Khanyari *et al. Pastoralism* (2022) 12:44
https://doi.org/10.1186/s13570-022-00257-1

Pastoralism: Research, Policy
and Practice

RESEARCH **Open Access**

Pastoralism in the high Himalayas: Understanding changing practices and their implications for parasite transmission between livestock and wildlife

Munib Khanyari[1,2,3*], Sarah Robinson[3], E. J. Milner-Gulland[3], E. R. Morgan[1,4], Rashmi Singh Rana[2] and Kulbhushansingh R. Suryawanshi[2,5]

Abstract

Rangelands are increasingly being affected by climatic variations, fragmentation and changes in livestock management practices. Along with resource competition between livestock and wildlife, disease transmission has implications for people and wildlife in these shared landscapes. We worked with two pastoral communities in the Western Indian Himalayas: the migratory *Kinnaura*s that travel to the Trans-Himalayan Pin valley in summer and the resident herders of Pin Valley. Asiatic ibex (*Capra sibirica*) is the predominant wild herbivore in Pin. The pastures in Pin are grazed by both livestock (migratory and resident) and ibex, with the potential for disease transmission. We investigate the effects of herding practices on livestock health and disease transmission, while focusing on gastro-intestinal nematodes (GINs) as they can spread by sharing pasture between wild and domestic ungulates. Surveys were carried out between June and August 2019, the period when migratory *Kinnauras*, local herders and Asiatic Ibex are found in Pin Valley. We found that the *Kinnaura* flocks share pasture with ibex during their time in Pin, exhibiting significantly higher endo-parasite burdens than sedentary livestock, and the *Kinnaura* flocks are increasing in number. This suggests GIN cross-transmission is possible, as GINs have low host specificity and a free-living, environmental stage that is trophically acquired. As local (sedentary) sheep and goats rarely share pasture with ibex, have low endo-parasite burdens and are few in number, they are unlikely to transmit parasites to ibex. However, increasingly large local stock numbers may be contributing to pasture degradation which could cause nutritional stress and resource competition, exacerbating GIN impacts. We also find evidence for transhumance persisting, in spite of signs of pasture degradation that are seemingly affecting livestock productivity and potentially disease transmission. It is critical that proactive measures are taken, like participatory disease management with the *Kinnauras*, to align livelihoods with wildlife and rangeland conservation.

Keywords: Migratory, Transhumance, Livestock, Asiatic ibex, *Capra sibirica*, Pasture, Rangelands, Gastro-intestinal nematodes

Introduction

Pastoralism—production systems and livelihoods that predominantly depend on livestock raised on either communal or private pastures, with varying amount of mobility (Niamir-Fuller et al. 2012)—is practised globally. Forms of pastoralism adapted to high levels of climatic variability are particularly present in the

---

*Correspondence: mk17337@bristol.ac.uk

[1] University of Bristol, Bristol, UK
[2] Nature Conservation Foundation, Mysore, India
[3] Interdisciplinary Center for Conservation Sciences, Oxford, UK
Full list of author information is available at the end of the article

rangelands of Asia and Africa (Goldstein and Beall 1990), where migratory livestock grazing is widely practised in areas of high seasonal variation and limited natural resources (McCabe 1994; Saberwal 1996; Coppolillo 2000; Axelby 2007; Bhasin 2011).

Rangelands are increasingly being impacted by climatic variation, ecosystem fragmentation and changes in livestock management practices, with implications for the people and wildlife that reside there (Mishra 2001; Galvin et al. 2008; Kerven et al. 2016). Over the past few decades, pastoralism has been particularly influenced by social-political changes affecting pastoralist rangeland use and management (Robinson and Milner-Gulland 2003; Nori and Scoones 2019). Reductions in pasture quality, sedentarization, increased livestock populations and conflict with wildlife are commonly observed impacts of these changes (Singh et al. 2013). Importantly, sharing of rangelands by different ungulate species can lead to resource competition between livestock and wildlife, and potentially disease transmission (Rhyan and Spraker 2010).

Disease transmission across multi-use rangelands can negatively affect pastoralist livelihoods (Reid et al. 2008) and wildlife conservation (Smith et al. 2009). Among wildlife species, ungulates are most likely to be affected, as they share resources and many pathogens with domestic ungulates (Walker and Morgan 2014). Endo-parasites, such as gastro-intestinal nematodes (GINs), are particularly important as they are determinants of fitness for wild and domestic ungulates (Gulland 1992; Perry and Randolph 1999) and are acquired by feeding on pastures. As they have free-living environmental stages, their transmission is enabled by indirect contact, which in turn is governed by host distributions and movement (Vosloo et al. 2002). Climate-induced changes in resource availability and socio-economic factors can thus impact transmission, as it can potentially alter host movement and, thus, contact patterns (Robinson and Milner-Gulland 2003; Weinstein and Lafferty 2015). Seasonal movements of wild and domestic ungulates, landscape management and aggregation at various spatial scales can strongly modify GIN transmission risk (Pruvot et al. 2020). In mixed-use systems, human interventions in GIN management can influence GIN presence in livestock and consequently the dynamics of co-transmission to wild ungulates (Weinstein and Lafferty, 2015). Changes in any of these factors may affect the adaptability and resilience of pastoral systems (Hruska et al. 2017). Evaluating host health and disease transmission in pastoral systems therefore requires an interdisciplinary perspective that can cover both the social and biological aspects of transmission risk (Tomaselli et al. 2018).

Migratory livestock grazing is a widespread form of pastoralism in the Himalayas and Trans-Himalayas (Saberwal 1996; Axelby 2007; Bhasin 2011). There is increasing evidence of the negative impact of livestock grazing manifested through pasture degradation and competition between livestock and wild ungulates (Mishra 2001; Bagchi et al. 2004). For instance, Bagchi et al. (2004) found interference competition between migratory livestock and Asiatic ibex *Capra sibirica* in Pin Valley. Similarly, exploitative competition between blue sheep *Pseudois nayaur* and resident livestock has been shown to reduce juvenile blue sheep survival (Mishra et al. 2004; Suryawanshi et al. 2010). Studies in the Indian Himalayan rangelands have also recorded several livestock diseases and parasitic infestations of relevance to wildlife, including foot and mouth disease (FMD), haemorrhagic septicaemia, *peste des petits ruminants* (PPR) and GINs (Dixit et al. 2009; Muthiah et al. 2013). Against this backdrop, understanding disease management and the impact of livestock husbandry practices on key aspects of disease risk, such as contact patterns, in the multi-use Indian Himalayan pastoral systems, has remained relatively unexplored. This is important, as there is a knowledge gap regarding disease information for ungulates globally (Pozo et al. 2021), which is particularly important for Himalayan pastures where wildlife co-exists with humans and livestock regardless of protected area status (Ghoshal 2017).

We worked with two pastoral communities in the Western Indian Himalayas—the migratory *Kinnaura* herders and local livestock herders of Pin valley—to investigate contemporary herding practices, in order to understand potential impacts on domestic and wild host health and disease transmission to wild ungulates in the Pin valley. We focus on GINs because these are acquired on co-grazed pastures, associated with host nutrition and body condition (with effects exacerbating and exacerbated by under-nutrition), and are strongly affected by season and climate. GINs are thus expected to be particularly affected by changes in the social-ecological system of the Himalayan rangelands. Our secondary focus was on pasture condition and implied (rather than demonstrated) impacts on GIN susceptibility and impact. We specifically assessed host contact patterns, endoparasite worm burdens, livestock holdings and composition for both communities, reasons for and persistence of migratory herding and state of pasture quality in Pin valley. Where possible, we assessed how these factors have changed since the turn of the twenty-first century (see Table 1). Insights gained from our work can be used to develop effective participatory rangeland management programmes to align pastoral livelihoods with wildlife conservation.

Table 1 Research questions that we addressed in the key-informant interviews, and the rationale behind them

Research question	Rationale[b]
Are domestic and wild hosts sharing pasture in Pin valley?	The majority of rangelands in the Western Trans-Himalayas, including Pin valley, are co-grazed (Bhatnagar 1997; Bagchi et al. 2004). This can lead not only to resource competition but also disease transmission. Being restricted to grazing around villages, local livestock are unlikely to share pasture with wild hosts.
What is the GIN burden and impact on host health?[a]	Due to increasing herd sizes and limited veterinary care/interventions, we predict that migratory livestock have substantial health issues, in particular that they have high GIN burdens.
How do current livestock holdings compare to those of 20 years ago?	Herd sizes of migratory livestock have been increasing across regions of the Western Trans-Himalayas (Ghoshal 2017) and we expect to find the same pattern in our study area. Resident livestock have seen major declines in the region due to a number of social and political factors (Singh et al. 2015).
What are the current reasons for undertaking the long-distance migration, is it likely to persist and what governs leasing of pasture?	Long-distance migrations occur for multi-faceted ecological and social reasons, many of which are likely to persist into the future (Ghoshal 2017). Therefore, we expect migration to continue.
What is the current state of the pasture quality in Pin valley and how has it changed over time?	There is evidence of increasing pasture degradation across the Western Trans-Himalayan rangelands (Mishra et al. 2001; Bagchi et al. 2004). Pasture degradation can impact resource competition and disease transmission. Degradation and transmission both have a common cause in high livestock stocking rates. Degradation adds to the problem of disease through nutritional stress and resource competition (Kock 2004)—which can exacerbate the impacts of GINs.

