Changes in prevalence of, and risk factors for, lameness in random samples of English sheep flocks: 2004 - 2013

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Abstract

The aims of this study were to update the prevalence of lameness in sheep in England and identify novel risk factors. A total of 1260 sheep farmers responded to a postal survey. The survey captured detailed information on the period prevalence of lameness from May 2012 - April 2013 and the prevalence and farmer naming of lesions attributable to interdigital dermatitis (ID), severe footrot (SFR), contagious ovine digital dermatitis (CODD) and shelly hoof (SH), management and treatment of lameness, and farm and flock details.

The global mean prevalence of lameness fell between 2004 and 2013 from 10.6% to 4.9% and the geometric flock mean period prevalence of lameness fell from 5.4% (95% CL: 4.7-6.0%) to 3.5% (95% CI: 3.3%-3.7%). In 2013, more farmers were using vaccination and antibiotic treatment for ID and SFR and fewer farmers were using foot trimming as a routine or in therapeutic treatment than in 2004.

Two over-dispersed Poisson regression models were developed with the outcome the period prevalence of lameness, one investigated associations with farmer estimates of prevalence of the four foot lesions and one investigated associations with management practices to control and treat lameness and footrot. A prevalence of ID >10%, SFR >2.5% and CODD >2.5% were associated with a higher prevalence of lameness compared with those lesions being absent, however, the prevalence of SH was not associated with a change in risk of lameness.

A key novel management risk associated with higher prevalence of lameness was the rate of feet bleeding / 100 ewes trimmed / year. In addition, vaccination of ewes once per year and selecting breeding replacements from never-lame ewes were associated with a decreased risk of lameness. Other factors identified as associated with a lower risk of lameness, for the first time in a random sample of farmers and a full risk model, were recognising lameness in sheep at locomotion score 1 compared with higher scores, treatment of the first lame sheep in a group compared with >5, treatment of lame sheep within 3 days, ease of catching lame sheep and quarantine for >21 days. A previously known factor associated with a lower risk of lameness was footbathing to prevent ID. We conclude that the prevalence of lameness in sheep in England has fallen and that this might be in part because of increased uptake of managements previously reported as beneficial to control lameness. Routine foot trimming should be avoided.

Introduction

Lameness costs the sheep industry in GB £24 - £80 million per annum (Nieuwhof and Bishop, 2005; Wassink, *et al.*, 2010). Financial losses occur because of reduced rates of lambs born and reared and slower growth rates of lame lambs (Wassink, *et al.*, 2010).

In 2004 a random sample of 3000 English sheep farmers were sent a one year retrospective questionnaire requesting information on types of foot lameness (Kaler and Green 2008) and management of lameness in their flock (Kaler and Green 2009). A total of 809 (27%) farmers replied after two reminders. The geometric mean prevalence of lameness was 5.4% (95% CI 4.7 - 6.0) and the global mean prevalence of all lameness was 10.6% with an estimated 6.9%, 3.7%, 2.4%, 1.9%, 0.9% and 0.8% of the sheep lame with at least one of interdigital dermatitis (ID), severe footrot (SFR), contagious ovine digital dermatitis (CODD), shelly hoof (SH), foot abscess and toe granuloma respectively. ID and SFR dominated the within and between flock prevalence of lameness with 80% lame sheep with these two lesions and 90% farmers reporting that it was the most common cause of lameness in their flock.

In the same study, factors associated with a higher annual period prevalence of all lameness (Kaler and Green 2009) were routine foot trimming once or more per year compared with no routine foot trimming, routine footbathing and a stocking density of >8 ewes/ha. Separating lame sheep from sound at pasture was associated with a lower risk of lameness. In other observational studies with non-random samples of farmers, lower farmer reported prevalence of lameness was associated with quarantine of new and returning stock, isolation and treatment of all sheep lame with ID or SFR with parenteral and topical antibacterial treatments (Wassink et al., 2003), footbathing and turning a flock to clean pasture to treat ID (Wassink et al., 2004) and catching the first mildly lame sheep in a group for treatment within 3 days of first becoming lame (Kaler and Green 2008). Factors associated with a higher prevalence of lameness were routine foot trimming (Grogono-Thomas and Johnston, 1997; Kaler and Green, 2009; Wassink, *et al.*, 2003; 2004; 2005), footbathing to treat footrot (Wassink et al., 2003, 2004) and a stocking density >8 ewes/ha (Wassink et al., 2003). Two clinical trials have demonstrated that recovery from footrot is most rapid when sheep are treated with parenteral and topical antibacterials with no paring of the diseased foot (Kaler et al., 2010; 2012).

In 2011 the Farm Animal Welfare Council proposed that the prevalence of lameness in 2004 of 10% should fall to 5% by 2016 and 2% by 2021 (FAWC, 2011) with farmer uptake of existing knowledge. Since 2006 there have been a series of campaigns in England run by AHDB Beef & Lamb (the levy body for beef and sheep farmers) comprising paper and electronic literature and farmer meetings. The aims of the current study were, given the above technology transfer, to test the hypothesis that the prevalence of lameness in sheep had fallen since 2004 and farmers had changed managements of lameness and to identify novel factors associated with low prevalence of lameness in 2013.

Materials and Methods

Questionnaire design and administration

A postal questionnaire (available on request) was developed by a group of researchers at the Universities of Warwick and Nottingham. Part of the questionnaire captured detailed information on the period prevalence of lameness, recognition of four foot lesions, management and treatment of lameness, ID and SFR and details about farm and flock. It was based on previous questionnaires designed for research into sheep lameness, available literature and expertise from within the group. Questions were based on the period May 2012 to April 2013. Most questions were closed or semi-closed with an ‘other’ option.

In June 2013, the questionnaire was sent to 4000 lowland sheep farmers in England with >199 ewes; lists were obtained from DEFRA and AHDB Beef & Lamb who selected flocks randomly stratified by county and size with duplicated farmers removed. Up to two reminder letters, the second with a second copy of the questionnaire, were sent to non-respondents; respondents were sent a thank you acknowledgement.

Data preparation and preliminary analysis

Double data entry was done by an outside agency (Wyman Dillon Ltd, Bristol) and data were stored in Microsoft Excel. Data cleaning was done using specifically written code in Python using Pandas, SciPy and NumPy toolkits (McKinney, 2010; Oliphant, 2007; Pérez and Granger 2007). Data were stored in Microsoft Access.

For each question, frequency distributions and measures of central tendency and dispersion were calculated. Farms were excluded from analysis if data on either the flock size or the annual period prevalence of lameness were missing. The geometric mean and s.e. were calculated for the annual period prevalence of lameness. The global arithmetic mean prevalence of lameness was calculated for the year from the total number of lame sheep divided by the total number of sheep in the study.

Characteristic images and descriptions of four foot lesions (ID, SFR, CODD and SH) were included in the questionnaire (e.g. Figure 1) and farmers were asked what they named each lesion, whether they had seen the lesion in their flock in the period and, if so, what percentage of their ewes had the lesion. It was possible to identify whether farmers were recognising but misnaming a lesion by comparing the distribution of responses of correctly an incorrectly named responses using the techniques described in full elsewhere (Kaler and Green 2008a). The global arithmetic mean prevalence of each lesion and the prevalence of each lesion as a percentage of all lesions were calculated.

From the management questions on routine foot trimming a single variable the rate of feet bleeding / 100 ewes trimmed / year was calculated from the frequency of routine trimming, the percentage of sheep trimmed at each trimming event and the percentage of sheep that bled during each routine trim.

Multivariable modelling of associations between prevalence of foot lesions and lameness and management practices and lameness

Two over-dispersed Poisson regression models (Dohoo, *et al.*, 2003) were used (MLwiN 2.30, (Rasbash, *et al.*, 2014) to estimate univariable and multivariable associations. The outcome variable was the period prevalence of lameness between May 2012 and April 2013 and the first model investigated associations with the four foot lesions and the second with management strategies.

The outcome was the number of lame sheep in the flock offset by the natural logarithm of the expected number of lame sheep in the flock. The model had a log link function and took the form

$$Number\ of\ cases\ on\ \boldsymbol{farm_j} = \boldsymbol{\alpha} + \boldsymbol{offset} + \boldsymbol{\beta j X_j} + \boldsymbol{e_j}$$

Where α is the intercept, $\sim$ is a log link function, *offset* is the natural logarithm of the number of expected lame sheep on each farm, β_j are the coefficients for a vector of X_j explanatory variables which vary by farm j, and e_j is the residual random error.

The prevalence of four foot lesions ID, SFR, CODD and SH were categorised and added into the model as explanatory variables to identify lesions associated with a change in the overall prevalence of lameness reported by farmers.

To investigate the management factors associated with the period prevalence of lameness, variables were grouped into 9 sub-categories and a model built for each sub-category. The sub-categories were recognising and catching lame sheep, treatment of sheep with footrot and interdigital dermatitis, routine flock trimming, flock footbathing, culling and replacement of ewes, vaccination, whole flock antibiotic treatment, biosecurity and characteristics of the farm and farmer.

In each sub-model univariable associations between all explanatory variables and the outcome were screened. Variables were considered significant when the 95% confidence intervals did not include unity (Wald's test for significance). A manual forward selection process (Dohoo, *et al.*, 2003) was used to test variables in the model and significant explanatory variables were retained in the model.

