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Uptake of the lameness Five-Point Plan and its association with farmer-reported lameness prevalence: A cross-sectional study of 532 UK sheep farmers

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ABSTRACT

The aims of this research were to determine the uptake of a national strategy to reduce lameness in the UK flock, known as the Five-Point Plan (5 P P); explore the association between footrot vaccination (Footvax®) use and 5 P P adoption; investigate the management practices associated with farmer-reported percentage lameness through risk factor analysis; and identify the population attributable fractions of these management practices. In 2014, the 5 P P was launched to provide a practical, farm-level framework to help farmers reduce lameness to reach Farm Animal Welfare Committee (FAWC) targets. No published studies have explicitly explored its uptake in UK flocks nor its association with lameness prevalence. Understanding what parts of the 5 P P farmers adopt and which elements contribute towards the greatest reduction in lameness are integral in informing future strategies.

Between November 2018 and February 2019, 532 UK sheep farmers completed a cross-sectional online and paper-based survey. The geometric mean of farmer-reported percentage lameness in ewes was 3.2 % (95 % CI: 2.8–3.6). Farmers adopted a median of 3 points of the plan, but was only fully-adopted by 5.8 % of farmers. The number of points adopted increased with flock size, with larger commercial flocks more likely to cull and vaccinate against footrot, but smaller, pedigree flocks were more likely to treat individual lame sheep. Vaccination was poorly associated with the uptake of other points of the 5 P P.

Eight flock management factors were associated with significantly higher percentage lameness in ewes; not carrying out measures to avoid lameness transmission, not quarantining bought in stock, not treating individual lame sheep within three days, maintaining an open flock and foot trimming were all associated with a higher risk of lameness in flocks studied. In addition, using Footvax® for ≤5 years was associated with a higher risk of lameness, although vaccination could be a consequence of high flock lameness or these farmers were not implementing other effective managements, such as treating promptly. The highest PAFs were calculated for trimming lame sheep (16.9 %), maintaining an open flock (13.5 %) and not carrying out measures to avoid lameness transmission (11.8 %).

We provide new evidence documenting the benefits of adopting parts of the 5 P P on reducing lameness prevalence in UK flocks, although uptake of these measures could be improved in flocks. Encouraging uptake of these measures could make an important contribution towards reducing the prevalence of lameness and reaching 2021 FAWC ≤ 2% lameness prevalence targets.

1. Introduction

Lameness is one of the most challenging health and welfare concerns of UK sheep flocks. Associated indirect and direct costs are responsible for lameness costing the sheep industry £24 million per annum (Nieuwhof and Bishop, 2005). The overall cost of lameness per ewe per year in UK flocks is estimated to be between £3.90 and £6.35, depending on flock lameness levels present (Winter and Green, 2017). Footrot (both clinical presentations; interdigital dermatitis and severe footrot) accounts for approximately 70 % of lameness and is present in over 95 % of flocks (Winter et al., 2015). Furthermore, contagious ovine digital dermatitis (CODD), which is thought to affect 50 % of flocks,

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accounts for up to 35 % of lameness in infected flocks (Winter et al., 2015; Angell et al., 2014).

Best-practice recommendations, underpinned by UK research into lameness in sheep, have been promoted widely to farmers over the last 20 years. Industry stakeholders such as AHDB Beef and Lamb, the levy board for beef and sheep farmers in England, have facilitated knowledge exchange of current recommendations through paper and electronic literature, including the 'Reducing Lameness for Better Returns' manual first published in 2006 which was initially sent to 50,000 producers. Furthermore, farm events and meetings, particularly those led by industry stakeholders such as veterinarians, flock health clubs and services (Flock Health Ltd), levy bodies (AHDB, HCC) and knowledge transfer advisory services (Farming Connect), have also had an important role in best-practice knowledge exchange through communicating key messages and initiating discussion. Promoting and facilitating best-practice uptake is understood to lead to a dose-response effect, where farmers receiving the greatest exposure, such as at one-to-one or group meetings, have the greatest change in lameness prevalence, in the case of treating footrot using the "Six steps to sound sheep" message (Grant et al., 2018). As a result of best-practice promotion and uptake of recommendations on farm, global mean period prevalence of lameness has halved from 10.6 % in 2004 (Kaler and Green, 2009) to 4.9 % in 2013 (Winter et al., 2015).

In 2014, best-practice recommendations were streamlined and consolidated into the Five-Point Plan (5 P P), a long-term management programme of practices to reduce lameness in sheep, which is promoted widely by industry professionals including AHDB and MSD Animal Health. This practical, farm-level tool was developed principally by FAI farms, in conjunction with industry stakeholders, in response to the "Opinion on Lameness in Sheep" report published by the Farm Animal Welfare Committee (FAWC) in 2011. This report reviewed the prevalence of lameness in flocks in Great Britain and set targets for sheep farmers to reduce, manage and control flock lameness to ≤5% by 2016 and to ≤2% by 2021. The 5 P P lists five key action points; avoiding the transmission of infection, culling repeatedly lame sheep, quarantining incoming stock, treating clinical cases promptly and appropriately, and vaccinating against footrot. Research contributing to and supporting recommended management practices under each point of the 5 P P are listed in Table 1.

Footvax® (MSD Animal Health, UK) is the only licensed vaccine against footrot in the UK. In 2015, 29.2 % of UK sheep farmers were reported to vaccinate their ewes against footrot (Prosser et al., 2019). The vaccine has an estimated efficacy of 62 % against footrot (Duncan et al., 2012) and on average reduces period prevalence of lameness by 20 % (Winter et al., 2015). The Responsible Use of Medicines in Agriculture Alliance (RUMA) monitor the sales of Footvax® and use this as a proxy for the uptake of the 5 P P in UK flocks (RUMA, 2017). However, this raises the important question of whether vaccination use is associated with the implementation of other points of the 5 P P, despite the manufacturer's recommendations to implement all five points concurrently. To date, no cross-sectional studies have specifically explored the uptake of the 'packaged' 5 P P in UK flocks, where uptake of management practices in 2013 (Winter et al., 2015) could provide a valuable baseline prior to the launch of the 5 P P.

Determining the impact of the 5 P P on lameness in UK flocks is timely considering its introduction as a national strategy over six years ago. Although the efficacy of the 5 P P was investigated in one case-study of three flocks, where percentage lameness reduced from 7.4 % to < 2% within three years of 5 P P implementation (Clements and Stoye, 2014), to date, no cross-sectional studies have investigated its relationship with lameness prevalence in UK flocks. This is a key gap in knowledge considering the uncertainty of whether the 5 P P needs to be implemented in its entirety, or whether specific elements are more effective than others. Therefore, this research could be invaluable in informing further exploration and refinement of future lameness control strategies. Furthermore, given the current period of economic uncertainty and pressures concerning antibiotic usage in farmed livestock, avoidable losses through lameness treatments and production costs could be mitigated by optimised lameness control programmes.