[a] This is supplemented by the endo-parasite analysis; see the "Endo-parasites in ibex and livestock" section. [b]While we are unable to rigorously or systematically test the hypotheses expressed here, we articulate them in order to clarify the rationale behind our research questions

Material and methods

Study area

We worked with two communities in Himachal Pradesh, India: the migratory herders of Rupi-Bhaba area, Kinnaur district (*Kinnauras*), and the resident herders of Pin valley, Lahual-Spiti district (Fig. 1). The *Kinnaura* herders undertake long-distance migration with their sheep and goats. Traditionally, they graze pastures of the Trans-Himalayan Pin Valley during summer (June–August), spending winters in the Himalayan foothills of the Sirmaur region (November–March) and a large part of spring and autumn in their native Rupi-Bhabha area (April–May and September–October; Figs. 1 and 2). Men are exclusively responsible for the care of migratory livestock herds, while their families live in settled villages in the Rupi-Bhabi area, where they grow wheat, millet, pulses (food crops), apple and apricots (cash crops). Agriculture is primarily taken care of by women. The Rupi-Bhabha region is located between 2100 and 3500 m, with some peaks reaching as high as c. 5900 m. Temperate and alpine conditions predominate, characteristic of the Greater Himalayas (Olson et al. 2001; Fig. 1).

The settled residents of Pin Valley are predominantly agro-pastoralists (Bagchi et al. 2004). They rear livestock including sheep, goats, horses, donkey, cow, yak and yak-cow hybrids called *Dzo*. Alongside, they grow a few crops during the short summer months including green pea, black pea and barley. Each village within Pin valley holds traditional rights to rangelands in Pin. Annually, the *Kinnaura* herders pay a "tax" to each village committee to use these pastures for the summer months. Pin valley falls within the Trans-Himalayan region, which is in the rain-shadow of the Greater Himalayas and adjacent to the Tibetan plateau. The altitude ranges from around 3200 m to above 6000 m, with rangelands located primarily between 3200 and 4200 m. Pin valley is a cold desert, characterized by rugged terrain and dry-alpine steppe meadows (Chandra Sekar and Sivastava 2009). The Asiatic ibex is the predominant wild herbivore in the region and also the primary prey of the snow leopard *Panthera uncia*, the apex predator of this ecosystem. As the ibex is a caprine, it is most likely to share pasture and GINs with sheep and goats (Bagchi et al. 2004; Walker and Morgan 2014); hence, we concentrated our work on these two species (livestock hereafter refers to sheep and goats, unless stated otherwise). Even though the migratory livestock share pasture with other ungulates to some extent throughout their migratory range, we concentrated our work in the Trans-Himalayan Pin valley as its rangelands are co-grazed by livestock and ibex during the short yet important growth season (Ghoshal 2017). Additionally, there is evidence that Pin valley is particularly heavily grazed by livestock compared to surrounding rangelands, causing conservation concern for wild ungulates, with calls for the integration of social and ecological considerations into management planning for the valley (Bagchi et al. 2004; Ghoshal 2017).

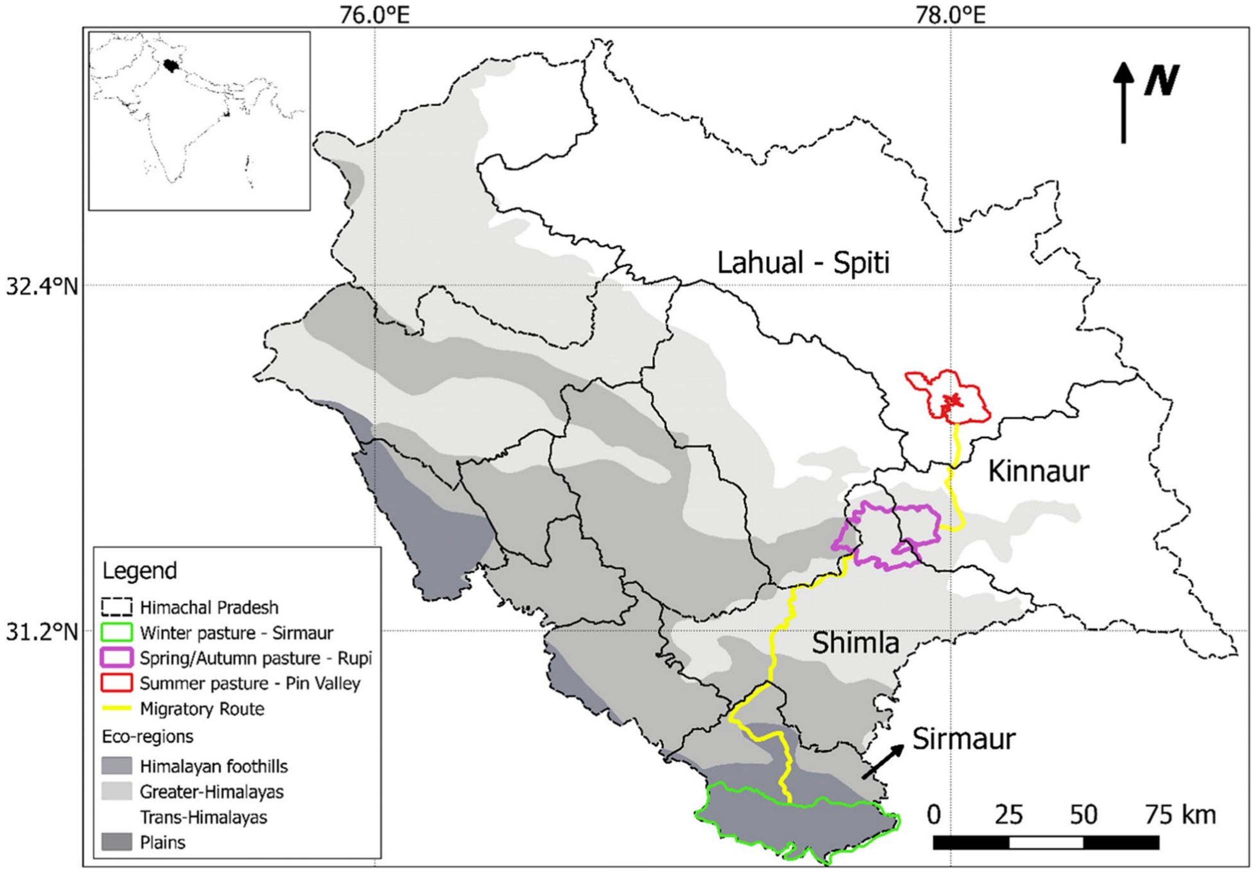

Fig. 1 Map displaying the migratory route and seasonal pastures of the *Kinnaura* herders. The inset map situates the state of Himachal Pradesh within India. Districts in Himachal Pradesh within which seasonal pastures of the *Kinnaura* herders are found are named on the map. Eco-regions were obtained from Olson et al. (2001). Our study area (Pin valley) is outlined in red

Data collection and analysis

Survey on livestock movement and management and its consequences

We used qualitative research methods to interview 41 key informants, at least one from each of 28 migratory livestock herds (called *tols*) and 13 villages in Pin valley between June and August 2019. The village heads in Pin valley and the Rupi-Bhaba area confirmed that these were all the *tols* that undertook the migration that year. Each *tol* is composed of animals belonging to many people, only some of whom actually travel with the animals. Usually, a *tol* comprises the *maldar*, i.e. the head of the *tol* and usually the one with the land rights to the pasture in Pin, along with three to four helpers. The key informants were chosen based on their knowledge of pastoral activities, the rangelands, livestock health and management and changes in these factors since the start of the twenty-first century. These usually were the *maldars* and another senior member of the *tol*. Key informants were only chosen after spending at least a week with them, to get to know them better. The interviews with the migratory herders were done in the form of a walking interview (Anderson 2004; Carpiano 2009) on their route from Rupi-Bhaba area to Pin valley (Figs. 1 and 2). The interviews with the resident livestock owners in Pin valley were conducted in their villages. These individuals were identified by speaking to the *Nambadar* of the village (i.e. village head person). Questions revolved around characterizing pastoral activities (e.g. individual livestock holdings and herd sizes), pasture overlap with ibex, perceptions of pasture quality changes, their livestock's health issues and treatments administered (see Table 1 for specific research questions). We also explored interactions between the two types of pastoralism, including their spatial overlap, pastoralists' interactions with Asiatic ibex, impact of livestock grazing on rangelands, the prevalence, impact and transmission of disease in general and other factors (e.g. climate) contributing to changes in livestock grazing on these rangelands.

