



Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Sheep scab in Northern Ireland: Its distribution, costs and farmer knowledge about prevention and control

Paul E. Crawford^{a,*}, Kim Hamer^b, Fiona Lovatt^c, Philip A. Robinson^a

^a Department of Animal Health, Behaviour and Welfare, Harper Adams University, Newport, Shropshire TF10 8NB, United Kingdom

^b School of Veterinary Medicine, University of Glasgow, 464 Bearsden Road, Glasgow G61 1QH, United Kingdom

^c School of Veterinary Science, Sutton Bonnington Campus, University of Nottingham & Flock Health Ltd, Eggesburn Farm, Eggleston, Barnard Castle, Co Durham DL12 0BD, United Kingdom

ARTICLE INFO

Key words:

Sheep scab
Sheep
Northern Ireland
Questionnaire
Psoroptes ovis

ABSTRACT

Sheep scab (psoroptic mange), which is endemic in the United Kingdom (UK) flock, has a significant, negative impact on sheep welfare. Nothing has previously been published about the distribution of sheep scab in Northern Ireland (NI), nor about Northern Irish farmers' knowledge and behaviours relating to the disease, its treatment, prevention and control. Between March and June 2021 an online questionnaire on the disease was completed by sheep farmers in NI. Forty-four respondents out of a total of 122 valid returns (36%) indicated that they had at least one outbreak of sheep scab in their flock within the previous five years. These flocks were spread throughout NI and included flocks grazing on common land. Farmers reporting sheep scab in their flock considered movements of sheep between flocks to be the main cause of flock infestation. Respondents demonstrated knowledge gaps in relation to the parasite biology, disease transmission, prevention and treatment options, as well as a lack of awareness of some of the relevant industry guidelines. We highlight that some farmers rely on clinical signs alone to rule out the possibility that newly purchased sheep are infested with sheep scab before mixing them with their flock. This activity poses a high risk for the introduction of sheep scab into previously uninfested flocks. The inadequacy of some farmers' quarantine rules, or their inability to follow them, was also reported by farmers as being the cause of their flock infestation. Sheep scab outbreaks were shown to result in significant financial cost, with some farmers reporting their most recent outbreak had cost over £2500 (\$3329). The paper also highlights that in addition to the animal health and welfare impact and financial cost, sheep scab was reported to have a social cost: 94 respondents (79%) agreed that a sheep scab outbreak caused emotional stress to affected farmers. These findings have provided evidence of the widespread nature of sheep scab in the NI flock, and of the knowledge gaps and behaviours which need to be addressed to improve sheep scab control. This will require a combination of focused research, knowledge exchange between farmers, advisors, policy makers and regulators, and co-developed disease control plans at a flock and national level.

1. Introduction

Sheep scab (psoroptic mange), caused by the ectoparasitic mite *Psoroptes ovis*, is currently endemic in the British Isles (van den Broek and Huntley, 2003; Geddes et al., 2021). Sheep scab was eradicated from Great Britain (GB) by 1952, before reintroduction in the autumn of 1971 (Loxam, 1974). Compulsory dipping failed to eradicate the parasite again, and when statutory sheep scab control was abandoned in 1992, case numbers rose rapidly (Cross et al., 2010; Chivers et al., 2018), as anticipated by state officials (MAFF, 1998).

Regarding Northern Ireland (NI), there is no specific published information on the incidence or geographical distribution of sheep scab, despite it being a notifiable disease, however an industry-led group is actively considering how eradication of sheep scab might be achieved (Lodder, 2019). The limited information that is available for the other countries of the British Isles suggests that the disease is currently widespread, but with particular geographic foci (O'Brien, 1992; Bisdroff et al., 2006; Rose et al., 2009; Chivers et al., 2018). The difficulty in obtaining accurate prevalence figures has been recognised (Jones et al., 2022; Paton et al., 2022). Jones et al. (2022) demonstrated from state

* Corresponding author.

E-mail addresses: pcrawford@live.harper.ac.uk (P.E. Crawford), kim.hamer@glasgow.ac.uk (K. Hamer), fiona.lovatt@nottingham.ac.uk (F. Lovatt), probinson@harper-adams.ac.uk (P.A. Robinson).

<https://doi.org/10.1016/j.prevetmed.2022.105682>

Received 14 December 2021; Received in revised form 21 May 2022; Accepted 24 May 2022

Available online 30 May 2022

0167-5877/© 2022 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

figures for Scotland a prevalence of 0.63% for the period 2014–19. This contrasts markedly with estimates of the annual flock level prevalence of sheep scab, reported by Rose (2011), as being 7.1% in the Scottish flock, 20.5% in the Welsh flock and 14% in the Northern English flock. In another survey, focusing on the situation in Wales, Chivers et al. (2018) found 15.8% of farmers reporting at least one outbreak of clinical sheep scab during 2015.

Clinical signs associated with acute sheep scab may be readily identified. An intense hypersensitive reaction to antigenic material within the mite's faecal deposits (van den Broek and Huntley, 2003) causes severe pruritis, which can become all-consuming, resulting in a significant welfare cost to the sheep through self-trauma, wool loss, starvation and, in extreme cases, death (Downing, 1936; Scott et al., 2007; Busin et al., 2015). However, in the extensively grazed hill flock, sheep scab can remain unnoticed because of the low numbers of sheep showing these overt clinical signs (Spence, 1951; Carson, 2020). Whereas, once a lowland flock is infested, the higher stocking rates, housing, trough feeding and frequent gathering for handling facilitate rapid spread within the flock (French et al., 1999). The endemically-infested hill flocks can therefore serve as a reservoir of infection to the national flock (Spence, 1951), meaning coordinated use of reliable diagnostic tests is needed to identify these subclinical infestations (Hamer et al., 2019; Carson, 2020).

Previously, diagnostic testing relied on physical examination and skin scrapes, which cannot rule infestation out and may miss some positive cases (Lodder, 2019). A reliable ELISA blood test (98.2% sensitivity, 96.5% specificity) is now commercially available which can detect *P. ovis* infestation from as early as two weeks post-infestation (Burgess et al., 2012). This allows more rapid detection of sheep scab, enabling prevention of transmission before clinical signs are present (Berriatua et al., 1999).

Once testing has identified sheep scab-infested animals, or where infestation is suspected, treatment is obligatory, as self-cure at a flock level does not occur (van den Broek and Huntley, 2003). Also, given the welfare implications of clinical sheep scab, non-treatment is inappropriate. While individual sheep may appear to self-cure, most are asymptomatic latent carriers of the parasite, and both recurrence of overt signs and onward transmission can occur, particularly as fleece length increases and winter approaches (Spence, 1949; van den Broek and Huntley, 2003). Treatment (or slaughter) of infested animals is mandatory in all regions of the United Kingdom (UK) under their varying sheep scab control measures (Animal Health and Welfare Wales, 2018).

When correctly administered, and in the absence of resistance to the chosen product, the licenced treatment options of organophosphate or an injectable macrocyclic lactone endectocide (ML) will eliminate *P. ovis* from treated sheep (Animal Health and Welfare Wales, 2018; Lodder, 2019). Resistance to MLs has been detected in some mite populations in the UK (Doherty et al., 2018; Sturgess-Osborne et al., 2019). In NI, both the supply of sheep dip concentrate and disposal of spent sheep dip are subject to control through two separate licencing systems (VMD, 2018; DAERA, 2019). The only licenced organophosphate in the UK must currently be administered by immersing the sheep in a plunge dipping tank (Anon, 2021). Some field operators, however, continue to use this product in shower or jet systems.¹ Use of such formulations in these systems is currently illegal in NI without a specific veterinary prescription (SCOPS, 2021). Guidelines on correct treatment protocols, and wider sheep scab control, are provided by the Sustainable Control of Parasites of Sheep (SCOPS) working group in the UK (Stubbings et al.,

¹ Showering, showers and jetting refer to systems used by some sheep farmers whereby pressurised liquid is directed down on sheep restricted in a pen (showering) or from multiple angles including from below (jetting) in an attempt to soak the fleece in ectoparasiticides, fly repellent or cosmetic colourant.

2020).

Despite these SCOPS guidelines, new outbreaks still occur across GB and NI (Geddes et al., 2021). This suggests that either: farmers are not familiar with the guidelines for prevention, diagnosis and treatment of sheep scab; they fail to recognise the presence of disease in their livestock; or they fail to accurately implement the guidelines. This failure may be due to a lack of capacity or unwillingness (Ritter et al., 2017), as there must be the capability, opportunity and motivation to bring about behavioural change (Michie et al., 2011).

Motivation should be high within the industry, as in addition to the animal welfare implications, the financial cost associated with sheep scab has been estimated at up to £ 202 million per year to the GB sheep industry or £ 1000-£ 2100 for a flock of 300 ewes (Nixon et al., 2020). The average gross margin for a 300-ewe flock, in the top 25% and bottom performing hill flocks in NI in 2019, were approximately £ 16000 and a loss of over £ 2000 respectively (DAERA, 2021). As such, an outbreak will be a significant financial burden on even the best-performing flocks.