The aims of this study were to (a) investigate the uptake of the 5 P P and other management factors associated with the control of lameness in UK flocks, (b) explore the association between Footvax® and 5 P P use, to determine whether vaccine sales are a reliable proxy for 5 P P adoption, (c) conduct a risk factor analysis to identify the management practices associated with farmer-reported percentage lameness in ewes, and (d) estimate the population attributable fractions of these management practices.

2. Materials and methods

This observational cross-sectional study was approved by the Harper Adams Research Ethics Committee.

Table 1
Non-exhaustive list of research publications contributing to, informing and supporting recommended management practices under each point of the 5 P P.

5 P P point	Management practice	Reference
Avoiding the transmission of infection	Stop footbathing as a preventative practice	Winter et al., 2015; Kaler and Green, 2009
	Reduce stocking density	Kaler and Green, 2009
	Isolate lame sheep at housing	Kaler and Green, 2009
	Limit indoor housing	Witt and Green, 2018
	Avoid poaching of ground	Angell et al., 2018
	Reduce grazing of rough or long pasture	Vittis and Kaler, 2019;
	Avoid unnecessary gathering events	Green et al., 2007
Culling repeatedly lame sheep	Accurately record lameness events (not by memory), to determine repeatedly lame sheep	Witt and Green, 2018; Winter et al., 2015
	Cull lame sheep when first implementing a lameness control programme	Witt and Green, 2018
Quarantine incoming stock	Isolate bought in sheep for > 3 weeks	Winter et al., 2015
Treating clinical cases of lameness promptly	Antibiotic treatment < 1 week, specifically within 3 days	Prosser et al., 2019; Winter et al., 2015; Wassink et al., 2010b
	Treat first lame sheep in group	Kaler and Green, 2008
	Avoid foot trimming lame sheep	Kaler et al., 2010
	Avoid routine foot trimming	Prosser et al., 2019; Winter et al., 2015; Kaler and Green, 2009
	Separating lame sheep at time of treatment	Witt and Green, 2018
Vaccinating the flock against footrot (Footvax®)	Vaccinate ewes with Footvax®	Winter et al., 2015
	Vaccinate with Footvax® for > 5 years	Prosser et al., 2019

2.1. Study design

An online (Jisc Online Surveys, Bristol, UK) and paper-based survey was developed. A copy of the online survey is available in Supplementary Material 1. The survey was piloted on 10 sheep farmers and five colleagues. Minor typographical amendments were made post-pilot. Farmers were asked questions regarding themselves, their flock and lameness management. Lameness prevalence was determined by asking farmers to estimate the percentage of lame ewes at the most recent flock inspection. Uptake of the 5 P P was determined by asking farmers to select which of the five points of the 5 P P were implemented on farm. The online survey utilised skip logic, allowing for specific questions to be directed at farmers, based on their previous answers provided. For example, farmers who vaccinate against footrot were directed to questions asking for their view on the impact of vaccination on lameness and antibiotic usage. In paper-based versions, questions were signposted, where appropriate. Only results from the survey pertinent to the aims of this paper were reported.

Eligibility to complete the survey was restricted to those who own or work with sheep in the UK, where participants were sampled voluntarily through non-probability, self-selected sampling. Informed consent was sought from all participants prior to completing the survey. A prize draw to win a £100 agricultural voucher was included as an incentive to participate.

The survey was launched on November 21, 2018 and was available until February 28, 2019. The online link was promoted and shared across social media, email, newsletters (electronic and paper) and other publications by UK industry stakeholders, including veterinary practices, sheep breed associations and societies, agricultural merchants, animal feed companies and levy boards. Participants and stakeholders were also canvassed at a number of relevant events, including the Royal Welsh Winter Fair. Paper versions were supplied with return envelopes. Additional paper copies were supplied upon request.

2.2. Data analysis

The online survey closed on February 28, 2019 at midnight. All paper copies were manually entered onto the online system and marked as a paper copy for analysis. All responses were exported into Microsoft Excel 2016 (Microsoft, Redmond, USA). Data was checked for duplications, cleaned and coded as appropriate for statistical analysis.

Not all farmers answered all questions. Only farmers who could provide an estimate of percentage lameness in ewes were included in analyses. The total number of farmers answering questions was reported and used as the denominator for calculating proportions.

All statistical analyses were performed using Genstat (VSN International, UK). Pearson Chi-Squared tests were used to investigate associations between categorical variables. Kruskal-Wallis tests were used to investigate associations between continuous and categorical variables. Probability values of < 0.05 were taken as significant, with < 0.10 considered as trends.

Flock percentage lameness in ewes, estimated by the farmer, was the primary outcome variable, which followed an over-dispersed distribution. The variance exceeded the mean and the dispersion parameter (residual deviance divided by residual degrees of freedom) was greater than one in both negative binomial and over-dispersed Poisson (quasi-Poisson) regression models. An over-dispersed Poisson regression model was considered a better fit than a negative binomial model, when comparing the predicted and observed percentage lameness per flock when ranked in deciles. As a result, two over-dispersed Poisson regression models were used to estimate univariable and multivariable associations between putative flock and lameness management practices and farmer-reported percentage lameness in ewes. Models were constructed using a generalised linear model, with a log link function, specifying a Poisson distribution, where the dispersion parameter was left unrestricted, instead of fixing to one, to account for overdispersion (Dohoo et al., 2003). Each putative variable was first tested individually in the univariable model before building the multivariable model using a backward elimination procedure. Collinearity between pairs of categorical variables was assessed using correlation coefficients; if a correlation coefficient of ≥ 0.70 was observed between two variables, then only one variable would be included in the model, based on biological plausibility. The maximum model was built before each variable was removed sequentially until none of the variables remaining in the model had a Wald test p value > 0.05. This strategy allows for the p value of variables to be assessed after adjustment for the confounding effect of other variables in the model (Dohoo et al., 2003). For each variable in the final model, the category associated with the lowest risk was considered the baseline (relative risk = 1). Correlations between explanatory variables in the final model were investigated using Pearson Chi-squared tests and direction of association was recorded where a significant correlation was identified. Model fit of the final quasi-Poisson regression model was checked by both visually assessing the predicted and observed percentage lameness per flock, when ranked in deciles, and evaluating the lack of fit p value generated in Genstat. Standardised residuals were plotted against predicted values to assess patterns in spread and identify outliers. Outliers were assessed to determine the impact on coefficients.