Where possible, quantitative and semi-quantitative data were analysed using descriptive statistics or by bootstrapping answers with replacement (10,000 iterations)

Fig. 2 A *Kinnaura* herder *tol* crossing the Bhaba pass from Rupi-Bhaba into Pin valley. Some livestock do not make it across the pass, as seen by the lone goat kid left behind the pass

to estimate means and 95% confidence intervals. Particularly for the open-ended questions, analysis followed open and axial coding as suggested for grounded theory generation (Creswell 1998). We performed inductive analysis to facilitate the emergence of patterns, themes and categories out of the data (Patton 1990). For each of the questions, cross-interview analysis was performed, bringing together responses from different key informants for the same question to illustrate broader patterns and categories under each theme (Patton 1990). The analysis was conducted in Microsoft Excel and the R statistical and programming environment (R Core Team 2020). Table 1 lists the set of research questions the key-informant interviews aimed to answer, along with their rationale (see Supplementary Material 1 for the entire questionnaire). The survey questionnaire was approved by the University of Bristol's Ethical committee. Consent was taken orally before conducting the surveys and all the responses were coded; names or other identities of respondents were not used, in order to ensure anonymity.

Endo-parasites in ibex and livestock

Our focus was on helminth infection; consequently, any reference to coccidia was limited to just presence. Fresh faecal pellet samples were collected from sheep, goats and ibex. The collection was opportunistic and covered the entire period that migratory livestock were in Pin valley (June-August). Livestock samples were pooled at the level of each livestock herd (migratory and sedentary separately), and ibex samples were pooled at the level of the study population (Morgan et al. 2005). Each pooled sample consisted of roughly 3-g faeces each from at least 10 different individuals from the said species group (Morgan et al. 2005). For ibex, samples were collected from all age-sex classes and were pooled from different groups from within Pin valley, albeit collected on the same day. Varying numbers of samples obtained for hosts were a function of availability and logistics. The date and location for each sample collected were recorded. Provided that the material is well-mixed, the faecal egg count (FEC) in an aliquot of pooled faecal sample is a good reflection of the average individual FEC (Morgan et al., 2005). FEC provides 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.

Infection intensity and contribution to pasture contamination were estimated by FEC on pellet samples, to evaluate endo-parasite worm burdens. The mini-FLOTAC technique (Cringoli et al. 2017) was used as a field-friendly, simple and cost-effective method for FECs in remote areas. This method estimates the abundance and diversity of endo-parasites, using sedimentation-flotation to separate ova of nematodes from the faecal matter and allow them to be identified and quantified under a microscope. The protocol given in Cringoli et al. (2017) was followed, with 5 ml of faeces analysed per sample in 45 ml of saturated sodium chloride 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 FEC in eggs per gramme (EPG) of faeces. The sensitivity of the mini-FLOTAC technique at this dilution is 5 EPG. We used the bootstrap *t*-test, which has lower probability of making a type 1 error than the usual *t*-test, to compare the difference in mean abundance of endo-parasites between ibex and livestock (Wilcox 2017). A unique bootstrapped *t*-test was conducted for each set of endo-parasites across hosts. Nevertheless, to ensure that we are reducing any potential chances of making a type 1 error by doing multiple *t*-tests, we also conducted a one-way ANOVA followed by a post hoc Tukey HSD test (after confirming normality in data using the Shapiro-Wilk test, giving the low sample sizes) to investigate differences in mean overall endo-parasite abundances and strongyle abundances among the hosts. The one-way ANOVA was restricted to overall endo-parasite abundances and only strongyle abundances as the prevalence of other parasites was low and did not meet the assumption of normality.

To supplement the FEC data for local and migratory livestock, we assessed the impact scores of endo-parasites

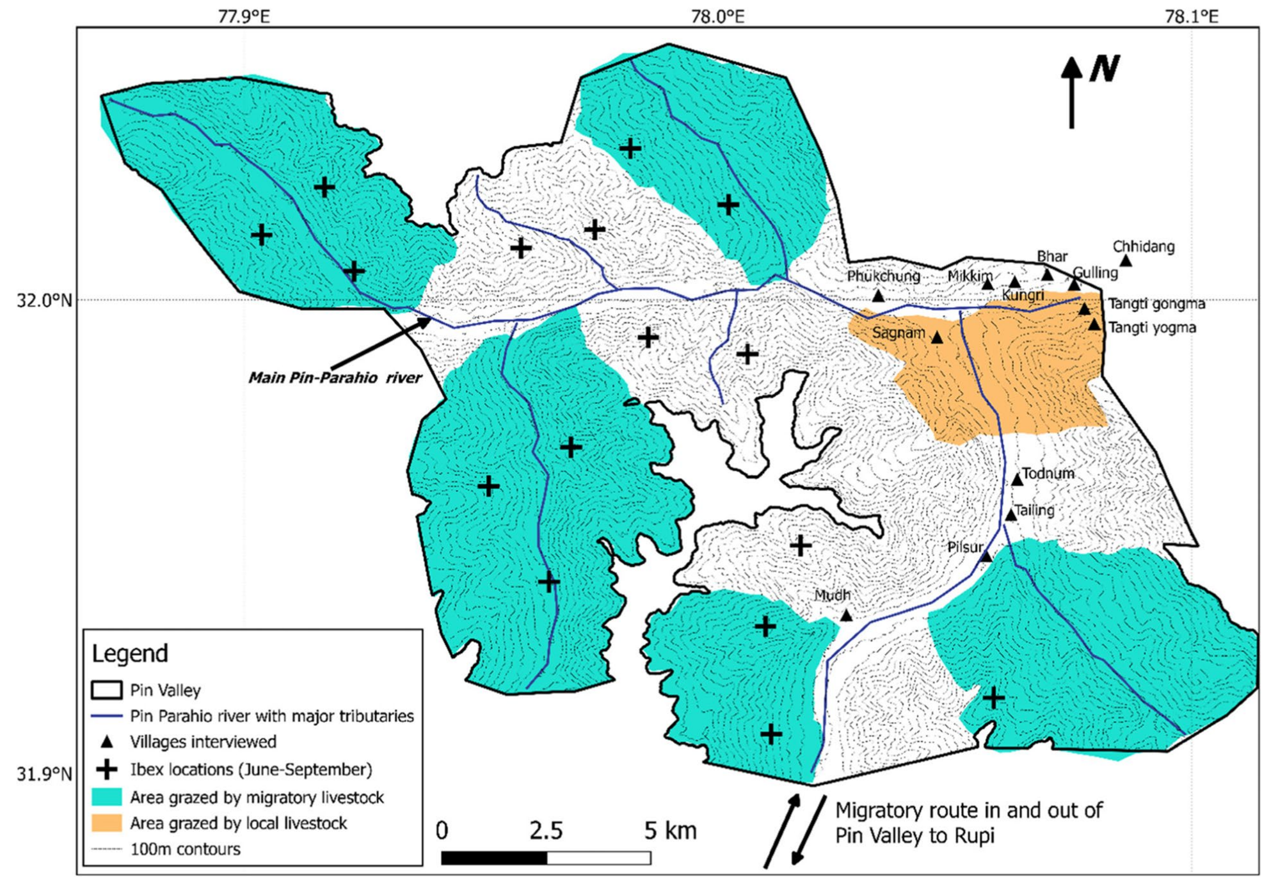

Fig. 3 Map displaying grazing areas of migratory and local livestock (sheep and goat) within Pin valley, along with locations of ibex and villages, for the months of June–September

Table 2 Endo-parasite prevalence, range (eggs per gramme) and mean (± standard error—eggs per gramme) across migratory livestock, local livestock and ibex. Sample sizes are number of pooled faecal samples, each representing a different host category: migratory livestock, local livestock and Asiatic Ibex. 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 Trichostrongyloidea

		Strongyloides[a]	Strongyle GINs[a]	*Nematodirus*[a]	*Trichuris*[a]	*Moniezia*
Migratory livestock (n = 65)	**Prevalence**	9%	89%	15%	11%	55%
	Range (EPG)	5–10	5–195	5–10	5–55	5–270
	Mean (± SE) EPG	0.7 (± 0.29)	25.6 (±4.35)	1.1 (± 0.34)	2.2 (± 1.03)	35.8 (± 7.56)
Local livestock (n = 86)	**Prevalence**	6%	47%	6%	-	34%
	Range	5–10	5–20	5–15	-	5–220
	Mean (± SE) EPG	0.4 (± 0.19)	4.7 (± 0.63)	0.5 (± 0.23)	-	15 (± 4.87)
Asiatic ibex (n = 74)	**Prevalence**	11%	47%	9%	-	26%
	Range	5–10	5–20	5–15	-	5–185
	Mean (± SE) EPG	0.8 (± 0.29)	4.1 (± 0.66)	0.7 (± 0.28)	-	5.5 (± 2.68)

[a] GINs. *Moniezia* is a GI platyhelminth. All hosts also had oocysts of coccidia (*Eimeria* sp.) present

on livestock health. This was done by direct questioning of the 41 key informants, who judged the impact of endoparasites (particularly GINs) on a scale of 1–5 [5, animal dies; 4, alive but useless (in terms of owner-defined measures of productivity); 3, severely impacted; 2, impacted but not so severely; 1, little to no impact]. As this was an ordinal score, we used the Mann-Whitney *U*-test to compare the difference in median impact scores between the migratory herds and sedentary herds (as done by Khanyari et al., 2022a).

