movements are now limited; and a changing climate is increasing farmers' dependence on hay pastures, which are shared with saigas.

3.2 | Livestock distribution and grazing patterns

Using available district land committee (cadastre) maps covering the saiga's spring and summer range, we were able to identify and visit



11 villages and 68 outlying farms. This included more than c. 70% of outlying farms within the saiga summer and calving distribution. A few of the outlying farms were abandoned or had absentee owners. Saigas and livestock share large areas of pastures throughout the saiga's summer and calving extent (Figure 3).

Livestock rearing was done in two ways: (a) village-based livestock and (b) outlying farms. In both management systems, livestock were present in a given area throughout the year. Outlying farms are located on owned or leased land parcels away from the village (>3 km). They usually have infrastructures such as housing, watering wells and a fixed area (not fenced) where livestock are housed and grazed. Outlying livestock herds were all too isolated to interact with other herds. Sheep/goats on these farms are taken out to pasture by the farm owners, or paid workers. After a day of grazing, they are collected and bought back to a corral (fenced livestock pens) for the night. Most flocks are stall-fed in winter due to the cold and lack of forage. For this, hay is collected from the farmland or purchased from other farms, in late summer/early autumn. If the winter is mild, then the flocks graze outside as during other months. Animals are taken to water points to drink, usually supplied from man-made wells or boreholes.

All village-based key-informants ($n = 11$) confirmed that villages used *khyzyks* to herd small ruminant livestock. Village-based sheep and goats roam within c. 2–3 km of the village; however, cattle and horses may go beyond the cadastral boundaries of 'village lands' and tend to be free-ranging. No significant difference was found in stocking densities of small ruminants between the villages and outlying farms ($p = 0.16$), while there was a significant difference in mean small ruminant numbers ($p = 0.01$). Thus, total and mean per-location livestock numbers are higher on outlying farms than in *Khyzyks*, while both graze up to similar distances from their night-time locations, thus using similar pasture area. Table 2 presents information regarding livestock numbers and stocking densities for outlying farms and village-based livestock (per *khyzyk*).

3.3 | Endoparasites in livestock and saigas

Outlying livestock had worm burdens comparable to those of saigas, as indicated by FEC data, while village-based livestock had

significantly higher burdens compared to both of them (bootstrap $p < 0.05$, Table 3). Strongyle nematodes and *Nematodirus* sp. GINs, along with the tapeworm *Moniezia* sp., were found in both saigas and livestock (Table 3).

As our focus is on GINs, information from 46 respondents ($n = 35$ outlying and $n = 11$ village based) on prevalent livestock health issues, their potential causes, impact on animal productivity and treatments is summarized in Appendix S3, Table S1. Respondents recognized GIN presence through symptoms such as diarrhoea, weight loss, pale ocular mucous membranes, liquid discharge from nose, loss of appetite and visible worms in faeces. While the Mann–Whitney *U*-test showed that overall perceived health impact is similar between outlying and village-based livestock ($w = 148.5$, $p = 0.89$; Figure 4b), the Fisher's exact test using proportions for each category (1–5) revealed that a larger proportion of village-based herders considered there to be some impact of GINs on health—albeit mild ($p = 0.0006$; e.g. 55% respondents in villages suggested '2—impacted but not severely' as an impact score, while only 29% suggested so for outlying livestock; Figure 4a).

3.4 | Treatment against endoparasites in livestock and saigas

We found that treatments against endoparasites (particularly GINs) depended on livestock location (Figure 5). For instance, village-based livestock predominantly used anthelmintics as they could be bought from Uralsk (nearest town), which was easier to travel to from villages given road access, while outlying farms mostly did nothing or consumed the affected individual before health further deteriorated. Plant-based treatments were mentioned by herders on outlying farms but not in villages.

Sheep and goats are reported to be vaccinated against rabies, pasteurellosis, anthrax, pox and glanders in our study area (official Kazakh vaccination plan, 2019). We did not find any official treatment mandate for GINs from the state, which was confirmed by the five veterinary key informants. Hence, it appears that GIN treatment was opportunistic, spatially variable and managed by livestock owners/shepherds. Livestock owners thus needed to source anthelmintic drugs themselves, which often came with a high expense as it

	Outlying livestock	Village livestock
Sample size (number of farms surveyed) of which supplied stock numbers	35	11
	28	11
Total small ruminant numbers surveyed	7,725	1,120
Total numbers in Zhanybek district	40,868	27,143
Mean small ruminant numbers per farm	276 (172–397)	102 (63–150)
Range small ruminant numbers per farm/ <i>Khyzyk</i>	0–1,300	30–250
Mean stocking density (head per km ²)	13.8 (4.6–27.1)	5.1 (3.2–7.1)
Range stocking density (head per km ²)	0–153	1.5–12.5

TABLE 2 Data on livestock abundance and stocking densities for outlying farms and village-based livestock, from key informant interviews supplemented with direct observations and literature. District numbers used official statistical bureau data

TABLE 3 Endoparasite prevalence, range (eggs per gram) and mean (\pm SD) (eggs per gram, EPG) across outlying livestock, village livestock and saigas. Sample sizes are number of pooled faecal samples, each representing a group (livestock) or sample location (saigas), and 15–20 individual faecal samples. Prevalence is expressed at the level of the pooled sample and not the individual animal. Livestock comprise mixed groups of sheep and goats. Strongyles include eggs morphologically characteristic of the Trichostrongylidae (see text)

	Strongyles*	Nematodirus*	Trichuris*	Moniezia	Dicrocoelium
<i>Outlying livestock (n = 38)</i>					
Prevalence (%)	34	32	16	37	13
Range (EPG)	5–35	5–25	5	5–110	5–10
Mean (\pm SE) EPG	4.6 (\pm 1.3)	3.2 (\pm 0.9)	0.8 (\pm 0.3)	11.2 (\pm 3.6)	0.8 (\pm 0.4)
<i>Village livestock (n = 38)</i>					
Prevalence (%)	74	45	47	82	18
Range	5–45	5–25	5–20	1–155	5–25
Mean (\pm SE) EPG	12.8 (\pm 2.0)	5.4 (\pm 1.2)	4.9 (\pm 1.0)	34.6 (\pm 6.0)	1.8 (\pm 0.8)
<i>Saiga antelope (n = 79)</i>					
Prevalence (%)	42	33	0	29	0
Range	5–45	5–25	—	5–30	—
Mean (\pm SE) EPG	4.7 (\pm 0.9)	3.2 (\pm 0.6)	—	3.8 (\pm 0.8)	—

*Gastrointestinal nematodes, GINs; others are platyhelminths. All hosts also had oocysts of coccidia (*Eimeria* sp.) present. *Marshallagia* were present solely in outlying livestock and were included in strongyles (prevalence = 29%, mean (\pm SE) = 3.5 (\pm 0.8)).

involved travelling to nearest town/city, which could be up to a day's drive away.