To further understand the impact on management practices, the attributable fraction (AF) in exposed flocks and the population attributable fraction (PAF) for each flock and lameness management variable in the final model were calculated:

$$AF = (RR - 1) / RR$$

and

$$PAF = AF\ (a_1 / m_1)$$

Where RR is the relative risk obtained from the quasi-Poisson regression model, a_1 is the number of flocks using the management practice and m_1 is the total number of flocks in the model (Dohoo et al., 2003). Both AFs and PAFs were expressed as percentages. The PAF estimates the percentage of lameness that is attributable to particular management practices, assuming a causal relationship (Dohoo et al., 2003).

3. Results

3.1. Survey response

Six farmers (1.1 %, n = 6/539) did not provide an estimate of percentage lameness and were excluded from subsequent analyses. Therefore, the usable survey response was 532 farmers. The majority (94 %, n = 500/532) completed the survey online. A response rate could not be generated due to the way in which the survey was distributed.

3.2. Respondent demographic

The majority (61.1 %, n = 325/532) of farmers were male. Median respondent age category was 36–45 years old (IQR: 25–35, 46–55 [range < 25 - > 65]), which was represented by 17.5 % (n = 93/532) of farmers. Farmers were geographically distributed across the UK (Fig. 1), although the majority (67.8 %, n = 348/513) resided in England. Most farmers (56.4 %, n = 300/532) were flock owners, with 23.5 % (n = 125/532) of farmers working as shepherds, farm workers or assistants.

3.3. General flock characteristics

Median flock size was 251–500 ewes (IQR 50–100, 501–1000 [range < 50 - > 1000]), which was represented by 20.7 % (n = 110/532) of farmers (Table 2). Most farmers (63.3 %, n = 337/532) farmed

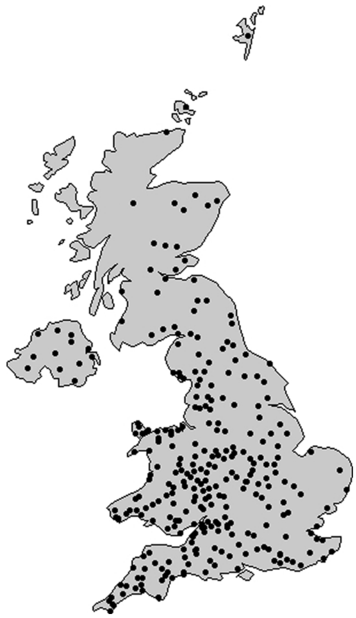

Fig. 1. Locations of the 513 farmers who provided the first four digits of their postcode when completing the survey.

Table 2
Frequency distribution of farmers (n = 532) by various flock characteristics.

Flock characteristic	*n*	%
Flock size		
< 50	83	15.6
50 to 100	75	14.1
101 to 250	101	19.0
251 to 500	110	20.7
501 to 1000	105	19.7
> 1000	58	10.9
Flock system		
Commercial	389	73.1
Pedigree	143	26.9
Stratification system		
Lowland	337	63.3
Upland	133	25.0
Hill	42	7.9
Combination	20	3.8
Management system		
Conventional (non-organic)	501	94.2
Organic	31	5.8
Buying in policies[a]		
Open	235	44.2
Part-closed	273	51.3
Closed	24	4.5
Ewe replacements[b]		
Breed own	370	69.5
Buy in replacements	306	57.5
Source of bought in ewe replacements[b]		
Breed sales	142	46.4
Market	132	43.1
Direct from farm	128	41.8
Other, e.g. dealers	8	2.6
Lambing location		
Indoors	270	51.1
Outdoors	99	18.8
Both	159	30.1

n: number of farmers; %: percentage of farmers.
[a] Open flock was defined as buying in any stock, part-closed when buying in rams only, closed flock when not buying in any stock.
[b] Farmers could include more than one response to the question concerning their source of ewe replacements, e.g. farmers might buy in replacements and breed their own.

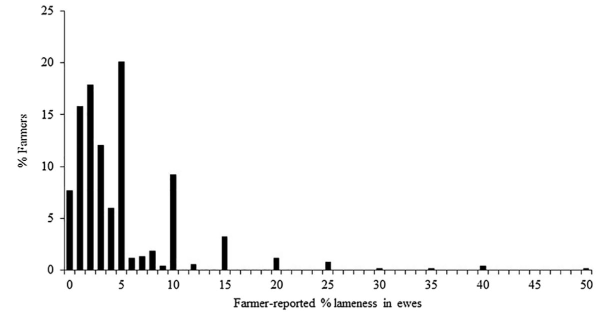

Fig. 2. Percentage of farmers (n = 532) by the farmer-reported percentage lameness in ewes at the most recent inspection provided in the survey.

sheep in a lowland system. The majority of flocks were farmed conventionally (non-organic) (94.2 %, n = 501/532) and in a commercial (non-pedigree) system (73.1 %, n = 389/532). Most flocks (51.3 %, n = 273/532) were part-closed, whereby buying in rams only. Mule was the most common breed of ewe (24.6 %, n = 131/532). Texel was the most common breed of ram (51.3 %, n = 237/532).

3.4. Farmer-reported percentage lameness in ewes

Over 90 % of farmers (92.3 %, n = 491/532) reported having lame ewes (> 0% ewes lame) at the time of completing the survey (Fig. 2). Overall, geometric mean farmer-reported percentage lameness in ewes was 3.2 % (95 % CI: 2.8–3.6). The distribution was highly skewed with five farmers reporting extremely high levels of lameness (≥30 % of flock). The majority of farmers (79.5 %, n = 423/532) reported percentage lameness estimates of ≤5%, of which 52 % (n = 220/423) reported levels of ≤2%.

3.5. Uptake of the 5 P P in UK flocks

Only 5.8 % (n = 31/532) of farmers adopted all five points of the 5 P P (Table 3). Excluding vaccination, only 14.7 % (n = 78/532) of farmers employed the remaining four points when managing lameness in their flocks. Overall, farmers were adopting a median of 3 (IQR 2–4 [range 0–5]) points of the plan. The number of points adopted had no association with farmer-reported prevalence of lameness (p > 0.05), but increased with flock size (p= 0.020). No other flock characteristics had an association with the number of points adopted (p > 0.05). Furthermore, there was no association between farmer age and number of points of the 5PP adopted nor likelihood of adopting individual points of the 5PP (p > 0.05).

Almost a third of all farmers (32.1 %, n = 171/539) adopted measures to avoid disease transmission, representing the least employed point of the 5 P P (Table 4). Farmers who perceived themselves to implement avoidance measures were more likely to lamb their flocks indoors than outdoors (p= 0.049).

Table 3
Frequency distribution of farmers (n = 532) by the reported number of points of the 5 P P adopted, from none to five, and geometric mean farmer-reported percentage lameness in ewes.