The variables that were significant in the 9 multivariable sub-models were tested in an overall multivariable model which was also built using a manual forward selection process. Significant variables (Wald's test for significance) were retained in the model. All variables, regardless of their inclusion in the sub-models, were re-tested in the final model and included in the model if significant (Cox and Wermuth, 1996). Model fit was assessed using Pearson's residuals against the predicted value.

Associations between variables

The Pearson chi-square test was used to investigate associations between categorical variables. ANOVAs and non-parametric equivalents were used to investigate associations between continuous and categorical variables.

Results

Response rate and descriptive statistics

A total of 1348 questionnaires were returned after two reminders. Questionnaires missing data on flock size or lameness prevalence were excluded from the analysis. There were 1260 (31.5%) usable responses. There were similar response proportions across counties. Some respondents were from hill or upland farms and others have <200 ewes. These factors were added to the models. Not all respondents answered all questions. The median flock size was 350 ewes (IQR: 230-550). The global mean prevalence of lameness in ewes was 4.9%, the data were skewed and the geometric mean period prevalence of ewe lameness per flock was 3.5% (95% CI: 3.3%-3.7%) and lamb lameness was 2.6% (95% CI: 2.3%-2.8%).

Prevalence, proportional prevalence and farmer naming of lesions (Table 1)

The most prevalent foot lesion by farm was ID, which was present on 90.5% of farms. SFR was present on 81.6% of farms, CODD on 48.7% of farms and SH on 67.0% of farms (Table 1). The geometric mean prevalence of lesions within flocks was 4.5% for ID and 3.1% for SFR, 2.3% for CODD and 2.9% for SH. The global mean prevalence of foot lesions was higher than the estimated prevalence of lameness at 10.2%, presumably because not all lesions were associated with lameness (Table 2); ID and SFR together account for 68.0% of lesions. SFR and CODD and SFR and ID were moderately correlated (0.46). Most farmers named ID

(88.5%) and SFR (81.2%) correctly but fewer named CODD (51.0%) and SH (57.6%) correctly. As in 2004, incorrectly identified foot lesions were most commonly misnamed SFR.

Models of four foot lesions associated with lameness (Table 2)

There was a higher RR of lameness in flocks with a prevalence of ID lesions >10% (RR 1.52, 95% CI: 1.20-1.92) compared with farmers who reported no ID lesions in their flocks, however, there was a significantly lower RR of lameness in flocks with a >0-2.5% prevalence of ID (RR 0.72, 95% CI: 0.57-0.91) compared with a zero prevalence of ID.

The RR of lameness was significantly higher in flocks as the prevalence of SFR lesions increased from >2.5-5% - >10% compared with flocks without SFR lesions. The RR of lameness was significantly higher in flocks with a prevalence of CODD of >2.5-5% - >10% compared with flocks without CODD lesions. There was a significantly lower RR of lameness in flocks with a low (<2.5%) prevalence of SH (RR 0.85, 95% CI: 0.75-0.97) compared to a zero prevalence of shelly hoof. Higher prevalences of SH were not associated with higher RR of lameness. There were strong positive correlations between the prevalence lesions.

Multivariable over dispersed Poisson model of management factors associated with the period prevalence of lameness in sheep (Table 3)

The variables and nine sub-models on management factors associated with the period prevalence of lameness are presented in Supplementary Tables 1 and 2. There has been an increase in the percentage of farmers who have stopped routine and therapeutic foot trimming and started to use vaccination, select replacements from non-lame ewes and always-use parenteral antibiotics to treat footrot (Supplementary tables).

In the final model, the RR of lameness was higher in flocks when farmers recognised sheep lame with a locomotion score (Kaler et al., 2009) of 2 (RR 1.19, 95% CI: 1.08-1.30) compared with a score of 1. The RR of lameness in the flock was higher when farmers waited until 6-10 sheep (RR 1.28, 95% CI: 1.08-1.52) or more than 10 sheep in a group were lame (RR 1.37, 95% CI: 1.16-1.62) compared with farmers who treated the first lame sheep in a group. The RR of lameness was higher in flocks where farmers treated sheep within a week (RR 1.36, 95% CI: 1.10-1.66) or longer than a week (RR 1.43, 95% CI: 1.14-1.80) compared with flocks where sheep were treated the first day farmers saw them lame; approximately 50% farmers waited a week or more before treating lame sheep. The RR of lameness was higher when farmers reported that catching individual lame sheep was difficult / very difficult (RR 1.13, 95% CI 1.00 - 1.28).

Farmers who reported none or <1 / 100 ewes / year feet bled during routine foot trimming did not have a significantly different RR of lameness in their flocks compared with farmers who did not routinely trim sheep feet. The RR was higher in flocks where 1 - <5% of sheep bled (RR 1.33, 95% CI: 1.19-1.49), 5 - 10% (RR 1.39, 95% CI: 1.18-1.63) or >10% of sheep bled (RR 1.69, 95% CI: 1.43-1.99).

Footbathing all ewes for any reason was not associated with a significantly different RR of lameness from never footbathing ewes. However, footbathing specifically to treat footrot was associated with a higher risk of lameness (RR 1.12, 95% CI: 1.01-1.24) compared with not footbathing for this reason, whilst footbathing to prevent ID was associated with a lower risk of lameness in the flock (RR 0.87, 95% CI: 0.79-0.96) compared with not footbathing to prevent ID. Footbathing at turnout, (RR 1.31, 95% CI: 1.07-1.59) and new sheep on arrival was associated with a higher risk of lameness (RR 1.18, 95% CI: 1.05-1.33) compared with not footbathing at these times.

Overall, culling sheep that had previously been lame was not associated with a significant change in the RR of lameness in the flock, regardless of the number of times that sheep had been lame before they were culled. However, flocks where farmers relied on their memory to identify sheep for culling had a higher RR of lameness (RR 1.22, 95% CI: 1.08-1.38) than flocks not managed in this way. Farmers who avoided selecting replacement ewes from mothers who were repeatedly lame had a lower RR of lameness (RR 0.77, 95% CI: 0.60-0.99) compared with farmers who did not practice this management. Flocks vaccinated with Footvax (MSD Animal Health) had a lower RR of lameness (RR 0.80, 95% CI: 0.71-0.90) than flocks not vaccinated.

Farmers who “sometimes” checked the feet of new sheep on arrival had a lower RR of lameness in their flocks (RR 0.81, 95% CI: 0.69-0.95) than flocks where farmers who “never” checked. Flocks where new sheep were isolated on arrival for more than three weeks had a lower RR of lameness (RR 0.82, 95% CI: 0.70-0.95) compared with flocks where new sheep were not isolated. Where sheep left the farm and then returned the RR of lameness was higher when sheep left for sheep shows, (RR 1.30, 95% CI: 1.08-1.56) and summer grazing (RR 1.19, 95% CI: 1.07-1.33) compared with flocks that did not leave for these reasons. Flocks where sheep left for market and later returned had a lower RR of lameness (RR 0.72, 95% CI: 0.53-0.96) compared with flocks that did not leave for this reason.

The RR of lameness was lower in hill flocks (0.70, 95% CI: 0.52-0.92) and lowland flocks (RR 0.82, 95% CI: 0.73-0.93) than upland flocks. The RR of lameness was lower on organic farms (RR 0.69, 95% CI: 0.54-0.88) than non-organic. Farmers whose flocks produced breeding stock had a lower RR of lameness (RR 0.87, 95% CI: 0.79-0.97) compared with flocks that did not produce breeding stock. The prevalence of lameness in lambs was positively associated with the prevalence of lameness in ewes; RR 1.03 (95% CI: 1.03-1.04) for each percent increase in lamb lameness. Increasing flock size was associated with a lower RR of lameness (RR 0.74, 95% CI: 0.63-0.86) for each log10 increase in flock size.

The plot of Pearson residuals against the predicted values (Supplementary Figure 1) indicated the model was a good fit.

Discussion

This paper is the first study of a random sample of English sheep flocks since 2004 (Kaler and Green, 2008b); we provide new evidence that the period prevalence of lameness in sheep in England has fallen from 2004 to 2013 from a global mean of 10.6% to 4.9% and a geometric flock mean of 5.4% (sheep) to 3.5% (ewes) and 2.6% (lambs). The 2013 figures were for ewes only whereas the 2004 figures were asked for ‘sheep’ and the period lameness for lambs was less than that for ewes, so it is possible that the prevalence of lameness has fallen more than to 3.5% for all sheep. In addition, the distribution of lesions causing lameness has changed and CODD is now contributing significantly to the prevalence of lameness.

This is the first observational study to provide evidence that routine foot trimming is associated with a higher prevalence of lameness when feet are trimmed and bleed and that prompt treatment of the first lame sheep in a group is associated with a lower prevalence of lameness, that quarantine for > 3 weeks, vaccination against footrot and selection of replacement stock from never-lame ewes have small but significant effects on reducing the period prevalence of lameness. Changes in management have also occurred with farmers adopting new recommendations when one compares farmers' responses to the two questionnaires. These new findings, together with other significant risk factors, are discussed below.