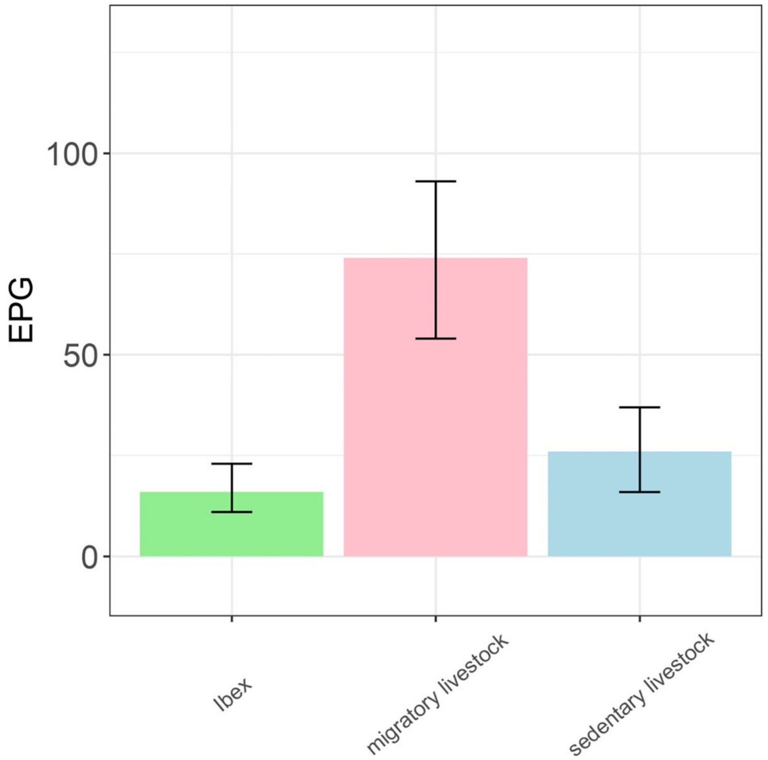

Fig. 4 Bar-plot displaying bootstrapped mean cumulative faecal egg counts (eggs per gramme, EPG) for helminthic endo-parasites across hosts. The bars display the 95% confidence intervals after bootstrapping the data. Sedentary = local livestock

Results

Pasture sharing between domestic and wild hosts in Pin valley

We mapped pasture use by local and migratory livestock (Fig. 3). It is clear that pastures are shared between ibex and migratory livestock throughout the summer. Ibex locations were mapped by the 41 key informants and were also triangulated by the annual population monitoring exercise conducted by the Nature Conservation Foundation (NCF unpublished data). We found no evidence for pasture sharing between local (sedentary) livestock (sheep and goats) and ibex (Fig. 3). While Fig. 3 represents data for the summer months (June–September), all 13 key informants from the Pin villages confirmed that local livestock distribution is limited to the orange polygon displayed in Fig. 3 and that they are stall-fed in the harshest winter periods (usually December-February). They also confirmed that even though ibex exhibit some degree of vertical movement seasonally, they rarely share pastures with local livestock.

Helminth burden and impact on host health

We analysed 65 pooled fresh faecal samples from migratory livestock, 86 pooled samples from sedentary livestock and 74 samples from ibex. Table 2 presents the endo-parasites present in these samples with their prevalence. Apparently, shared GINs between both types of livestock and ibex were *Strongyloides* sp., strongyle GINs and *Nematodirus* sp. They also shared the platyhelminth *Moniezia* sp.

When considering overall endo-parasite loads, migratory livestock had significantly higher egg output (measured in EPG) than local (sedentary) livestock ($t = 4.79$, df = 95.81, $p < 0.001$) and ibex ($t = 5.94$, df = 76.71, $p < 0.001$), while sedentary livestock and ibex had similar loads ($t = 1.47$, df = 139.89, $p > 0.05$) (Fig. 4). This was also confirmed by the one-way ANOVA test ($p < 0.001$; post hoc Tukey HSD: migratory livestock vs. ibex p-value < 0.001, migratory livestock vs. sedentary livestock p-value < 0.001, and ibex vs. sedentary livestock p-value > 0.05—see Supplementary Material 2). This was also true when considering strongyle GINs alone when comparing bootstrapped means (Table 2) using the one-way

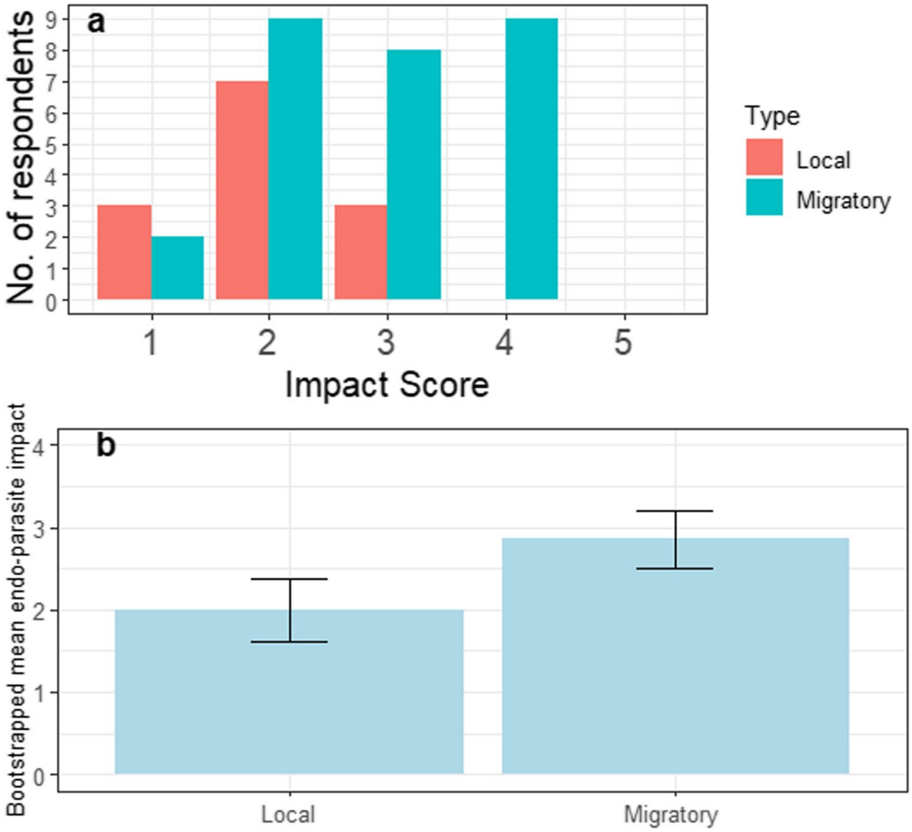

Fig. 5 Panel graph displaying **a** impact scores of endo-parasites on livestock health and **b** bootstrapped mean and 95% CI endo-parasite impact scores for outlying and village-based livestock. 5, animal dies; 4, alive but useless (in terms of owner-defined measures of productivity); 3, severely impacted; 2, impacted but not so severely; 1, little impact; 0, barely noticeable

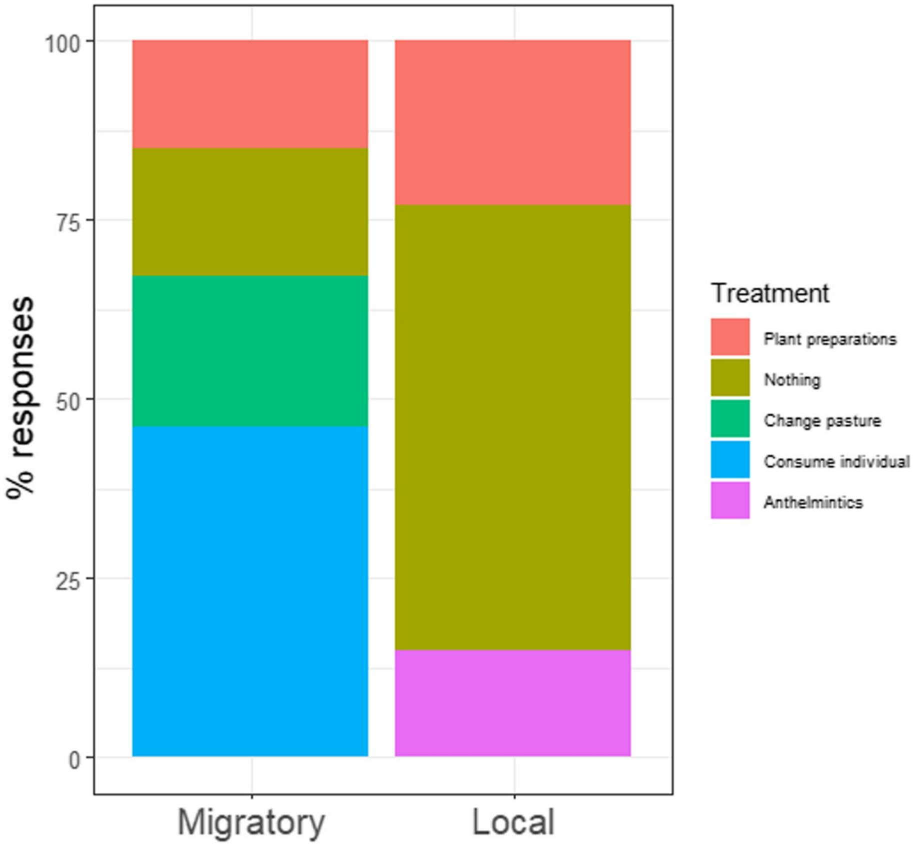

Fig. 6 Stacked bar graph displaying the bootstrapped mean % responses of different treatment types between migratory ($n = 28$) and local ($n = 13$) livestock

ANOVA test ($p < 0.001$; post hoc Tukey HSD: migratory livestock vs. ibex p-value < 0.001, migratory livestock vs. sedentary livestock p-value < 0.001, and ibex vs. sedentary livestock p-value > 0.05—see Supplementary Material 2). The Mann-Whitney U-test reported significantly worse impacts in migratory livestock compared to local livestock (w = 93.5, p-value = 0.009) (Fig. 5).