3.5 | Regional factors influencing disease transmission

3.5.1 | Increasing demand for livestock products

Participants in 14 of the 15 FDGs arrived at the consensus that livestock numbers have increased in the region since the immediate post-Soviet period (1990s). Survey respondents ($n = 41$) associated this change with government subsidies aiming to increase sale of livestock products (meat and dairy). Official data from the statistics bureau of Kazakhstan confirmed that between 2014 and 2020, Zhanybek district has seen a significant increase in small ruminants numbers owned by registered farmers (mostly outlying) and a relatively stable population owned by households (mostly in villages; Figure 6). This is similar to the trends in other livestock in Zhanybek and generally for Western Kazakhstan province (Figures S1 and S2 in Appendix S3).

All respondents suggested that markets to sell livestock products (e.g. meat) were more accessible now than in the 1990s; before 1991 procurement of livestock and its products were the state's responsibility. Additionally, the number of individual livestock owners was reported to be increasing. This has resulted in increasing occupation of outlying lands.

Furthermore, participants in 12 out of 15 FDGs arrived at a consensus that over time land parcels available to own or lease (as farms) in outlying areas are getting smaller, thus increasing stocking densities. Given pasture sharing, this is leading to potential resource competition with saigas. This possibility was confirmed when 41 out

of the 46 key informants suggested they had negative perceptions towards saigas as these reduce the available forage for livestock, especially during summer and autumn, a time when hay is also being collected for the winter.

3.5.2 | Laws regarding land use

Focus group discussions revealed that during Soviet times, livestock herders used two state-owned locations, *zimovka* (winter house) and *letovka* (summer house), and migrated annually between them. In Ural, these movements were short in distance and duration (usually one day in transit), unlike in other parts of Kazakhstan where migrations could last several days or even weeks (Robinson et al., 2016). Today, even the short *zimovka* to *letovka* migrations are seldom occurring as most outlying farms are single sedentary entities leased by single owners (usually as family) and used throughout the year (see Section 3.1). Reasons for the loss of the two-season migration were not established with any certainty but are likely to include the costs of movement, establishment and maintenance of infrastructure at two sites (Kerven et al., 2016), and high transaction costs of obtaining the 49-year land lease, which are now allocated through a complex auction process (Robinson et al., in press).

In all, 13 FDGs arrived at a consensus that the reasons for non-mobility were interconnected, and involved complications with legal access to land, high capital costs of investment in movement and the availability of feed during the winters facilitating sedentarization. The other two FDGs suggested that the reasons for non-mobility were that individual livestock holdings were not large enough for movement to either be necessary or cost-effective. Of the 35 survey respondents based in outlying farms, 29 said they collected hay for winter from their own farms while six suggested they purchased hay

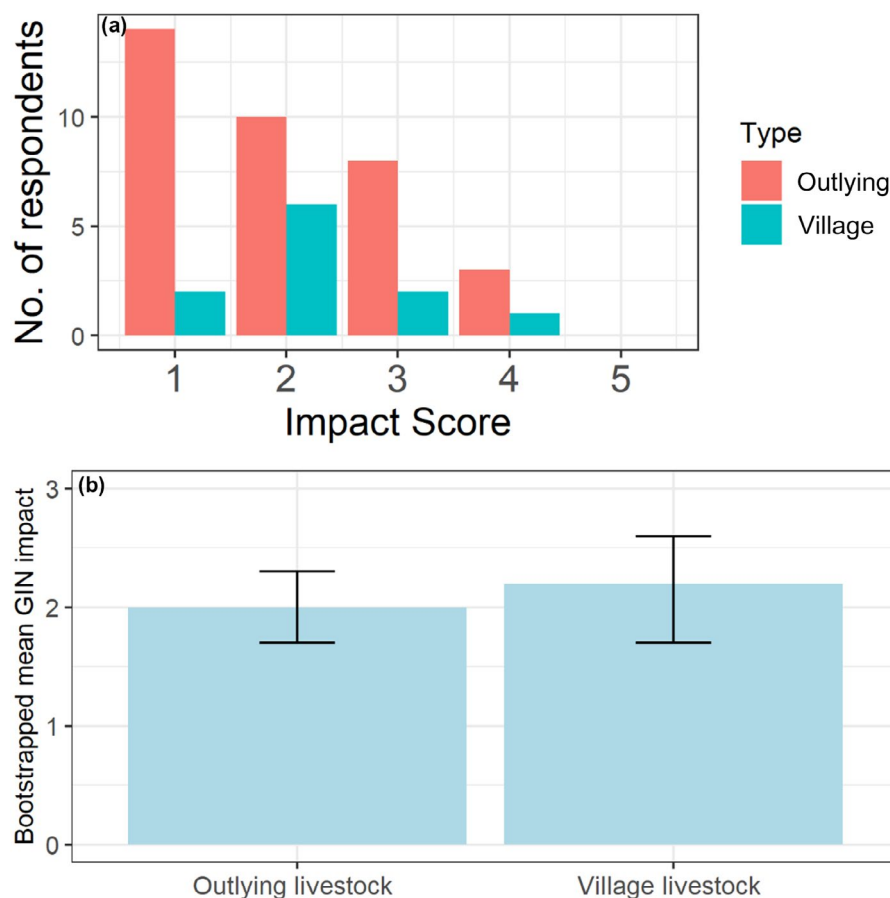


FIGURE 4 Graphs displaying (a) impact scores of endoparasites (particularly gastrointestinal nematodes, GINs) on livestock health and (b) bootstrapped mean and 95% CI of impact scores as related to herder perceptions of level of damage to health, for outlying and village-based livestock. 5—animal dies; 4—alive but useless (in terms of what they define productivity to be); 3—severely impacted; 2—impacted but not so severely; 1—little impact; 0—barely noticeable

for winter from neighbouring farms or from markets in nearby towns like Uralsk. All 11 village-based respondents said they purchased hay for winter either from neighbouring outlying farms with surplus hay or from nearby towns like Uralsk. All 46 respondents suggested that availability of hay during winter was a key facilitator of non-mobility, as adverse weather during winter, often means they have to stall-feed their livestock.

3.5.3 | Current climate and potential changes

Eleven of the 15 FGDs agreed that summers have become hotter and drier since the break-up of the Soviet Union. Since 2000, we found statistically significant evidence of warming summers in Ural as well as indications of decrease in summer precipitation, albeit not statistically significant (Figure 6).

The 11 FGDs also agreed that winters had worsened, that is, increased snowfall and narrowing *dzud* cycles. *Dzud* describes winter conditions leading to an icy snow surface, and is often associated with mass death of livestock and saigas from lack of food. *Dzud* conditions are associated with low temperatures accompanied by high precipitation. Since 2000, we find evidence for a trend towards

lower winter temperature and increasing winter precipitation, albeit non-significant (Figure 7). Temperature and precipitation data alone, however, might not capture the conditions leading to *dzud*. Respondents ($n = 43$) suggested that one consequence of increased perceived *dzud* risk in Ural is that herders need to prepare more hay for the winter. This is challenging as the quality and quantity of grass have declined according to respondents. FGDs agreed that this affects livestock health, resulting in compromised productivity and even death. Forty-one of the 46 key informants expressed concern at not being able to collect enough hay, as the saigas were eating grass that farmers normally harvest for this purpose. All five veterinary key informants acknowledged that drier summers and large saiga numbers had minimized the amount of hay being collected by farms to sustain their stocks in winters. They suggested that this adversely affected livestock health and numbers, particularly in *dzud* years.