Previous studies have reported an association between routine foot trimming and higher flock prevalence of lameness (Kaler and Green, 2009; Wassink, *et al.*, 2003); this is the first study to report that this association is due to the rate of sheep whose feet bleed when routinely trimmed. There was a biological gradient (dose effect) adding to the weight of evidence for a causal relationship (Bradford Hill, 1965). Once the rate of bleeding was accounted for, routine trimming alone was not significantly associated with the prevalence of lameness. We conclude that it is damage to living tissue in the foot that causes lameness (either directly or through increased susceptibility to pathogens) rather than trimming itself. Routine foot trimming was not significantly associated with prevalence of lameness once adjusted for the percentage of feet bleeding (Table 3) and this indicates that there is no benefit to lameness prevalence from routine foot trimming. In the current study 57% of farmers were practising routine foot trimming, this is a substantial reduction from the 2004 estimate of 76% of farmers (Kaler and Green, 2009); farmers are changing their habits and this might be in part because of technology transfer. Reduction in foot trimming practices might also explain some of the reduction in the geometric mean prevalence of lameness from 2004 (Kaler and Green, 2008a; Kaler and Green, 2009) because if feet are not trimmed there is no risk of them being over trimmed and bleeding. Given that it takes one working week for a farmer to trim 500 ewes (Wassink, *et al.*, 2005), this practice uses a considerable amount of time. The results from the current study therefore add weight to the proposal that routine foot trimming should not be practised.

This is also the first study to capture information on time to treatment and number of lame sheep to initiate treatment in a random sample of farmers and in a model with all managements recorded; indications that these factors are important in management of lameness were first reported by Kaler and Green (2008b) in a study of farmer recognition of lameness in sheep. Previous papers have reported the impact of treating sheep lame at locomotion score ≥2 (Kaler, *et al.*, 2011; Wassink, *et al.*, 2010) and Kaler *et al*., (2009) and Angell et al., (2015) reported that a locomotion score of ≥2 is a highly reliable score to detect lame sheep but that score 1 has less reliability. In the current study, the locomotion score (Kaler et al., 2009) at which farmers recognised lameness was highly correlated with the score at which they caught sheep for treatment; and farmers who waited until sheep were locomotion score ≥2 had a higher prevalence of lame sheep than those treating sheep at score ≥1. This suggests that farmers are able to recognise this low score consistently, possibly because they become sensitised to identifying lame sheep. If farmers are now reporting lameness from sheep with locomotion score 1, it is therefore possible that the prevalence of lameness has fallen more than indicated by the results when previously farmers routinely reported sheep with locomotion score >1 as lame (King and Green, 2011).

Waiting until more than five sheep were lame before treating individual lame sheep was associated with significantly higher prevalence of lameness (Table 3). Cure rates without treatment are low (Wassink, *et al.*, 2010), and so delaying treatment until more sheep are lame for longer maintains the prevalence of lameness. Treating the first lame sheep in a group promptly will also reduce the incidence of new cases of lameness caused by infectious diseases. For footrot, the bacterial load of *Dichelobacter nodosus* on the feet of sheep with signs of ID is high (Witcomb, *et al.*, 2014), indicating that these sheep are infectious and contribute to the spread footrot. Delay in time to treatment might also occur when farmers found it difficult to catch lame sheep; these flocks had a higher prevalence of lameness. The results from the current study reinforce the efficacy of prompt individual treatment, both to cure individual sheep (Kaler, *et al.*, 2010) and to reduce the spread of disease through the flock (Wassink, *et al.*, 2010).

Recent evidence indicates that rapid cure from footrot (both ID and SFR) occurs when sheep are treated with parenteral and topical antibiotics and that therapeutic foot trimming reduces the rate of recovery (Kaler, *et al.*, 2010; Kaler, *et al.*, 2012; Wassink, *et al.*, 2010). The proportion of farmers who treated all cases of footrot with parenteral and topical antibiotics increased from 10% (where farmers stated they treated 100% sheep) in 2004 (Kaler and Green, 2009) to 24% (where farmers stated they 'always' treated such sheep) in 2013, the proportion who trimmed the feet of all lame sheep fell from 69% to 44%. Because SFR and ID accounted for 90% lameness in 2004, these changes in management have also probably contributed to the decrease in the absolute prevalence of lameness between observed in 2013 and the relative proportion attributable to footrot and ID. However, as in Kaler and Green (2009), individual treatments with antibiotic injections and topical spray or therapeutic foot trimming were not significantly associated with the prevalence of lameness in the multivariable model in the current study (Table 3). This could be because there is still an insufficient proportion of farmers always using the recommended treatments (Supplementary tables) or because not all lameness (the outcome in our model) is caused by ID and SFR. It is also likely that the time to treatment overrides the treatment given; for example, a farmer that always using antibiotic treatment but treats sheep less than once a week would still have a high prevalence of lameness in their flock because of the generation time of footrot. There was no correlation between time to treatment and the type of treatment used but, as discussed above, rapid time to treatment was associated with a low prevalence of lameness.

The efficacy of Footvax (MSD Animal Health) has been reported in several clinical trials (Glenn, *et al.*, 1985; Hindmarsh, *et al.*, 1989; Lewis, *et al.*, 1989; Morck, *et al.*, 1994; MSDAnimalHealth, 2014). In all these trials the initial prevalence of lameness was high (10 - 50%), with vaccination with Footvax reported to reduce the prevalence of footrot by 60-90% (Glenn, *et al.*, 1985; Hindmarsh, *et al.*, 1989; Lewis, *et al.*, 1989). This is the first observational study to demonstrate a reduced risk of lameness in flocks that vaccinated ewes with Footvax; previous studies, where few farmers were vaccinating all ewes at least once a year, have not reported a significant association (Kaler and Green, 2009; Wassink, *et al.*, 2003). In the current study approximately 10% farmers were vaccinating ewes at least once per year and the results indicate that vaccination contributed a small, but significant, reduction in the prevalence of lameness of approximately 20%. These results are consistent with what is known about the vaccine, that it has low efficacy and can contribute to reducing the prevalence of footrot when used with other management practices. In addition to reducing susceptibility through vaccination there was a small but significant effect from farmers selecting offspring from never-lame ewes for replacement breeding stock. The heritability of footrot resistance is estimated at about 10% (Bishop, *et al.*, 2010). It is therefore interesting to report that this is detectable through an observational study.

As in previous studies, footbathing to prevent ID was associated with a lower risk of lameness (RR 0.87) whilst footbathing to treat SFR was associated with an increased risk (RR 1.12) (Table 3) (Kaler and Green, 2009; Wassink, *et al.*, 2003; 2004) and is quite logical because footbaths contain disinfectants (e.g. formalin, zinc sulphate) that can disinfect the surface of the foot but cannot penetrate to treat infection deep in the foot and so only superficial infection is likely to respond to footbathing. In the current study, footbathing was linked to behaviours that were associated with higher prevalence of lameness (delaying treatment of lame sheep for more than three days or until more than five sheep in a group were lame, an increased proportion of sheep bleeding during routine foot trims and delaying culling until sheep had been lame more than twice or were persistently lame, Supplementary Tables 3 and 4). These results suggest that footbathing may not truly increase the risk of lameness but because it is correlated with a sufficient number of factors that do increase the risk of lameness; footbathing identifies of a group of flocks managed in this way. Alternatively, the risk of lameness may be increased by close gathering sheep; if some sheep in the group are lame, bringing these sheep into close proximity to other sheep of recently used facilities contaminated by sheep with footrot (Whittington, 1995) may facilitate transmission of *D. nodosus.* Whatever the situation, footbathing groups of sheep is still practised by 60% of farmers, using a variety of products, but there is little evidence of its usefulness except to treat or prevent ID.

Culling sheep lame twice or more is strongly recommended in the UK without an evidence base other than case studies, although not many farmers are practising this recommendation (Table 3). In the current study, although culling sheep that had been lame more than once was significant at the univariable level (Supplementary Table 1) and in the multivariable sub-model (Supplementary Table 2), it was not significant in the final model. This may be because farmers are still inconsistent in this practice or because farmers who treated individual lame sheep promptly were less likely to cull previously lame sheep. Prompt treatment results in high cure rates, lower reoccurrence, better foot conformation and low flock prevalence of lameness (Kaler, *et al.*, 2010; Wassink, *et al.*, 2010) and so it is possible that farmers who treated lame sheep promptly and appropriately had no need to cull sheep. Among the poor practices for culling, relying on memory to identify sheep for culling was associated with not culling sheep until they had been lame more than twice or were persistently lame and with causing bleeding during routine foot trims; all of these managements were associated with higher prevalences of lameness.

Quarantine of new sheep on arrival was associated with a decreased risk of lameness only if sheep were isolated for more than 3 weeks. This has been a suggested management but never with an evidence base. It has been hypothesised that sheep with footrot are most infectious in the early stages of disease (Witcomb, *et al.*, 2014), and so isolating for more than 3 weeks means that disease can be recognised and treated before new sheep are introduced into the flock. The incubation period for CODD is unknown and so duration of quarantine to prevent introduction of CODD is unknown. Sheep leaving the farm and later returning were associated with an increased or decreased risk of lameness depending on the reason for re-introduction. Increased prevalence of lameness would arise from increased exposure to pathogens, exposure to new strains of pathogens, poor biosecurity or lack of treatment (shows, summer grazing) and reduced prevalence might arise from a cold climate and naïve pasture (e.g. winter grazing).