Additionally, we found that different treatments against endo-parasites were employed depending on the type of livestock (Fig. 6). For instance, predominantly migratory livestock that were clinically sick (including with clinical signs ascribable to helminthic infections) were mostly reported to be consumed if the effects of endo-parasites became a problem. More rarely, herders used plant preparations from local herbs to treat endo-parasite infections and in some instances changed the location of livestock grazing to deal with endo-parasitic infestation. No measures were taken by owners of resident (= local = sedentary) livestock to deal with endo-parasitism, including by the local veterinary services.

Changes in livestock holdings and flock composition compared to 20 years ago

The respondents were asked for the herd sizes in 2019 and in the early 2000s but also asked to comment verbally on change. Sheep and goats are herded together. In 2019, the average size of the 28 migratory herds was 809 sheep and goats (SE ± 39.2). While respondents mentioned that herd sizes have fluctuated across the years, the survey data suggest an increase in overall herd sizes since the start of the century of 44% (from 560 sheep and goats, SE ± 27.7, in the early 2000s). In 2019, the average number of goats in a herd was 504 (SE ± 24.5) and the average number of sheep was 305 (SE ± 18), while in early 2000s the average herd size was 260 goats (SE ± 14.7) and 299 sheep (SE ± 12.7). Twenty-five of the 28 key informants practised migratory grazing in both the early 2000s and in 2019 and respondents suggested that, since early 2000s, the total number of *tols* had remained relatively stable, albeit with annual fluctuations. Collectively, this suggests not only a definite increase in average

Table 3 Frequency (F) of reasons for villagers to lease pasture in Pin to migratory livestock herders (based on 13 interviews with Pin villagers) and frequency (F) of reasons that result in the *Kinnaura* herders undertaking migration, based on 28 interviews

Reasons for leasing pasture	*F* (*n*=13)	Reasons for undertaking the migration	*F* (*n*=28)
Spiritual—a local deity in the Rupi-Bhaba area is worshipped by both the people of Pin and the migratory *Kinnaura* herders. It is said that the deity demarcated Pin valley as an important seasonal area for the migratory herders. The local community in Pin valley continues to comply with this.	12	**Nutrition**—Migration is essential for finding both quality and quantity of forage.	27
Monetary—Migratory herders pay a fee to access the grazing pastures in Pin. Income from this is used for communal activities such as repairing community halls and contributions to religious activities.	11	**Space**—Rupi-Bhaba pastures aren't large enough to feed the livestock during summers, when they need nutritious forage before being sold in the autumn.	24
Fertilizer—The faeces from the large migratory sheep/goat herds is considered to be an effective manure, particularly for agricultural pea and barley fields. Dung is collected in autumn (after the herds leave Pin) for use in the following spring.	9	**Disease—**The rains hit Rupi-Bhaba during the time the livestock are in Pin. The wet weather increases the prevalence of diseases like endo-parasites, ecto-parasites and FMDV.	21
Meat—Based on long-standing relationships, migratory herders are known to share meat from their sheep/goats with certain members of the Pin valley community. The latter in turn share the meat with other villagers.	5	**Weather—**Due to the rains in Rupi-Bhaba, the mountains get extremely misty. This increases the chance of losing livestock	19
		Tradition—It is tradition and thus needs to continue	9

herd size, but a likely increase in the total head of migratory livestock.

Across the 13 villages in Pin valley, there were a total of 930 sheep and goats in 13 herds (433 sheep and 497 goats) in 2003 (Spiti livestock census 2003). These numbers have seen a drastic decline to a total of 55 (48 sheep and 7 goats) across 3 herds in the valley in 2019. Key informants were unanimous in confirming this decline, which they attributed to an increase in green-pea cultivation in the past two decades, similar to patterns in certain other areas in Spiti (Singh et al. 2015). Accounting for the increase in migratory stock and decrease in resident small stock, there seems to be a net increase in small stock grazing in Pin valley in 2019 compared to early 2000s.

Given the fact that local livestock rarely share pasture with ibex (3.1), have low endo-parasite burdens (3.2) and are few in number (3.3), we focused our remaining questions on the migratory livestock.

Current reasons for undertaking the long-distance migration, its likely persistence and governance of leasing pastures to migratory herders

Given the consistency of responses, these are presented together rather than individually. Resident villagers hold the rights to lands across the Pin valley. These lands are used to graze local livestock, sow crops and collect natural resources. Pastures have been leased to the migratory herders for decades, for various reasons (Table 3).

The reasons for undertaking the migration from the migratory herder's perspective include the acquisition of good quantity and quality of forage, tied closely to the lack of pasture land in Rupi (Table 3). Illustrating this point, a migratory herder said:

> *… the high altitude and the harsh climate of Pin results in a short but bountiful growing season for the vegetation. The plants really try to make best use of the short growth season, and hence are full of nutrients. Unlike Rupi or Sirmaur, Pin is a vast region, with very few people. This gives our livestock large areas to roam and graze. Back in Rupi, grazing land is limited to mountain tops, as the other areas are either agricultural lands or forests. (Key informant, Herder Tol 2)*

Other reasons cited were weather-related increases in disease incidence and difficulty in finding livestock due to the mist during the rainy summers in Rupi, as well as tradition.

Current pasture quality in Pin valley and changes in it over time

Interviews with migratory herders revealed three indicators of pasture quality (Table 4). The presence of certain herbs and grasses was the main indicator, while absence/limited coverage of unpalatable species was also a factor. An elderly herder emphasized this by saying:

> *… the main reason why we undertake the long and treacherous migration from Rupi to Pin is for the forage it provides our livestock. It is during the summer time (June-September), that the forage in Pin is at its*

Table 4 Frequency (*F*) of indicators of pasture quality based on interviews with 28 migratory herders

Indicators of pasture quality	*F* (*n*=28)
Presence of certain herb species (particularly *Cicer* spp., *Aconogonum* spp., *Artemisia* spp.)	26
Presence of certain grass species (particularly *Leymus* spp., *Stipa* spp. and *Elymus* spp.)	24
Absence/limited coverage by unpalatable species (particularly *Caragana* spp. and *Eremurus* spp.)	13
Absence/limited denudation and rock-cover	11

Table 5 Frequency (*F*) of reasons for changes in pasture quality, based on interviews with 28 migratory herders

Reasons for changes in pasture quality	*F* (*n*=28)
Irregular winter snows result in a lack of summer forage	19
Increased temperature and rainfall during the grazing season result in less nutritious forage	18
Restricted access to some traditionally grazed pastures by the local authorities to collect fodder for the increased number of large-bodied livestock is resulting in repeated grazing on the same pasture by higher number of migratory livestock.	18
Increased soil erosion due to glacial melt	13
Increased intensity of livestock grazing compared to before—driven by increase in migratory livestock numbers, with relatively stable local livestock numbers (precipitous decline of sheep/goat and a slight increase in large-bodied livestock)	9
Increased fodder collection by locals to sell	7

Table 6 Frequency (*F*) of implications of changes in pasture quality, based on interviews with 28 migratory herders

Implications of changes in pasture quality	*F* ($n = 28$)
Occurrence of frequent disease events (Foot and mouth disease, respiratory diseases and endo-parasites outbreaks)	21
Decreasing body size of livestock	20
Lowered pasture regeneration—herders reported that previously they could use the same pasture year on year; however, now pastures need to be changed every 3–6 years.	18
Reduced milk production in livestock	10

> *best in terms of nutrition. Back in Rupi, it is so wet and hence the forage is far too lush and unpalatable for our sheep and goats. (Key informant, Herder Tol 4)*

