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Small Ruminant Health, Parasite Risk, and Information Exchange: Stakeholder Knowledge, Attitudes and Practices

Abstract

This study evaluates farmer and veterinarian perspectives on small ruminant health management and information sourcing practices, challenges and needs. Local vs. scientific animal health knowledge, meningeal worm risk perceptions and attitude change, parasite control strategies, information resources, veterinarian-client-patient relationships, and the role of small ruminant educators are discussed.

Abbreviations: KAP (knowledge, attitude, and practices)

Keywords: education, meningeal worm parasites, risk perception, small ruminant, veterinarian-client-patient relationship.

Introduction

Animal caretakers, such as farmers and veterinarians, make decisions about animal health based on prior education and experience, advice from mentors and peers, and more recently, the internet and social media (Alarcon et al., 2014; Ellis-Iversen et al., 2010, Pires et al., 2019; Roybal, 2012; Svensson et al., 2019). Unfiltered information may influence how farmers perceive animal health and parasitic risk and thus may cause challenges for responding veterinarians (Kogan et al., 2017; Kogan et al., 2012; Shortal et al., 2018). Small ruminant veterinarians (who practice on llamas, alpacas, sheep, and goats) have multifaceted jobs; they care for their animal patients and also serve as educators for farmers at all education levels and production scales. Examining information feedback loops about parasites, zoonotic diseases, and general health management may highlight knowledge gaps in educational programming.

Farmers who have good relationships with their veterinarians often reach out to them as a primary source to seek advice and information on animal health, thus creating high levels of trust between vets and farmers (Garforth et al. 2013; Gunn et al. 2008; Ruston et al. 2016). These veterinarian-client-patient relationships (VCPR) between farmers and veterinarians enhance sustainable and efficient health management strategies; reasons for not establishing a VCPR include producer economic constraints and veterinarian availability (Lee et al., 2022). Replacement of a VCPR with animal health misinformation, often found online, can result in management “firestorms” (Pfeffer et al, 2014). This effect can cause challenges for veterinarians trying to remedy the poor health management practices of producers. Good relationships with clients allow veterinarians to transition from a focus on individual animals to a whole herd health approach. Shifting from a ‘”test and treat” model to a “predict and prevent” model allows the veterinarians to have a more robust outlook on disease and parasite impacts on herd/flock productivity (Barkema et al. 2015; Brockett et al., 2021).

In small ruminant production, parasites are a major contributing factor to poor performance and mortality. Nematodes, such as *Haemonchus contortus* (barber pole worm) and *Parelaphostrongylus tenuis* (meningeal worm), can cause illness and death

of small ruminants, reducing productivity and profitability. Since meningeal worm cannot reproduce in aberrant hosts, such as small domestic ruminants, there is no premortem diagnostic test to help farmers and veterinarians with management or treatment decisions. Worms migrating in the nervous system may be found at necropsy, or a presumptive diagnosis may rule out other causes of neurological symptoms and/or a response to anthelmintic treatment. Parasitic risk to animals varies from farm to farm due to differences in management and environment. Other factors, such as a changing climate and parasites' increasing anthelmintic resistance, highlight the need for alternative control strategies (Taylor, 2013). By adopting a "predict and prevent" mindset about parasite management, farmers may lower infection risk in livestock.

Scientific learning opportunities can have mixed effects within the farming community, and advice on ways to improve practices may or may not get adopted. For social, economic, and physical reasons, farmers may not heed scientific advice (Brocket et al., 2021; Higgins et al., 2012). If allowed to contribute to scientific understanding, farmers may be more willing to adopt these practices. Combining local knowledge (i.e., farmers) with scientific knowledge (i.e., veterinarians and Extension) can improve acceptance of recommendations, enhancing sustainability (Mantyka-Pringle et al., 2017).

The aim of this project was to record local knowledge about small ruminant producers' animal health management and scientific knowledge about parasite and health management strategies, challenges, and needs based on the perspectives of farmers and veterinarians. This information may help inform managers and veterinarians about sustainable solutions to animal health and parasite control, in addition to capturing emergent themes related to knowledge gathering and sharing preferences.

Methods

Participant recruitment

Stakeholders included small ruminant farmers and large animal veterinarians practicing in the state of Maine. For this report, six producers, who were previously involved in a

separate on-farm research experiment analyzing risk and prevalence of *P. tenuis,* were interviewed, in addition to four clinical veterinarians active in small ruminant practice.

Sample collection

In the winter of 2022-2023, farmers and veterinarians were asked a series of questions via individual, semi-structured interviews; each group was asked a unique set of questions (see supplemental documents). This format, and the open-ended structure of several questions, allowed participants to expand freely on their answers and to bring up any content related to the topics of the study. Interviews were held in person or virtually and audio was recorded. The transcription software Dovetail (Dovetail Research Pty. Ltd.) was used to transcribe conversations. Interview methods and content were approved by the University of Maine Institutional Review Board; all data are confidential.

Prior to the interviews reported in this study, farmers were presented with their farm-specific results from the previous two years *of P. tenuis* risk assessment These results included prevalence of *P. tenuis* intermediate hosts (snails and slugs) on pastures, prevalence of *P. tenuis* larva within those hosts, a heat map of pasture risk derived from prevalence data and other risk factors, comprising a rating of overall risk across the grazing area (i.e., low, moderate, moderate-high, high), and recommendations for risk mitigation. A pre-interview discussion included a synopsis of the research results across all farms; however, farm identities and specific locations were not revealed. A similar synopsis was shared with the four veterinarians prior to their interviews. For both groups, we asked questions about their previous and current knowledge, attitudes, and any management changes that might stem from these data.