Due to the importance of this disease within GB, several pilot sheep scab control programmes have been developed based on prior research, which had considered the prevalence and risk factors for scab in these areas (Animal Health and Welfare Wales, 2018). A sheep scab control pilot in Wales has recently reported initial results (Paton et al., 2022). Three pilot projects are underway in England. In Scotland, where sheep scab remains notifiable, free testing of skin and wool samples for the presence of the *P. ovis* mite continues to be offered, and a pilot control programme for one region was recently announced (SCOPS, 2022). Comparable data for NI is currently missing from the literature.

Aiming to address the lack of published research on sheep scab and its control in NI, this paper presents the findings of a farmer questionnaire which was designed to gather information about the geographic distribution of sheep scab in NI as well as farmers' understanding and awareness of the disease, its risks to their flock, and their willingness and capacity to tackle it.

2. Materials and methods

2.1. Questionnaire development

Ethics approval was sought from and granted by the Research Ethics Committee of Harper Adams University (approval number: 0010-202101-PGMPHD). An online questionnaire was developed (Jisc Online Surveys, Bristol, UK) and subjected to pilot testing. Pilot testing was undertaken initially by colleagues outside the target population. After consideration and implementation of the typographical and structural feedback, a second pilot was undertaken by farmers within the target population. No substantial changes to the questions resulted from the second pilot, and the responses were retained and included in the analysis. A copy of the questionnaire is available as [supplementary material one](#).

The questionnaire was completed anonymously. Farmers were asked to answer questions about the location and structure of their flock; the history and experience of sheep scab therein, and its treatment; as well as some more general questions about their flock's veterinary care. No incentives were offered for completion of the questionnaire.

2.2. Questionnaire distribution

The questionnaire was targeted at sheep farmers in NI and made available online from March to June 2021. It was promoted widely through the first author's connections in the agricultural and veterinary community, author-generated printed press and radio coverage, farming and veterinary associations, industry stakeholders and agricultural sales merchants. These groups used social media and direct member contact to raise awareness. This promotion encouraged sheep farmers to complete the questionnaire regardless of their previous experience of sheep

scab, and regardless of the numbers of sheep they owned. The promotional material included telephone contact information for the first author, to enable those unable to access the internet to have their questionnaire responses entered by the researcher.

2.3. Consent and validation

Informed consent was obtained by providing information about the questionnaire and use of an initial screening question. To ensure respondents were farming in NI, a partial postcode was a required question on the first page, and these were manually checked before data analysis. Partial postcodes, rather than full postcodes, were requested to increase respondent confidence in the anonymity of the questionnaire.

2.4. Analysis

Responses from the questionnaire were downloaded and entered into a series of spreadsheets (Microsoft® Excel® 2016 MSO 32-bit). Free text responses were separated from the quantitative data into separate spreadsheets. This qualitative data was reviewed and coded by the first author to identify common themes in the responses for each question. Additional statistical analysis was conducted using Genstat for Windows version 20 (VSN International Ltd., 2021). A Kruskal-Wallis analysis of variance was used to determine the significance of the effect of having had a sheep scab outbreak on respondents' opinions about the effects of sheep scab. The Circles tool on the mapping website Doogal (<https://www.doogal.co.uk/Circles.php> 2021) was used to demonstrate the geographical distribution of reported sheep scab outbreaks.

2.5. Government data on sheep scab incidence

Owing to the lack of published official data on sheep scab, a Freedom of Information (FOI) request was made to the Department of Agriculture, Environment and Rural Affairs (DAERA) to determine how many reports of suspected sheep scab they had investigated in the years 2016–2020, and how often the presence of *P. ovis* was confirmed in NI in this period.

3. Results

3.1. Demographic data

A total of 126 completed questionnaires were retrieved from the system. Four were excluded as they did not contain a valid NI postcode, leaving 122 valid responses. Only the responses to questions relating to sheep scab and related disease control measures are reported here. The

Table 1

Frequency distribution of Northern Irish sheep farmers that responded to a questionnaire on sheep scab (n=122) by age category and gender as reported by the respondents and their role in flock management (n=120).

45. What age bracket do you fall into?	44. Are you?	46. Which best described how you undertake the day-to-day management (excluding specialist services such as scanning) of your flock.
0-18	1 (1%) Female	I farm the sheep alone with occasional help. 36 (30%)
19-30	14 (11%) Male	I farm the sheep as (full or part-time) employed shepherd. 1 (1%)
30-50	48 (39%) Prefer not to say	I farm the sheep with regular family help and paid help. 14 (12%)
50-65	41 (34%) Other	I farm the sheep with regular family help. 66 (55%)
65+	15 (15%)	I farm the sheep with regular paid help. 3 (3%)

majority of respondents were male (85%), with 48% of all respondents being over 50 years of age (Table 1). The majority of flocks (85%) were being managed either solely by the respondent or with assistance from family members (Table 1). Forty four percent of the respondents reported having no formal agricultural education, and 12% reported no formal secondary (or higher) education (Table 2).

A wide range of farm and flock sizes were represented in the questionnaire responses, including a small number of farms that only keep store lambs (Table 3). Thirty-one individual breeds and 16 specified crossbreeds (e.g. Greyface; Texel x Rouge) were reported in addition to a range of non-specific crossbreds. Twenty-four farms (20%) reported no other farming enterprises, 56 farms (46%) one other enterprise and 41 farms (34%) had more than one other enterprise. Cattle-based enterprises were the most commonly reported (75%).

Only 24 respondents (22%) reported having a sheep dipper and the necessary licences to purchase and use OP dip (Table 4). Problems accessing a mobile dipper when they needed, and misconceptions around the licence requirements, were revealed. Respondents' comments covered a wide range of topics, including health and safety risks, lack of access to equipment and training, and endorsement of dipping as a solution to sheep scab (Table 4).

3.2. Sheep scab knowledge

Only five (4%) respondents correctly answered all of the sheep scab knowledge questions (questions 13–21) (Table 5). While 116 (95%) of respondents were aware that infestation could be spread via wool tags from infested sheep, 77 (64%) indicated that 21 days was a sufficient quarantine period to see if sheep scab was present on sheep, with ten (8%) respondents underestimating how long *P. ovis* mites survive off the sheep. With regard to the incorrect interpretation of SCOPS treatment guidelines, 31 (25%) indicated that they considered showering to be a recommended treatment for sheep scab, 14 (11%) that pour-ons were recommended, and 30 (25%) acknowledged they were unaware of the SCOPS guidelines.

3.3. Biosecurity and quarantine plans

Eighty percent of sheep were kept adjacent to other flocks and, while 15 (12%) respondents claimed to run a closed flock, further analysis indicated that 11 (73%) of these 15 purchased rams (Table 6). Regarding specific plans to prevent the entry of sheep scab into flocks, 89 (73%) of respondents had a plan in place (Table 7). Twenty-nine (24%) mentioned the use of quarantine; careful purchase policies were followed by 36 (30%); pharmacological interventions, involving the use of dips by 20 (16%) and injectable products by 24 (20%). Other themes

Table 2

Frequency distribution of Northern Irish sheep farmers that responded to a questionnaire on sheep scab (n=122) by highest level of educational attainment generally and specifically in an agricultural subject.

48. What is the highest level of educational qualification you have achieved, regardless of subject?	49. What is the highest level of agriculture-specific qualification do you hold?
Bachelor's degree	Bachelor's degree
22 (18%)	17 (14%)
GCSE or equivalent / NVQ level 2	GCSE or equivalent / NVQ level 2
26 (21%)	16 (13%)
Master's degree or higher	Master's degree or higher
11 (9%)	1 (1%)
Nothing formal	Nothing formal
14 (12%)	53 (44%)
HNC / HND / Foundation degree	HNC / HND / Foundation degree
16 (13%)	13 (11%)
Post graduate certificate or diploma	Post graduate certificate / diploma
5 (4%)	2 (2%)
A-level / NVQ level 3 / BTEC level 3	A-level / NVQ level 3 / BTEC level 3
27 (22%)	19 (16%)

Table 3

Frequency distribution of Northern Irish sheep farmers that responded to a questionnaire on sheep scab by farm size (n=120) and flock size (n=122) with comparative data from the Northern Ireland 2019 agricultural census taken in June of that year (DAERA, 2020). Farm size distribution data includes all farms included in census, not only sheep farms.

3. In total how many hectares do you graze with your sheep (including owned, conacre(rented) & common land)			6. How many breeding sheep do you have (including rams and ewe lambs retained for breeding but not yet put to the ram)?			
Hectares	Respondents	2019 census data - farm size	Breeding ewes	Respondents	2019 census data – flock size	
0-9.9	14 (12%)	4760 (19%)	1-25	12 (10%)	1-24	2177 (22%)
10-19.9	19 (16%)	5402 (22%)	26-50	12 (10%)	25-49	2142 (22%)
20-29.9	42 (35%)	4000 (16%)	51-100	31 (25%)	50-99	2369 (24%)
30-49.9	27 (23%)	4453 (18%)	101-200	31 (25%)	100-199	1830 (18%)
50-99.9	14 (12%)	4176 (17%)	201-500	22 (18%)	200-499	1016 (10%)
100+	3 (3%)	2036 (8%)	Over 500	10 (8%)	Over 500	160 (2%)
			Store lambs only	4 (3%)	No breeding ewes	227 (2%)

Table 4

Frequency of responses regarding access to sheep dippers and the necessary licences for the purchase, use and disposal of sheep dip and select comments about sheep dippers. The frequency that corresponds to the correct response is underlined.