Some of the results from this paper used farmer naming of foot lesions. There has been no substantial change in the percentage of farmers correctly naming SFR (85%

in 2004 and 81% in 2013) or ID (83% in 2004 and 89% in 2013) over the last ten years. In contrast, the percentage of farmers correctly naming CODD has risen from 36% to 51% and SH has risen from 28% in 2004 (Kaler and Green, 2008a) to 58% in 2013 (Table 1). The misclassification of other lesions as SFR has decreased but remains substantial (Table 1). As in Kaler et al., (2008b), in 2013 when farmers named lesions incorrectly they ascribed the lesion to the correct name, it is therefore not a misclassification but a misnaming. Data were managed as in 2004 to account for the misnaming of lesions. Approximately 68% of foot lesions in flocks in 2013 were one of the two forms of footrot, ID or SFR (Table 1). Using farmer reported lameness (farmers estimate the prevalence of lameness similar to a trained researcher but with some underestimation once lameness reaches a prevalence of 10% (Kaler and Green, 2008b; King and Green, 2011)), and the multivariable model (Table 2) we conclude that the prevalence of SFR and CODD contribute most to the prevalence of lameness. There is much discussion about SH in the UK and some farmers consider it a major cause of lameness in their flock, however, shelly hoof did not contribute significantly to the prevalence of lameness in the current study, despite accounting for approximately 20% of all foot lesions.

This was a large study of English sheep flocks selected from the whole population of flocks in England using stratified random sampling. The response rate was reasonable and there is no evidence for response bias by geographical location. The data were selected to omit hill and upland farms and flocks <200 ewes, however, some flocks were in hill or upland areas with <200 ewes because the data for selection were not entirely accurate. These flocks were included in the models and flock size and lowland, hill, upland included in the model as explanatory variables. The sample would not necessarily be representative of hill and upland flocks.

Conclusions

This is the first observational study to demonstrate that it is the proportion of sheep feet that bleed during routine foot trimming that is associated with a higher prevalence of lameness and that there is no benefit to foot health from routine foot trimming when no sheep bleed compared with not routine foot trimming. It is also the first to quantify the association between prompt treatment (within three days, and when less than five sheep were lame, ease of catching sheep) and lower prevalence of lameness, and a lower prevalence of lameness in flocks where the farmer recognised and treated sheep lame at locomotion score 1 rather than >1. It is also the first to demonstrate a lower period prevalence of lameness in flocks where ewes were vaccinated with Footvax compared with unvaccinated flocks and where never-lame ewes were used to provide future breeding animals. Factors that continued to be associated with low prevalence of lameness were inspection and isolation of purchased and returning sheep and factors associated with a higher prevalence included footbathing and a higher prevalence of lameness in lambs. There has been an increase in the percentage of farmers who have stopped routine and therapeutic foot trimming and started to use vaccination, select replacements from non-lame ewes and always-use parenteral antibiotics to treat footrot (Supplementary tables). This indicates that results from previous research is being adopted by sheep farmers. The results from the model indicate that these changes in management might explain some the reduction in geometric mean prevalence of lameness in sheep from 5.4% in 2004 when the last random survey of farmers was done to 2.6% - 3.5% in 2013. Prompt treatment of lame sheep still remains a barrier to further reduce the prevalence of lameness in sheep in England.

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Table 1: The number and percentage of flocks by four foot lesions, correlations between prevalence of lesions and farmer ability to name lesions

	ID	Severe footrot	CODD	Shelly hoof
Number (%) of flocks	897 (90.5)	735 (81.6)	447 (48.7)	601 (67.0)
*Geometric mean prevalence of lesion (%)	4.5	3.1	2.3	2.9
*Proportional prevalence	42.9	25.1	11.7	20.3
Correlations between flock prevalence of lesions P<0.001				
ID				
Severe footrot	0.465			
CODD	0.284	0.460		
Shelly hoof	0.334	0.240	0.187	
Farmer name			Correct name	
Footrot (severe footrot)	81.2	5.7	22.2	17.5
ID	1.8	88.5	1.4	0.2
CODD	4.6	0.6	51.0	2.6
Shelly hoof	2.4	0.8	7.1	57.6
Other	0.3	0.8	0.8	1.4
No answer	9.8	5.1	17.5	20.7

ID: interdigital dermatitis, **CODD**: contagious ovine digital dermatitis
*Only farms where the lesion was present were included in prevalence estimates

Table 2: Multivariable overdispersed Poisson regression model of associations between foot lesions and the proportion of lame sheep on 1207 flocks 2012 - 2013

Variable	Number	%	RR	95% CI	
Prevalence of ID					
Zero	72	6.0	1.00		
>0 - 2.5%	289	23.9	**0.72**	0.57	0.91
>2.5 - 5%	414	34.3	1.05	0.84	1.30
>5 - 10%	215	17.8	1.14	0.91	1.43
>10%	110	9.1	**1.52**	1.20	1.92
Prevalence of SFR					
Zero	139	11.5	1.00		
>0 - 2.5%	420	34.8	0.90	0.75	1.08
>2.5 - 5%	332	27.5	**1.26**	1.05	1.51
>5 - 10%	150	12.4	**1.62**	1.33	1.98
>10%	58	4.8	**2.35**	1.89	2.93
Prevalence of CODD					
Zero	421	34.9	1.00		
>0 - 2.5%	373	30.9	**1.13**	1.00	1.26
>2.5 - 5%	163	13.5	**1.35**	1.18	1.53
>5 - 10%	55	4.6	**1.73**	1.46	2.06
>10%	37	3.1	**1.49**	1.23	1.80
Prevalence of shelly hoof					
Zero	234	19.4	1.00		
>0 - 2.5%	413	34.2	**0.85**	0.75	0.97
>2.5 - 5%	216	17.9	1.05	0.92	1.20
>5 - 10%	104	8.6	1.03	0.88	1.21
>10%	64	5.3	0.77	0.63	0.94

N: number, **%**: percent, **RR**: risk ratio, **CI**: confidence interval, **ID**: interdigital dermatitis, **SFR**: severe footrot, **CODD**: contagious ovine digital dermatitis

Risk Ratios that are significantly different from the baseline (according to Wald's test for significance) are marked in **bold**

Table 3: Multivariable over dispersed-Poisson regression model of factors associated with the proportion of lame sheep on 1207 English farms, May 2012 - April 2013

Variable		Number	%	RR	95% CI	
Lowest locomotion score at which the farmer recognised sheep as lame						
1		620	52%	1.00		
2		417	35%	**1.19**	1.08	1.30
3+		155	13%	0.95	0.82	1.09
Number of sheep lame at locomotion score when farmers treated them						
1		163	14%	1.00		
2-5		608	52%	1.12	0.97	1.31
6-10		216	18%	**1.28**	1.08	1.52
10 +		185	16%	**1.37**	1.16	1.62
Did not treat individuals		8	1%	1.45	0.94	2.24
Time to treatment of lame sheep						
First day		82	7%	1.00		
Within 3 days		506	43%	1.13	0.92	1.39
Within a week		462	39%	**1.36**	1.10	1.66
More than a week		136	11%	**1.43**	1.14	1.80
Ease of catching individual lame sheep						
Easy / Very easy		250	21%	1.00		
Neither easy nor difficult		539	46%	1.02	0.91	1.15
Difficult / Very difficult		393	33%	**1.13**	1.00	1.28
Method of catching individual sheep						
Corner of field	No	848	70%	1.00		
	Yes	360	30%	**0.88**	0.80	0.97
Dog that can catch individuals	No	848	70%	1.00		
	Yes	360	30%	**1.20**	1.07	1.34
Percentage of sheep that bled during a routine foot trim, per year						
Did not trim		499	44%	1.00		
Zero		64	6%	1.10	0.86	1.39
< 1%		179	16%	0.99	0.86	1.13
1 - <5%		257	23%	**1.33**	1.19	1.49
5 - <10%		71	6%	**1.39**	1.18	1.63
10% +		61	5%	**1.69**	1.43	1.99
Footbath all ewes ever 2012 - 2013						
	No	485	40%	1.00		

	Yes	723	60%	1.11	0.97	1.26
Footbath to treat footrot	No	769	64%	1.00		
	Yes	439	36%	**1.12**	1.01	1.24
Footbath to prevent ID	No	779	64%	1.00		
	Yes	429	36%	**0.87**	0.79	0.96
Occasion footbathed						
At turnout	No	1,156	96%	1.00		
	Yes	52	4%	**1.31**	1.07	1.59
New sheep on arrival	No	767	63%	1.00		
	Yes	202	17%	**1.18**	1.05	1.33
No new sheep		238	20%	1.12	0.75	1.67
Culled sheep previously lame	No	646	56%	1.00		
	Yes	498	44%	1.03	0.94	1.13
Relied on memory to identify culls	No	1,046	87%	1.00		
	Yes	162	13%	**1.22**	1.08	1.38
Avoided selecting breeding ewes to sell from mothers that were repeatedly lame	No	1,170	97%	1.00		
	Yes	38	3%	**0.77**	0.60	0.99
Vaccinated ewes with Footvax	No	1010	84%	1.00		
	Yes	198	16%	**0.80**	0.71	0.90
Checked feet of new sheep on arrival						
Never		147	13%	1.00		
Sometimes		151	13%	**0.81**	0.69	0.95
Usually		242	21%	0.94	0.81	1.09
Always		387	33%	0.89	0.78	1.03
No new arrivals		239	20%	0.87	0.48	1.57
Isolated new sheep on arrival						
Did not isolate new sheep		152	13%	1.00		
Isolated for < 3 weeks		465	40%	0.93	0.80	1.08
Isolated for > 3 weeks		316	27%	**0.82**	0.70	0.95
No new arrivals		228	20%	0.87	0.52	1.46
Sheep left farm then returned						
For shows	No	1,157	96%	1.00		
	Yes	51	4%	**1.30**	1.08	1.56
For summer grazing	No	1,031	85%	1.00		
	Yes	177	15%	**1.19**	1.07	1.33
For market	No	1,177	97%	1.00		

	Yes	31	3%	**0.72**	0.53	0.96
Farm location						
Upland		120	10%	1.00		
Hill		31	3%	**0.70**	0.52	0.92
Lowland		1032	87%	**0.82**	0.73	0.93
Organic status						
Not organic		1124	95%	1.00		
Organic		63	5%	**0.69**	0.54	0.88
Production of breeding stock						
	No	880	73%	1.00		
	Yes	328	27%	**0.87**	0.79	0.97
Flock size (log 10)						
Each 10-fold increase in flock size		1208	100%	**0.74**	0.63	0.86
Lamb lameness prevalence						
1% increase in prevalence		1178	98%	**1.03**	1.03	1.04

N: number, **%**: percent, **RR**: risk ratio, **CI**: confidence interval
Risk Ratios that are significantly different from the baseline (according to Wald's test for significance) are marked in **bold**.