The remaining four of the 15 FGDs arrived at a consensus that climate has been relatively similar throughout the post-Soviet period, with marginally less rain in spring and summer. These four FGDs did not indicate any discernible impacts of climate on the rangelands (including hay collection) and host health. Nevertheless, they still indicated that saiga numbers were limiting hay collection.

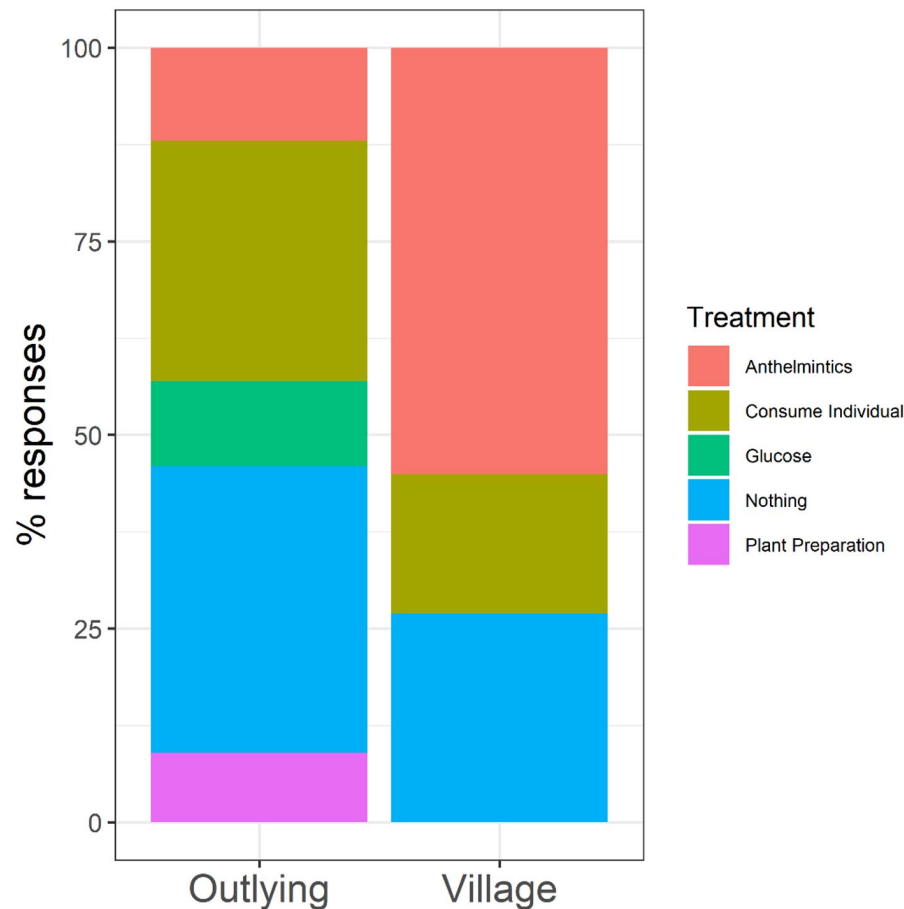


FIGURE 5 Stacked bar graph displaying the % responses of key informants for different treatment types against gastrointestinal nematodes. $n = 35$ outlying and $n = 11$ village-based key informants

4 | DISCUSSION

Our aim was to understand the inter-relationships between factors affecting ungulate health in the Western Kazakh rangeland, which is home to saigas and livestock. We specifically investigated the evidence for links between different factors, while considering uncertainties, with a focus on GINs. Below we discuss these links and the likelihood and possible consequences of future change.

4.1 | Local social factors affecting host health

All respondents suggested some—albeit mild—impacts of GINs on livestock health in outlying farms and village-based livestock. Outlying livestock—likely to share pasture with saigas—were less likely to be treated for GINs than village-based animals. Whether this is because GINs are less common or problematic in outlying areas or the logistical difficulty in accessing treatment, needs investigation. As a result, GINs are likely to persist in livestock and transfer to saigas. However, the impact on livestock health and consequently the impact on saiga health of current interventions, if any, also need investigation. Across Kazakhstan, outlying farms are

increasing (Kerven et al., 2021). While vaccination regimes seem to be effectively implemented, delivery of antiparasite care does not seem to have followed that trend. This could negatively impact both livestock and saiga health.

Given low levels of anthelmintic treatment of livestock on outlying farms, the spread of anthelmintic-resistant parasites to saigas and onward transfer between livestock farms, as observed in other wild ungulates using shared pastures (Chintoan-Uta et al., 2014), seems unlikely. With increasing modernization, more outlying farms will likely become connected by road to nearby towns (Pomfret, 2009). This could increase anthelmintic access, which may reduce GIN transmission to saigas. Yet, if done as whole-herd treatments, this risks the development and spread of anthelmintic resistance (Charlier et al., 2014). Some outlying farmers reported using plant-based therapies against GINs. A wide range of plants can have combined antiparasitic and nutritional benefits (Hoste et al., 2012), and such ‘nutraceutical’ plants could help to support livestock health with less dependencies on external inputs and lower risk of fostering drug resistance (French, 2018). Such plants are presumably also accessible to saigas. Further research could identify likely plant-based interventions using ethno-veterinary and epidemiological studies, to improve prospects for sustainable GIN control.

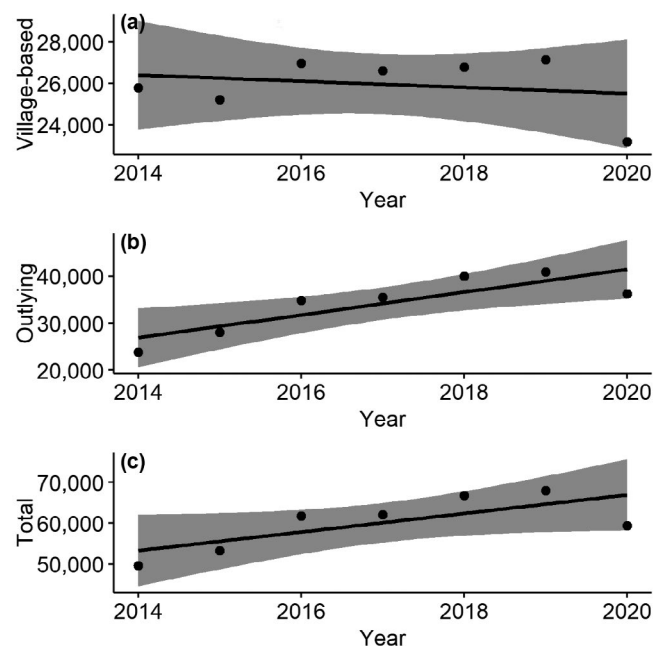


FIGURE 6 A panel graph showing the number of small ruminants (sheep and goats) (a) belonging to households (mostly village based) ($r = -0.23$, $p = 0.62$), (b) belonging to registered farms (mostly outlying) ($r = 0.85$, $p = 0.016$) and (c) total holdings ($r = 0.73$, $p = 0.061$), over time (2014–2020) in Zhanybek district. Data from Kazakh Statistics Bureau. $p < 0.05$ is considered significant. Shaded area in the graph is the 95% confidence interval
Note: Although the number of livestock has dropped in 2020 compared to previous years, we do not have evidence as to why this has happened.