Number of 5 P P points	*n*	%	95 % CI	Geometric mean [a]	95 % CI
0	10	1.9	1.2 – 2.6	3.1	2.4 – 3.8
1	63	11.8	8.0 – 15.6	3.7	2.9 – 4.5
2	141	26.5	19.3 – 33.7	3.2	2.5 – 3.9
3	182	34.2	25.9 – 42.5	3.4	2.9 – 4.0
4	105	19.7	13.9 – 25.5	2.8	2.2 – 3.4
5	31	5.8	3.8 – 7.8	2.8	2.3 – 3.3

n: number of farmers; %: percentage of farmers; CI: Confidence intervals; [a] Geometric mean farmer-reported percentage lameness in ewes.

Table 4
Frequency distribution of farmers (n = 532) by the five individual points of the 5 P P adopted and details of managements within each point.

5 P P points	n	%	95 % CI
Use measures to avoid spread of disease			
No	361	67.9	59.9 – 75.9
Yes	171	32.1	24.1 – 40.1
Cull repeatedly lame sheep after 2 or 3 bouts of lameness			
No	197	37.0	28.4 – 45.6
Yes	335	63.0	54.4 – 71.6
Quarantine all bought in stock			
No	146	27.4	20.1 – 34.7
Yes	386	72.6	65.3 – 79.9
Quarantine length (n = 378)			
< 21 days	169	44.7	35.6 – 53.8
≥21 days	209	55.3	46.2 – 64.4
Treat lame sheep within 3 days of first observation			
No	150	28.2	20.7 – 35.7
Yes	382	71.8	64.3 – 79.3
Foot trim when lame			
No	259	48.7	39.5 – 57.9
Yes	273	51.3	42.1 – 60.5
Foot trim to correct misshapen claws without signs of active infection			
No	283	53.2	44.0 – 62.4
Yes	249	46.8	37.6 – 56.0
Routine foot trim			
No	426	80.1	74.2 – 86.0
Yes	106	19.9	14.0 – 25.8
Routine trimming frequency (n = 106)			
Once yearly	48	45.3	36.2 – 54.4
Twice yearly	28	26.4	19.2 – 33.6
Three times yearly	9	8.5	5.6 – 11.4
Four times yearly	12	11.3	7.6 – 15.0
> Four times yearly	9	8.5	5.6 – 11.4
Vaccinate with Footvax®			
No	340	63.9	55.4 – 72.4
Yes	192	36.1	27.6 – 44.6
Vaccination protocol (n = 183)			
Annual	128	69.9	62.1 – 77.7
Biannual	55	30.1	22.3 – 37.9
Stock vaccinated (n = 192)			
Whole flock (including rams)	147	76.6	70.0 – 83.2
Whole flock (excluding rams)	16	8.3	5.5 – 11.1
Rams only	5	2.6	1.7 – 3.5
Replacements only	16	8.3	5.5 – 11.1
Lame sheep only	7	3.6	2.3 – 4.9
Bought in sheep only	1	0.5	0.3 – 0.7
Length of time vaccinating (n = 189)			
≤1 year	77	40.7	31.8 – 49.6
> 1 ≤ 2 years	40	21.1	15.0 – 27.2
> 2 ≤5 years	26	13.8	9.4 – 18.2
> 5 years	46	24.3	17.5 – 31.1
No 5 P P points adopted	10	1.9	1.2 – 2.6

Bold: five management points listed on the 5 P P; *Italics*: measures within each point obtained from the survey; Total number of farmers reported in brackets if not n = 532; n: number of farmers; %: percentage of farmers; CI: confidence intervals.

Culling repeatedly lame sheep after two or three bouts of lameness was reported by 63 % (n = 335/532) of farmers (Table 4). Farmers with > 250 ewes were more likely to cull repeatedly lame sheep, than those with smaller flocks (p= 0.008). Commercial flocks were also more likely to cull, compared to pedigree flocks (p= 0.001). The source of ewe replacements, whether homebred or purchased, had no effect on likelihood of culling (p > 0.05). Farmers choosing to cull repeatedly lame sheep were significantly more likely to adopt measures to avoid disease transmission (p < 0.001).

Quarantining bought in stock was adopted by 72.6 % (n = 386/532) of farmers (Table 4). Of those who bought in replacements, 71.2 % (n = 218/306) quarantined on arrival. On average, farmers were quarantining purchased stock for 28.9 days (95 % CI: 23.9–33.9), ranging from 24 h to 1.5 years. Farmers buying replacements from market were less likely to quarantine than those who sourced elsewhere (p= 0.021), whereas those who sourced replacements direct from farm were more likely to quarantine (p= 0.048). Farmers with lowland or upland flocks were more likely to quarantine stock, compared to those with hill flocks (p= 0.036). Farmers were no more likely to quarantine if running a commercial or pedigree flock (p > 0.05), but of those that quarantine, commercial flocks were more likely to quarantine for ≥21 days (p= 0.007). Implementing a quarantine period was not associated with flock size (p > 0.05), but of those who quarantine, flocks with > 100 ewes were more likely to quarantine for ≥21 days (p= 0.008). Farmers who quarantine were more likely to cull repeatedly lame sheep (p < 0.001).

Treating lame sheep within three days of first observation was carried out by 71.8 % (n = 382/532) of farmers (Table 4). Four farmers (2.7 %, n = 4/150) who did not treat, stated that they would only treat when most convenient to them, such as when gathering for worming. Farmers with ≤250 ewes (p < 0.001), pedigree (p= 0.008) or indoor lambing flocks (p= 0.033) were more likely to treat, than those with larger, commercial or outdoor lambing flocks, respectively. However, farmers who treat individually lame sheep were less likely to cull (p < 0.001). Female farmers were more likely to treat, than males (p < 0.001).

Over half (51.3 %, n = 273/532) of farmers would trim lame sheep. Farmers aged ≤35 years old were more likely to trim lame sheep, than older farmers (p= 0.013). Farmers with > 250 ewes were more likely to trim lame sheep (p < 0.001), in addition to those with commercial flocks (p < 0.001). Almost a fifth (19.9 %, n = 106/532) of farmers routinely foot trimmed. These farmers were trimming, on average, twice yearly (95 % CI: 1.8–2.3). Pedigree flocks (p < 0.001) and those with ≤250 ewes (p < 0.001) were more likely to routinely trim. Furthermore, nearly half (46.8 %, n = 249/532) of farmers reported to trim misshapen claws without signs of active infection. No associations were found between farmer age and routine trimming or trimming misshapen claws (p > 0.05).