Model coefficient: 0.427, **Standard Error**: 0.247

Figure 1: An example question investigating farmer ability to name common foot lesions

What you might notice when you look at the foot	Example picture of the lesion	7. What did you call this lesion? *Circle only one answer in each box below*	8. Did you see this lesion in your flock between May 2012 and April 2013? *Circle one answer and fill in % for each box below*
• Red, wet interdigital space • Foul smell • May be grey pasty scum • Loss of hair in interdigital space		**Footrot** **Scald** **CODD** **Shelly hoof** **Other** ***(please state)***	**Yes** ***If yes,*** **what percentage of ewes** **had this lesion?___________%** **No** **Do not know**

Supplementary material

Supplementary Table 1. The number and percentage of farmers using different management strategies relating to lameness, and the geometric mean prevalence of lameness for each group of farmers

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
Lowest locomotion score at which farmer recognised sheep lame					
1	622	52.0	3.1	2.9	3.4
2	419	35.0	4.1	3.7	4.4
3	136	11.4	4.1	3.6	4.8
4+	19	1.6	4.8	3.1	7.4
Lowest locomotion score at which farmer caught lame sheep for treatment					
1	313	26.3	3.1	2.8	3.5
2	488	41.0	3.8	3.5	4.1
3	303	25.5	3.8	3.4	4.1
4	62	5.2	4.1	3.4	5.0
5	8	0.7	4.0	2.2	7.6
6	1	0.1	5.0	-	-
Did not treat individuals	14	1.2	1.3	0.3	5.6
Number lame at above score when farmers caught lame sheep for treatment					
1	163	13.8	2.5	2.1	2.9
2-5	608	51.4	3.3	3.1	3.6
6-10	216	18.2	4.6	4.1	5.2
> 10	185	15.6	5.0	4.4	5.6
Did not treat individuals	12	1.0	0.8	0.2	3.9
Time to treatment for lame sheep					
First day	82	6.9	2.4	1.9	3.0
Within 3 days	506	42.5	3.2	2.9	3.5
Within 1 week	462	38.8	4.2	3.9	4.5
Within 2 weeks	115	9.7	4.6	3.9	5.4
Longer than 2 weeks	21	1.8	5.1	3.3	7.9
Did not treat any lame sheep	4	0.3	0.0	0.0	0.3
Ease of catching individual lame sheep					
Very difficult	49	4.1	4.4	3.5	5.5
Difficult	344	29.0	3.9	3.6	4.3
Neither easy nor difficult	541	45.7	3.5	3.3	3.8

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
Easy		202	17.0	3.4	3.0	4.0
Very easy		49	4.1	2.6	1.9	3.7
Methods of catching individual lame sheep						
Central handling facility	No	511	42.3	3.2	2.9	3.5
	Yes	696	57.7	3.9	3.6	4.1
Mobile handling facility	No	947	78.5	3.6	3.4	3.9
	Yes	260	21.5	3.3	3.0	3.7
Corner of field	No	847	70.2	3.6	3.3	3.8
	Yes	360	29.8	3.5	3.2	3.9
Dog to gather flock	No	836	69.3	3.6	3.3	3.8
	Yes	371	30.7	3.6	3.2	3.9
Dog to catch individuals	No	1031	85.4	3.6	3.4	3.8
	Yes	176	14.6	3.3	2.8	3.8
Food	No	822	68.1	3.6	3.3	3.8
	Yes	385	31.9	3.6	3.2	3.9
From vehicle	No	1050	87.0	3.6	3.4	3.8
	Yes	157	13.0	3.3	2.9	3.7
Frequency of trimming the feet of ewes lame with footrot						
Never		33	2.9	1.8	1.2	2.7
Sometimes		222	19.7	3.5	3.1	3.9
Usually		382	33.9	3.9	3.6	4.2
Always		490	43.5	3.8	3.5	4.1
Frequency of treating ewes lame with footrot with antibiotic injection						
Never		82	7.3	2.8	2.2	3.6
Sometimes		475	42.2	3.9	3.7	4.3
Usually		295	26.2	4.0	3.7	4.4
Always		273	24.3	3.2	2.9	3.6
Frequency of treating ewes lame with footrot with antibiotic spray						
Never		25	2.2	2.0	1.0	3.8
Sometimes		108	9.5	3.5	2.9	4.2
Usually		258	22.6	3.8	3.4	4.2
Always		751	65.8	3.8	3.6	4.0
Frequency of separating ewes lame with footrot from the flock						
Never		508	47.6	3.6	3.3	3.9
Sometimes		472	44.2	3.9	3.7	4.2
Usually		61	5.7	2.9	2.1	4.0

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
Always		26	2.4	3.0	1.9	4.9
Type of foot spray used to treat sheep with footrot or ID						
Lincospectin solution	No	1084	89.8	3.5	3.3	3.7
	Yes	123	10.2	3.9	3.4	4.5
Antibiotic aerosol	No	165	13.7	2.7	2.2	3.3
	Yes	1042	86.3	3.7	3.5	3.9
Disinfectant aerosol	No	1054	87.3	3.6	3.4	3.8
	Yes	153	12.7	3.4	2.9	4.0
Did not use	No	1192	98.8	3.6	3.4	3.8
	Yes	15	1.2	1.2	0.4	3.0
Injectable antibiotic used to treat sheep with footrot or ID						
Oxytetracycline LA	No	458	37.9	3.2	2.9	3.5
	Yes	749	62.1	3.8	3.6	4.0
Draxxin	No	1189	98.5	3.6	3.4	3.8
	Yes	18	1.5	2.4	1.6	3.4
PenStrep	No	788	65.3	3.5	3.3	3.8
	Yes	419	34.7	3.6	3.3	3.9
Did not use	No	1137	94.2	3.6	3.4	3.8
	Yes	70	5.8	2.6	2.0	3.4
Frequency of routine foot trimming						
Never		501	42.7	3.0	2.8	3.3
Once		408	34.8	3.6	3.2	4.0
Twice		186	15.8	4.4	3.9	5.0
More than twice		79	6.7	5.3	4.3	6.6
Approximate number of sheep trimmed during a routine trim						
<25%		221	30.5	3.5	3.1	3.9
25%		122	16.9	4.7	4.0	5.6
50%		70	9.7	5.1	4.1	6.2
75%		78	10.8	4.3	3.6	5.1
100%		233	32.2	3.6	3.2	4.1
Approximate percentage of sheep that bled during a routine foot trim						
Did not trim		501	43.3	3.0	2.8	3.3
0		70	6.0	2.3	1.6	3.2
0< - 1		187	16.1	3.4	3.0	3.9
1< - 2		130	11.2	3.8	3.2	4.4
2< - 3		50	4.3	4.3	3.5	5.2

Variable		All responses N	%	Prevalence of lameness Geometric Mean	95% CI	
3<		220	19.0	5.6	5.1	6.3
Flock footbathing ewes						
	No	484	40.1	2.9	2.7	3.2
	Yes	723	59.9	4.1	3.8	4.3
Flock footbathing lambs						
	No	521	43.2	3.1	2.8	3.4
	Yes	686	56.8	4.0	3.7	4.3
Reason for footbathing						
Treating ID	No	613	50.8	3.2	2.9	3.4
	Yes	594	49.2	4.0	3.8	4.3
Treating footrot	No	768	63.6	3.1	2.9	3.3
	Yes	439	36.4	4.5	4.2	4.9
Preventing ID	No	778	64.5	3.5	3.2	3.7
	Yes	429	35.5	3.7	3.4	4.1
Preventing footrot	No	780	64.6	3.4	3.2	3.6
	Yes	427	35.4	3.9	3.6	4.3
Substance used for footbathing						
Zinc sulphate	No	956	79.2	3.5	3.3	3.7
	Yes	251	20.8	3.9	3.4	4.3
Copper sulphate	No	1136	94.1	3.5	3.3	3.7
	Yes	71	5.9	4.6	3.9	5.4
Formalin	No	643	53.3	3.2	2.9	3.5
	Yes	564	46.7	4.0	3.7	4.3
Lincospectin	No	1088	90.1	3.5	3.3	3.7
	Yes	119	9.9	4.2	3.6	4.9
Occasion when sheep were footbathed						
Before Housing	No	951	78.8	3.4	3.2	3.6
	Yes	256	21.2	4.3	3.9	4.7
At turnout	No	1155	95.7	3.5	3.3	3.7
	Yes	52	4.3	4.2	3.3	5.3
Moving between fields	No	966	80.0	3.3	3.1	3.6
	Yes	241	20.0	4.6	4.1	5.0
After gathering	No	852	70.6	3.3	3.1	3.5
	Yes	355	29.4	4.3	3.9	4.7
New sheep on arrival	No	775	64.2	3.5	3.3	3.8
	Yes	202	16.7	4.1	3.6	4.6