Actual risk was assessed in a separate study from May to September of 2021 and 2022; risk reduction methods were studied only during the summer of 2021. During those studies, methods for risk analysis included a bi-monthly visit to each respective farm to assess gastropod population measurements on livestock grazing spaces frequented by White-tailed deer (*Odocoileus virginianus*; WTD; *P. tenuis* definitive host) and to document host habitat and climatic variables. The risk reduction study methods included

pasturing laying hens on, or mowing of, high-risk pastures; both were effective methods of gastropod host reduction.

Analysis

Qualitative analysis included combining targeted (structured) and emergent (unstructured) themes from stakeholder conversations. Topics were analyzed in the context of real-world experiences, with an inductive thematic approach to the data. Dovetail transcription software enabled categorization of topics and key words highlighted in recorded conversations. Sentences or whole paragraphs that corresponded to concepts or beliefs within the realm of our question outline were coded by the first author. After all transcripts were coded, codes were merged based on question number or concept. Transcripts were reread to confirm that the context of content accurately represented the data.

Results

Characteristics of participants

Participants profiles are found in Table 1 and Table 2. Reported purposes for keeping animals included meat and/or wool production, dairy, breeding stock, education, and agrotourism. Veterinarian interviewees included three women and one man. Farmer interviewees included three women and three men.

Table 1. Farmer profiles.

Farmer ID	# Years of Sheep/ Goat Care Experience	Herd Size (max)	Has VCPR
A	42	200	**Y**
B	2	30	**Y**
C	7	40	**Y**
D	25	200	**N**
E	55	120	**Y**
F	29	180	**Y**

Table 2. Veterinarian profiles.

Vet ID	# Years of Practice	Owns Livestock
A	11	Y
B	15	Y
C	4	Y
D	2	N

General animal health management practices by farmers

Responses indicated that all farmers interviewed cared deeply about the health of their animals and adopted multiple practices to maintain good herd/flock health (Figure 1). All reported observing animals daily; 50% physically handle their animals daily. Other reported farmer practices used included offering free-choice minerals (100%), frequent body condition scoring (83%), annual vaccinations (83%), and periodic selenium supplementation or annual selenium injection (33%).

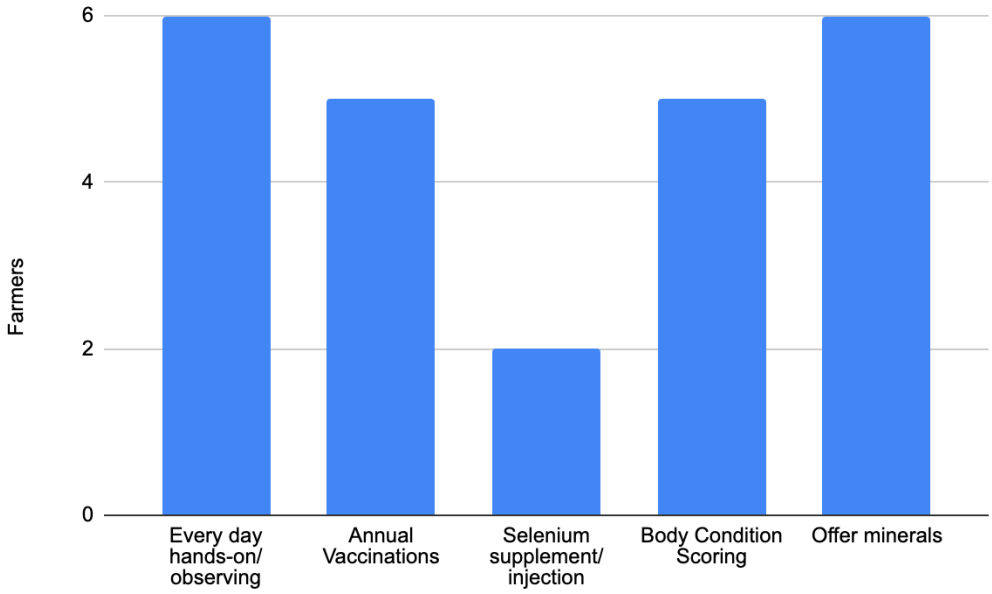

Figure 1. Farmer reported animal health practices.

All farmers claim to value advice from veterinarians, though the group had differing levels of veterinary involvement (Table 1, VCPR). Two farmers with the most animals only utilize a vet for extreme emergencies (e.g., cesarian sections, hard prolapse situations) and rely on human medical professionals for advice on treatments before

seeking veterinary care. Two farmers with 120 to 150 animals occasionally have a vet come out, but only for biosecurity panels or emergencies and claim that they have strong VCPRs which allow them to acquire over-the-phone advice from their veterinarians before mutually deciding whether the event is worth a visit to the farm. These four farmers incorporated a “survival of the fittest” model; animals requiring health care were culled., Each producer cited a unique threshold for culling (e.g., emotional connection to an individual animal, economic limits to veterinary expenditures, repeated illness in one animal). Two farmers with smaller herds/flocks use veterinarians multiple times a year for blood draws and pregnancy checks, in addition to annual check-ups and vaccinations. These farmers had fewer years of experience in years and would be considered new farmers by the USDA definition (USDA, 2024).

Themes

Our interviews with stakeholders included prompts about knowledge, perceptions, and adoption of animal health best practices. The use of open-ended questions allowed participants to freely expand on their experiences. Analysis generated themes of parasite and zoonotic disease risk, animal health information exchange, and challenges of best practice implementation.