9. Which of the following statements apply to you regarding access to and use of a sheep dipper: (Select all that apply)	9.a. Do you have any other comments about sheep dippers?
I use a mobile dipper	32 (29%) <i>'Dangerous!'</i>
I used to have a dipper but filled it in	27 (25%) <i>'Hard to get one when it's needed.'</i>
I have one and the necessary certificates to dip and dispose of spent dip	24 (22%) <i>'Haven't used our sheep dip in last 7 or 8 years but think of it like a last chance saloon if problem arises.'</i>
I struggle to find a mobile dipper when I need one	21 (19%) <i>'Health and safety concerns.'</i>
I have one but lack certificates	15 (14%) <i>'I believe sheep dip is dangerous.'</i>
I would like training	6 (6%) <i>'Labour issue so would consider a mobile sheep dipper.'</i> <i>'Mobile dippers aren't grant funded at present.'</i>
12. With regard to licences for sheep dipping, which of the following are true? (Select all that apply). A licence is needed to	<i>'Mobile plunge dippers are impossible to get - I have to resort to shower which is pretty useless, have my own plunge one but can't get trained to use it!!!!'</i>
Dispose of dip?	88 (83%) <i>'Plunge sheep dipper is the only thing that does the job right.'</i>
Purchase dip?	85 (80%) <i>'Sheep dippers or sheep showers? A big difference.'</i>
Use dip?	82 (77%) <i>'Think it's the only way to control scab and fly strike.'</i>
Own a (fixed) dipper on your farm?	22 (21%) <i>'Very labour intensive.'</i>

mentioned by a smaller number were secure boundaries, 'closed' flock, and non-specific pharmacological interventions. Showering was specifically mentioned by nine (7%) as part of their sheep scab prevention plan. However, nine respondents (7%) acknowledged and provided details of how they had failed to stick to their plan in the past year, particularly with regard to the movement or purchase of sheep.

3.4. Experience of sheep scab

A total of 44 (36%) farmers reported sheep scab in their flock (Table 8). Of these, four respondents (9%) reported that the outbreak involved sheep on common grazing. As shown in Fig. 1, outbreaks were reported throughout NI. The Freedom of Information response from DAERA revealed that 29 reports of suspected sheep scab had been investigated during the period 2016–2020 (Table 8). Nine of these investigations confirmed the presence of sheep scab. In addition, during the survey reported here, further outbreaks were reported by at least one farmer in each of the years 2010–2015. Seventeen (39% of those with

Table 5

Frequency of responses to questions addressing participants knowledge about select aspects of sheep scab mite biology and control. The frequency that corresponds to the correct response is underlined.

	True	False		
13. Sheep must physically contact each other to pass scab on. (n=121)	32 (26%)	89 (74%)	16. According to SCOPS guidelines the options for treatment of sheep scab are: (Select all that apply) (n=122)	
14. Scab is a notifiable disease in Northern Ireland. (n=121)	94 (78%)	27 (22%)	Plunge dip	92 (75%)
15. Wool from infected sheep on trailers, hedges, fences and yards can transmit scab to other sheep. (n=122)	116 (95%)	6 (5%)	An injectable endectocide (ivermectin, doramectin, moxidectin)	82 (67%)
18. Scab can be diagnosed using a blood test before the sheep are itching? (n=117)	68 (58%)	49 (42%)	Showering or jetting	31 (25%)
19. Showering is as effective as dipping for the scab control. (n=120)	33 (28%)	87 (73%)	I am not aware of SCOPS guidelines	30 (25%)
20. A 21-day quarantine period is sufficient to see if purchased sheep have signs of scab. (n=121)	77 (64%)	44 (36%)	Pour-ons	14 (11%)
21. Some scab mites have developed resistance to injectable treatments? (n=118)	95 (81%)	23 (19%)	17. Scab mites can survive off a sheep for at least ... (n=121)	
			7 days?	4 (3%)
			11 days?	6 (5%)
			16 days?	40 (33%)
			21 days?	39 (32%)
			28 days?	32 (26%)

outbreaks) farmers reported having suffered multiple outbreaks or a prolonged infestation, the longest of which spanned four years. Sixty-seven incidences of suspected sheep scab were reported in flocks not under the control of the respondent with the range of locations detailed in Table 9.

3.5. Diagnosis and treatment of sheep scab

The majority of farmers felt confident in diagnosing sheep scab based on previous experience and/or personal knowledge (Table 10). In the 19 (43%) cases where veterinary assistance was sought, the veterinarian was reported to have undertaken additional tests to confirm the diagnosis in only four cases (9% of outbreaks). Several respondents indicated

Table 6

Frequency distribution of responses to two questions relating to potential flock-to-flock contact.

8. Do your neighbours have flocks that run directly up to your boundary fences at any part of the year (including neighbours grazing store lambs or providing winter grazing for others)?	
Yes	98 (80%)
No	24 (20%)
10. Please select as many of these activities as are applicable to your business over the past 2 years: (Select all that apply)	
I buy breeding ewes/lambs	80 (66%)
I buy rams only	66 (54%)
I buy store lambs.	27 (22%)
I never buy in any sheep - I run a closed flock.	15 (12%)
I take sheep to shows.	13 (11%)
I buy pet lambs and / or foster ewes.	12 (10%)

they sought advice from more than one source. Nine farmers (20%) treated based on their suspicion and watched for a response to treatment to confirm their diagnosis.

Seventy five percent of respondents who had suffered an outbreak of sheep scab treated the whole flock. All respondents that did not treat the whole flock justified their actions based on lack of contact between affected and unaffected sheep or lack of clinical signs, particularly for groups of finishing lambs that were approaching slaughter weight.

An injectable product was the most commonly chosen treatment option, used nearly twice as frequently as plunge dipping (Table 11). Doramectin was the predominant injectable product used (14 of the 21 responses that specified a product). Veterinary advice and ease of use were cited as reasons for this choice. An unwillingness to dip in winter was also mentioned by some who chose an injectable product. Plunge dipping was favoured in some cases due to previous poor experiences with injectable treatments and showering, and a belief that dipping is the only effective treatment. Showering was mentioned by five (12%) farmers as the treatment option they chose.

In addition to injection or dipping, 23 respondents (52%) outlined other activities that they had undertaken as part of the management of a sheep scab outbreak, such as clipping the sheep or moving to clean pasture. One respondent highlighted they would appreciate further guidance:

'Would be very keen to get a full understanding of best management methods.'

Isolation and close monitoring following treatment of sheep scab were also mentioned by a farmer who initially treated with an injectable moxidectin product:

'Treated whole flock; isolated flock in one part of farm; monitored over a four to five-week period. Had to treat whole flock a second time as one ewe showed signs again.'

Five farmers (11% of outbreaks) reported that the treatment they delivered was not effective (or there was a rapid re-infestation of the flock) and all outlined reasons they considered to explain why the treatment had failed, and the steps they took to address the outbreak (Table 12). Two of these farmers sought additional advice from their veterinarian or agricultural merchant. A single respondent who used a shower system for initial treatment indicated that they were unsure why initial treatment had failed, and they subsequently used a combination of injectable products on advice from their agricultural merchant.

Eighty percent of farmers were able to work out how sheep scab entered their flock (Table 13); movement of sheep predominated in these reasons. In 36 (59%) of sheep scab outbreaks both the suspected route of sheep scab entry to a flock and a description of their plan to keep sheep scab out were provided by a respondent. When these were compared, 11 (25%) outbreaks were linked to a failure to follow the control plan outlined, and 15 (34%) were linked to biosecurity elements

Table 7

Frequency of having a plan in place to keep scab out of respondents' flocks and selected comments about the plan or reasons for not having a plan.

11. Do you have a plan to keep scab out of your flock? (This may be a specific scab plan or part of a more general plan to keep disease out)	11.b. What is your reason for not having a plan to keep scab out of your flock?
Yes 91 (75%)	Comments:
No 31 (25%)	<i>'Don't know about it.'</i>
Comments:	<i>'Have never needed one and when buying replacements, they have been dipped before sale.'</i>
<i>'Always buy sheep at a certain time of the year and isolate them until I get them showered.'</i>	<i>'I can't inoculate the breeding ewe lambs I buy for every eventuality.'</i>
<i>'Bought sheep are kept in isolation for a period of two months.'</i>	<i>'Impossible with an open flock, try to watch for signs especially in store lambs.'</i>
<i>'Isolate any sheep bought in from flock for 2 weeks before introducing them along with general farm health practices.'</i>	<i>'It's not possible with the amount of it about.'</i>
<i>'Never mix with home flock until there plunge dip.'</i>	<i>'Lack of information and direction/training.'</i>
<i>'Plan is based on quarantining all bought-in sheep for 28 days and visual inspection. This also applies to any sheep which break into other flocks.'</i>	<i>'Laziness.'</i>
	<i>'No scab in extended area and I buy from only one flock I know well to be clean.'</i>
	<i>'Uncommon disease in area.'</i>

Table 8

The frequency distribution of the number of DAERA flock investigations into suspected sheep scab and the number of cases which were confirmed and outbreaks reported in this survey by calendar year.