Vaccinating sheep against footrot was adopted by 36.1 % (n = 192/532) of farmers (Table 4). The majority (76.6 %, n = 147/192) vaccinated the entire flock, including rams. Most farmers administered the vaccine annually (69.9 %, n = 128/183) and had been vaccinating for ≤1 year (40.7 %, n = 77/189), with 24.3 % (n = 46/189) vaccinating for > 5 years. The length of time vaccinating had no effect on whether the vaccine was administered annually or biannually (p > 0.05). September was the most common month for administering the vaccine, where 34.9 % (n = 67/192) of farmers chose to administer the vaccine before tupping. Farmers with commercial flocks (p= 0.043) or those with > 500 ewes (p < 0.001) were more likely to vaccinate than those with pedigree flocks or ≤500 ewes, respectively. Farmers who do not vaccinate reported that they would implement vaccination when, on average, flock percentage lameness reaches 19.2 % (95 % CI: 17.4–21). This was, on average, a 15.7 % (95 % CI: 13.9–17.5) increase in percentage lameness before they would consider vaccinating their flock against footrot.

In flocks where Footvax® vaccination was implemented, irrespective of length of time vaccinating, 46.2 % (n = 85/184) reported the effect of Footvax® on lameness rates as moderate and 48.4 % (n = 89/184) reported a major effect (Fig. 3a). Similarly, when asked to rate the effect of Footvax® on antibiotic usage, 43.3 % (n = 81/187) reported the effect as moderate and 35.8 % (n = 67/187) reported a major effect (Fig. 3b).

3.6. Association between footrot vaccination (Footvax®) use and 5 P P adoption

Farmers who vaccinated with Footvax® were more likely to cull (p < 0.001) and quarantine (p= 0.042). There was a trend to suggest that those vaccinating for ≤2 years were less likely to treat individual

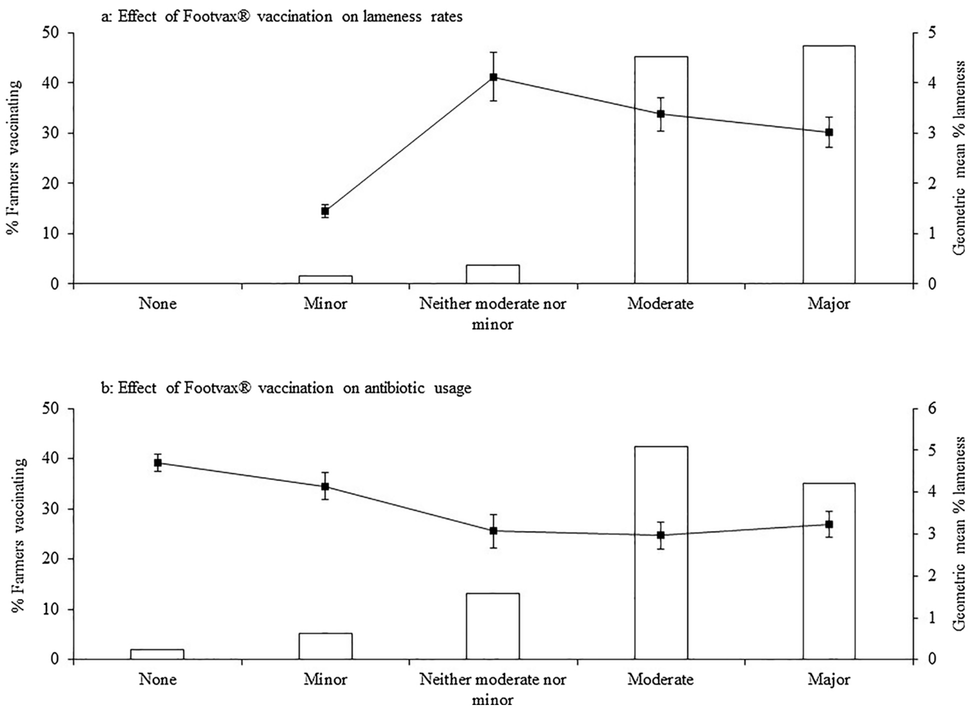

Fig. 3. **(a)** Percentage of responses (n = 184) to the question "What effect has Footvax® had on your lameness rates?" and the geometric mean farmer-reported percentage lameness in ewes; **(b)** Percentage of responses (n = 187) to the question "What effect has Footvax® had on your antibiotic usage (for lameness only)?" and the geometric mean farmer-reported percentage lameness in ewes. Error bars are standard deviation.

lame sheep promptly, than those vaccinating for > 2 years (p = 0.066). The number of the remaining 5 P P points adopted had no association with the likelihood of implementing vaccination (p > 0.05).

3.7. Multivariable quasi-Poisson regression model of risk factors associated with farmer-reported percentage lameness in ewes

The univariable associations between putative variables relating to the flock and lameness management and farmer-reported percentage lameness in ewes are presented in Supplementary Table 1.

In the final multivariate model, eight flock and lameness management variables were significantly associated with farmer-reported percentage lameness in ewes (Table 5). The dispersion parameter of the final model was 3.9 (residual deviance = 1925, df = 497), confirming an overdispersed distribution.

The prevalence of lameness was higher in flocks where farmers did not employ measures to avoid the spread of lameness (RR 1.21, 95 % CI: 1.10 − 1.32) than in flocks where avoidance measures were implemented. Farmers had a higher percentage lameness when new stock were not quarantined (RR 1.25, 95 % CI: 1.14 − 1.36), compared to those who implemented a quarantine period. The prevalence of lameness was greater in flocks where farmers did not treat lame sheep within three days of first observation (RR 1.14, 95 % CI: 1.04 − 1.24), compared to those who treat promptly. Furthermore, prevalence of lameness was also higher in flocks where farmers trimmed lame sheep (RR 1.49, 95 % CI: 1.36 − 1.63), compared to those who did not trim lame sheep. The prevalence of lameness was greatest in flocks where farmers routinely trimmed (RR 1.59, 95 % CI: 1.42 − 1.77) than in flocks where routine trimming was not practised. Furthermore, farmers who trim misshapen claws to correct shape without signs of active infection (RR 1.17, 95 % CI: 1.07 − 1.28) had higher percentage lameness, compared to those who did not trim. The prevalence of lameness was greater in flocks where farmers reported to vaccinate for > 1 ≤ 2 years (RR 1.47, 95 % CI: 1.29 − 1.81), compared with flocks that were vaccinated for > 5 years. Culling repeatedly lame sheep, the final point of the 5 P P, was not retained in the final model (Wald test p > 0.05). Farmers who maintained an open flock (buy in ewes and rams) (RR 1.44, 95 % CI: 1.32 − 1.56) had a higher prevalence of lameness than those who kept part-closed (buy in rams only) flocks.

A number of variables were significantly (p < 0.05) correlated in the final multivariable quasi-Poisson regression model Supplementary Table 2. There were negative correlations between routine trimming, trimming lame sheep and trimming to correct shape, and positive correlations between 'treat' and routine trimming and trimming to correct shape.