Theme 1: Knowledge, perception, and management of small ruminant parasites and zoonotic disease risk

Theme 1.1 Meningeal worm risk to small ruminants

Prior to this study, four of six farmers had heard of or experienced meningeal worm on their farm. After learning the results of this study, most of the farmers reported a change in their knowledge, attitudes and practices regarding *P. tenuis*. At the beginning of the separate risk study (White, et al., in preparation), farmers were described as having low (66%), moderate (17%), or high (17%) perceived risk of meningeal worm transmission to their livestock. After seeing their farm-specific result and a heat map of risk on their pastures, all farmers reported a change in knowledge about *P. tenuis*, notably about life-cycle and intermediate host ecology.

Results of a study of gastropod treatments on pastures using poultry and mowing techniques were shared with participants. All veterinarians said they would consider sharing these methods with farmers experiencing meningeal worm-related illness in their livestock. All farmers implemented management policies consistent with the level of actual risk detected by on-site evaluation for *P. tenuis* intermediate hosts on their farm (Table 3).

Table 3. Producer-perceived vs. actual risk of *P. tenuis* and reported KAP post-sharing on-farm risk analysis results. *= No prior knowledge of the parasite.

Producer	Perceived risk	Actual risk	Knowledge change	Attitude change	Change in management
A	Moderate-High	Low	Yes	Yes	Yes; target of intermediate host plant habitat via mowing, install fence to limit WTD movement
B	Low*	High	Yes	Yes	Yes; target of intermediate host plant habitat via spraying and mowing, addition of pastured poultry
C	Low	Moderate	Yes	Yes	Yes; Addition of pastured poultry
D	Low	Low	Yes	No	No
E	Low*	High	Yes	Yes	Yes; target of intermediate host plant habitat via mowing, addition of pastured poultry, install fence to limit WTD movement
F	Moderate	High	Yes	Yes	Yes; target of intermediate host plant habitat via mowing

All veterinarians reported meningeal worm cases in practice, but cited challenges ruling out differential diagnoses, some of which are serious/potentially zoonotic (transmissible between animals and humans), citing a lack of producer support (expenses and time) for diagnostic testing to rule out differential diagnoses (Table 4, Theme 1.1.A).

Table 4. Theme 1.1: responses from stakeholder respondents regarding *P. tenuis* risk and challenges.

Theme 1.1	Participant Response
A. P. tenuis diagnostic challenges for veterinarians	• Vet A: "Yeah, we definitely have suspected cases. I've never been able to diagnostically confirm a case." • Vet C: "I tend to down go down the differential list and of course rabies is always on with neurological signs. Have I ever actually diagnosed the worm? No, I haven't. I will say some of the animals got better, some of them died. So it's like, 'maybe one of these things will work'- throw a bunch of stuff at the wall and see what sticks…It's a precarious situation that kind of leads to the shotgun approach to treatment and skipping of diagnostics with the very time critical, time sensitive nature of neurological processes in these animals and then [the farmer's] money concerns related to that testing." • Vet D: "I almost never diagnose it. It is almost always a diagnosis by resolution based on treatment because people don't want to spend the money on diagnosis. It's much, much cheaper just to give the slew of neurological medicine and kind of hope it works out from there. But usually when I see a neurological goat, there's like four things that you think about right off the top of your head. One of them is rabies, another one is CAE, a third one's polio, the fourth one's listeria. And then the fifth one is *P. tenuis*. And the three that we can treat, we usually all treat at the same time because it's like $20 to do that rather than to go through and diagnose everything. As a clinician, that frustrates me, I'll be honest, but there's just not a push for diagnosis from producers."
B. P. tenuis not a part of routine animal health conversations	• Vet C: "It's a topic that's not very commonly broached, unfortunately, because of all of the other basic parasite, nutrition, and vaccination information I need to give. It gets lost and it's not prioritized." • Vet D: "I will say I do not routinely talk about that. I have to be selective and talk about the higher priority areas."

When asked about their conversations with farmers assessing risk of, and taking preventative methods against *P. tenuis*, three of the four veterinarians reported not routinely discussing meningeal worm with clients, except with camelid owners (Table 4,

Theme 1.1.B). Llamas and alpacas are thought to be highly sensitive to meningeal worm (Ismail et al., 2011). With clients who own other small ruminant species, concerns about other internal parasites, primarily *H. contortus*, take precedence: it is the most common parasite they treat and advise farmers on. Generally, only when suspected cases were detected would they discuss *P. tenuis* with their clients.

Theme 1.2 Small ruminant parasites

Both farmers and veterinarians were asked about the frequency with which they observe parasitic illness within small ruminants (Table 5). All veterinarians reported that parasite-related illnesses are extremely common and observed more often in small ruminants than in cattle or equids. All the farmers reported to have had past or current problems with parasites, namely *H. contortus*, coccidia, lice, and *P. tenuis*.

All participants were asked to rate their concern about anthelmintic (chemical deworming) resistance in parasites (1= not at all concerned, 2= somewhat concerned, 3= very concerned). All of the veterinarians were very concerned; 60% of farmers were very concerned while 40% were somewhat concerned.

Table 5. Theme 1.2: stakeholder responses about parasitic anthelmintic resistance concern.