Year	DAERA Investigations	DAERA Sheep scab confirmed cases	Farmer-reported cases in this questionnaire
2016	6	3	6
2017	5	0	3
2018	4	1	10
2019	2	1	12
2020	12	4	16
2021	-	-	7

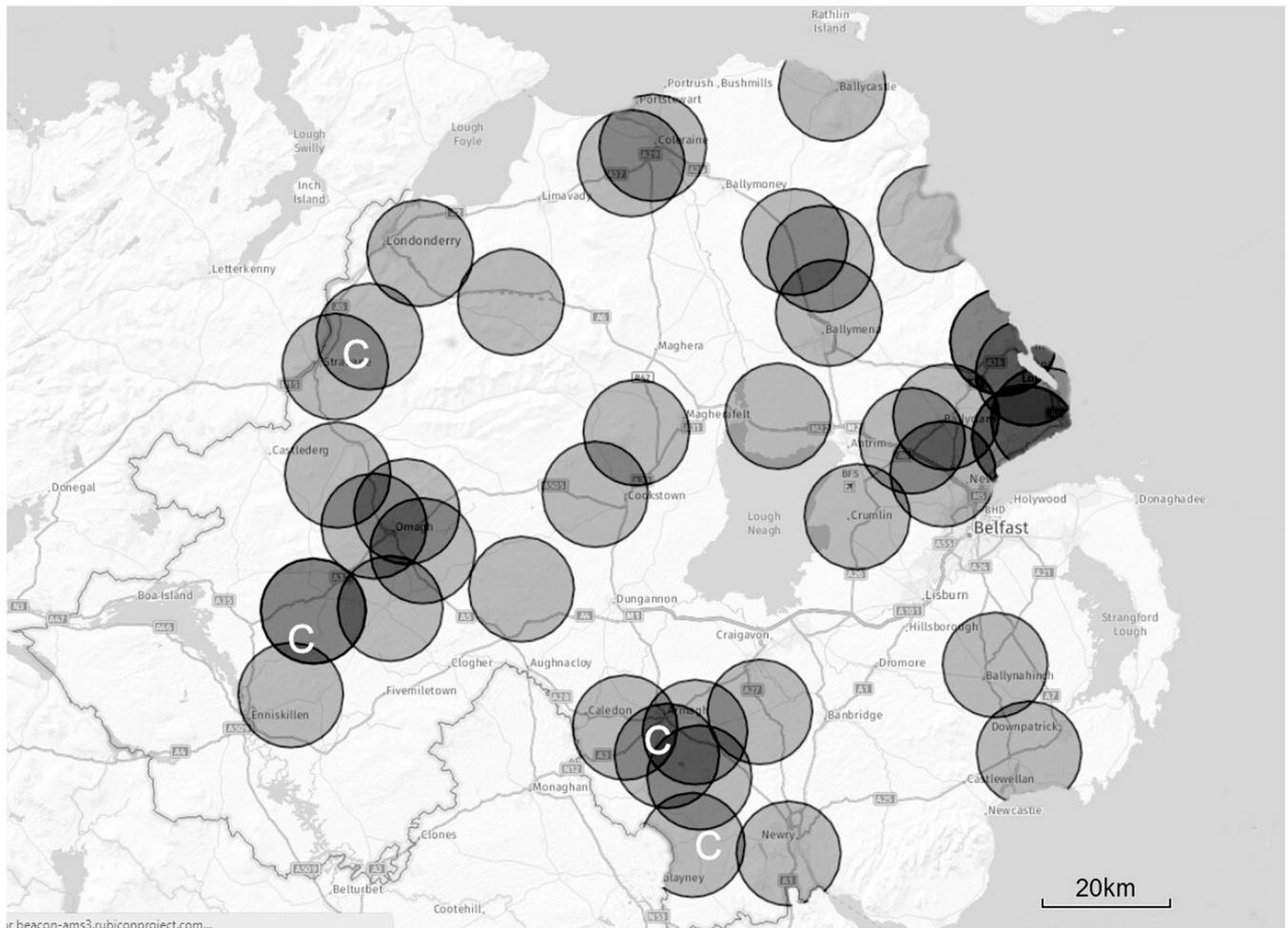


Fig. 1. The location of the 44 suspected cases of sheep scab in Northern Ireland suffered by respondents during the period 2016–2021, based on the partial postcode as reported by farmers completing an online questionnaire. Total number of responses was 122. The use of a circle of radius 5 miles (8 km) indicates the level of uncertainty in the exact location of the flock inherent in using partial postcodes. C: The approximate location of common land that an affected flock was grazing. (Figure generated by <https://www.doogal.co.uk/Circles.php> 2021).

Table 9

Frequency distribution of where respondents believe that they have seen sheep they suspected had sheep scab, and the frequency with which they informed either state officials or the flock owners of their suspicion.

22.a. Have you ever seen sheep you suspect, or knew, had scab...	
in an immediate neighbour's field?	9 (12%)
within a mile or so of your farm?	14 (18%)
further afield?	27 (35%)
in a market yard?	14 (18%)
in an abattoir?	2 (3%)
in a collection centre	1 (1%)
I've never seen sheep I suspected had scab	33 (42%)
22.a.i. Did you inform DAERA or the farmer affected when you suspected sheep scab in another flock?	
Yes	12 (27%)
No	33 (73%)

not covered in the plan.

3.6. Costs of sheep scab

The estimated cost of the most recent outbreak of sheep scab that the respondent's flock had suffered included loss of production and labour as well as treatment, which was over £ 2500 (US\$3355) in two cases (Table 14). Overall, 94 (78%) strongly agreed that there was a

Table 10

The frequency distribution of how the diagnosis was reached and the main source of advice on treatment of the most recent outbreak of sheep scab that the 44 reporting Northern Irish sheep farmers had suffered.

24. How was a diagnosis reached? (Select all that apply)		26. Who was the main source of advice on how to treat the sheep scab?	
Another farmer gave me advice	6 (14%)	I asked another farmer	3 (7%)
I asked in the farm shop / sales rep for advice	9 (20%)	I asked at the farm shop / sales rep.	2 (5%)
I asked the vet for advice	19 (43%)	I already knew the treatment options	13 (30%)
I was suspicious and watched for them to respond when I treated them	9 (20%)	I asked my vet	23 (52%)
I've seen it before and had knowledge to diagnose it myself	27 (61%)	Other - Online information	1 (2%)
My vet did tests to make sure	4 (9%)	Other - Dipping contractor	1 (2%)
Other - informed by slaughterhouse	1 (2%)	Did not respond	1 (2%)

Table 11

Frequency with which the 44 respondents who reported a sheep scab outbreak in their flock selected different treatment methods and a sample of the comments explaining their decision.

29. Considering your most recent outbreak did you treat the affected sheep using:		29.b. Why did you choose...	
Injectable endectocide	24 (56%)	dipping?	<i>'Because injectable had not been entirely successful.'</i> <i>'Believe that it is most effective treatment.'</i>
Plunge dipping	13 (30%)	showering?	<i>'Had used showering but it was not effective and injectables are too expensive and not reliable either.'</i> <i>'I don't have a dipper and I only have 40 - 50 sheep and I use a contractor to do it.'</i> <i>'Quick easy and effective.'</i>
Showering	5 (12%)	an injectable?	<i>'Advice from vet.'</i> <i>'Was winter and didn't want to dip.'</i> <i>'Single injection and easy to use.'</i>
Pour-on	1 (2%)		
No response	1 (2%)		

Table 12

Comments made by respondents explain why sheep scab treatment failed and the remedial treatment undertaken to eradicate the mite.

31.a.i. Did you discover why treatment failed? Please explain the reason(s).	31.a.ii. What treatment (include drug names and management activities as appropriate) was undertaken to eradicate the scab?
<i>'Clipping did not remove the mites'</i> <i>'It was on their underside and shower didn't get it'</i>	<i>'ClosamectinTM and Ivomec SuperTM.'</i> <i>'DectomaxTM.'</i>
<i>'It worked to a degree but at that point didn't realize the sheep needed a second injection to kill off remaining mite'</i>	<i>'I plunge dipped whole flock'</i>
<i>'No, I was unable to determine why treatment failed'</i> <i>'Yes, there is resistance to DectomaxTM.'</i>	<i>'Ivomec SuperTM and DectomaxTM.'</i> <i>'Two doses of DectomaxTM were given at the rate 1ml per 33kg under the skin 7 days apart'</i>

Table 13

Frequency distribution of how 44 Northern Irish farmers believed sheep scab entered their flock.

32. Were you able to work out how scab came into your flock?	
Yes, it came in with sheep I purchased.	17 (39%)
Yes, it came in over the fence from a neighbour.	8 (18%)
Yes, it came when my sheep strayed / other sheep broke into my land.	7 (16%)
Yes, it came from another farmer's sheep that share common grazing with mine.	2 (5%)
Yes, it came in via shared equipment or facilities.	1 (2%)
No.	9 (20%)

significant financial cost associated with a sheep scab outbreak.

Respondents indicated that there is an emotional, as well as an economic, cost to sheep scab outbreaks (Table 15). This was articulated by one respondent who said:

'It really destroys a flock and is very uncomfortable for the sheep. It is absolutely horrible and soul-destroying. I have had it twice from buying in store lambs and it is a mess. It is embarrassing when you have to tell your neighbours and very worrying that your sheep don't break into your neighbour's field.'