Of the 28 herders, 26 suggested that pasture quality had changed for the worse. The remaining two herders said the pasture quality remained largely similar. Climate-related irregularities were the predominately cited reasons behind this degradation, although interestingly they were less unanimous about these reasons than they were about the main reasons for migration and indicators of pasture quality (Table 5). A village elder from Pin valley summed up the problem:

> *The winter never came to Pin Valley in 2018-2019! No wonder there wasn't much for the migratory herds to eat. Many of the villagers also suffered losses for their pea cultivation, as lack of snow in the winter meant very little glacial melt water for their crops in the summer. (Key informant, Villager 2)*

Additionally, while the migratory herders visited Pin valley each year, they would try not to graze the same pasture annually, giving it time to regenerate. However, in recent years, the villagers of Pin have increased restrictions to certain pastures, citing their importance for fodder collection for their large-bodied livestock (Yaks, *Dzos,* cows, donkey and horses). Key informants in Pin suggested this is primarily as large-bodied livestock numbers have slightly increased in number, from 1326 in 2003 (Spiti livestock census 2003) to 1866 in 2019. This is due to their importance for meat (particularly in winter), milk and as a commercial commodity—for instance, horses are often sold to the military as pack animals. This leads to pasture degradation in two ways: (i) the migratory herders having to graze similar pasture year after year and (ii) large amounts of fodder being extracted from the pastures for large-bodied livestock. Four major implications of the changes in pasture quality were noted by the migratory herders, with disease, including GINs, being the most-cited implication of the worsening pasture quality (Table 6).

Discussion

Lessons for our work

We worked with two pastoral communities in Western Indian Himalayas—the migratory *Kinnaura* herders and local livestock herders of Pin valley—to investigate contemporary herding practices and their changes since the beginning of the twenty-first century. Our aim was to understand potential impacts on host health and disease transmission to Asiatic ibex in Pin valley, with a focus on GINs as a prevalent and important cause of reduced livestock productivity.

We found that the migratory *Kinnaura* flocks share pasture with ibex during their time in Pin, are increasing in both mean herd size and overall numbers and have higher GIN burdens—hence are likely to make a larger contribution to the shedding of these parasites into the environment—than other hosts. However, the copromicroscopic analysis is not able to identify helminth infections at parasite species level, and therefore, it cannot be assumed that GINs in this system are in facet transmitted between host groups. Given the high proportion of generalist species among trichostrongylid GIN of ungulates (Walker & Morgan, 2014), however, cross-susceptibility seems likely. New genetic methods such as nemabiome can be applied in the future to determine more precisely the parasite species composition in each host category and hence the chances of cross-transmission (Avramenko et al. 2015). Also, to get a true sense of contact patterns, future studies could leverage collaring data of different hosts, if possible. Nevertheless, the numerical dominance of GIN eggs shed from migratory livestock points to their potentially significant role in GIN cross-transmission, as GINs have free-living, environmental stages that are trophically acquired due to co-grazing pastures (Anderson, 2004).

Alongside more precise parasite identification, further investigation is also needed to understand if worm burdens for each host are at physiologically detrimental levels. For instance, the mean EPG values for all three groups of animals are low, compared to others reported in literature. Thus, Carcereri et al. (2021) report mean GI strongyle EPG for Alpine ibex *Capra ibex* to be 261.5 (SE 15.1) and for sheep to be 277.1 (SE 85.5), which is magnitudes higher than the values in our study (Table 2).

While subclinical GIN infection can reduce growth rates in ungulates (Forbes et al. 2000), it is possible that low host density and migratory movement in this system keep parasite burdens below the level at which they influence health and production. In that case, helminths are not a major risk of pasture sharing in this system, and other infectious diseases are perhaps a higher priority.

Theoretically, migration can reduce infection pressure through escape from contaminated habitats; however, recent work has shown that migratory hosts have higher parasite species richness and little support for migratory escape of infection pressure (Teitelbaum et al. 2018). Interestingly, the migratory livestock had one endo-parasite (*Trichuris*) that was not found in sedentary livestock or ibex (Table 2). Whether this is acquired through migration needs further investigation. Our sampling strategy for endo-parasites did not enable us to identify various other potential helminths, including those found in the Indian Himalayas in previous studies (e.g. *Fasciola*) (Muthiah et al. 2013). The seasonal migration of the *Kinnauras* could result in their livestock carrying novel infection of endo-parasites, than those present in Pin valley—from the lower regions, into Pin. As local small-bodied livestock rarely share pasture with ibex, have low endo-parasite burdens and are few in number, they are likely to have minimal interactions with, or impacts on, either ibex or the Pin valley's rangelands.

Alongside lower egg outputs from diluted host densities at high altitude, it is possible that the low temperatures and limited precipitation of the trans-Himalayan pastures also limit the development of GINs. This could contribute to low GIN loads for the Ibex and sedentary livestock in comparison to the migratory livestock, which experience warmer and wetter climes, more conducive for GIN development (Walker et al. 2018; Khanyari et al. 2021). Discerning the relative roles of host movement and climate in driving parasite infection in migratory ungulates is complex and likely to differ between systems (Morgan et al., 2005). In the absence of long-term year-round monitoring and intervention studies, transmission models can help to address this question and to explore scenarios around host population and climate change (e.g. Walker et al., 2018; Khanyari et al., 2022b; Peacock et al., 2022) and have been applied to Himalayan pastures shared between livestock and Bharal (Khanyari et al., 2021).

The high and increasing number of migratory livestock sharing limited pasture areas with low numbers of ibex (*c.* 200–250 ibex; NCF unpublished data) suggests that an increasing level of cross-transmission of GINs from migratory livestock to ibex may be taking place. This is likely to be exacerbated by an increased number and proportion of goats in the migratory flocks (3.3), as goats are more closely related to ibex than sheep and hence use similar environments (i.e. rugged areas)—while sheep prefer more undulating areas. Even though it was not possible to do so for this study as sheep and goat graze together in large flocks resulting in difficulty distinguishing between faeces, it would be valuable for future studies to separately analyse faecal egg counts and evaluate the relative importance of eggs shed from each host to general pasture contamination with different GIN species. This possibility could be further explored and validated by modelling the transmission loop incorporating the life histories of the endo-parasites concerned, relevant climatic factors and the spatial dynamics of the migratory herds (Rose et al. 2015). The extent of cross-transmission, however, cannot be properly evaluated without further taxonomic investigation of the parasite species present, since eggs are morphologically similar among GIN taxa in particular. Additionally, more research is needed to understand the impact of treatment and mitigation actions by herders on endo-parasite burdens, and how these might be improved in the future.

The *Kinnaura* herders' home district, Kinnaur, experienced growth in the cash-based and market-oriented cultivation of apples in the 1980s (Sharma 2005; Basannagari and Kala 2013). Around the same time, across Spiti valley (in which Pin is located), the same trend was observed with green pea cultivation (Mishra 2001). A key consequence of this for the *Kinnauras* was that large singular family units broke down into several smaller nuclear families, predominantly cultivating apples. This shift seems to have played a major role in the decline of traditional polyandry and increase in monogamy in the area (Gautam and Kshatriya 2011). However, even predominantly apple-cultivating households own a few livestock as an additional economic safety net. Therefore, more people now own at least some livestock—albeit usually in smaller numbers—than before. Today, these smaller livestock holdings are clubbed together into large livestock groups—*tols*. These are herded by people owning limited land and large livestock holdings (hence with no or limited dependence on apple cultivation), who practise migratory pastoralism. This is the reason why migratory livestock herd sizes have increased while individual livestock herd sizes are decreasing (Ghoshal 2017). A similar trend of increasing contracting among herders can be observed in the Gaddi community of migratory herders from other districts of Himachal Pradesh (Axelby 2007), as well as in Tibetan herder communities (Yeh et al. 2017).

While we restrict our work to sheep and goats, some larger-bodied livestock like donkeys, horses and yaks from Pin villages also co-graze pastures with ibex (Bagchi et al. 2004; Ghoshal 2017) and appear to have contributed to recent restrictions in grazing by migratory livestock. How and if these local large-bodied livestock interact with ibex with respect to disease transmission needs research. For instance, we know large-bodied livestock can contribute to competition with ibex in Pin valley (Bagchi et al. 2004). Increasing numbers of large stock are likely to eat more forage from the shared pasture and require increased fodder collection for their winter stall feed, particularly if climatic factors are lowering pasture productivity (Murthy and Bagchi 2018). Such practices have caused pasture degradation in Spiti (Mishra et al., 2004; Bagchi et al., 2004). Degradation could add to the problem of disease through nutritional stress and resource competition, in turn exacerbating GIN impacts (Kock 2004).

The slight increase in large-bodied livestock numbers, and hence the requirement for increased fodder in Pin, has several reasons. The increase in the dependence on green peas as a cash crop, which requires demanding work in the field, has resulted in many households ceasing to keep livestock that need daily care—sheep and goats. Large-stock like yaks and horses are free-ranging for large parts of the year (Singh et al. 2015). Economic gains from green peas have also enabled locals to purchase more large-stock from neighbouring regions as additional economic safety nets. The market value of livestock may also be important. For instance, the local *Chumurti* breed of horse is bred for sale in Ladakh, while some yaks are sold to tourism operators from lower Himachal (eg. Manali). Yaks and *Dzos* remain important for meat (particularly in the winter) and milk, while donkeys are important beasts of burden used for transporting drinking water and dung collected from pastures (Bagchi et al. 2004). More research into the role of large-stock in driving changes in pasture use and condition, and the knock-on impacts on small-stock and ibex, is required.