4.2 | Local ecological factors affecting host health

We found that saigas are carrying GIN burdens when grazing in their calving and summer range, although it is not known if they are at physiologically detrimental levels. We do have some evidence for this in livestock. The levels of FEC observed here are consistent with negative correlations with body condition in saigas (Morgan, Shaikenov, et al., 2005). This is concerning for females as worm burdens may further compromise their immunologically stressed-state during calving; and in other wild ungulates have been associated with decreased fecundity (Albon et al., 2002). In Ural, contact with sympatric livestock is likely to increase in coming years as saiga and livestock numbers are both seeing an increase (Zuther, 2020). The contribution of migration to worm burdens needs investigation. For instance, Morgan et al. (2006, 2007) show that saigas probably contributed to GIN transmission from their winter range, to sheep in their summer range in Betpak-Dala, under prior conditions of high livestock densities and close contact with livestock in the winter range, which likely no longer hold as saigas do not migrate as far south in the winter. Alternatively, migration could inhibit parasite transmission by reducing host availability (Altizer et al., 2011), and could be adaptive in wild ungulates (Folstad et al., 1991).

Saigas are most likely to share pasture with outlying livestock (Khanyari, Robinson, Morgan, Brown, et al., 2021) which have

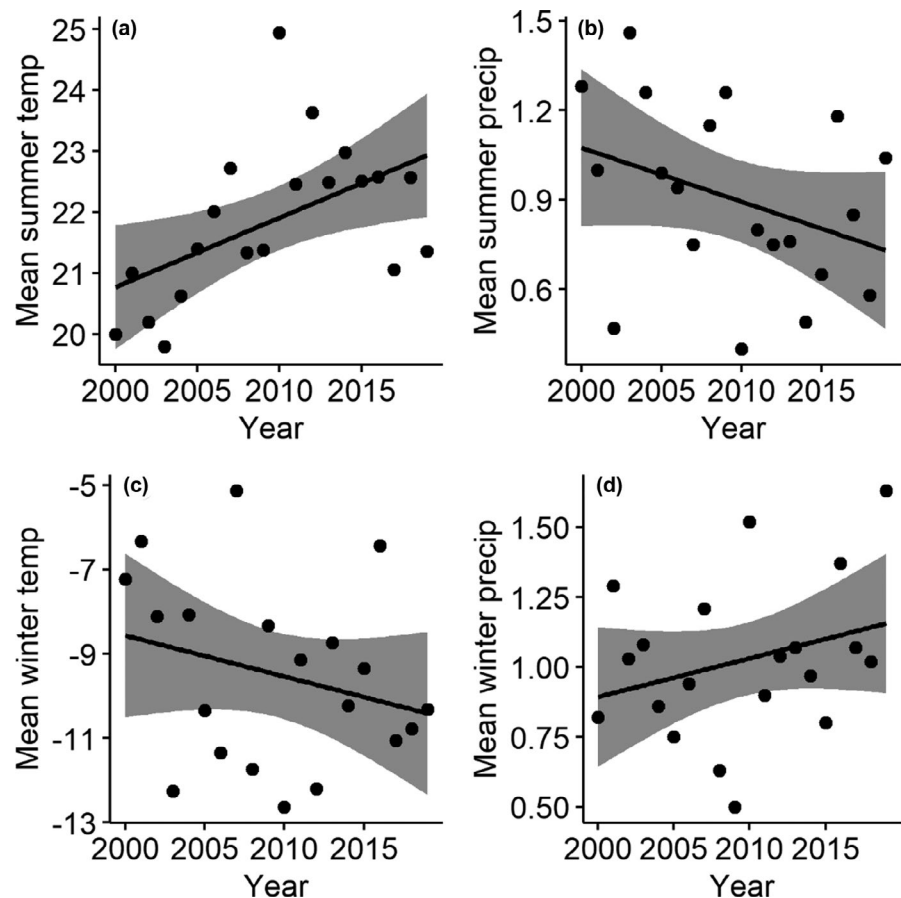
significantly lower worm burdens than village-based livestock, and comparable burdens to saigas. However, this situation may worsen with further increase in livestock numbers and increased resource competition. Our results and official online digital cadastre records of Kazakhstan indicate that although there are areas of the steppe without farms, large areas are in fact leased indicating possibility of pasture overlap between saigas and outlying livestock (stat.gov.kz, 2020).

4.3 | Regional factors affecting the system

As state support dwindled following the breakdown of the Soviet Union, the Kazakh rangelands witnessed an abandonment of outlying areas (Dara et al., 2020). For the first decade following the Soviet Union's collapse, the livestock sector received limited state attention—which was predominately concerned with developing oil and gas reserves (Pomfret, 2009). Recently, the Kazakh government has introduced large subsidy programmes supporting livestock production (Petrick et al., 2018), but these tend to benefit large-scale livestock owners, while households (livestock owners not registered as farms) are ineligible (Kerven et al., 2021). There is evidence that many larger livestock operations have become much more mobile in recent years as they rebuild economies of scale for movement (Kerven et al., 2016; Robinson et al., 2016; Robinson et al., in review), but smaller farms and household remain more sedentary. Our study showed that in Ural outlying farms were entirely sedentary, in contrast to areas in Central and Southern Kazakhstan where the above-cited studies were conducted. Overall, a general reduction in livestock mobility is a trend observable across temperate Asia and indeed globally (Dong et al., 2011; Fernandez-Gimenez & LeFebre, 2006). The end of collectivized agriculture and subsequent reforms in most Central Asian and Caucasian states have tended towards reduction in herd sizes and individualization of pastoral tenure (Robinson et al., 2017). China's Grassland Contract Policy, mandating privatization and fencing of pasture, has affected the ability of herders to exploit rangeland variability and led to environmental deterioration (Li & Huntsinger, 2011; Næss, 2013).

Concerning the effects of these changes on livestock–wildlife interactions, Western et al. (2009) showed that sedentarization was a factor in wildlife declines in Southern Kenya, attributed to direct displacement of wildlife and the reduction in grass production following a swap from seasonal to permanent grazing. While we do not have evidence of this yet in Kazakhstan's rangelands, the literature certainly cautions that it is possible and the availability of subsidies for fencing may yet have negative impacts in this respect. Additionally, sedentarization can lead to increased opportunities for GIN transmission linked to tighter contact patterns (given saiga presence) and increased stocking densities. Although we have no data on the impact of sedentarization on livestock parasite loads, modelling suggests that for saigas, migration broadly results in lower overall infection pressure (Khanyari et al., in review) and such a finding might reasonably be expected for livestock. However, the impacts

FIGURE 7 Panel graph presenting climate data over time across the calving and summer range of Ural saigas. Temperature in °C, and precipitation in mm. (a) mean summer temperature ($r = 0.53$, $p = 0.017$), (b) mean summer precipitation ($r = -0.35$, $p = 0.13$), (c) mean winter temperature ($r = -0.27$, $p = 0.26$), (d) mean winter precipitation ($r = 0.29$, $p = 0.21$). Data from POWER Data access viewer (POWER, 2020). $p < 0.05$ is considered significant. Shaded areas in the graphs are the 95% confidence interval



of reduced livestock mobility on host health might vary across the saiga's range, which need reconciling into more spatially explicit impacts.