When considering the responses from farmers who reported that they had sheep scab in their flocks, they expressed a significantly higher level of agreement with the statement 'Do scab outbreaks cause emotional stress to the affected farmer?' (Kruskal Wallis H statistic=4.574, df=1, p < 0.05). All farmers who had experience of sheep scab in their flock ranked this question 3 (out of 6) or above - slight disagreement with the statement (Fig. 2). No statistically significant relationship was found in the responses to any of the other questions.

3.7. Disease notification

Only three respondents (7% of outbreaks) informed the state veterinary authorities (DAERA) of their sheep scab outbreak (Table 16), despite sheep scab being a notifiable disease in NI. A lack of awareness of the requirement to notify DAERA (10 respondents, 23%), was the most commonly expressed reason for this lack of reporting; other reasons centred on minimising the importance or impact of the outbreak, and negative perceptions around the involvement of state officials. Regarding contact with neighbouring farms, valid reasons for not contacting them included, 'they have no sheep', however other reasons related to poor between-neighbour relationships.

3.8. Management changes to prevent disease recurrence

Thirty farmers (68%) reported having made changes to their flock management after a sheep scab outbreak (Table 17). These changes were aimed at preventing the parasite from entering the flock and increased use of preventative whole group treatments. Of the farmers that did not report any changes to their flock management, some felt pre-existing measures were sufficient. Others reported they lacked knowledge of what further measures could be undertaken or expressed resignation concerning their inability to keep the parasite out of their flock (Table 7), some stated a desire for additional training (Table 4). Calls for greater state intervention where farmers allowed their flocks to remain persistently infested were also made (Table 16).

4. Discussion

This study provides a novel insight into both the geographic distribution of sheep scab in NI, as well as Northern Irish sheep farmers' knowledge of, and attitudes towards, the disease. Sheep scab outbreaks were reported by farmers from all six counties of NI and associated with four areas of common grazing, which were widely dispersed across NI. This is in agreement with work in other parts of the British Isles that suggested a widespread distribution of the parasite, which, when uncontrolled, will spread diffusely across a region over time (French et al., 1999; Nixon et al., 2021), particularly when common grazing is involved (O'Brien, 1992, 1999; Armstrong and Davies, 2007; Rose et al., 2009; Rose and Wall, 2012).

A wide range of farm sizes are represented in the current study, both in terms of hectares farmed and number of sheep on the farm. However, when the responses are compared with the DAERA 2019 farm census data (DAERA, 2020), small farms and flocks appear to be under-represented. That the respondents are mainly male and older than 50 years, was similar to that observed by Jack et al. (2017), and may reflect reports that the farming community is an ageing community (DAERA, 2018). While educated, the respondents were often not formally educated to a high level in agriculture. Specific agricultural education may bring particular benefit, however, there are positive associations between a farmer's overall level of education and better seeking and uptake of advice as well as propensity to invest in or make necessary changes to their business (Gasson, 1998).

It is not clear from our results why high numbers of respondents do not have any specific agricultural education; nor whether higher attainment in general education is actually positively impacting flock management in NI. Further, the effect of many farmers having to work

Table 14

The frequency distribution of the estimated cost for the most recent outbreak of sheep scab that 43 Northern Irish sheep farmers had suffered, grouped by flock size.

33. How much do you estimate your most recent scab outbreak cost you? Consider lost production, medical treatment, any losses and your labour costs.		£0-100	£101-250	£251-500	£501-1000	£1001-2500	£2501+
number of breeding ewes in respondent's flock	1-25	2	1	1	0	0	0
	26-50	2	4	1	0	0	0
	51-100	1	2	1	2	0	0
	101-200	1	2	3	3	1	1
	201-500	1	5	2	1	0	1
	over 500	0	0	1	2	2	0
Total respondents		7	14	9	8	3	2

Table 15

The frequency distribution of the number of respondents who strongly agreed or agreed at any level with statements addressing the emotional costs of sheep scab categorised by whether they reported a recent scab outbreak or not. * significant difference (Kruskall Wallis H statistic=4.574, df=1, p<0.05).

	Has the respondent reported a recent sheep scab outbreak in their flock?	Strongly agree	Agree at any level
42.3. Scab outbreaks cause emotional stress to the farmers affected	Yes*	31 (70%)	38 (86%)
	No*	43 (57%)	56 (74%)
42.4. Seeing scab in neighbouring flock cause emotional stress to the farmers affected	Yes	28 (64%)	35 (80%)
	No	33 (43%)	54 (71%)

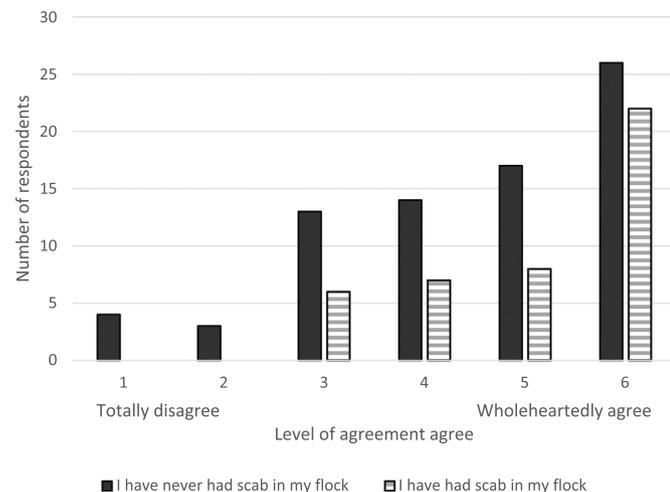


Fig. 2. The distribution of rankings, given by respondents, on a scale from 1, I totally disagree with, to 6, I wholeheartedly agree with the question ‘Do scab outbreaks cause emotional stress to the affected farmer?’ The responses have been segregated into two groups: respondents reporting a sheep scab outbreak in their flock (44 farmers) and those who had not (76 farmers). The response was significantly different between the two groups (Kruskall Wallis H statistic=4.574, df=1, p < 0.05).

off the farm to supplement income (DAERA, 2020) on their ability to access agricultural education, training or advice should be explored so further knowledge transfer can be targeted in an accessible manner.

4.1. The spread of sheep scab through flocks in NI

The largest single suspected cause of sheep scab outbreaks reported by participants in this questionnaire was sheep movements, planned or unplanned, followed secondly by direct infestation from a neighbouring flock. In the Republic of Ireland, a similar pattern has been observed,

Table 16

Frequency with which the 44 respondents who reported a sheep scab outbreak in their flock informed state officials and their neighbours about the outbreak and a sample of the comments explaining their decision not to inform them.

	Yes	No	Can you tell us why you did not tell them?
34. Did you contact DAERA and inform them you had a scab outbreak?	3 (7%)	41 (93%)	‘Department officials should be more active against the same few farmers that delay treatment of stock.’ ‘They [state officials] make a mountain out of a molehill, and they focus just on the farm in question and not all those in the area.’ ‘I didn’t want penalised in some way.’
35. Did you inform all your neighbours who own or graze sheep on land adjacent to where your affected sheep had recently grazed?	18 (41%)	26 (59%)	‘It would destroy your ability to sell.’ ‘No communication with neighbour for several years.’ ‘They had the same problem and gave it to us.’ ‘Shame.’

Table 17

Frequency of respondents implementing change in their flock’s management following a sheep scab outbreak and select comments outlining the change(s) they made or why they did not make any changes.

		Briefly describe the changes you have made or why have you not made any changes.
36. Have you changed how you manage your flock to try and prevent scab returning to your flock?		
Yes	30 (68%)	‘Won’t let the contract clipper use his trailer again.’ ‘Strict quarantine, and going to plunge dip in future - moving away from shower.’ ‘Any bought in sheep are isolated and treated as if they do have scab.’ ‘Repaired fence to prevent sheep coming in from neighbouring land.’ ‘All purchased sheep are isolated and showered before mixing with others.’ ‘I shower sheep twice a year.’ ‘Be more observant in purchasing and a blanket treatment of Ivermectin on arrival.’
No	14 (32%)	‘Still open flock, so can’t stop it.’ ‘Treat when needed.’ ‘It’s everywhere.’ ‘There is only a simple wire fence between my land and neighbouring flock.’ ‘Still unsure what it [effective control] is.’

with 73% of outbreaks attributed to infested sheep entering the flock (O’Brien, 1992). Very low levels (3%) of pre-entry treatment were reported on these Irish farms, however in this current study much higher levels of treatment were reported, albeit some of these treatments are not advised within industry guidance (Stubbings et al., 2020).