Theme 1.2	Participant Response
Concern about parasite anthelmintic resistance	• Farmer A: “I am very concerned because there aren't a lot of deworming options out there. So I don't want to lose faith in my options.” • Farmer E: “One has to keep changing one’s drench on a regularly basis and being very careful not to over-drench. So there are all sorts of ways in which this can become a major problem of parasites and it's a bad way of controlling them in general. Plus, the internal organs, which I often like to eat, concentrate these worms- as I say, a whole bunch of reasons for human health and animal health why I think resistance is a really big concern.” • Vet A: “In order to effectively treat any of these things that we're talking about, you have to use off-label dewormers, which means that you're really supposed to

	be doing that with veterinary oversight because off-label drug use is legally supposed to be done with a veterinary prescription." • Vet B: "We have resistance already regardless of what species we're dealing with. We know that most sheep and goats are resistant to most anthelmintics out there. To the point where now we have to give them a borderline toxic dose to make any of these medications effective. We have to start thinking outside the box and again, fasting them, FAMACHA scoring with a retest of the burden of the eggs… We're essentially using medications that could be toxic to fetuses in order to treat these animals for parasites and not even be able to effectively kill all the parasites that we're dealing with."

Farmers were asked to discuss their general parasite management practices which were then compared with the recommendations given by the veterinarians in this study (Table 6). Veterinarians reported advising farmers to use a range of management methods, ideally using multiple methods. These included fecal egg count (FEC), FAMACHA (i.e., visual scoring of anemic index) scoring followed by selective treatment of only the affected animals, using more than one class of anthelmintic when treating, rotational grazing (and avoiding grazing on very short vegetation), frequently surveilling for symptoms suggesting parasite burden (e.g., slow growth, weight loss, etc.), and using culling and selective breeding practices to build genetic resistance to/tolerance of endemic parasites. All veterinarians advised that these methods be prioritized over routinely scheduled deworming to prevent anthelmintic resistance by parasites. However, three out of four veterinarians also suggested anthelmintics be given to camelids monthly (i.e., llamas and alpacas; often co-pastured with sheep and goats) due to their heightened sensitivity to meningeal worm-induced damage. Parasite management practices varied among farmers; most adopted multiple practices that aligned with veterinarian recommendations (Table 6).

Table 6. Participant-reported parasite management recommendations and practices. Total participants: Veterinarian n=4; Farmer n=6.

Parasite management method	Farmers Practicing (n=)	Veterinarians Recommending (n=)
Diagnostics		
• Fecal Egg Counts (FEC)	1	3
• FAMACHA then treat	6	4
• Symptomatic then treat (e.g., ill thrift, diarrhea)	6	3
Treatment		
• Scheduled deworming (excluding camelids)	0	0
• Dose with 2 classes of anthelmintic treatment	1	4
Control/ Prevention		
• Cull & build genetic resistance/ tolerance	4	4
• Rotational grazing	6	3
• Natural anthelmintics as preventatives	1	0
• Co-grazing other livestock on shared pasture	2	2

Theme 1.3 Zoonotic disease risk

Participants were asked to rate their concern (same scale as anthelmintic resistance, above) about zoonotic pathogen or parasite risk. Farmers ranged from not at all (20%), slightly (60%), to very (20%) concerned about zoonotic pathogens. When asked for the reasoning supporting their rankings, those who were not or only slightly concerned stated they had no knowledge of or had not been exposed to zoonotic pathogens/parasites (Table 7, Theme 1.3.A).

Half of veterinarians were very concerned, 25% were somewhat concerned and 25% were not at all concerned about zoonoses. Veterinarians who were very concerned claimed it was due to their personal high risk of exposure (Table 7, Theme 1.3.B). Half of the veterinarians reported that they mention zoonotic pathogen risk during every farm visit.

Table 7. Theme 1.3; responses from stakeholder respondents about zoonotic disease concern.

Theme 1.3	Participant Response
A. Farmer understanding about zoonotic parasites or pathogens	• Farmer A: "I haven't really experienced those things and so they're not really on my radar yet." • Farmer E: "I'm concerned, but not very knowledgeable."
B. Veterinarian concern about zoonotic parasites or pathogens	• Vet A: "I think that at this point I sort of feel comfortable with what is zoonotic and we have those discussions. And for the most part, I really haven't seen much. I feel like it's pretty avoidable, like, it's not hard to not get these diseases if you're smart and educated about it." • Vet C: "I think a competent immune system is a wonderful thing. Healthy people, competent immune systems are wonderful things. Not everybody is fortunate enough to have that, and that's why we have to worry about zoonosis." • Vet D: "I am very concerned for myself, honestly more than anyone else. I would say I'm a three for me and a two for other people… We're interacting with blood and their fluids and it happens so often that I don't even think about it. And so, you know, you have blood on your hand, then you bite a sandwich and you don't even think about it until it's too late. I have never once put a glove on for a goat or sheep dystocia just because it doesn't work out as well. I think veterinarians are more in these high-risk situations like that."

Theme 2: Information exchange about animal health topics

Theme 2.1 Farmer animal health information sources

Farmers were asked to list their sources of animal health information (Figure 2). The most utilized by all farmers was the internet (i.e., search engine). Veterinarian advice and reading books were the second most used sources, followed by Facebook groups, peers or mentors, peer-reviewed literature and Extension literature. Webinars, list-serves and local associations were used the least.