Lastly, we found some evidence of climate change. Climate can affect livestock and saiga health, their numbers and distributions (Bekenov et al., 1998). Salnikov et al. (2015) demonstrated statistically significant decreases in precipitation and increased temperatures, particularly during summer, across Kazakhstan since 1941. Although there is limited information from Western Kazakhstan, studies have indicated an increasing frequency and severity of *dzud* (harsh winters), coupled with a warming and drying trend across other parts of Central Asia, since the turn of the 21st century (e.g. Shinoda, 2017). Mobility has been cited as being a key reason why pastoralists do relatively well during extreme climatic events and its loss can limit pastoralists' resilience (Næss, 2013). In Central Asia, studies in Turkmenistan have shown that, where transport and capital costs of pasture occupation are low, and formal barriers to land access absent, livestock owners remain highly mobile and responsive to vegetation variability, which is high in that drought-prone state (Behnke et al., 2016). The severe drought of 2021 in Kazakhstan may highlight the importance of policies which promote easier access to pasture, both physically through infrastructure like machinery for hay cutting and administratively through simplified leasehold allocation and transfer between users, or common property systems.

Climatic factors are contributing to increased need for hay for livestock. Mechanized hay cutting can exacerbate resource

competition and tighten contact patterns during the calving and summer periods, with consequent impacts on livestock and saiga health. Other studies show exacerbated grassland degradation and desertification across Kazakhstan, particularly Western Kazakhstan (Hu et al., 2020). This could also lead to interference and exploitative resource conflict across the autumn saiga range. Nevertheless, we need to triangulate interview data which predominantly concerns perceptions, with other sources such as remotely sensed data, to draw firm conclusions.

4.4 | Implications for saiga health in Ural

It is apparent from our results that saiga health is not only intertwined with sympatric livestock health, but also is affected by a number of factors across varying scales. It is key to consider saiga health in conservation planning, in addition to threats like poaching, to ensure that populations remain large enough to deal with future mass mortality events (Kock et al., 2018). This requires considering the complex inter-connected factors affecting saiga health and their potential future changes, and filling of current knowledge gaps. As conservation is a resource- and time-limited discipline, such interdisciplinary exercises can help shape interventions that take account of such pluralistic interactions, rather than implementing silo solutions (Williams et al., 2020). For example, in this case, it seems that livestock and wildlife health cannot be disentangled from issues of

resource competition (particularly for hay meadows, both in calving/summer and autumn saiga range), both of which are likely to be exacerbated by climate change.

Nevertheless, there are some key caveats to consider about our work. Our results are not an exhaustive representation of inter-connections between factors, as we lacked data on various aspects. For instance, because of limited ability to differentiate between nematode species using egg morphology alone, the extent to which particular species of GIN are shared between saigas and livestock in this population is unknown. Previous studies in the Betpak-Dala population showed that of 38 helminth species found in saigas, 36 were also found in sympatric livestock (Morgan, Shaikenov, et al., 2005), but to demonstrate this required post-mortem recovery of adult worms. Genetic sequencing of parasites in host faeces can provide species-level information on parasite presence (Avramenko et al., 2019), on which to base inferences about parasite overlap between hosts.

While uncertainties remain, our study demonstrates the importance of viewing host health in rangelands as a complex adaptive social-ecological system. Such systems have many dynamic components, determining the ability of rangelands and their inhabitants to cope with disturbances and respond to changes, including those affecting disease transmission. Adaptation needs to be a continual and iterative process and is linked to resilience, ensuring that the system adapts to new forces without losing functionality or transforming in fundamental ways (Hruska et al., 2017). These aspects are relevant for saigas in Ural and across their global range, as they are surviving in a dynamic world in which livestock increasingly use outlying steppe areas (Kerven et al., 2016); climatic changes potentially alter host-pathogen interactions (Kock et al., 2018) and resource acquisition (Pruvot et al., 2020); and state policies push towards more intensive livestock production systems (Kerven et al., 2021). It will be crucial for saiga conservationists to engage in multi-pronged conservation interventions, which are evaluated and adapted through the lens of rural livelihoods and the livestock health on which they depend.

5 | CONCLUSION

In conclusion, multi-use rangelands across the world are socially and ecologically important for a variety of reasons and are characterized by complex interactions between various factors. While there have been some advances in understanding these interactions for the functioning of rangelands themselves (Hruska et al., 2017; Reid et al., 2014), there has been little done on understanding their impact on animal health. Our work provides insights into the social-ecological factors affecting host health in rangelands, as well as the complex interactions among species that share and potentially compete for space and forage. Overall, this work fills an important gap in the rangeland and pastoralism literature, because measuring the impacts—positive and negative—for wild and domestic species of sharing space and resources is one of the biggest challenges for

wild herbivore conservation and local livelihoods. We hope our work will provide researchers and practitioners with an avenue to better understand these complex inter-relationships, while viewing host health from an interdisciplinary perspective—ultimately working towards wildlife conservation while safeguarding livelihoods across the world's rangelands.

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CONFLICT OF INTEREST

None.

AUTHORS' CONTRIBUTIONS

M.K., E.J.M.-G. and E.R.M. conceived the idea of this work and designed the study; S.R. provided critical inputs on the study design; E.J.M.-G. was pivotal in providing the broader social-ecological perspective of the work; M.K. and A.S. conducted the field work; A.S. provided various bits of existing saiga data; M.K. led the data analysis. All authors provided critical inputs on various drafts of the manuscript.

DATA AVAILABILITY STATEMENT

All data, except interview transcript as we did not have the required consent to archive these, used in this manuscript are either presented in the main text through figures and tables or available on the data dryad repository at <https://doi.org/10.5061/dryad.31zcrjdn4> (Khanyari, Robinson, Morgan, Salemgareyev, et al., 2021).