Model fit was reasonable, where predicted values followed a similar pattern to observed values (Supplementary Fig.1). Observed values were higher than predicted values in the 10th decile, suggesting that some farmers reporting high percentages of lameness were not predicted by the model. Removing outliers, identified by plotting standardised residuals (farmer-reported percentage lameness ≥30 %), did not impact upon coefficients nor significantly improve model fit. Lack of fit test (Genstat) indicated no evidence of lack of fit (p = 0.121). Model coefficients are found in Supplementary Table 3.

3.8. Population attributable fractions (PAF) of risk factors for farmer-reported percentage lameness in ewes

The AFs and PAFs of the explanatory variables in the final multivariate quasi-Poisson regression model are presented in Table 6. The final model estimated that 67.8 % of farmer-reported percentage lameness in ewes was attributable to the eight explanatory variables. The PAFs for not adopting measures to avoid lameness transmission and not quarantining new stock were 11.8 % and 5.5 %, respectively. Not treating individual lame sheep within three days of observation had a PAF of 3.5 %. Trimming lame sheep had the largest PAF of 16.9 %, whilst foot trimming routinely and trimming to correct shape had PAFs of 7.4 % and 6.8 %, respectively. The PAF for vaccinating short-term (> 1 ≤ 2 years) with Footvax® was 2.4 %. Farmers maintaining an open flock by buying both ewes and rams had a PAF of 13.5 %.

4. Discussion

To the best of our knowledge, this is the first study to explicitly investigate the use of the 5 P P and its impact on farmer-reported lameness in UK sheep flocks. Firstly, we provide evidence that only a small minority of farmers were fully adopting all five points of the plan (5.8 %), or the remaining four points excluding vaccination (14.7 %).

Table 5
Multivariable quasi-Poisson regression model identifying flock and lameness management practices associated with farmer-reported percentage lameness in ewes in 532 UK sheep flocks.

Variable	n	%	RR	95 % CI	p
Use measures to avoid spread of disease					
Yes (baseline)	171	32.1	1.00		
No	361	67.9	**1.21**	**1.10 – 1.32**	**< 0.001**
Quarantine all bought in stock					
Yes (baseline)	386	72.6	1.00		
No	146	27.4	**1.25**	**1.14 – 1.36**	**< 0.001**
Treat lame sheep within 3 days of first observation					
Yes (baseline)	382	71.8	1.00		
No	150	28.2	**1.14**	**1.04 – 1.24**	**0.010**
Foot trim when lame[a]					
No (baseline)	259	48.7	1.00		
Yes	273	51.3	**1.49**	**1.36 – 1.63**	**< 0.001**
Routine foot trim[a]					
No (baseline)	426	80.1	1.00		
Yes	106	19.9	**1.59**	**1.42 – 1.77**	**< 0.001**
Foot trim to correct misshapen claws without signs of active infection[a]					
No (baseline)	283	53.2	1.00		
Yes	249	46.8	**1.17**	**1.07 – 1.28**	**0.004**
Length of time vaccinating with Footvax®					
> 5 years (baseline)	46	8.7	1.00		
> 2 ≤5 years	26	4.9	1.13	0.87 – 1.46	0.356
> 1 ≤ 2 years	40	7.5	**1.47**	**1.29 – 1.81**	**< 0.001**
≤1 year	77	14.5	1.17	0.97 – 1.42	0.109
Do not vaccinate	340	63.9	1.17	0.99 – 1.42	0.063
Buying in policy					
Part-closed (baseline)[b]	273	51.3	1.00		
Closed	24	4.5	1.07	0.87 – 1.33	0.517
Open	235	44.2	**1.44**	**1.32 – 1.56**	**< 0.001**

BOLD: categories significantly different from the baseline, indicated by Wald's test ($p < 0.05$). n: number of farmers; %: percentage of farmers; RR: relative risk; CI: Confidence intervals. Lack of fit $p = 0.121$.

[a] Farmers could include more than one response to the question concerning foot trimming, e.g. farmers might routinely trim, trim lame sheep and trim to correct shape. Trimming to correct shape was defined as trimming misshapen claws without active signs of infection.

[b] Part-closed was defined as buying in rams only, closed flock when not buying in any stock and open flock as buying in any stock.

Table 6
The estimated attributable fractions (AF) and population attributable fractions (PAF) of eight flock and lameness management practices associated with farmer-reported percentage lameness in ewes in 532 UK sheep flocks.

Variable	n	%	RR	AF%	PAF%
Use measures to avoid spread of disease					
Yes (baseline)	171	32.1	1.00	0.0	0.0
No	361	67.9	1.21	17.4	11.8
Quarantine all bought in stock					
Yes (baseline)	386	72.6	1.00	0.0	0.0
No	146	27.4	1.25	20.0	5.5
Treat lame sheep within 3 days of first observation					
Yes (baseline)	382	71.8	1.00	0.0	0.0
No	150	28.2	1.14	12.3	3.5
Foot trim when lame					
No (baseline)	259	48.7	1.00	0.0	0.0
Yes	273	51.3	1.52	32.9	16.9
Routine foot trim					
No (baseline)	426	80.1	1.00	0.0	0.0
Yes	106	19.9	1.57	37.1	7.4
Foot trim to correct misshapen claws without signs of active infection					
No (baseline)	283	53.2	1.00	0.0	0.0
Yes	249	46.8	1.14	14.5	6.8
Length of time vaccinating with Footvax®					
> 5 years (baseline)	46	8.7	1.00	0.0	0.0
> 1 ≤ 2 years	40	7.5	1.47	32.0	2.4
Buying in policy					
Part-closed (baseline)	273	51.3	1.00	0.0	0.0
Open	235	44.2	1.44	30.6	13.5

n: number of farmers; %: percentage of farmers; RR: relative risk; AF: attributable fraction (exposed), expressed as percentage; PAF: population attributable fraction, expressed as percentage.

Secondly, we demonstrate that Footvax® use is not a reliable predictor of 5 P P adoption, despite approaches claiming to quantify 5 P P use through sales of Footvax®. Finally, we provide some new evidence documenting the benefits of adopting elements of the 5 P P on reducing lameness prevalence in UK flocks.