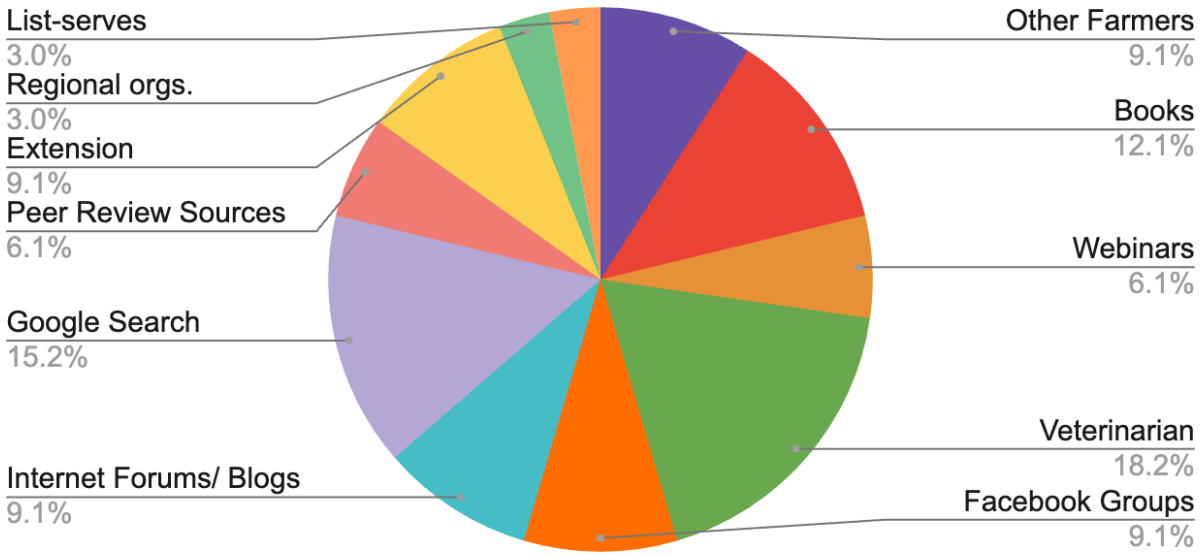

Figure 2. Pie chart of animal health information source use based on farmer response.

Farmers vary in their opinions about, and use of social media and the internet as information sources. Half of these farmers reported giving advice on social media but having little trust in it as a resource. Four out of six farmers cross-reference information when using internet searches and/or social media to inform their management decisions (Table 8, Theme 2.1.A). Farmers expressed a need for other information sources, such as peer and professional networking (Table 8, Theme 2.1.B).

Table 8. Theme 2.1: responses from farmers about animal health information resources.

Theme 2.1	Participant Response
A. Farmer use of social media and internet for animal health information	• Farmer B: “If two people say similar things, I will give it a try.” • Farmer C: "I do multiple searches, take the average of that knowledge, then make a decision based on that." • Farmer D: “You know, it used to be books or word of mouth, of course. But that's harder and harder to do. You know, there's not a lot of sheep farmers that have more than just pets to get advice for large operations. There's a lot of good information online. So I look at that,

	somewhat, but generally if there's a problem I call a trusted friend that has even more experience than me or do a Google search. Or call the vet and the vet goes to Google."
B. Need for local networking and information sharing	• Farmer A: "Farmers need a platform where we can share what issues we are having in relation to the same weather and other similar variables. Quarterly meetings with local farmers and scientific professionals would be so helpful." • Farmer F: "It would be great to connect with others and share these [animal health] experiences and see what they've experienced, specifically with systems-based approaches."

Theme 2.2 Veterinarian communication barriers

Veterinarians were asked to describe what they needed to enhance their communication about management for farmers regarding parasites and animal health. All veterinarians reported that most clients are small farm operations and/or hobby farmers, many of whom lack basic animal husbandry education. All of the veterinarians in this study wished for more educational resources that they could direct their clients (Table 9, Theme 2.2.A). All reported to frequently refer clients to scientific online sources, notably Extension websites, though 75% of veterinarians wanted to have access to physical handouts to give to new farmers. Two of the four veterinarians mentioned a desire for tutorials and credential programs on basic care and parasite management to which they could refer clients.

Table 9. Theme 2.2 responses from stakeholders regarding veterinarians' communication needs and barriers.

Theme 2.2	Participant Response
A. More educational resources for basic animal health and husbandry best practices	• Vet A: "I think it would be great to have more client education materials which you could just send to people that were easy to understand, like a one- or two-page handout. I would definitely support more sort of client education resources through the Extension service because I considered that to be a very reliable source that I can recommend to people."

	• Vet B: "It's kind of overwhelming as a veterinarian trying to educate someone on basic goat, sheep, alpaca management and address all they need to do to prevent the forest fire that they have created. These issues prevent us from reaching larger goals like herd growth or production. So I think as far as something that could help these kind of clients is some sort of brochure or chart to be able to give them for basic ways they can help their pasture improve and for parasite management." • Vet C: "We need interactive tidbits or tutorials that can be sort of computer-based learning where they could go in and really assess their learning and comprehension at the end of it, say with a little quiz or something like that. Or maybe gain some sort of certification once they complete these things. Have it be a consistent and accurate source of information that we all can sort of point small ruminant clients towards. Once we're all speaking the same language, then the communication becomes entirely more efficient. Then we can go out to address herd health and how to maximize productivity."
B. Limited time for animal health education at farm visits	• Vet B: "New and hobby farmers get hit with a lot of information during my visits, especially for initial herd health evaluations. They get a glazed look in their eyes, so I try to cover the basics: body condition scoring, FAMACHA, pasture rotation, and nutrition." • Vet D: "When I talk about things with producers, they seem to take home probably 10% of what I'm saying."
C. Misinformation effects on animal care	• Vet A: "A problem with parasite issues is that a lot of the research and recommendations are really new. A lot of people are talking to their old farmer friends who aren't staying on top of it…We get people who call all the time that are not clients and a lot of time they've already looked on the internet and on forums. They maybe have already dewormed their animal and with something based on that research and the sources that people use, or what they find first, don't tend to be very reliable sources." • Vet C: "There is so much information out there on the web and Facebook groups that these small ruminant producers are kind of utilizing each other for that exchange of information and they try multiple things. They try to handle it on their own and sometimes some of them do very well and sometimes they don't do as