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REFERENCES

- Albon, S. D., Stien, A., Irvine, R. J., Langvatn, R., Ropstad, E., & Halvorsen, O. (2002). The role of parasites in the dynamics of a reindeer population. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 269(1500), 1625–1632.
- Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., & Sanderson, M. (2011). An international terminology for grazing lands and grazing animals. *Grass and Forage Science*, 66, 2–28. <https://doi.org/10.1111/j.1365-2494.2010.00780.x>
- Altizer, S., Bartel, R., & Han, B. A. (2011). Animal migration and infectious disease risk. *Science*, 331(6015), 296–302. <https://doi.org/10.1126/science.1194694>

- Avramenko, R. W., Redman, E. M., Melville, L., Bartley, Y., Wit, J., Queiroz, C., Bartley, D. J., & Gilleard, J. S. (2019). Deep amplicon sequencing as a powerful new tool to screen for sequence polymorphisms associated with anthelmintic resistance in parasitic nematode populations. *International Journal for Parasitology*, 49(1), 13–26. <https://doi.org/10.1016/j.ijpara.2018.10.005>
- Bagchi, S., Mishra, C., & Bhatnagar, Y. V. (2004). Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan mountains. *Animal Conservation*, 7(2), 121–128. <https://doi.org/10.1017/S1367943003001148>
- Behnke, R., Robinson, S., & Milner-Gulland, E. J. (2016). Governing open access: Livestock distributions and institutional control in the Karakum Desert of Turkmenistan. *Land Use Policy*, 52, 103–119. <https://doi.org/10.1016/j.landusepol.2015.12.012>
- Bekenov, A. B., Grachev, I. A., & Milner-Gulland, E. J. (1998). The ecology and management of the saiga antelope in Kazakhstan. *Mammal Review*, 28(1), 1–52. <https://doi.org/10.1046/j.1365-2907.1998.281024.x>
- Boone, R. B., Conant, R. T., Sircely, J., Thornton, P. K., & Herrero, M. (2018). Climate change impacts on selected global rangeland ecosystem services. *Global Change Biology*, 24(3), 1382–1393. <https://doi.org/10.1111/gcb.13995>
- Brock, P. M., Murdock, C. C., & Martin, L. B. (2014). The history of ecoimmunology and its integration with disease ecology. *Integrative and Comparative Biology*, 54(3), 353–362. <https://doi.org/10.1093/icb/icu046>
- Brooks, D. R., & Hoberg, E. P. (2007). How will global climate change affect parasite–host assemblages? *Trends in Parasitology*, 23(12), 571–574. <https://doi.org/10.1016/j.pt.2007.08.016>
- Brunson, M. W. (2012). The elusive promise of social-ecological approaches to rangeland management. *Rangeland Ecology and Management*, 65, 632–637. <https://doi.org/10.2111/REM-D-11-00117.1>
- Cash, D. W., Adger, W. N., Berkes, F., Garden, P. O., Lebel, L., Olsson, P., Pritchard, L., & Young, O. (2006). Scale and cross-scale dynamics: Governance and information in a multilevel world. *Ecology and Society*, 11(2), 8. <https://doi.org/10.5751/ES-01759-110208>
- Charlier, J., Morgan, E. R., Rinaldi, L., van Dijk, J., Demeler, J., Höglund, J., Hertzberg, H., Ranst, B. V., Hendrickx, G., Vercruysse, J., & Kenyon, F. (2014). Practices to optimise gastrointestinal nematode control on sheep, goat and cattle farms in Europe using targeted (selective) treatments. *Veterinary Record*, 175(10), 250–255. <https://doi.org/10.1136/vr.102512>
- Chintoan-Uta, C., Morgan, E. R., Skuce, P. J., & Coles, G. C. (2014). Wild deer as potential vectors of anthelmintic-resistant abomasal nematodes between cattle and sheep farms. *Proceedings of the Royal Society B: Biological Sciences*, 281(1780), 20132985. <https://doi.org/10.1098/rspb.2013.2985>
- CMS Saiga MoU. (2015). *Third meeting of the signatories to the Saiga MoU (MOS3)*. Retrieved from <https://www.cms.int/saiga/en/meeting/third-meeting-signatories-saiga-mou-mos3>
- Cringoli, G., Maurelli, M. P., Leveck, B., Bosco, A., Vercruysse, J., Utzinger, J., & Rinaldi, L. (2017). The Mini-FLOTAC technique for the diagnosis of helminth and protozoan infections in humans and animals. *Nature Protocols*, 12(9), 1723. <https://doi.org/10.1038/nprot.2017.067>
- Dara, A., Baumann, M., Freitag, M., Hölzel, N., Hostert, P., Kamp, J., Müller, D., Prishchepov, A. V., & Kuemmerle, T. (2020). Annual Landsat time series reveal post-Soviet changes in grazing pressure. *Remote Sensing of Environment*, 239, 111667. <https://doi.org/10.1016/j.rse.2020.111667>
- Dong, S., Wen, L. U., Liu, S., Zhang, X., Lassoie, J. P., Yi, S., Li, X., Li, J., & Li, Y. (2011). Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. *Ecology and Society*, 16(2), 10–33. <https://doi.org/10.5751/ES-04093-160210>
- Fernandez-Gimenez, M. E., & Le Febre, S. (2006). Mobility in pastoral systems: Dynamic flux or downward trend? *The International Journal of Sustainable Development and World Ecology*, 13(5), 341–362. <https://doi.org/10.1080/13504500609469685>
- Folstad, I., Nilssen, A. C., Halvorsen, O., & Andersen, J. (1991). Parasite avoidance: The cause of post-calving migrations in Rangifer? *Canadian Journal of Zoology*, 69(9), 2423–2429.
- French, K. E. (2018). Plant-based solutions to global livestock anthelmintic resistance. *Ethnobiology Letters*, 9(2), 110–123. <https://doi.org/10.14237/eb1.9.2.2018.980>
- Gulland, F. M. D. (1992). The role of nematode parasites in Soay sheep (*Ovis aries* L.) mortality during a population crash. *Parasitology*, 105(3), 493–503.
- Hobbs, N. T., Galvin, K. A., Stokes, C. J., Lockett, J. M., Ash, A. J., Boone, R. B., Reid, R. S., & Thornton, P. K. (2008). Fragmentation of rangelands: Implications for humans, animals, and landscapes. *Global Environmental Change*, 18(4), 776–785. <https://doi.org/10.1016/j.gloenvcha.2008.07.011>
- Hoste, H., Martinez-Ortiz-De-Montellano, C., Manolaraki, F., Brunet, S., Ojeda-Robertos, N., Fourquaux, I., Torres-Acosta, J. F. J., & Sandoval-Castro, C. A. (2012). Direct and indirect effects of bioactive tannin-rich tropical and temperate legumes against nematode infections. *Veterinary Parasitology*, 186(1–2), 18–27.
- Hruska, T., Huntsinger, L., Brunson, M., Li, M., Marshall, N., Oviedo, J. L., & Whitcomb, H. (2017). Rangelands as social-ecological systems. In D. D. Briske (Ed.), *Rangeland systems* (pp. 263–302). Springer.
- Hu, Y., Han, Y., & Zhang, Y. (2020). Land desertification and its influencing factors in Kazakhstan. *Journal of Arid Environments*, 180, 104203. <https://doi.org/10.1016/j.jaridenv.2020.104203>
- Kerven, C., Robinson, S., & Behnke, R. (2021). Pastoralism at scale on the Kazakh rangelands: From clans to workers to ranchers. *Frontiers in Sustainable Food Systems*, 4, 298.
- Kerven, C., Robinson, S., Behnke, R., Kushenov, K., & Milner-Gulland, E. J. (2016). A pastoral frontier: From chaos to capitalism and the recolonisation of the Kazakh rangelands. *Journal of Arid Environments*, 127, 106–119. <https://doi.org/10.1016/j.jaridenv.2015.11.003>
- Khanyari, M., Milner-Gulland, E. J., Oyanedel, R., Vineer, H. R., Singh, N. J., Robinson, S., Salemgareyev, A., & Morgan, E. R. (in review). Investigating parasite dynamics of migratory ungulates for sustaining healthy populations: Applications to critically-endangered saiga antelopes *Saiga tatarica*.
- Khanyari, M., Robinson, S., Morgan, E. R., Brown, T., Singh, N. J., Salemgareyev, A., Zuther, S., Kock, R., & Milner-Gulland, E. J. (2021). Building an ecologically-founded disease risk prioritisation framework for migratory wildlife species based on contact with livestock. *Journal of Applied Ecology*, 58, 1838–1853. <https://doi.org/10.1111/1365-2664.13937>
- Khanyari, M., Robinson, S., Morgan, E. R., Salemgareyev, A., & Milner-Gulland, E. J. (2021). Data from: Identifying relationships between multi-scale social-ecological factors to explore ungulate health in a Western Kazakhstan rangeland [Dataset]. *Dryad*, <https://doi.org/10.5061/dryad.31zcrjdn4>
- Kock, R. A., Orynbayev, M., Robinson, S., Zuther, S., Singh, N. J., Beauvais, W., Morgan, E. R., Kerimbayev, A., Khomenko, S., Martineau, H. M., Rystaeva, R., Omarova, Z., Wolfs, S., Hawotte, F., Radoux, J., & Milner-Gulland, E. J. (2018). Saigas on the brink: Multidisciplinary analysis of the factors influencing mass mortality events. *Science Advances*, 4(1), eaao2314. <https://doi.org/10.1126/sciadv.aao2314>
- Li, W., & Huntsinger, L. (2011). China's grassland contract policy and its impacts on herder ability to benefit in Inner Mongolia: Tragic feed-backs. *Ecology and Society*, 16(2), 1–15. <https://doi.org/10.5751/ES-03969-160201>
- Macpherson, C. (1995). The effect of transhumance on the epidemiology of animal diseases. *Preventive Veterinary Medicine*, 25(2), 213–224. [https://doi.org/10.1016/0167-5877\(95\)00539-0](https://doi.org/10.1016/0167-5877(95)00539-0)