Ten farmers in this study stated they had observed sheep they suspected of having sheep scab in livestock markets. In addition to cases displaying clinical signs, there is the potential for latently infested sheep, with no visible signs, passing through markets. In their study of disease transmission in sheep, Volkova et al. (2010) determined that 80% of farm-to-farm movements of sheep in Scotland were via a market. Scottish and NI have stratified sheep industries which are structurally similar, resulting in significant seasonal movement of breeding and finishing sheep from farm to farm (NSA, 2021). The conditions in the livestock market include close sheep-to-sheep contact and multiple or all sheep passing through common handling areas. With off-sheep survivability of mites being approximately 17 days (Babcock and Black, 1933; Lodder, 2019), one batch of infested sheep could contaminate an environment through which thousands of sheep might pass before mite viability is lost. Although Loxam (1974) did not find evidence of spread within markets from one lot of sheep to another (cross-contamination), dissemination from one farm to another via a market was identified, a concern echoed by Nixon et al. (2021). In NI there are seasonal sales of sheep where an individual vendor may sell ten or more lots (Armitage, 2022). These may be purchased by a number of different farmers, thus potentially disseminating the disease widely, even if no transmission occurs in the market. Preventing infected sheep entering the marketplace should therefore be a priority. There is ongoing research to develop a pen-side test (Busin, 2015) which could in future potentially revolutionise checking the spread of sheep scab through markets, but in so doing will raise significant practical and ethical questions surrounding interpretation of results, particularly where sheep have recently been treated for sheep scab, and how to manage any uninfested sheep in adjacent penning.

4.2. Farmer knowledge of sheep scab and its diagnosis

The low number of respondents who correctly answered all the questions about sheep scab highlights the potential for knowledge exchange initiatives to improve the control of sheep scab. Of particular concern is the assumption of 77 respondents (64%) that a 21-day period of quarantine and observation for clinical signs is sufficient to detect infested sheep before releasing them to mix with the rest of the flock. Given the long incubation period and latent infestation that is a feature of sheep scab (Spence, 1949; van den Broek and Huntley, 2003), this creates the opportunity for undetected, infested sheep, to spread sheep scab within the main flock before clinical signs develop. This risky practice needs to be challenged. Similarly, the reliance on showering to prevent sheep scab needs to be challenged urgently. The importance of farmers having a robust, informed plan covering all realistic risks, and adhering to it, is highlighted by the respondents who had a sheep scab outbreak despite having a plan, or those who admitted how they failed to implement their plans, resulting in *P. ovis* infestation in their flock.

The levels of diagnostic testing for sheep scab reported here are minimal and the reasons for this are unclear, although high numbers of respondents claimed to recognise sheep scab based on previous experience. The use of response to treatment as a diagnostic tool reported here, could facilitate the spread of sheep scab where treatment has failed or delay a definitive diagnosis where *P. ovis* is not the cause of the observed signs. The lack of reported use of the ELISA as part of quarantine processes, to detect sheep scab before clinical signs appear, may be due to low levels of knowledge about the test and its efficacy. Its use as part of quarantine processes should be encouraged in place of routine, whole group pharmacological approaches. Farmers made positive comments seeking additional knowledge and training in the current study, as well as requests for further action from state authorities to improve sheep scab control. Taken together, and recognising the presence in NI of an industry led group focused on sheep scab (Lodder, 2019) this suggests a wider motivation for concerted control measures.

4.3. A co-ordinated response

In this study levels of farmer communication about a disease outbreak to state officials or neighbours was low (Table 9 and 16). This is similar to the findings of O'Brien (1999), who found levels of reporting of sheep scab outbreaks in Ireland to be under 50%, despite it being a legal requirement, alongside suspicions raised by Paton et al. (2022) and Jones et al. (2022) concerning under-reporting of sheep scab outbreaks. This reluctance may be driven, in part, by shame and the economic consequences of other farmers knowing that a farm has sheep scab, as well as concern over what restrictive actions may result from state involvement. The actual or perceived poor working relationship between farmers and state officials in NI reported here and elsewhere (Robinson, 2017), may also contribute to under-reporting.

In the 1940s, it was recognised that some hill farmers with chronic sheep scab in their flocks did not treat it as they did not realise the severity of the disease when their infested sheep were sold into lowland flocks (Spence, 1951). Through education they were encouraged to see their role in the collective effort to maintain a healthy national flock, and they undertook treatment programmes for the greater good of the national flock. This collaborative spirit needs to be revived, as it is essential to eradicate sheep scab and prevent its recurrence (Spence, 1951; Rose and Wall, 2012; Carson, 2020). Local strategies, that all the stakeholders will agree to, are required to achieve the behavioural changes needed to rapidly identify sheep scab and slow (and ultimately aim to stop) each outbreak (Spence, 1951; Animal Health and Welfare Wales, 2018). Local strategies then need to scale up to be part of a national, co-ordinated strategy for sheep scab control and eradication. However, given the reluctance some farmers expressed in this study to communicate with their neighbours, further work to develop communications solutions and a collaborative approach will be needed. Combining improved communication with a risk-based use of both contiguous flock serology testing and movement tracings, may present optimal opportunity to arrest the spread of disease both at source and in areas of recent spread.

4.4. Treatment strategies

Treatment strategies for sheep scab control are documented and effective (Stubbings et al., 2020), although the advent of resistance to MLs will impact on the future efficacy of these (Doherty et al., 2018). While 57% of respondents asked for advice on treatment from their veterinarian or agricultural merchant, many relied on retained knowledge or unqualified sources. Some of the treatments reported do not align with current recommendations, such as the use of shower systems, pour-on products and injectable products or combinations not currently licenced for use in sheep in NI. Of additional concern is that one quarter of respondents believed that showering was recommended by SCOPS. Other comments regarding injectables not resolving a sheep scab outbreak could suggest either a failure of treatment technique or emergence of resistant mite populations. Lack of awareness of the SCOPS guidelines was also prevalent in the questionnaire responses.

Taken together, these results suggest that there are areas of misunderstanding among the farming community, potentially including medicine prescribers, as to the most effective control measures for sheep scab, although future research is required to elucidate this. There is further outreach work to be undertaken within the industry, as diagnostic and treatment guidelines will only be efficacious if they are communicated clearly and followed precisely. This is a multi-agency task with farmers, advisors, the pharmaceutical industry and prescribers all shouldering a legal and ethical responsibility to ensure that the most appropriate treatments are correctly prescribed and delivered. In particular, the specific requirements in relation to route of administration, number of doses, the interval between dose administration and the duration of any persistent activity, as well as the illegal use of OP products in shower systems, must all be addressed. Where there is a

suspected case of treatment failure, this needs to be reported and robustly investigated (SCOPS, 2018).

4.5. Limitations to control strategies identified

Practical limitations reported here regarding farmers' ability to enhance their control of sheep scab include ready access to dippers and licences to dip, and boundary issues. Farmer access to dippers is critical if dipping is to be promoted as the first-choice option for sheep scab control (Animal Health and Welfare Wales, 2018). The need for a Certificate of Competency was introduced in 1994 as a requirement to purchase sheep dip (VMD, 2018), and some are unable to use their on-farm dippers because of the lack of training opportunities to achieve the necessary certificate of competency.

The use of mobile dipping trailers could be considered as a viable alternative to fixed dippers, provided appropriate biosecurity measures are adhered to when moving from farm to farm. Qualified contractors should ensure accurate bath preparation, dip replenishment and dipping technique. They would also provide additional labour, so often lacking on farms, for undertaking the dipping (Animal Health and Welfare Wales, 2018; Lodder, 2019). However, farmers report experiencing difficulty in getting mobile dippers, and the seasonal nature of the work, combined with the limited number of mobile dippers operating, could be contributing to this. To further expand capability, state-supported investment in both training and equipment may be needed.

4.6. The role of trusted advisors

The influence of peers or peer pressure on farmer behaviour has previously been demonstrated (Farrell et al., 2021) and is revealed in this study, as farmers reported seeking advice on diagnosis and treatment from peers rather than professionals. Specific testimonial from peer farmers about a disease and its treatment through educational activities has been shown to assist in uptake of recommended guidelines (Spence, 1951; Adam et al., 2021), and this should be encouraged in relation to sheep scab control programmes.

Of equal or greater importance to peer influence is the opinion and advice of trusted advisors, particularly the farm's veterinarian (Lowe, 2009). To be effective, veterinarians have to have accurate and up-to-date advice to offer, and farmers have to ask them for that advice. Highlighted in the findings of this questionnaire is the inadequacy of the quarantine plans, and reliance on inappropriate or off-label medicine treatments. These findings suggest a failure of veterinary input into flock health planning and disease treatment, or a failure for such advice to be implemented. The full reasons for this will require further research to elaborate. However, veterinarians need to improve their ability to demonstrate to sheep farmers that they can add value and profit to the farm business (Lovatt, 2015), and sheep farmers need to invest in routine advisory visits from their veterinarians (Kaler and Green, 2013).

4.7. The cost of sheep scab

Increasing awareness of the economic, personal and environmental costs of a sheep scab outbreak may help with engaging farmers and other industry stakeholders to more effectively control the disease. In their estimations of the economic cost of sheep scab infestation, Nixon et al. (2020) presented figures, based on spreadsheet analysis, suggesting that a flock cost (per 300 ewes) could be between £1000 and £2400 depending on treatment used, time of year and upland or lowland flock. The actual cost of a 'flock' outbreak can vary, as reported in this study, depending on the need to treat either a small group of animals in isolation or the entire flock, potentially repeatedly. The range of farmer-estimated costs for sheep scab outbreaks reported here (Table 14) reflect the theoretical figures of Nixon et al. (2020), supporting their overall, national flock estimations, and are significant in relation to the current low (or negative) profit margins generated by NI

flocks.