	well. And then I get called at two o'clock in the morning, animal down, start of death, nobody knows what's going on and probably will never know what's going on. That's usually that's a euthanasia kind of thing…It leads to a lot of confusion and a lot of lack of confidence in the veterinarian." • Vet D: "I hear a lot of things that are like, 'well my neighbor said', or 'the breeder said', or 'I saw on Facebook'… Another big one that happens is people do not understand body condition scoring of goats. The number one emergency that we see at this practice, second to none, is an emaciated starving goat. Not because people are purposely starving their animals, but because they don't understand that that goat is skinny and someone might have told them that the goat is fat because it's fluffy. There's misinformation out there. I'm assuming it comes from the internet or like a neighbor and it's super frustrating. It also extends to drugs. People get drugs from other places and I'm like, 'You're a client of ours. I've seen you every other month for like the past two years. Where did you get that?' I guess a long story short, I see it a lot and the very, very real outcomes of it."

All veterinarians experienced communication limitations with new farmers, largely due to the overwhelming amount of information delivered during time-constrained visits (Table 9, Theme 2.2.B). All veterinarians mentioned competing with, or dealing with the repercussions from misinformation, namely advice from farmer-to-farmer or social media sources (Table 9, Theme 2.2.C).

Theme 3: Challenges to implementation of animal health best practices

Veterinarian feedback

It is evident from the previous theme that a lack of basic animal husbandry knowledge combined with misinformed practice adoption by farmers impacted the ability to provide effective veterinary services. Additionally, barriers described by the veterinarians (Figure 3) contribute to a positive feedback loop: since many farmers don't have a VCPR, they tend to make their own diagnosis and treatment decisions, and this often results in emergency veterinary intervention, which is often "too little too late" and may

end in euthanasia. This poor outcome then contributes to both the veterinarian and the farmer's lack of confidence, thus starting the cycle over.

All veterinarians commented that the lack of relationships with farmers was correlated with low effectiveness of animal response to treatments and the creation of the exacerbation of animal health problems on farms (Table 10, Theme 3.A). Lack of record keeping by farmers was another challenge veterinarians mentioned (Table 10, Theme 3.B).

Table 10. Theme 3: responses from veterinarians regarding barriers to animal health.

Theme 3	Participant Response
A. Lack of VCPR creates extended health problems for farmers	• Vet A: "[Non-client emergency] situations get frustrating and I don't know that there's necessarily a perfect solution for that because you can't reach out to people that you don't already have a connection with. When it really starts to go downhill, that's when they call. And at that point the effectiveness of your treatment plan is not as good as if you caught it earlier. I think the people who we have relationships with call earlier because we've had a relationship with them and we've talked about this kind of stuff. So those are going to have better outcomes and I think the client education part of it has already been done, at least to the degree that they know that they should reach out." • Vet B: "Really the biggest thing is compliance and follow up. I'd probably say that is my biggest struggle with these guys. They'll usually have me come out and put out whatever fire they're dealing with, and then they'll kind of forget about it and I'll never hear from them again." • Vet C: "I have clients that call up and say 'Hey, I want to establish a vet client patient relationship with you." And then they say, "Okay, well here's a, here's a laundry list of medications that my Facebook friends say I need."
B. Lack of animal health records create barrier for whole-herd health profiling	• Vet B: "Another struggle I have is getting people to keep track of their animals. I go to farms and ask to see their records, and they just say everything is in their brain. That isn't helpful for me to get a herd health profile." • Vet D: "I would say there's an extraordinary low percentage of people who keep records and identifiers on animals. It's really hard to see which populations are affected because we don't know how old they are. We

	don't know how many babies they've had. We don't know if they've had any health problems in the past. We don't know if they've suddenly lost weight or not. We have no idea what their previous body condition score is. It's hard to have a big picture look at a herd from a management perspective without individual identifiers and records of things like that"