- Morgan, E. R., Cavill, L., Curry, G. E., Wood, R. M., & Mitchell, E. (2005). Effects of aggregation and sample size on composite faecal egg counts in sheep. *Veterinary Parasitology*, 131(1–2), 79–87. <https://doi.org/10.1016/j.vetpar.2005.04.021>
- Morgan, E. R., Lundervold, M., Medley, G. F., Shaikenov, B. S., Torgerson, P. R., & Milner-Gulland, E. J. (2006). Assessing risks of disease transmission between wildlife and livestock: The Saiga antelope as a case study. *Biological Conservation*, 131(2), 244–254. <https://doi.org/10.1016/j.biocon.2006.04.012>
- Morgan, E. R., Medley, G. F., Torgerson, P. R., Shaikenov, B. S., & Milner-Gulland, E. J. (2007). Parasite transmission in a migratory multiple host system. *Ecological Modelling*, 200(3–4), 511–520.
- Morgan, E. R., Torgerson, P. R., Medley, G. F., & Milner-Gulland, E. J. (2005). Helminths of saiga antelope in Kazakhstan: Implications for conservation and livestock production. *Journal of Wildlife Diseases*, 41(1), 149–162.
- Mori, E., Bagnato, S., Serroni, P., Sangiuliano, A., Rotondaro, F., Marchianò, V., Cascini, V., Poerio, L., & Ferretti, F. (2020). Spatiotemporal mechanisms of coexistence in an European mammal community in a protected area of southern Italy. *Journal of Zoology*, 310(3), 232–245. <https://doi.org/10.1111/jzo.12743>
- Næss, M. W. (2013). Climate change, risk management and the end of nomadic pastoralism. *International Journal of Sustainable Development & World Ecology*, 20(2), 123–133.
- Niamir-Fuller, M., Kerven, C., Reid, R., & Milner-Gulland, E. (2012). Co-existence of wildlife and pastoralism on extensive rangelands: Competition or compatibility? *Pastoralism*, 2(1), 1–14. <https://doi.org/10.1186/2041-7136-2-8>
- Noy, C. (2008). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology*, 11(4), 327–344. <https://doi.org/10.1080/13645570701401305>
- Nyumba, T., Wilson, K., Derrick, C. J., & Mukherjee, N. (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. *Methods in Ecology and Evolution*, 9(1), 20–32. <https://doi.org/10.1111/2041-210X.12860>
- Odadi, W. O., Karachi, M. K., Abdulrazak, S. A., & Young, T. P. (2011). African wild ungulates compete with or facilitate cattle depending on season. *Science*, 333(6050), 1753–1755. <https://doi.org/10.1126/science.1208468>
- Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., & Kassem, K. R. (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth. A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, 51(11), 933–938. [https://doi.org/10.1641/0006-3568\(2001\)051\[0933:TEOTW A\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTW A]2.0.CO;2)
- Otte, J., Costales, A., Dijkman, J., Pica-Ciamarra, U., Robinson, T., Ahuja, V., Ly, C., & Roland-Holst, D. (2012). *Livestock sector development for poverty reduction: An economic and policy perspective*. Livestock's many virtues. Food and Agriculture Organization of the United Nations (FAO).
- Perry, B. D., & Randolph, T. F. (1999). Improving the assessment of the economic impact of parasitic diseases and of their control in production animals. *Veterinary Parasitology*, 84(3–4), 145–168. [https://doi.org/10.1016/S0304-4017\(99\)00040-0](https://doi.org/10.1016/S0304-4017(99)00040-0)
- Petrack, M., Raitzer, D., & Burkittbayeva, S. (2018). Policies to unlock Kazakhstan's agricultural potential. In K. Anderson, G. Capannelli, E. Ginting, & K. Taniguchi (Eds.), *Kazakhstan: Accelerating economic diversification* (pp. 21–72). Asian Development Bank.
- Pomfret, R. (2009). Using energy resources to diversify the economy: Agricultural price distortions in Kazakhstan. *Comparative Economic Studies*, 51, 181–212. <https://doi.org/10.1057/ces.2008.48>
- POWER. (2020). Data Access Viewer. Retrieved from <https://power.larc.nasa.gov/data-access-viewer/>
- Pozo, R. A., Cusack, J. J., Acebes, P., Malo, J. E., Traba, J., Iranzo, E. C., & Corti, P. (2021). Reconciling livestock production and wild herbivore conservation: challenges and opportunities. *Trends in Ecology & Evolution*, 36(8), 750–761. <https://doi.org/10.1016/j.tree.2021.05.002>
- Pruvot, M., Fine, A. E., Hollinger, C., Strindberg, S., Damdinjav, B., Buuveibaatar, B., Chimeddorj, B., Bayandonoi, G., Khishgee, B., Sandag, B., Narmandakh, J., Jargalsaikhan, T., Bataa, B., McAloose, D., Shatar, M., Basan, G., Mahapatra, M., Selvaraj, M., Parida, S., ... Shiilegdamba, E. (2020). Outbreak of Peste des Petits Ruminants among critically endangered Mongolian Saiga and other wild ungulates, Mongolia, 2016–2017. *Emerging Infectious Diseases*, 26(1), 51. <https://doi.org/10.3201/eid2601.181998>
- Reid, R. S., Fernandez-Gimenez, M. E., & Galvin, K. A. (2014). Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annual Review of Environment and Resources*, 39, 217–242. <https://doi.org/10.1146/annurev-environ-020713-163329>
- Reid, R. S., Galvin, K. A., & Kruska, R. S. (2008). Global significance of extensive grazing lands and pastoral societies: An introduction. In K. A. Galvin, R. S. Reid, R. H. Behnke Jr., & N. T. Hobbs (Eds.), *Fragmentation in semi-arid and arid landscapes* (pp. 1–24). Springer.
- Rhyan, J. C., & Spraker, T. R. (2010). Emergence of diseases from wildlife reservoirs. *Veterinary Pathology*, 47(1), 34–39. <https://doi.org/10.1177/0300985809354466>
- Robinson, S., Bozayeva, J., & Mukhamedova, N. (in review). Towards intensification? Specialisation and livestock mobility among cattle farmers in south-eastern Kazakhstan.
- Robinson, S., Jamsranjav, C., & Gillin, K. (2017). Pastoral property rights in Central Asia. *Estudes Rurales*, 200(2), 220–253.
- Robinson, S., Kerven, C., Behnke, R., Kushenov, K., & Milner-Gulland, E. J. (2016). The changing role of bio-physical and socio-economic drivers in determining livestock distributions: A historical perspective from Kazakhstan. *Agricultural Systems*, 143, 169–182. <https://doi.org/10.1016/j.agsy.2015.12.018>
- Robinson, S., & Milner-Gulland, E. J. (2003). Political change and factors limiting numbers of wild and domestic ungulates in Kazakhstan. *Human Ecology*, 31(1), 87–110.
- Robinson, T. P., Thornton, P. K., Franceschini, G., Kruska, R. L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G., & See, L. (2011). *Global livestock production systems* (p. 152). Food and Agriculture Organization of the United Nations (FAO) and International Livestock Research Institute (ILRI).
- Rose, H., Wang, T., van Dijk, J., & Morgan, E. R. (2015). GLOWORM-FL: A simulation model of the effects of climate and climate change on the free-living stages of gastro-intestinal nematode parasites of ruminants. *Ecological Modelling*, 297, 232–245. <https://doi.org/10.1016/j.ecolmodel.2014.11.033>
- Sæther, B. E. (1997). Environmental stochasticity and population dynamics of large herbivores: A search for mechanisms. *Trends in Ecology & Evolution*, 12(4), 143–149. [https://doi.org/10.1016/S0169-5347\(96\)10068-9](https://doi.org/10.1016/S0169-5347(96)10068-9)
- Salnikov, V., Turulina, G., Polyakova, S., Petrova, Y., & Skakova, A. (2015). Climate change in Kazakhstan during the past 70 years. *Quaternary International*, 358, 77–82. <https://doi.org/10.1016/j.quaint.2014.09.008>
- Satke, R. (2020). *Saving Central Asia's ice age antelope*. The Third Pole. Retrieved from <https://www.thethirdpole.net/en/nature/saving-central-asias-ice-age-antelope/>
- Shinoda, M. (2017). Evolving a multi-hazard focused approach for arid Eurasia. In T. Sternberg (Ed.), *Climate hazard crises in Asian societies and environments* (pp. 73–102). Routledge.
- Singh, N. J., Grachev, I. A., Bekenov, A. B., & Milner-Gulland, E. J. (2010). Saiga antelope calving site selection is increasingly driven by human