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
No new sheep		230	19.1	3.2	2.8	3.6
Sheep returning to farm	No	1103	91.4	3.5	3.3	3.7
	Yes	104	8.6	4.7	4.1	5.4
Frequency of routine footbathing of ewes at pasture						
Once a week		8	1.3	4.6	2.6	8.0
Once a fortnight		78	12.9	4.4	3.8	5.2
Once a month		216	35.6	4.6	4.2	5.2
Other		20	3.3	3.5	2.5	4.9
Did not routinely footbath ewes at pasture		284	46.9	3.3	2.9	3.7
Frequency of routine footbathing lambs at pasture						
Once a week		16	2.6	5.9	4.2	8.4
Once a fortnight		93	14.8	4.3	3.6	5.0
Once a month		199	31.7	4.3	3.9	4.8
Other		14	2.2	2.7	2.0	3.7
Did not routinely footbath lambs at pasture		305	48.6	3.3	2.9	3.8
Frequency of routine footbathing ewes when housed						
Once a week		34	4.6	4.1	3.2	5.4
Once a fortnight		53	7.1	4.8	3.9	5.9
Once a month		85	11.4	4.5	3.9	5.2
Other		4	0.5	3.8	2.5	5.8
Did not routinely footbath ewes when housed		368	49.5	3.8	3.5	4.2
Did not house ewes		199	26.8	3.3	2.9	3.8
Frequency of routine footbathing lambs when housed						
Once a week		28	3.8	3.9	3.1	5.0
Once a fortnight		43	5.9	5.5	4.3	7.1
Once a month		28	3.8	4.0	3.1	5.1
Other		4	0.5	3.8	2.5	5.8
Did not routinely footbath lambs housed		180	24.6	3.9	3.3	4.5
Did not house lambs		448	61.3	3.7	3.4	4.1
Cull sheep when they are lame						
No		783	66.9	3.4	3.1	3.6
Yes		387	33.1	4.0	3.6	4.3
Cull sheep that had been lame previously						
No		648	56.5	3.4	3.2	3.7
Yes		499	43.5	3.7	3.4	4.0

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
Number of lameness episodes prior to culling						
Did not cull		626	54.7	3.4	3.1	3.7
1		38	3.3	1.7	1.1	2.7
1< - 2		142	12.4	3.3	2.9	3.8
2<		299	26.1	4.2	3.9	4.6
Persistently lame		40	3.5	4.3	3.4	5.4
Method for identifying sheep for culling						
Memory	No	1045	86.6	3.4	3.2	3.6
	Yes	162	13.4	4.5	3.9	5.0
EID ear tag	No	1148	95.1	3.6	3.4	3.8
	Yes	59	4.9	3.2	2.5	4.3
non-EID tag	No	1074	89.0	3.5	3.3	3.8
	Yes	133	11.0	3.7	3.2	4.2
Coloured spray	No	764	63.3	3.4	3.2	3.7
	Yes	453	37.5	3.8	3.5	4.1
Avoid selection of replacement ewes from mothers that were repeatedly lame						
Not at all	No	672	55.7	3.4	3.2	3.7
	Yes	535	44.3	3.7	3.4	4.0
Yes, for my flock	No	877	72.7	3.6	3.4	3.8
	Yes	330	27.3	3.5	3.1	3.8
Yes, for other peoples flocks	No	1169	96.9	3.6	3.4	3.8
	Yes	38	3.1	2.5	1.8	3.5
Did not breed replacement ewes	No	901	74.6	3.5	3.3	3.7
	Yes	306	25.4	3.8	3.4	4.3
Vaccination with Footvax						
Ewes	No	1009	83.6	3.7	3.5	3.9
	Yes	198	16.4	2.9	2.4	3.4
Rams	No	987	81.8	3.7	3.5	3.9
	Yes	220	18.2	2.9	2.5	3.4
Sheep with footrot	No	1172	97.1	3.5	3.4	3.8
	Yes	35	2.9	3.9	2.6	5.9
Bought-in sheep	No	1122	93.0	3.7	3.5	3.9
	Yes	85	7.0	2.4	1.8	3.2
Frequency of vaccination with Footvax						
Once a year	No	16	7.3	3.6	3.4	3.8
	Yes	204	92.7	3.4	2.3	5.0

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
Twice a year	No	172	78.2	3.6	3.4	3.8
	Yes	48	21.8	3.4	2.6	4.5
Before an expected peak	No	198	90.0	3.6	3.4	3.8
	Yes	22	10.0	2.8	1.4	5.6
Once in sheep's lifetime	No	201	91.4	3.6	3.4	3.8
	Yes	19	8.6	4.4	3.5	5.6
Whole flock antibiotic injection						
	Yes	82	6.8	4.2	3.6	5.1
	No	1109	91.9	3.5	3.3	3.7
Reason for injection						
Footrot	No	31	37.8	3.5	3.3	3.7
	Yes	51	62.2	4.5	3.7	5.4
Toxoplasma abortion	No	46	56.1	3.5	3.4	3.8
	Yes	36	43.9	3.9	3.0	5.1
Enzootic abortion	No	25	30.5	3.5	3.3	3.7
	Yes	57	69.5	4.2	3.4	5.1
Antibiotic used						
Oxytetracycline LA	No	20	24.4	3.5	3.3	3.7
	Yes	62	75.6	4.3	3.7	5.1
PenStrep	No	75	91.5	3.5	3.4	3.7
	Yes	7	8.5	4.3	3.2	5.7
Micotil	No	78	95.1	3.6	3.4	3.8
	Yes	4	4.9	4.6	3.2	6.5
Draxxin	No	79	96.3	3.6	3.4	3.8
	Yes	3	3.7	5.2	2.6	10.4
Check the feet of sheep before purchase						
Never		189	15.9	3.9	3.5	4.4
Sometimes		173	14.5	4.0	3.4	4.6
Usually		249	20.9	4.1	3.7	4.6
Always		324	27.2	3.1	2.8	3.4
Did not purchase		255	21.4	3.3	2.9	3.7
Check the feet of new sheep on arrival						
Never		147	12.6	3.7	3.1	4.5
Sometimes		151	12.9	4.0	3.5	4.5
Usually		243	20.8	4.3	3.8	4.7
Always		388	33.2	3.2	2.9	3.5

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
No new arrivals		241	20.6	3.2	2.9	3.6
Treat new sheep with footrot or ID on arrival						
Never		312	27.6	3.5	3.1	3.9
Sometimes		194	17.2	4.0	3.5	4.5
Usually		121	10.7	4.7	4.2	5.3
Always		265	23.5	3.4	3.0	3.8
No new arrivals		238	21.1	3.2	2.8	3.6
Isolation of new sheep on arrival						
Never		153	13.1	4.0	3.3	4.7
Sometimes		99	8.4	3.7	3.1	4.5
Usually		169	14.4	4.2	3.7	4.7
Always		521	44.5	3.3	3.1	3.7
No new arrivals		230	19.6	3.2	2.8	3.6
Duration of isolation of new sheep on arrival						
Isolated for < 1 week		74	9.3	3.9	3.3	4.6
Isolated for 1-3 weeks		402	50.3	3.9	3.6	4.2
Isolated for > 3 weeks		323	40.4	3.2	2.8	3.6
Sheep leaving the farm and later returning						
Yes, for shows	No	1156	95.8	3.5	3.3	3.7
	Yes	51	4.2	4.0	3.1	5.1
Yes, when sharing rams	No	1182	97.9	3.6	3.4	3.8
	Yes	25	2.1	2.9	2.2	4.0
Yes, for summer grazing	No	1030	85.3	3.5	3.3	3.7
	Yes	177	14.7	4.1	3.6	4.7
Yes, for winter grazing	No	890	73.7	3.5	3.3	3.7
	Yes	317	26.3	3.7	3.4	4.1
Yes, back from market	No	1176	97.4	3.6	3.4	3.8
	Yes	31	2.6	2.7	2.1	3.6
Isolation of sheep returning to the farm						
Never		287	54.7	3.9	3.5	4.3
Sometimes		89	17.0	3.7	3.0	4.6
Usually		93	17.7	3.9	3.3	4.5
Always		56	10.7	3.8	3.0	4.7
Duration of isolation of sheep returning to the farm						
< 1 week		50	19.7	3.9	3.2	4.7
1 - 3 weeks		144	56.7	4.3	3.7	4.9