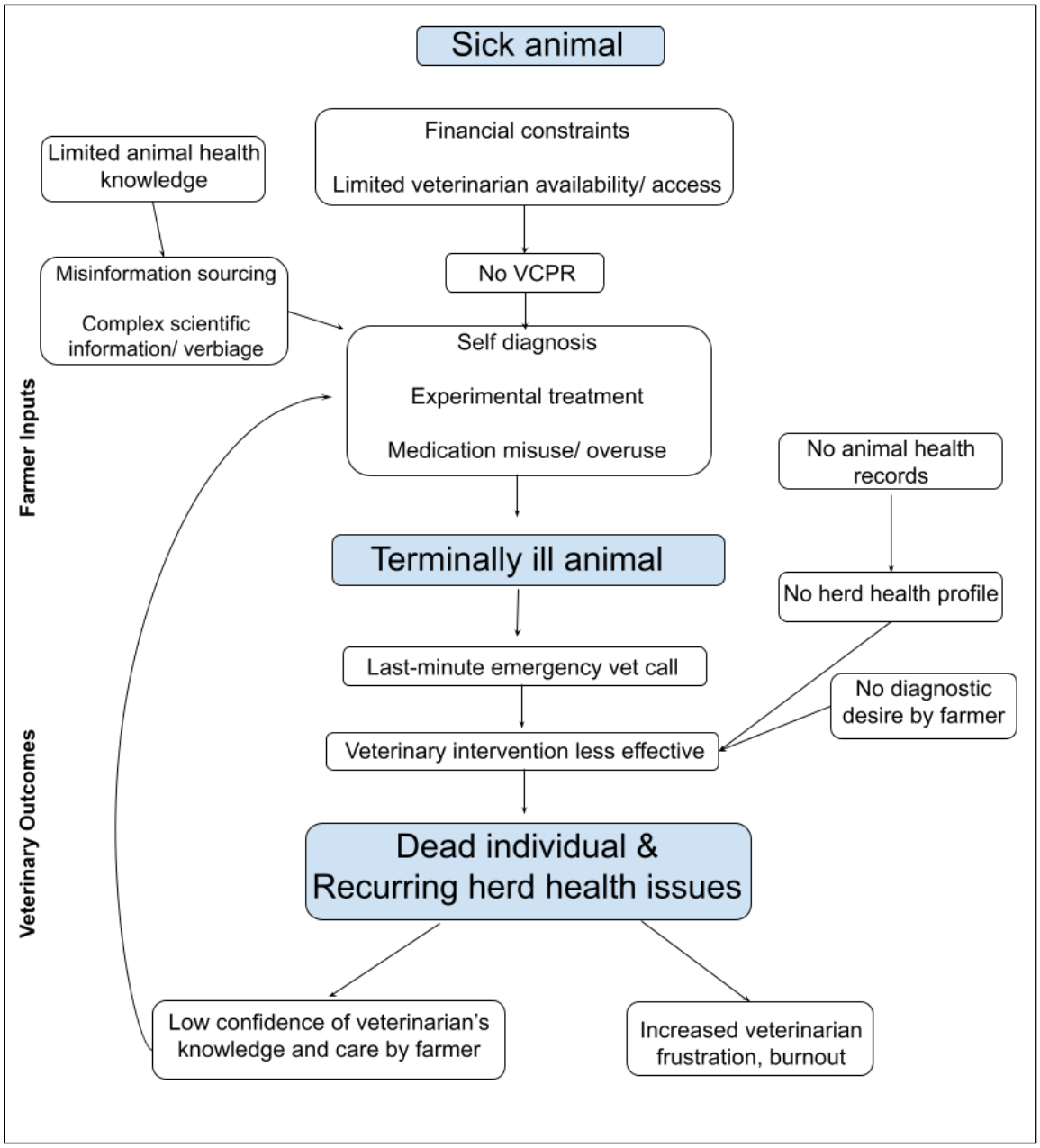

Figure 3. Positive feedback loop of animal health management firestorms (content informed by veterinary stakeholders). Farmer inputs impact veterinary outcomes, leading to a cycle of poor animal health decision-making on the part of the farmer.

Farmer feedback

In the interviews, farmer stakeholders freely brought up management challenges and needs regarding animal health best practices, listed in Figure 4.

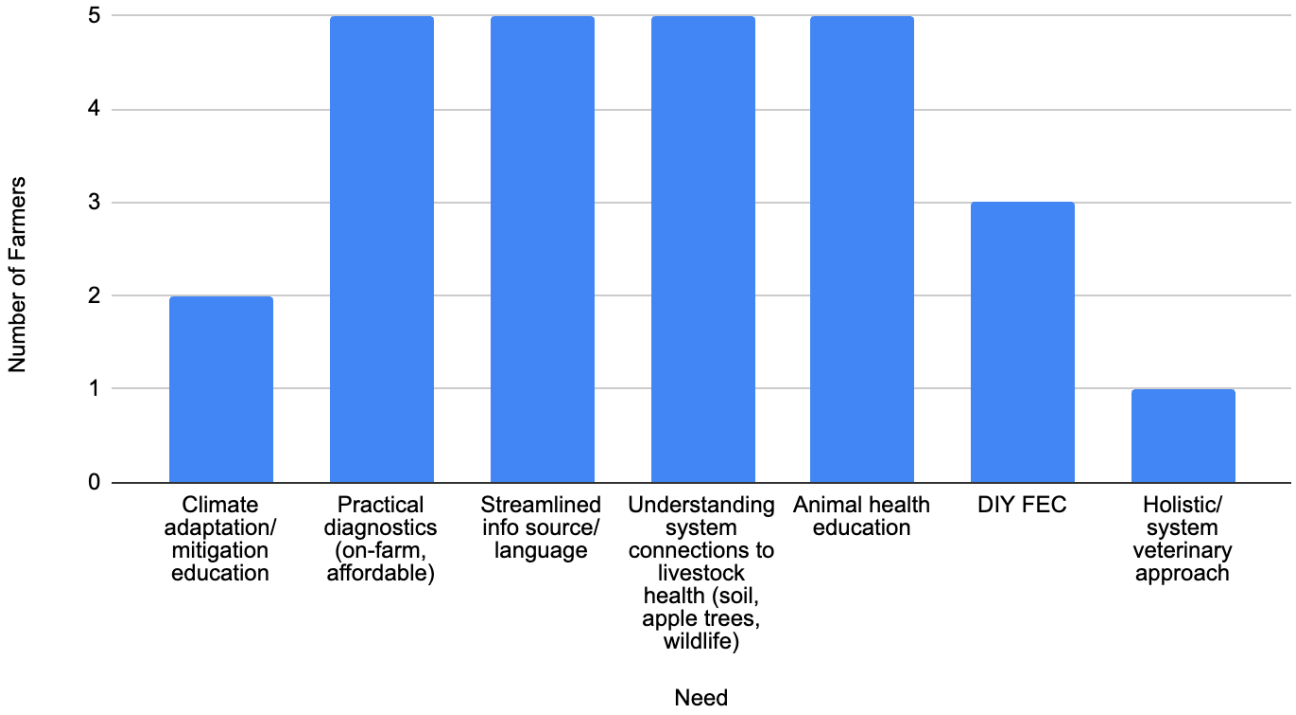

Figure 4. Farmer responses regarding needs for animal health practice improvement. Six farmers interviewed; topics derived from coded conversations about animal health management practice improvement.