- disturbance. *Biological Conservation*, 143(7), 1770–1779. <https://doi.org/10.1016/j.biocon.2010.04.026>
- Singh, N. J., & Milner-Gulland, E. J. (2011). Conserving a moving target: Planning protection for a migratory species as its distribution changes. *Journal of Applied Ecology*, 48(1), 35–46. <https://doi.org/10.1111/j.1365-2664.2010.01905.x>
- Smith, K. F., Acevedo-Whitehouse, K., & Pedersen, A. B. (2009). The role of infectious diseases in biological conservation. *Animal Conservation*, 12(1), 1–12. <https://doi.org/10.1111/j.1469-1795.2008.00228.x>
- Stat.gov.kz (2020). Kazakh Bureau of National Statistics. Retrieved from <https://stat.gov.kz/>
- Thornton, P. K. (2010). Livestock production: Recent trends, future prospects. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2853–2867. <https://doi.org/10.1098/rstb.2010.0134>
- Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: A review. *Global Change Biology*, 20(11), 3313–3328. <https://doi.org/10.1111/gcb.12581>
- Valente, A. M., Acevedo, P., Figueiredo, A. M., Fonseca, C., & Torres, R. T. (2020). Overabundant wild ungulate populations in Europe: Management with consideration of socio-ecological consequences. *Mammal Review*, 50(4), 353–366. <https://doi.org/10.1111/mam.12202>
- Van Veen, T. S. (1997). Sense or nonsense? Traditional methods of animal parasitic disease control. *Veterinary Parasitology*, 71(2–3), 177–194. [https://doi.org/10.1016/S0304-4017\(97\)00031-9](https://doi.org/10.1016/S0304-4017(97)00031-9)
- Vosloo, W., Bastos, A., Sangare, O., Hargreaves, S. K., & Thomson, G. R. (2002). Review of the status and control of foot and mouth disease in sub-Saharan Africa. *Revue Scientifique et technique-Office International Des Épizooties*, 21(3), 437–445. <https://doi.org/10.20506/rst.21.3.1349>
- Walker, J. G., & Morgan, E. R. (2014). Generalists at the interface: Nematode transmission between wild and domestic ungulates. *International Journal for Parasitology: Parasites and Wildlife*, 3(3), 242–250.
- Weinstein, S. B., & Lafferty, K. D. (2015). How do humans affect wildlife nematodes? *Trends in Parasitology*, 31(5), 222–227. <https://doi.org/10.1016/j.pt.2015.01.005>
- Western, D., Groom, R., & Worden, J. (2009). The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation*, 142(11), 2538–2546. <https://doi.org/10.1016/j.biocon.2009.05.025>
- Wilcox, B. A., & Colwell, R. R. (2005). Emerging and reemerging infectious diseases: Biocomplexity as an interdisciplinary paradigm. *EcoHealth*, 2(4), 244–257. <https://doi.org/10.1007/s10393-005-8961-3>
- Williams, D. R., Balmford, A., & Wilcove, D. S. (2020). The past and future role of conservation science in saving biodiversity. *Conservation Letters*, 13(4), e12720. <https://doi.org/10.1111/conl.12720>
- Zuther, S. (2020). The 2019 aerial survey reveal significant growth in all of Kazakhstan's saiga populations. Saiga News issue 25. Retrieved from <https://www.saigaresourcecentre.com/content/saiga-news-magazine>

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