The environmental impacts of sheep scab, not covered in our survey, have yet to be fully calculated, both from the perspective of loss of production efficiency (Scott et al., 2007) and the environmental impact of the treatments (Anon, 2021).

However, in this study the emotional cost to farmers and the wider personal impact of having sheep scab in their flock is reported. This is underlined by 79% of all respondents agreeing that there is an emotional cost of having sheep scab in their flock. It further appears that there is a long-term effect of having a sheep scab outbreak on a farmer's emotional response. Those farmers who reported an outbreak in their flock were more likely than non-affected farmers to agree that there is emotional cost of having sheep scab outbreaks. The individual testimonies from farmers about the impact of the disease, and their resignation at being unable to maintain sheep scab-free flocks, also exemplify the social cost of this disease.

Findings in this study parallel work in other fields, such as bovine tuberculosis (bTB), where some farmers reported chronic stress at being unable to control aspects of disease incursion, even being fatalistic as to the inevitability of the next outbreak (Robinson, 2017), while others were concerned about a stigma associated with disease impacting their ability to sell livestock.

Only relatively recently has the focus on the farmers' mental health and wellbeing turned from the occasional, but devastating, outbreaks of exotic disease, to that caused on an ongoing basis by endemic disease (Mort et al., 2008; Crimes and Enticott, 2019). Improved mental health of farmers has been associated with success in BVD eradication programmes (Moennig and Yarnall, 2021).

In the light of the recent developments of both an accurate blood test and emerging resistance in some mite populations to the effects of the injectable MLs, decision making by individual farmers and at a national level has to move beyond the purely economic considerations (Nixon et al., 2017). A wider understanding of the true costs of sheep scab - sheep welfare, economic, environmental and emotional impacts - need to be developed, which should then prompt re-evaluation of the risk-cost-benefit decisions at all levels.

4.8. Study limitations

Insufficient detail was obtained from the respondents to determine if misdiagnosis of sheep scab resulted in inappropriate or delayed treatment, nor if they fully understood the range of clinical presentations that can be seen with sheep scab or what specific measures, they felt, could be introduced to improve sheep scab control.

From a potential population of approximately 10000 flocks (DAERA, 2020) the response rate was low, and not statistically representative of the whole population. Sheep scab is recognised as a taboo or sensitive subject (Cross et al., 2010; Priestly, 2018; Veterinary Practice, 2020) and as with BVD, (Heffernan et al., 2016) there is difficulty getting farmers to talk about their disease status, which may be incorrectly assumed or unknown to them. Cross et al. (2010) highlighted the problematic nature of obtaining accurate estimates regarding sheep scab prevalence, even when using questionnaires. The reliance on internet-based dissemination of the questionnaire, enforced by the Covid-19-related restrictions in place at the time of the study, may also have excluded potential respondents. However, the high completion rate of questionnaires submitted provides a great depth to the data. A self-selection bias may have been introduced, in particular with those who have suffered from sheep scab outbreaks, as has been documented previously in sheep scab investigations (Rose et al., 2009). As responses which were technically wrong or in conflict with best practice guidance were presented, it is unlikely that social desirability has critically affected the findings. Regardless of not defining what we meant by 'emotional stress', as each respondent was being asked about their opinion, their personal values regarding the stressfulness of sheep scab were being sought, and as such are valid without an external reference point. The beliefs and practices

described in this study are therefore likely to be indicative of the wider NI sheep farmer population.

5. Conclusion

The results from this questionnaire highlight the presence of sheep scab throughout NI – the disease is widely dispersed and endemic. They also demonstrate knowledge gaps, inadequate resources, poor treatment decisions, under-reporting and low levels of testing which are impacting sheep scab control in NI. However, there is a willingness among respondents to see further action taken against the disease and to learn how to prevent sheep scab in their flocks.

Sheep scab is controllable, and ultimately, as shown by history, eradication is possible, even in a densely populated sheep-producing region (Spence, 1951). The existing motivation should be harnessed and built upon to improve the collective capability of NI sheep farmers to seize the opportunity that exists, while effective treatments are still available to eradicate this disease for the betterment of animal and farmer welfare, the environment and the economy.

Funding

This work was undertaken as part of the first author's PhD programme, which is funded by a Department of Agriculture, Environment and Rural Affairs (DAERA), Northern Ireland scholarship. This funding is also gratefully acknowledged.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: co-author voluntary (non remunerated) chairman of Northern Ireland Sheep Scab group. PC.

Acknowledgements

The authors gratefully acknowledge the participation of the farmers in the questionnaire. The authors also thank their colleagues who proofread the questionnaire and drafts of the final manuscript, and in particular Janet Roden for her help with the statistical analysis.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2022.105682.

References

- Adam, K.E., Bruce, A., Corbishley, A., 2021. Veterinary interventions to improve neonatal survival on British beef and sheep farms: a qualitative study. *Front. Vet. Sci.* 8, 619889.
- Anon, 2021. Datasheet search results. 2021. National Office for Animal Health. Available at: (<http://www.noahcompendium.co.uk/datasheets>) (Accessed 31/01/2021).
- Animal Health and Welfare Wales, 2018. Working towards the eradication of Psoroptes ovis in Wales. Available at: (<https://www.rvc.ac.uk/Media/Default/BVD/documents/sheep-scab-report-2018.pdf>) (Accessed: 28/03/2022).
- Armitage, D., 31/8/21. Ewe lambs selling to a top price of £248 at the Torr sale. 2022, Farming Life. Available at: (<https://www.farminglife.com/country-and-farming/e-we-lambs-selling-to-a-top-price-of-ps248-at-the-torr-sale-armoy-3365505>) (Accessed 09/03.2022).
- Armstrong, D., Davies, L., 2007. Sheep ectoparasites in Wales. *Vet. Rec.* 160, 775–776. <https://doi.org/10.1136/vr.160.22.775-a>.
- Babcock, O.C., Black, W.L., 1933. The common sheep-scab mite and its control. College station, Agricultural and Mechanical College of Texas, Texas. Available at: (<http://hdl.handle.net/2027/txa.tarb004254>) (Accessed: 28/03/2022).
- Berriatua, E., French, N.P., Wall, R., Smith, K.E., Morgan, K.L., 1999. Within-flock transmission of sheep scab in naive sheep housed with single infested sheep. *Vet. Parasitol.* 83, 277–289.
- Bisdorff, B., Wall, R., Milnes, A., 2006. Prevalence and regional distribution of scab, lice and blowfly strike in Great Britain. *Vet. Rec.* 158, 749–752.
- Burgess, S.T.G., Innocent, G., Nunn, F., Frew, D., Kenyon, F., Nisbet, A.J., Huntley, J.F., 2012. The use of a Psoroptes ovis serodiagnostic test for the analysis of a natural outbreak of sheep scab. *Parasite Vector* 5, 7.
- Busin, V., Burgess, S., Sargison, N., 2015. Sheep scab, future perspective for disease diagnosis and control. *Livestock* 20, 156–159.
- Carson, A., 2020. Herdwick sheep breeders' association sheep scab project for sheep grazing common land. The Moredun Foundation. Newsheet Col 7. No.6 May 2020. Available at: (<https://moredun.org.uk/wp-content/uploads/2021/09/Mfns-7-6-p-rotected.pdf>) (Accessed 16/10/2021).
- Chivers, C., Vineer, H.R., Wall, R., 2018. The prevalence and distribution of sheep scab in Wales: a farmer questionnaire survey. *Med. Vet. Entomol.* 32, 244–250.
- Crimes, D., Enticott, G., 2019. Assessing the social and psychological impacts of endemic animal disease amongst farmers. *Front. Vet. Sci.* 6, 342.
- Cross, P., Edwards-Jones, G., Omed, H., Williams, A.P., 2010. Use of a randomized response technique to obtain sensitive information on animal disease prevalence. *Prev. Vet. Med.* 96, 252–262.
- DAERA (2018) Equality indicators for Northern Ireland Farmers. Department of Agriculture, Environment and Rural Affairs. Available at: (<https://www.daera-ni.gov.uk/publications/equality-indicators-report>) (Accessed: 10/11/2020).
- DAERA (2019) Groundwater authorisations. Available at: (<https://www.daera-ni.gov.uk/articles/groundwater-authorisations#toc-2>) (Accessed: 17/11/2020).
- DAERA, 2020. Agricultural census in Northern Ireland 2019. Department of Agriculture, Environment and Rural Affairs. Available at: (<https://www.daera-ni.gov.uk/publications/agricultural-census-northern-ireland-2019>) (Accessed: 03/11/2020).
- DAERA, 2021. Farm incomes in Northern Ireland 2019–2020. Department of Agriculture, Environment and Rural Affairs. Page 29. Available at: (<https://www.daera-ni.gov.uk/publications/farm-incomes-northern-ireland-2004-onwards>) (Accessed 03/11/2021).
- Doherty, E., Burgess, S., Mitchell, S., Wall, R., 2018. First evidence of resistance to macrocyclic lactones in Psoroptes ovis sheep scab mites in the UK. *Vet. Rec.* 182, 106. <https://doi.org/10.1136/vr.104657>.
- Downing, W., 1936. The life-history of Psoroptes communis var. ovis with particular reference to latent or suppressed scab. *J. Comp. Pathol. Ther.* 49, 183–209.
- Farrell, S., McKernan, C., Benson, T., Elliott, C., Dean, M., 2021. Understanding farmers' and veterinarians' behavior in relation to antimicrobial use and resistance in dairy cattle: a systematic review. *J. Dairy Sci.* 104 (4), 4584–4603. <https://doi.org/10.3168/jds.2020-19614>.
- French, N.P., Berriatua, E., Wall, R., Smith, K., Morgan, K.L., 1999. Sheep scab outbreaks in Great Britain between 1973 and 1992: spatial and temporal patterns. *Vet. Parasitol.* 83, 187–200.
- Gasson, R., 1998. Educational qualifications of UK farmers: a review. *J. Rural Stud.* 14 (4), 487–498. [https://doi.org/10.1016/S0743-0167\(98\)00028-X](https://doi.org/10.1016/S0743-0167(98)00028-X).
- Geddes, E., Mohr, S., Mitchell, E.S., Robertson, S., Brzozowska, A.M., Burgess, S.T.G., Busin, V., 2021. Exploiting scanning surveillance data to inform future strategies for the control of endemic diseases: the example of sheep scab. *Jul 16 Front. Vet. Sci.* 8, 647711. <https://doi.org/10.3389/fvets.2021.647711>.
- Hamer, K., Burgess, S., Busin, V., Sargison, N.D., 2019. Performance of the Psoroptes ovis antibody enzyme-linked immunosorbent assay in the face of low-level mite infestation. *Vet. Rec.* 185, 107. <https://doi.org/10.1136/vr.105304>.
- Heffernan, C., Azbel-Jackson, L., Brownlie, J., Gunn, G., 2016. Farmer attitudes and livestock disease: exploring citizenship behaviour and peer monitoring across two BVD control schemes in the UK. *PLOS ONE* 11, e0152295.
- Jack, C., Hotchkiss, E., Sargison, N.D., Toma, L., Milne, C., Bartley, D.J., 2017. A quantitative analysis of attitudes and behaviours concerning sustainable parasite control practices from Scottish sheep farmers. *Prev. Vet. Med.* 139, 134–145.
- Jones, R.O., Geddes, E., Mohr, S., Bell, I.R., Ganser Brulisauer, A., Pritchard, C., Nisbet, A.J., Burgess, S.T.G., Busin, V., 2022. Spatial and temporal analysis of sheep scab notifications in Scotland, 2014–2019. *Vet. Rec.* 2022, e1488 <https://doi.org/10.1002/vetr.1488>.
- Kaler, J., Green, L.E., 2013. Sheep farmer opinions on the current and future role of veterinarians in flock health management on sheep farms: a qualitative study. *Prev. Vet. Med.* 112, 370–377.
- Lodder, R., 2019. Sheep scab - a disease overview. *Ir. Vet. J.* 9, 442–444.
- Lovatt, F., 2015. Safeguarding the role of the vet in sheep farming. *Vet. Rec.* 176 (25), 644–647. <https://doi.org/10.1136/vr.h2549>.
- Lowe, P., 2009. Unlocking potential. A report on veterinary expertise in food production. Department for Environment Food and Rural Affairs, UK Government.
- Loxam, J.G., 1974. Sheep scab epidemic: January 1973. *State Vet. J. (Engl.)* 29, 1–10.
- MAFF, 1998. Future Sheep Scab Policy. State veterinary Service, consultation documents. 21st December 1988. Ministry of Agriculture, Fisheries and Food, Toby Jug Site, Surbiton, Surrey.
- Michie, S., van Stralen, M.M., West, R., 2011. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement. Sci.* 6, 42.
- Moennig, V., Yarnall, M.J., 2021. The Long Journey to BVD Eradication. In: Pathogens (Basel, Switzerland), 10, p. 1292. <https://doi.org/10.3390/pathogens10101292>.
- Mort, M., Convery, I., Baxter, J., Bailey, C., 2008. Animal Disease and Human Trauma: The Psychosocial Implications of the 2001 UK Foot and Mouth Disease Disaster. *J. Appl. Anim. Welf. Sci.* 11 (2), 133–148. <https://doi.org/10.1080/10888700801925984>.
- Nixon, E.J., Rose Vineer, H., Wall, R., 2017. Treatment strategies for sheep scab: An economic model of farmer behaviour. *Prev. Vet. Med.* 137, 43–51.
- Nixon, E.J., Wall, R., Vineer, H.R., Stubbings, L., 2020. The high cost of sheep scab. *Vet. Rec.* 187, 325.