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
> 3 weeks		60	23.6	3.2	2.7	3.9
Mixing of sheep with neighbouring flocks						
Yes		53	4.5	4.3	3.6	5.1
No		1116	94.9	3.6	3.4	3.8
Don't know		7	0.6	1.5	0.4	6.5
Farmer sex						
Male		1040	87.1	3.5	3.3	3.8
Female		154	12.9	3.6	3.1	4.2
Farmer age						
< 25		21	1.8	4.6	3.2	6.7
26-35		73	6.1	3.6	3.0	4.3
36-45		178	14.8	3.4	3.0	3.9
46-55		399	33.3	3.6	3.3	4.0
56-65		313	26.1	3.7	3.3	4.0
> 65		211	17.6	3.3	2.8	3.8
Do not wish to say		4	0.3	4.1	1.6	10.2
Land type						
Hill		32	2.7	2.6	1.7	4.1
Upland		120	10.1	3.8	3.2	4.6
Lowland		1035	87.2	3.6	3.4	3.8
Organic status						
Not organic		1128	94.7	3.7	3.5	3.9
Organic		63	5.3	2.3	1.8	3.0
Approximate stocking rate of ewes						
< 4 ewes / acre		521	44.7	3.2	3.0	3.5
4 - 8 ewes/acre		593	50.9	3.9	3.6	4.2
> 8 ewes/acre		51	4.4	3.8	2.7	5.4
Source of replacement ewes						
Bought-in	No	705	58.4	3.2	2.9	3.5
	Yes	502	41.6	3.9	3.6	4.1
Homebred	No	790	65.5	4.0	3.6	4.3
	Yes	417	34.5	3.4	3.1	3.6
Production on farm						
Finished lambs	No	99	8.2	3.6	3.1	4.2
	Yes	1108	91.8	3.6	3.4	3.8
Store lambs	No	875	72.5	3.6	3.4	3.9

Variable		All responses N	%	Prevalence of lameness Geometric Mean	95% CI	
	Yes	332	27.5	3.4	3.1	3.7
Breeding stock	No	879	72.8	3.8	3.5	4.0
	Yes	328	27.2	3.0	2.7	3.3
Housing of sheep						
Ewes	No	341	28.3	3.1	2.8	3.5
	Yes	866	71.7	3.7	3.5	4.0
Lambs	No	968	80.2	3.6	3.4	3.8
	Yes	239	19.8	3.5	3.1	3.9
Frequency fresh bedding added to pens for ewes						
Daily		374	47.1	3.6	3.3	4.0
Every two days		328	41.3	4.2	3.8	4.5
Weekly		92	11.6	3.6	3.0	4.5
Condition of bedding in pen when fresh bedding added						
Dry	No	718	59.5	3.6	3.3	3.8
	Yes	488	40.4	3.5	3.2	3.8
Damp	No	856	70.9	3.4	3.1	3.6
	Yes	351	29.1	4.1	3.7	4.4
Wet	No	1188	98.4	3.6	3.4	3.8
	Yes	19	1.6	3.3	2.3	4.6
Soiled	No	1013	83.9	3.5	3.3	3.8
	Yes	194	16.1	3.7	3.2	4.2

N: number, %: percent, CI: confidence interval

Supplementary Table 2: Overdispersed Poisson regression models of nine sub-categories from the questionnaire

a)factors relating to the recognition and catching of lame sheep associated with the proportion of lame sheep May 2012 - April 2013

Variable		**All responses N**	**%**	**RR**	**95% CI**	
Lowest locomotion score at which the farmer recognised sheep as lame						
1		620	51.5	1.00		
2		417	34.7	**1.31**	1.17	1.46
3		136	11.3	**1.26**	1.06	1.50
4+		19	1.6	**1.59**	1.10	2.31
Number of sheep required to be lame at the above locomotion score for farmers to catch and treat them						
1		163	13.5	1.00		
2-5		608	50.5	**1.22**	1.00	1.48
6-10		216	18.0	**1.64**	1.33	2.02
>10		185	15.4	**1.59**	1.29	1.95
Did not treat individuals		8	0.7	1.10	0.63	1.93
Time to treatment for lame sheep						
First day		82	6.8	1.00		
Within 3 days		506	42.1	1.11	0.86	1.44
Within 1 week		462	38.4	**1.32**	1.02	1.70
Within 2 weeks		115	9.6	**1.54**	1.17	2.03
Longer than 2 weeks		21	1.7	1.30	0.89	1.91
Did not treat any lame sheep		Excl.	Excl.			
Method of catching individual lame sheep						
Central handling facility	No	515	42.4	1.00		
	Yes	693	57.6	**1.17**	1.05	1.30
Food	No	823	68.0	1.00		
	Yes	385	32.0	**1.14**	1.02	1.28
From vehicle	No	1,051	86.9	1.00		
	Yes	157	13.1	**0.81**	0.69	0.95

b) factors relating to the treatment of sheep with footrot associated with the proportion of lame sheep in 2013

Variable	**All responses N**	**%**	**RR**	**95% CI**	
Frequency of trimming feet of ewes when **lame with footrot**					
Never	32	2.8	**0.51**	0.34	0.77
Sometimes	222	19.7	**0.78**	0.67	0.91
Usually	382	33.9	0.91	0.80	1.04
Always	490	43.5	1.00		
Frequency of treating ewes lame with footrot with an antibiotic injection					
Never/ Sometimes/ Usually	851	70.7	1.00		

Always		273	22.7	**0.78**	0.68	0.90
Injectable antibiotic used to treat sheep with footrot or ID						
PenStrep	No	720	65.3	1.00		
	Yes	418	34.7	**0.86**	0.76	0.97

c) factors relating to the routine foot trimming of sheep associated with the proportion of lame sheep in 2013

Variable	All responses N	All responses %	RR	95% CI	
Average number of foot trims per sheep per year					
Zero	499	41.5	1.00		
0.125	84	7.0	1.21	0.88	1.67
0.25 - 1.5	501	41.6	**1.45**	1.12	1.88
2	67	5.6	**1.65**	1.18	2.31
3+	13	1.1	**2.70**	1.47	4.95
Approximate percentage of sheep that bled during a routine foot trim					
Did not trim	499	41.5	1.00		
0	70	5.8	**0.67**	0.46	0.97
0< - 1	187	15.5	0.90	0.68	1.20
1< - 2	129	10.7	0.98	0.73	1.32
2< - 3	50	4.2	1.00	1.00	1.00
3<	220	18.3	**1.39**	1.06	1.81

d) association between the percentage of sheep on a farm that bled during a routine foot trim in 2013 and the proportion of lame sheep in 2013

Variable	All responses N	All responses %	RR	95% CI	
Percentage of sheep that bled during a routine foot trim, per year					
Did not trim	499	44%	1.00		
Zero	64	6%	1.10	0.86	1.40
<1%	179	16%	0.99	0.86	1.13
1 - <5%	257	23%	**1.33**	1.19	1.49
5 - <10%	71	6%	**1.39**	1.19	1.64
10% +	61	5%	**1.69**	1.43	1.99

e) factors relating to whole flock footbathing associated with the proportion of lame sheep in 2013

Variable		All responses N	All responses %	RR	95% CI	
Flock footbathing						
	No	772	63.9			
	Yes	436	36.1	1.16	0.79	1.72
Reason for footbathing						
Treating ID	No	614	50.8	1.00		
	Yes	594	49.2	**0.82**	0.69	0.97
Treating footrot	No	769	63.7	1.00		
	Yes	439	36.3	**1.30**	1.13	1.50

Preventing ID	No	779	64.5	1.00		
	Yes	429	35.5	**0.71**	0.61	0.82
Time at which sheep were footbathed						
Moving between fields	No	966	80.0	1.00		
	Yes	241	20.0	**1.37**	1.18	1.59
After gathering	No	852	70.6	1.00		
	Yes	355	29.4	**1.18**	1.02	1.35
New sheep on arrival	No	767	63.5	1.00		
	Yes	202	16.7	**1.22**	1.04	1.43
No new sheep		238	19.7	0.91	0.75	1.12
Frequency of routine footbathing of lambs at pasture						
Once a week		16	1.3	1.00		
Once a fortnight		93	7.7	0.74	0.52	1.06
Once a month		199	16.5	0.83	0.60	1.15
Other		14	1.2	**0.45**	0.23	0.89
Did not routinely footbath lambs at pasture		304	25.3	**0.68**	0.48	0.95
Frequency of routine footbathing of lambs when housed						
Once a week		28	2.3	1.00		
Once a fortnight		43	3.6	**1.68**	1.17	2.41
Once a month		28	2.3	0.96	0.62	1.49
Other		4	0.3	1.26	0.60	2.66
Did not routinely footbath lambs when housed		180	15.0	1.11	0.79	1.58
Did not house lambs		447	37.2	1.03	0.74	1.42

f) factors relating to culling and replacement ewes associated with the proportion of lame sheep in 2013

Variable		**All responses**		**RR**	**95% CI**	
		N	**%**			
Number of lameness episodes prior to culling						
Did not cull		589	49.0	1.00		
Once		36	3.0	**0.54**	0.34	0.83
Twice		142	11.8	**0.77**	0.60	0.99
More than twice		299	24.9	0.90	0.71	1.14
Persistently lame		40	3.3	1.29	0.92	1.79
Method of identifying sheep for culling						
Memory	No	1,046	86.5	1.00		
	Yes	162	13.5	**1.27**	1.05	1.55

g) factors relating to biosecurity associated with the proportion of lame sheep in 2013

Variable		All responses N	%	RR	95% CI	
Checking the feet of sheep before purchase						
Never/Sometimes/Usually		610	50.7	1.00		
Always		324	26.9	**0.73**	0.64	0.83
Did not purchase		253	21.0	0.93	0.63	1.39
Duration of isolation of new sheep on arrival						
No new arrivals		228	19.0	0.79	0.52	1.22
Did not isolate		152	12.6	1.00		
Isolated for <1 week		68	5.7	0.85	0.64	1.14
Isolated for 1-3 weeks		397	33.0	0.98	0.81	1.18
Isolated for >3 weeks		316	26.3	**0.80**	0.66	0.97
Sheep leaving the farm and returning later						
Yes, for summer grazing	No	1,031	85.3	1.00		
	Yes	177	14.7	**1.18**	1.03	1.35

h) factors relating to characteristics of the farm and farmer associated with the proportion of lame sheep in 2013

Variable		All responses N	%	RR	95% CI	
Land type						
Upland		120	10.0	1.00		
Hill		31	2.6	0.78	0.59	1.04
Lowland		1,032	85.8	**0.84**	0.74	0.97
Organic status						
Not organic		1,124	93.4	1.00		
Organic		63	5.2	**0.70**	0.54	0.90
Flock size (log 10)						
For each 10-fold increase in flock size		1,208	100.0	**0.76**	0.66	0.87
Average prevalence of lameness in lambs						
For each percent increase in lamb lameness prevalence		1,178	97.9	**1.04**	1.04	1.04
Production on farm						
Breeding stock	No	880	72.7	1.00		
	Yes	328	27.3	**0.83**	0.75	0.93
Housing of ewes						
	No	344	28.2	1.00		
	Yes	864	71.8	**1.17**	1.05	1.31

N: number, **%**: percent, **RR**: risk ratio, **CI**: confidence interval
Risk Ratios that are significantly different from the baseline (according to Wald's test for significance) are marked in **bold**.