Lastly, we find evidence that long-distance migrations are likely to persist, even though there are worrying signs of pasture degradation contributed to by increased migratory livestock numbers and cutting of fodder for large-bodied local livestock. We also find that pasture degradation can result in a perceived increase endo-parasite outbreaks (Table 6). There is a link between livestock density and GIN transmission, wherein more livestock using the same areas can contribute to both increased degradation related to resource competition and GIN transmission (Grenfell 1992). The respondents perceived this to be a major issue. However, perception of respondents, albeit extremely valuable for understanding the dynamics of traditional systems where data are limited (Tomaselli et al., 2018), can still have biases. Most perceptions expressed in our interviews are not triangulated with primary data. In our parasitological investigation, levels of endo-parasites in general and GIN in particular were higher in the migratory herds, suggesting that sedentary management did not constrain livestock to highly infected pastures. Nonetheless, there is evidence of extensive livestock grazing and climate change contributing to degradation in our study area (Mishra 2001; Mishra et al. 2004; Bagchi et al. 2004; Murthy and Bagchi 2018). Moreover, parasites were held by migratory herders to impact their animals more severely than for sedentary livestock, while they were more likely to intervene through grazing management, plant-based medicines, and culling and consumption of weakened individuals. It is possible that the arduous migration and the need to survive the outward and return journeys both increase the consequences of moderate parasite burdens and motivate herders to reduce their impacts. If successful co-existence is to be maintained into the future, ensuring viable ibex populations persist along with livestock that support people's livelihoods, it will be critical for managers to proactively tackle interconnected issues such as resource competition, disease transmission and pasture degradation, rather than just looking at them as singular issues—the latter may have unintended consequences. For instance, community-based livestock grazing free reserves are often used in the Indian Trans-Himalayas to limit resource competition from livestock to wild ungulates (Mishra et al. 2016). However, in Pin valley, this could result in increased stocking densities of migratory livestock in certain areas, accelerating its degradation while also potentially compromising their health through increased GIN transmission.

Steps into the future

Given this understanding, it is critical that proactive measures are taken to align people's livelihoods with wildlife conservation. It will be crucial for conservationists to work with both the migratory *Kinnaura* herders and the resident livestock owners to better understand and limit pasture use in Pin valley, so that the pasture is not further degraded in the face of accelerating climate change. Participatory approaches to explore climate change scenarios and how they would impact pasture quality of Pin and its hosts' health (migratory livestock, local livestock and the ibex) can help guide potential ways forward for co-existence.

Given that herders felt that disease was a potentially important implication of reduced pasture quality, innovative approaches such as herder-run livestock insurance schemes to offset losses through diseases (GIN or otherwise) might be of interest to them. Building herder capacity to identify early signs of parasitism in livestock, combined with selective treatment using anthelmintics, could help to develop resilient and healthy livestock herds that are less likely to transmit disease to ibex. Anthelmintics if used non-selectively are known to cause GIN resistance in both livestock and wildlife (Barone et al. 2020).

Collectively, these interventions not only would help address the ecological and economic interests of the migratory livestock herders, but also can contribute to the conservation of the high Himalayan rangelands and the wildlife that call it home.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13570-022-00257-1.

Additional file 1: Supplementary Material 1. Questionnaire

Additional file 2: Supplementary Material 2. Results of the one-way ANOVA

Acknowledgements

This work would not have been possible without the generous support of the *Kinnaura* herders and the people of Pin Valley. Their hospitality and insights are the foundation upon which this work has been done. A special thanks to Padma Anchuk and Heshey from Sagnam village in Pin Valley for their constant support throughout this project. We would also like to thank the Himachal Pradesh Forest Department for being supportive throughout the life of the project and also providing the necessary research permits for it. We would also like to thank Siddharth Biniwale for helping out with part of the data collection. The publication of this paper was kindly supported by the Yolda Initiative.

Authors' contributions

MK, ERM, EJMG and KRS conceived the study. MK and RSR collected the data. MK analysed the data and led the writing of the manuscript. All authors contributed to revising the drafts. The authors read and approved the final manuscript.

Funding

This project was funded by the Ruffords Foundation grant number 24486-2. MK would also like to thank the Zutshi-Smith Foundation for their support.

Availability of data and materials

All the data associated with this paper is either presented in the manuscript or uploaded as supplementary material.

Declarations

Ethics approval and consent to participate

The study was approved by the University of Bristol's Ethical committee. Consent was taken orally before conducting the surveys and all the responses were coded; names or other identities of respondents were not used, in order to ensure anonymity.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]University of Bristol, Bristol, UK. [2]Nature Conservation Foundation, Mysore, India. [3]Interdisciplinary Center for Conservation Sciences, Oxford, UK. [4]Queen's University Belfast, Belfast, UK. [5]Snow Leopard Trust, Seattle, USA.

Received: 24 April 2022 **Accepted:** 9 September 2022

References

Anderson, J. 2004. Talking whilst walking: A geographical archaeology of knowledge. *Area* 36 (3): 254–261.

Avramenko, R. W., Redman, E. M., Lewis, R., Yazwinski, T. A., Wasmuth, J. D., & Gilleard, J. S. (2015). Exploring the gastrointestinal "nemabiome": deep amplicon sequencing to quantify the species composition of parasitic nematode communities. *PLoS One*, 10(12): e0143559.

Axelby, R. 2007. 'It takes two hands to clap': How Gaddi shepherds in the Indian Himalayas negotiate access to grazing. *Journal of Agrarian Change* 7 (1): 35–75.

Bagchi, S., C. Mishra, and Y.V. Bhatnagar. 2004. Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan mountains. *Animal Conservation* 7 (2): 121–128.

Barone, C.D., J. Wit, E.P. Hoberg, J.S. Gilleard, and D.S. Zarlenga. 2020. Wild ruminants as reservoirs of domestic livestock gastrointestinal nematodes. *Veterinary Parasitology* 279: 109041.

Basannagari, B., and C.P. Kala. 2013. Climate change and apple farming in Indian Himalayas: A study of local perceptions and responses. *PloS one* 8 (10): e77976.

Bhasin, V. 2011. Pastoralists of Himalayas. *Journal of Human Ecology* 33 (3): 147–177.

Bhatnagar, Y.V. 1997. *Ranging and habitat utilization by the Himalayan ibex (Capra ibex sibirica) in Pin Valley National Park*. Rajkot: Saurashtra University.

Carcereri, A., L. Stancampiano, E. Marchiori, E. Sturaro, M. Ramanzin, and R. Cassini. 2021. Factors influencing gastrointestinal parasites in a colony of Alpine ibex (Capra ibex) interacting with domestic ruminants. *Hystrix 32* (1).

Carpiano, R.M. 2009. Come take a walk with me: The "go-along" interview as a novel method for studying the implications of place for health and well-being. *Health Place* 15 (1): 263–272.

Chandra Sekar, K., and S.K. Srivastava. 2009. *Flora of the Pin Valley National Park, Himachal Pradesh*. New Delhi: Botanical Survey of India, Ministry of Environment and Forests.

Coppolillo, P.B. 2000. The landscape ecology of pastoral herding: Spatial analysis of land use and livestock production in East Africa. *Human ecology* 28 (4): 527–560.

Creswell, J.W. 1998. *Qualitative inquiry and research design: Choosing among five traditions*. 1st ed. Thousand Oaks: Sage.

Cringoli, G., M.P. Maurelli, B. Levecke, A. Bosco, J. Vercruysse, J. Utzinger, and L. Rinaldi. 2017. The Mini-FLOTAC technique for the diagnosis of helminth and protozoan infections in humans and animals. *Nature protocols* 12 (9): 1723.

Dixit, V.B., A. Bharadwaj, R.K. Sethi, and R. Gupta. 2009. Rural environment vis-à-vis buffalo husbandry: Assessement of perceptions of scientists and veterinary surgeons. *Indian Journal of Animal Sciences* 79 (12): 1273–1276.

Forbes, A.B., C.A. Huckle, M.J. Gibb, A.J. Rook, and R. Nuthall. 2000. Evaluation of the effects of nematode parasitism on grazing behaviour, herbage intake and growth in young grazing cattle. *Veterinary Parasitology* 90 (1-2): 111–118.

Galvin, K.A., R.S. Reid, R.H. Behnke, and N.T. Hobbs, eds. 2008. *Fragmentation in semi-arid and arid landscapes, consequences for human and natural systems*. Dordrecht: Springer.

Gautam, R.K., and G.K. Kshatriya. 2011. Polyandry: A case study of Kinnauras. *Indian Journal of Physical Anthropology and Human Genetics* 30 (1-2): 145–161.