- Nixon, E., Brooks-Pollock, E., Wall, R., 2021. Sheep scab transmission: A spatially explicit dynamic metapopulation model. *Vet. Res.* 52, 54.
- NSA (2021) UK Sheep Farming. Available at: (<https://www.nationalsheep.org.uk/for-the-public/culture/uk-sheep-farming/>) (Accessed: 22nd April 2022).
- O'Brien, D.J., 1992. Studies on the epidemiology of psoroptic mange of sheep in Ireland (PhD Thesis). National University of Ireland.
- O'Brien, D.J., 1999. Treatment of psoroptic mange with reference to epidemiology and history. *Vet. Parasitol.* 83, 177–185.
- Paton, N., Burgess, S., Bartley, K., Griffiths, J., Jones, E., 2022. Piloting an approach to scab control on Welsh sheep farms. *Vet. Rec. Open* 9, e30.
- Priestly, M., 2018. *Dipping sheep to control scab - what you need to know*. Farmers Weekly. Available at: (<https://www.fwi.co.uk/livestock/dipping-sheep-to-control-scab-what-you-need-to-know>) (Accessed 12/10/2021).
- Ritter, C., Jansen, J., Roche, S., Kelton, D.F., Adams, C.L., Orsel, K., Erskine, R.J., Benedictus, G., Lam, Theo, J.G.M., Barkema, H.W., 2017. Invited review: Determinants of farmers' adoption of management-based strategies for infectious disease prevention and control. *J. Dairy Sci.* 100, 3329–3347.
- Robinson, P.A., 2017. Framing bovine tuberculosis: A 'political ecology of health' approach to circulation of knowledge(s) about animal disease control. *Geogr. J.* 183, 285–294.
- Rose, H., Learmount, J., Taylor, M., Wall, R., 2009. Mapping risk foci for endemic sheep scab. *Vet. Parasitol.* 165, 112–118.
- Rose, H., 2011. Ovine Psoroptic Mange: Risk And Management (PhD Thesis). Faculty of Science, University of Bristol.
- Rose, H., Wall, R., 2012. Endemic sheep scab: Risk factors and the behaviour of upland sheep flocks. *Prev. Vet. Med.* 104, 101–106.
- SCOPS, 2018. Sheep scab resistance to treatment. Available at: (<https://www.scops.org.uk/external-parasites/scab/resistance-to-treatment/>) (Accessed 10/10/2021).
- SCOPS, 2021. SCOPS launches Code of Practice to ensure safe and effective sheep dipping. Available at: (<https://www.scops.org.uk/news/13475/scops-launches-code-of-practice-to-ensure-safe-and-effective-sheep-dipping/>) (Accessed 10/10/2021).
- SCOPS, 2022. Sheep scab control in the four UK nations. Press release. Available at: (<https://www.scops.org.uk/news/14241/scops-welcomes-agricultural-journalists-to-sheep-scab-press-briefing/>) (Accessed 10/03/2022).
- Scott, P.R., Sargison, N.D., Wilson, D.J., 2007. The potential for improving welfare standards and productivity in United Kingdom sheep flocks using veterinary flock health plans. *Vet. J.* 173, 522–531.
- Spence, T., 1949. The latent phase of sheep scab: Its nature and relation to the eradication of the disease. *J. Comp. Path.* 59, 305–318.
- Spence, T., 1951. Control of sheep scab in Britain. *Aus. Vet. J.* 27, 136–146.
- Stubbings, L., Bartley, D., Busin, V., Lovatt, F., Page, P., Rose Vineer, H., Skuce, P., 2020. SCOPS technical manual. Available at: (<https://www.scops.org.uk/advisers-technical-info/>) (Accessed 10/10/2021).
- Sturgess-Osborne, C., Burgess, S., Mitchell, S., Wall, R., 2019. Multiple resistance to macrocyclic lactones in the sheep scab mite *Psoroptes ovis*. *Vet. Parasitol.* 272, 79–82.
- van den Broek, A.H., Huntley, J.F., 2003. Sheep scab: The disease, pathogenesis and control. *J. Comp. Path.* 128, 79–91.
- Veterinary Medicines Directorate (VMD), 2018. Retail of veterinary medicines. Available at: (<https://www.gov.uk/guidance/retail-of-veterinary-medicines>) (Accessed 27/01/2021).
- Veterinary Practice, 2020. Study into sheep scab aims to increase transparency. Available at: (<https://www.veterinary-practice.com/2020/study-into-sheep-scab-aims-to-increase-transparency>) (Accessed 12/10/2021).
- Volkova, V.V., Howey, R., Savill, N.J., Woolhouse, M.E.J., 2010. Sheep movement networks and the transmission of infectious diseases. *PLOS ONE* 5, e11185.
- VSN International, 2021. Genstat for Windows. 20, Hemel Hempstead, UK.