Quarantining purchased stock was the most employed (72.6 %) point of the 5 P P, with 28.8 % of farmers failing to quarantine bought in replacements. This is an increase in non-compliance from 13 % in 2013 (Winter et al., 2015), although differences in farmer study sample may partly explain this finding. Nonetheless, quarantining was associated with lower farmer-reported lameness prevalence than those who did not quarantine bought in stock, supporting findings from Wassink et al. (2003) and Winter et al. (2015). Despite this, we report that not quarantining stock was only associated with a small PAF of 5.5 %. This could be explained by only the minority of farmers (27.4 %) choosing not to quarantine stock. Furthermore, quarantine length ranged enormously between farmers in our study, which could impact upon the contribution of quarantining on lameness prevalence. Winter et al. (2015) reported that only isolating new stock for > 3 weeks was associated with a lower lameness prevalence, compared to not isolating. However, quarantine length was not identified as significant in our final model. This interpretation could be further strengthened by our finding that percentage lameness was greater in open flocks, similar to (Winter et al., 2015), with a PAF of 13.5 %. This indicates that, although quarantining new stock is a vital biosecurity measure, interventions to discourage or limit farmers buying in stock in the first instance could have a greater impact on the control of lameness in flocks.

Treating lame sheep within three days of first observation was the second most frequently (71.8 %) employed point of the 5 P P. In 2013, 43 % of farmers reported to treat individual lame sheep within three days (Winter et al., 2015), and in 2015, only 28.6 % reported to carry out this practice (Prosser et al., 2019). Therefore, we provide evidence that the majority of farmers in our study treated lame sheep promptly and that the 5 P P introduction and continued promotional efforts could be responsible for increasing best-practice uptake. In hindsight, the survey could have asked whether farmers changed their management practices since 5 P P introduction in 2014, which could have provided stronger evidence for change. Prompt treatment, in our study, was also associated with a reduced percentage lameness, similar to other observational studies (Prosser et al., 2019; Winter et al., 2015; Kaler and Green, 2008; Wassink et al., 2003) and clinical trials (Wassink et al., 2010b). Further information could have been sought on the intricacies of lameness treatment protocols, where variability in treatment protocols could partly explain the small PAF of 3.5 % reported in our study.

Foot trimming was still widely used (51.3 %) by farmers in the treatment of lame sheep. Although foot trimming lame sheep has reduced over time, from 69 % of farmers in 2004 (Kaler and Green, 2009), to 44 % in 2013 (Winter et al., 2015), we provide evidence to suggest that a large proportion of farmers are still incorporating foot trimming into lameness treatment protocols, despite best-practice recommendations. In our study, trimming lame sheep was associated with an increase in percentage lameness, where almost a fifth (PAF 16.9 %) of percentage lameness in ewes could be avoidable by ceasing this practice. This is unsurprising considering the body of published evidence reporting that trimming lame ewes is detrimental; therapeutic trimming reduces recovery time (Kaler et al., 2010), increases risk of non-infectious lameness types such as granulomas (Reeves et al., 2019) and reduces subsequent lamb-derived revenue per ewe (Lima et al., 2020). However, farmers' personal beliefs that foot trimming is indicative of a "good farmer" and helps to heal footrot, are reported as major barriers in accepting recommendations to stop trimming for treatment (Green et al., 2020). Furthermore, of particular concern was our finding that younger farmers aged ≤35 years were more likely to trim lame sheep. Clifton et al. (2019) reported that agricultural college students would still trim lame sheep to treat footrot, despite being taught evidence-based practice recommending antibiotic treatment without trimming to treat lame sheep. In hindsight, level of education was an omission from our survey, which may have provided some further detail to our finding.

We also report novel findings to suggest that trimming misshapen claws without signs of active infection, to correct shape, was widely used (46.8 %) by farmers and was associated with an increase in percentage lameness, albeit only a small PAF of 6.8 %. This suggests that trimming even 'healthy' feet is associated with increased lameness. Poor trimming technique or carelessness could cause damage to living tissue, which causes lameness rather than the act of trimming itself (Winter et al., 2015). This damage to hoof horn can lead to permanently misshapen feet (Egerton et al., 1989) or poor hoof conformation which increases susceptibility to lameness (Kaler et al., 2010). Furthermore, claw growth is self-regulating and overgrowth is the result of reduced weight bearing when lame (Smith et al., 2014), so farmers should be encouraged to treat individual lame sheep promptly and appropriately to increase recovery time and reduce likelihood of misshapen feet. Therefore, recommendations should continue to discourage farmers from carrying out all foot trimming.

Routine trimming was implemented, on average, twice yearly by almost a fifth of farmers in our study. Although this contributes towards our understanding that routine trimming is decreasing, from 76 % of farmers in 2004 (Kaler and Green, 2009), 66 % in 2013 (Winter et al., 2015) and 20.8 % in 2015 (Prosser et al., 2019), routine trimming is still implemented by a significant proportion of sheep farmers today. We report that routine trimming increases risk of lameness, which has been widely reported elsewhere (Reeves et al., 2019; Winter et al., 2015; Kaler and Green, 2009; Wassink et al., 2003). However, our study did not obtain data on rate of feet bleeding unlike Winter et al. (2015) and Prosser et al. (2019). We observed that flocks with ≤250 ewes or pedigree flocks were more likely to routinely trim, suggesting that efforts must be made to target these smaller flocks with best-practice recommendations.

Over two-thirds of farmers do not implement measures to avoid the transmission of lameness, representing the least employed point of the 5 P P. A marked increase in percentage lameness was associated with failure to adopt this practice and a PAF of 11.8 %, which suggests that encouraging efforts to minimise lameness transmission will continue to make a valuable contribution to lameness reduction. In the interests of survey brevity, farmers were not asked to include examples of avoidance measures, which could have provided further detail to this finding. Future work could look to identify what avoidance measures are used by sheep farmers, such as those reducing disease transmission at pasture and housing, and which measures are associated with the lowest risk of lameness.

Nearly two-thirds of farmers reported that they culled repeatedly lame sheep, suggesting an increase in uptake from 44 % in 2013 (Winter et al., 2015), but a decrease from 81.8 % in 2015 (Prosser et al., 2019). Farmers with larger, commercial flocks were more likely to cull; these farmers may find it easier to cull repeatedly lame sheep and maintain flock size in larger flocks, or equally have the financial pressures that mitigate zero tolerance towards repeatedly lame sheep. Understanding the priority that lameness is given in culling decisions may prove valuable. Lameness, infertility, prolapse and poor body condition were indicated by 2% of farmers as reasons for culling in one study of commercial sheep farmers, in contrast to age, mastitis and tooth loss which were most frequently stated (Lima et al., 2019). In our study, there was no association between culling repeatedly lame sheep and lameness prevalence, similar to Prosser et al. (2019) and Winter et al. (2015). Findings from Witt and Green (2018) suggest that culling only makes the most impact on reducing lameness during the initial stages of implementing a lameness control plan. Furthermore, in our study, farmers who treated lame sheep promptly were less likely to cull, similar to Winter et al. (2015), which could explain why culling lame sheep was not significant in the final model. We propose that our study does not provide evidence that is contrary to the recommended practice of culling repeatedly lame sheep in order to reduce exposure to infection.