Ghoshal, A. 2017. *Determinants of occurrence of snow leopards and its prey species in the Indian Greater and Trans Himalaya*. Rajkot: Wildlife Science department, Saurashtra University.

Goldstein, M.C., and C.M. Beall. 1990. *Nomads of Western Tibet: The survival of a way of life*. Berkeley: University of California Press.

Grenfell, B.T. 1992. Parasitism and the dynamics of ungulate grazing systems. *The American Naturalist* 139 (5): 907–929.

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.

Hruska, T., L. Huntsinger, M. Brunson, W. Li, N. Marshall, J.L. Oviedo, and H. Whitcomb. 2017. Rangelands as social–ecological systems. In *Rangeland systems*, 263–302. Cham: Springer.

Kerven, C., S. Robinson, R. Behnke, K. Kushenov, and E.J. Milner-Gulland. 2016. A pastoral frontier: from chaos to capitalism and the re-colonisation of the Kazakh rangelands. *Journal of Arid Environments* 127: 106–119.

Khanyari, M., E.J. Milner-Gulland, R. Oyanedel, H.R. Vineer, N.J. Singh, S. Robinson, et al. 2022b. Investigating parasite dynamics of migratory ungulates for sustaining healthy populations: Application to critically-endangered saiga antelopes Saiga tatarica. *Biological Conservation 266*: 109465.

Khanyari, M., K.R. Suryawanshi, E.J. Milner-Gulland, E. Dickinson, A. Khara, R.S. Rana, et al. 2021. Predicting parasite dynamics in mixed-use Trans-Himalayan pastures to underpin management of cross-transmission between livestock and bharal. *Frontiers in Veterinary Science* 1108;8: 714241.

Khanyari, M., S. Robinson, E.R. Morgan, A. Salemgareyev, and E.J. Milner-Gulland. 2022a. Identifying relationships between multi-scale social–ecological factors to explore ungulate health in a Western Kazakhstan rangeland. *People and Nature 4* (2): 382–399.

Kock, R.A. 2004. The Wildlife Domestic Animal Disease Interface—should Africa adopt a hard or soft edge? *Transactions of the Royal Society of South Africa* 59 (1): 10–14.

McCabe, J.T. 1994. Mobility and land use, old conceptual problems and new interpretations. In *African Pastoralist Systems: An Integrated Approach*, ed. E. Fratkin, K.A. Galvin, and E.A. Roth, 68–89. Boulder: Lynne Reinner Publications.

Mishra, C. 2001. *High altitude survival: Conflicts between pastoralism and wildlife in the Trans-Himalaya*. Ph.D. Thesis. The Netherlands: Wageningen University.

Mishra, C., S.E. Van Wieren, P. Ketner, I. Heitkönig, and H.H. Prins. 2004. Competition between domestic livestock and wild bharal Pseudois nayaur in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41 (2): 344–354.

Mishra, C., Redpath, S. R., and Suryawanshi, K. R. 2016. Livestock predation by snow leopards: conflicts and the search for solutions. In Snow leopards (pp. 59-67). Academic Press.

Morgan, E.R., L. Cavill, G.E. Curry, R.M. Wood, and E.S.E. Mitchell. 2005. Effects of aggregation and sample size on composite faecal egg counts in sheep. *Veterinary Parasitology* 131 (1–2): 79–87.

Murthy, K., and S. Bagchi. 2018. Spatial patterns of long-term vegetation greening and browning are consistent across multiple scales: Implications for monitoring land degradation. *Land Degradation & Development* 29 (8): 2485–2495.

Muthiah, M., D.B. Lal, B. Bankey, K. Suresh, C. Singh, M. Dabasis, K. Ambrish, and K. Rakesh. 2013. Assessing extension methods for improving livestock health care in the Indian Himalayas. *Mountain Research and Development* 33 (2): 132–141.

Niamir-Fuller, M., C. Kerven, R. Reid, and E. Milner-Gulland. 2012. Co-existence of wildlife and pastoralism on extensive rangelands: Competition or compatibility? *Pastoralism: Research, Policy and Practice* 2(1):1-14.

Nori, M., and I. Scoones. 2019. Pastoralism, uncertainty and resilience: Global lessons from the margins. *Pastoralism* 9 (1): 1–7.

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V. Powell, E.C. Underwood, J.A. D'amico, I. Itoua, H.E. Strand, J.C. Morrison, and C.J. Loucks. 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.

Patton, M.Q. 1990. *Qualitative evaluation and research methods*. Thousand Oaks: Sage.

Peacock, S.J., S.J. Kutz, B.M. Hoar, and P.K. Molnár. 2022. Behaviour is more important than thermal performance for an Arctic host–parasite system under climate change. *Royal Society Open Science 9* (8): 220060.

Perry, B.D., T.F. Randolph, and 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.

Pozo, R.A., J.J. Cusack, P. Acebes, J.E. Malo, J. Traba, E.C. Iranzo, et al. 2021. Reconciling livestock production and wild herbivore conservation: Challenges and opportunities. *Trends in Ecology & Evolution 36* (8): 750–761.

Pruvot, M., A.E. Fine, C. Hollinger, S. Strindberg, B. Damdinjav, B. Buuveibaatar, et al. 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.

R Core Team (2020). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. https://www.R-project.org/. Accessed 30 July 2021.

Reid, R.S., K.A. Galvin, and R.S. Kruska. 2008. Global significance of extensive grazing lands and pastoral societies: An introduction. In *Fragmentation in semi-arid and arid landscapes: consequences for human and natural systems*, ed. K.A. Galvin, R.S. Reid, J.R.H. Behnke, and N.T. Hobbs, 1–24. Dordrecht: Springer.

Rhyan, J.C., and T.R. Spraker. 2010. Emergence of diseases from wildlife reservoirs. *Veterinary pathology* 47 (1): 34–39.

Robinson, S., and E.J. Milner-Gulland. 2003. Political change and factors limiting numbers of wild and domestic ungulates in Kazakhstan. *Human Ecology* 31 (1): 87–110.

Rose, H., T. Wang, J. van Dijk, and E.R. Morgan. 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.

Saberwal, V.K. 1996. Pastoral politics: Gaddi grazing, degradation, and biodiversity conservation in Himachal Pradesh, India. *Conservation Biology* 10 (3): 741–749.

Sharma, H.R. 2005. Agricultural development and crop diversification in Himachal Pradesh: Understanding the patterns, processes, determinants and lessons. *Indian Journal of Agricultural Economics* 60 (1): 71–93.

Singh, N.J., Y.V. Bhatnagar, N. Lecomte, J.L. Fox, and N.G. Yoccoz. 2013. No longer tracking greenery in high altitudes: Pastoral practices of Rupshu nomads and their implications for biodiversity conservation. *Pastoralism: Research, Policy and Practice* 2(1):1–14.

Singh, R., R.K. Sharma, and S. Babu. 2015. Pastoralism in transition: Livestock abundance and herd composition in Spiti. *Trans-Himalaya. Human ecology* 43 (6): 799–810.

Smith, K.F., K. Acevedo-Whitehouse, and A.B. Pedersen. 2009. The role of infectious diseases in biological conservation. *Animal Conservation* 12 (1): 1–12.

Suryawanshi, K.R., Y.V. Bhatnagar, and C. Mishra. 2010. Why should a grazer browse? Livestock impact on winter resource use by bharal Pseudois nayaur. *Oecologia* 162 (2): 453–462.

Teitelbaum, C.S., S. Huang, R.J. Hall, and S. Altizer. 2018. Migratory behaviour predicts greater parasite diversity in ungulates. *Proceedings of the Royal Society B: Biological Sciences* 285 (1875): 20180089.

Tomaselli, M., S. Kutz, C. Gerlach, and S. Checkley. 2018. Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. *Biological Conservation* 217: 337–348.

Vosloo, W., K. Boshoff, R. Dwarka, and A. Bastos. 2002. The possible role that buffalo played in the recent outbreaks of foot-and-mouth disease in South Africa. *Annals of the New York Academy of Sciences* 969: 187–190.

Walker, J.G., and E.R. Morgan. 2014. Generalists at the interface: Nematode transmission between wild and domestic ungulates. *International Journal for Parasitology: Parasites and Wildlife* 3 (3): 242–250.

Walker, J.G., K.E. Evans, H. Rose Vineer, J.A. van Wyk, and E.R. Morgan. 2018. Prediction and attenuation of seasonal spillover of parasites between wild and domestic ungulates in an arid mixed-use system. *Journal of Applied Ecology 55* (4): 1976–1986.

Weinstein, S.B., and K.D. Lafferty. 2015. How do humans affect wildlife nematodes? *Trends in Parasitology* 31: 222–227.

Wilcox, R. 2017. *Modern statistics for the social and behavioral sciences: A practical introduction*. Boca Raton: CRC Press.

Yeh, E.T., L.H. Samberg, E. Volkmar, and R.B. Harris. 2017. Pastoralist decision-making on the Tibetan Plateau. *Human Ecology*;45:333–343. https://doi.org/10.1007/s10745-017-9891-8.

Publisher's Note