Discussion

This research focused on the knowledge, perceptions, and methods of farmers and clinical veterinarians regarding small ruminant health management practices. These findings highlight the complex and diverse dynamics of management decision-making by farmers, and of the relationships between veterinarians and livestock producers.

Factors such as lived experience, perceived risk of illness, and alternative information sourcing by farmers can influence these dynamics of decision making. This study shows that site-specific data collection and result sharing can improve farmer and veterinarian knowledge, attitude, and management practices concerning parasites. Farmers greatly valued having farm-specific results and recommendations, even if their meningeal worm

risk was low, and many adopted prevention methods recommended during the study. All farmers stated that they learned more about the meningeal worm's lifecycle and about factors that elevate risk of meningeal worm infection of animals. Veterinarians also expressed appreciation of this research regarding meningeal worm risk and prevention strategies to share with their clients.

Veterinarians and farmers perceive higher risks to animals or to themselves when they have had personal experience with a specific health concern. Zoonotic pathogen concern differed among veterinarians, with high risk rankings associated with higher exposure rates due to the nature of their work; lower risk ratings were credited to a healthy immune system and the availability of first-world medical systems. Farmers with no experience of, or no prior knowledge about zoonotic pathogens had little to no concerns about zoonoses. Perceived high risk of anthelmintic resistance was observed in participants who had experience with dewormer-resistant internal parasites in their own livestock or who were aware of how few dewormers remain effective against internal parasites of small ruminants.

All farmers in this study reported having trust in their veterinarian, although their veterinary relationships differed greatly dependent on their level of livestock experience. Farmers with more experience ($\geq$ 25 years) relied on their own knowledge of animal health best practices and would call a veterinary professional only in unusual or extreme cases, for regulatory testing (such as for travel across state borders), or for food safety testing. In contrast, farmers with fewer years of experience relied more heavily on veterinary visits and phone calls for animal health guidance.

The practices used by farmers in this study to provide animal health care are often informed by scientific sources in addition to social and peer networking. Farmers were informed primarily by internet searches, veterinarians and books, though many of the seasoned producers attributed their successes to trial-and-error experiences. Reasons producers gave for turning to alternative sources, verses solely to veterinarians, for information included the need to better investigate the broad span of topics their veterinarians briefly mentioned during on-farm visits. Additionally, bonding with other

farmers to create a “small farm culture/ community” was highly sought after by farmers. Seeking information via other farmers can help cement mentoring relationships, but farmer-sourced information that is outdated or harmful can lead to poor health outcomes for animals.

Veterinarians perceived two types of cultural practices by farmers in this study that contribute to the success or failure of small ruminant health management. The first entailed responsible and attentive care by producers who have built trust with their veterinarian, thus creating a climate for scientific learning and implementing best practices. The second involved uneducated or misinformed individuals, primarily new, hobby, or economically disadvantaged farmers. Veterinarians perceived farmers who primarily utilize internet searches and social media comments for information on livestock health management as looking for “cheap fixes” to problems that could have been prevented with the well-informed practices. In this study, all veterinarians reported that having no VCPR or having only limited time on farms restricted their ability to teach all the facets of animal health to new farmers.

The need for reliable information for small farmers as to augmentation of veterinarian-derived advice is evident in this research. Challenges to implementation of new animal health strategies were reported by farmers in this study to be largely due to the lack of educational experiences and resources available. Within this context, farmers requested more information about ecological system processes (e.g., watershed effects, wildlife visits, weed growth, etc.). Additionally, farmers sought affordable, on-farm diagnostic tools to inform treatment decisions and to enhance their skills, cut costs, and improve animal health. Farmers sought information about a holistic approach to animal health, and about climate-driven challenges in animal health management. Farmer-veterinarian-service provider collaborative information networks may be solutions to address these needs, perhaps in the form of round tables, digital platforms, listservs, and credential programs, as suggested by the stakeholders in this study. This integration of local/experiential and scientific understanding could comprise a regional animal health system capable of creating more resilient farming communities by generating new tools and ideas which support long-term sustainability.

Limitations

Given the localized geography and small sample size of our stakeholders (N=10), this study should not be used to generalize about veterinarian-farmer relationships, perspectives, and practices as a whole. Subject-specific sampling ensured a range of descriptions to be included, but it may have included some bias. As coded words and thoughts were independently selected by one observer, subjective bias may have occurred.

Conclusion

This research explores the complex way that animal health risks are defined, evaluated and acted upon in the context of communities. These patterns of behavior are constantly being modified by lived experiences that includes mentors, social media and veterinary professionals. This holistic perspective toward food animal farming is a necessary foundation for improving veterinarian-client-patient relationships and reducing management firestorms created by misinformation. More educational outreach by agricultural service providers (including academicians), scientifically-informed farmers and veterinarians is needed to improve small ruminant health best practice knowledge and practices, especially with new and hobby farmers.

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