Vaccination against footrot was adopted by 36.1 % of farmers. This suggests an increase in the uptake of vaccination since the launch of the 5 P P; from 16 % of farmers in 2013 (Winter et al., 2015) and 29.2 % in 2015 (Prosser et al., 2019). Commercial flocks and those with > 500 ewes, were most likely to vaccinate. These flocks are more likely to be financially-driven, where the benefits of vaccinating may outweigh the financial costs. Pedigree flocks may also be concerned with vaccination site abscesses when selling breeding stock (Winter, 2009).

We observed that vaccinating with Footvax® for > 5 years was associated with a reduction in reported lameness prevalence, compared to vaccinating for > 1 ≤ 2 years, which had a PAF of 2.4 %, similar to findings from Prosser et al. (2019). This is in contrast to studies reporting no association between vaccination and lameness prevalence (Kaler and Green, 2009; Wassink et al., 2003). Although this finding is difficult to interpret, we provide evidence that farmers consider vaccination as a reactive tool, rather than a preventative measure, as non-vaccinating farmers were only willing to implement vaccination in response to high percentage lameness (19.2 %). However, as the survey did not ask for the previous level of lameness prior to vaccination, it is difficult to determine the effect of short-term vaccination on lameness prevalence, although farmers in our study were satisfied with the reduction of lameness and antibiotics following vaccination, irrespective of vaccination duration. Inconsistencies between farmer satisfaction and efficacy of Footvax® vaccination have been previously reported, where farmers endorsed Footvax® vaccination even though it was not associated with a prevalence of footrot < 5% (Wassink et al., 2005). Wassink et al. (2010a) later reported that farmers did not wish to appear irrational, and as a result, were found to endorse Footvax® vaccination because they already implemented it, despite having a higher prevalence of lameness. This could be an example of cognitive dissonance (Festinger, 1957) where people change their beliefs to match their behaviour, even if the behaviour is sub-optimal.

We provide evidence to suggest that monitoring the sales of Footvax® is unlikely to provide a reliable quantification of 5 P P adoption, as there was little association between Footvax® use and adoption of the remaining points of the 5 P P. This could further explain the lack of association between vaccination and lameness, as for maximum effect, Footvax® should be used in conjunction with the remaining points of the 5 P P. Furthermore, in our study, farmers vaccinating in the short-term were less likely to treat individual lame sheep promptly, albeit a trend association. This is concerning as preference towards whole flock-level managements and reduced reliance on individual prompt treatments has detrimental effects on lameness prevalence (Prosser et al., 2019). A number of flocks detailed in this survey would be key candidates where vaccination, and other points of the 5 P P, could be implemented to reduce lameness to acceptable levels.

The geometric mean flock prevalence of lameness in ewes (3.2 %) was similar to figures from both 2013 (3.5 %) (Winter et al., 2015) and 2014 (3.2 %) (Grant et al., 2018), although a marked reduction from the 4.1 % observed in 2015 (Prosser et al., 2019). Our study provides new evidence that the majority (79.5 %) of farmers have met 2016 FAWC targets of achieving flock percentage lameness to ≤5%, but there is still improvement to be made with farmers outside of this target and in reaching 2021 FAWC targets of ≤2% lameness. However, findings from this current study utilise farmer-reported percentage lameness in ewes at one time point during the winter, which could be highlighted as a limitation. This is pertinent considering the seasonal nature of lameness, particularly in relation to rainfall (Smith et al., 2014), although increased lameness prevalence has been observed in the summer and autumn (Angell et al., 2015).

Farmer-reported estimates of lameness are widely used in cross-sectional studies of sheep lameness, but assumes that estimates are reliable and acceptable. Although sheep farmers can consistently identify even mildly lame sheep (Kaler and Green, 2008), farmer estimates are subject to reporting bias. Farmers could consciously under-report lameness prevalence to 'acceptable' levels due to perceived negative implications of reporting high prevalence, particularly when lameness targets are widely publicised. This could explain the over-dispersed distribution in the final model, due to data clustering around 'acceptable' lameness targets such as 2% and 5%. Furthermore, farmers with high lameness prevalence may underestimate levels due to becoming desensitised to lame sheep (Whay, 2002). Efforts were made to maximise accuracy of responses by encouraging honest answers and maintaining confidentiality.

Farmers completing this survey were geographically dispersed across the UK. Although the farmers were on average younger than the 'ageing' national average of farm holders at 60 years old (DEFRA, 2012) and did not reflect previous studies (Lima et al., 2018), flock characteristics were similar to other publications (Grant et al., 2018; Winter et al., 2015). We argue that although an online survey may have appealed to the younger generation, we may have inadvertently captured a wider demographic of younger individuals who work directly with sheep, as opposed to targeting farm holders. Importantly, there was no association between farmer age and adoption of the 5 P P, suggesting that our results were not biased by age. As farmers volunteered to complete the survey, the administration mode of an online survey may have caused some volunteer bias, where participating farmers may be different to those who did not volunteer to take part. This has been acknowledged in similar studies using online surveys (Lima et al., 2019). However, this may have been balanced to some extent by disseminating paper copies. Nonetheless, the degree of bias which may have occurred is difficult to estimate, in the absence of information from non-participating farmers. Therefore, we acknowledge that some caution must be taken in case bias in our sample has occurred, despite efforts made to attract a random and representative sample.

5. Conclusion

Despite its introduction in 2014, we document that only the minority of UK sheep farmers are rigorously adopting the 5 P P, where some are favouring ill-advised flock managements such as foot trimming. Our results suggest that using sales of Footvax® is not a reliable proxy for 5 P P adoption in flocks, despite advice to implement vaccination and 5 P P measures concurrently. Although a number of farmers reported acceptable percentage lameness in their flock, our results indicate that efforts must be made by farmers in order to reduce lameness to meet FAWC targets in 2021. Evidence-based knowledge exchange is crucial in encouraging farmers to adopt best-practice recommendations, where our findings, sourced from a variety of sheep production systems in the UK, provide new insights supporting the benefits of adopting some elements of the 5 P P, notably to avoid transmission of lameness, quarantine stock on arrival, treat individual sheep promptly and vaccinate for > 5 years. Furthermore, all types of trimming had a detrimental association on reported percentage lameness, where continued efforts to encourage farmers to cease all foot trimming could successfully reduce lameness prevalence. Findings from this study could help inform further research guiding the refinement of future lameness control strategies. However, we acknowledge that the complexities of behavioural change and decision making are major hurdles in the implementation of disease control programmes. Emphasis must also be placed on the importance of long-term commitment to lameness control strategies, as there is no one, short-term panacea for controlling lameness.

Declaration of Competing Interest

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.105064.

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