Correlations and associations between variables in the final model and significant variables in the sub-multivariable models

Factors associated with catching and treating lame sheep

The score at which farmers recognised lameness was highly correlated with the score at which they caught lame sheep for treatment ($P < 0.001$). Farmers who recognised lameness at score 1 typically found it easy to catch lame sheep, and were more likely to catch sheep for treatment when less than five sheep were lame in a group than farmers who recognised lameness at score 2 (Table 10). These behaviours were associated with smaller flock sizes.

Farmers who found catching individual lame sheep 'easy' were more likely to catch sheep for treatment within three days of seeing them lame than farmers who found it difficult to catch individual lame sheep. Farmers who caught lame sheep the first day they saw them lame typically caught them in the corner of the field. Farmers who treated individual lame sheep promptly were less likely to cull sheep that had been lame whereas farmers who delayed treating individual lame sheep were more likely to either cull sheep after a single lameness episode or wait until sheep were persistently lame before culling (Table 11).

Farmers who used a central handling facility to catch individual lame sheep were more likely to wait until more than ten sheep were lame before treating them, less likely to treat individual lame sheep within three days and typically found it more difficult to catch individual lame sheep.

Farmers who always treated individual lame sheep with footrot with an antibiotic injection were less likely to routinely foot trim their flocks than farmers who never treated lame sheep with an antibiotic injection. Farmers who always treated lame sheep with an antibiotic injection were more likely to vaccinate ewes, cull sheep that had been lame, isolate new sheep and check the feet of new sheep on arrival than farmers who did not always inject sheep with footrot.

Factors associated with routine and therapeutic foot trimming

Farmers who treated lame sheep within three days of seeing them lame were less likely to routinely foot trim and cause bleeding than farmers who delayed treatment by longer than three days (Table 10).

There was a positive association between therapeutic foot trimming and the proportion of sheep bleeding during a routine foot trim. Therapeutic foot trimming was negatively associated with footbathing to treat footrot and culling sheep that had been lame, but was positively associated with relying on memory to identify sheep for culling. There was a positive association between recognition of lameness at higher lameness scores and an increased likelihood of therapeutic foot trimming. Farmers who found catching individual lame sheep easy were more likely to always trim the feet of lame sheep than farmers who found it difficult to catch individual lame sheep (Table 11). Farmers who always trimmed the feet of individual lame sheep typically had smaller flocks than farmers who never trimmed lame sheep.

Factors associated with routine and therapeutic footbathing

Farmers who footbathed routinely were more likely to routinely trim feet and cause bleeding than farmers who did not footbath (Table 10). They were also more likely to check the feet of new sheep on arrival and isolate new sheep for more than three weeks. Farmers who footbathed were likely to wait until more than 5 sheep were lame before treating lame sheep. Organic farmers were more likely to routinely footbath than farmers who did not farm farm organically. Routine footbathing was also associated with increased flock size.

Factors associated with culling and biosecurity

Farmers who vaccinated their sheep with Footvax were more likely to cull sheep that had been lame than farmers who did not vaccinate their sheep (Table 10). Culling sheep that had been lame was associated with delaying treating lame sheep for longer than a week. Farmers who footbathed to treat footrot were likely to delay culling sheep until they had been lame more than twice or were persistently lame (Table 11). Farmers who selected replacement ewes from non-lame mothers were more likely to cull sheep that had been lame. Farmers relying on their memory to identify sheep for culling were more likely to cull persistently lame sheep or sheep that had been lame more than twice.

Farmers who culled lame sheep after a single lameness episode were more likely to "always" check the feet of new sheep on arrival. Farmers who did not cull sheep for lameness were less likely to purchase new sheep. Culling lame sheep after a single lameness episode was associated with isolating new sheep for more than three weeks (Table 11). Farmers who did not cull until sheep were persistently lame or had been lame more than twice were likely to isolate for less than three weeks. Farmers with smaller flocks were less likely to cull sheep that had been lame (Table 10). Farmers producing breeding stock were more likely to select replacement ewes from mothers that had not been lame.

Farmers were more likely to ‘always’ check the feet of new sheep before purchase or on arrival if they also recognised lameness at low locomotion scores (Table 10) and treated individual lame sheep promptly (Table 11). Checking the feet of new sheep before purchase or on arrival were positively associated with routine footbathing, isolating new sheep and producing breeding stock.

Supplementary Table 3: Significant ($P \leq 0.05$) associations (as determined by χ^2 test or ANOVA) between variables in the full risk factor model

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Score at which farmer recognises lameness		+		-																				-		
Number of lame sheep in a group before treating lame sheep	+		+		-			+	+								-							-	+	+
Time to treatment		+		-			+		+		-		+		+		-								+	+
Ease of catching (Difficult to easy)	-		-			+					+			+	-								+			
Catch in corner of field		-				+								+				+						+	+	
Catch individuals with a dog				+	+		-						+					+		+		a		+	+	
Percentage of sheep that bled during a routine foot trim, per year			+			-		+	+				-	+		-	b								c	+
Routine footbath any sheep		+					+		+	+	+	+	+			+	+	+					+		+	+

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Footbath to treat footrot		+	+				+	+		+	+	+		+			+			+			+		+	+
Footbath to prevent ID								+	+		+	+		+		+	+	+	+				+	+	+	
Footbath at turnout			–	+				+	+	+		+														
Footbath new sheep on arrival								+	+	+	+					+	+	+	+						+	
Cull sheep that had been lame			+			+	–	+						+	+	+	+	+							+	
Rely on memory to identify sheep for culling				+	+		+		+	+			+							+	+				+	+
Select replacement sheep from non-lame mothers			+	–									+											+		
Vaccinate ewes							–	+		+		+	+									[d]			+	
Check feet of new sheep on arrival		–	–				[b]	+	+	+		+	+					+					[e]	+	+	[f]
Duration of isolation of new sheep					+	+		+		+		+	+				+						+		+	
Sheep left farm for shows										+		+								+	+			+		
Sheep left farm for summer grazing						+			+					+					+		+				+	+

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Sheep left for market														+					+	+				+		
Farm location						a										d									g	
Organic status				+				+	+	+							e	+								−
Produce breeding stock	−	−			+	+				+					+		+		+		+					
Flock size (small to large)		+	+		+	+	c	+	+	+		+	+	+		+	+	+		+		g				
Lamb lameness prevalence		+	+				+	+	+					+			f			+			−			

+ indicates a positive association, − indicates a negative association. Non-significant associations are not shown, P values for all associations are shown in Appendix 4

Non-ordinal associations:

a: Using a dog to catch individual sheep was more likely on hill or upland farms than lowland farms, **b**: "Never" checking feet on arrival was associated with not foot trimming, **c**: Not foot trimming was associated with a larger flock size, **d**: No ewes were vaccinated with Footvax on hill farms, **e**: Organic farms were more likely to have no new sheep, **f**: Having no new sheep or "always" checking feet on arrival was associated with a higher prevalence of lameness in lambs than "usually" checking feet on arrival, **g**: Lowland flocks were typically smaller than hill or upland flocks

Supplementary Table 4: Significant ($P \leq 0.05$) associations (as determined by χ^2 test or ANOVA) between variables in the full risk factor model (columns) and variables that were significant in the multivariable sub-models but not significant in the final model (rows)

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Proportion of sheep bleeding during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Catch using a central handling facility		+	+	–		–		+		+							+[a]	+[a]							+	
Catch using food			–		+									+			–[b]				+				+	
Catch using a vehicle					+	+	–						+								+		–		+	
Therapeutic use of foot trimming	+			+			+		–				–	+											–	
Therapeutic use of antibiotic injection						+	–						+			+	+	+							+	
Use of PenStrep antibiotic injection				+	+		+																		+	
Footbathing to prevent footrot							+	+	+	+	+	+		+			+	+					–			
Footbathing when moving between fields							+	+	+	+	+	+					+							–		+
Footbathing after gathering		–						+	+	+	+	+	+	+			+	–		+			–		–	+
Number of lameness episodes before culling			+			+	–	+	+			+	+	+	+		+	+[c]					+		+	+

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Proportion of sheep bleeding during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Check feet of new sheep before purchase	−		−				+	+	+	+		+	+		+		+	+			d		e	+	+	−
Housing of ewes	−					−				−	+	+					f	f	+			g	h			

+ indicates a positive association, − indicates a negative association. Non-significant associations are not shown, P values for all associations are shown in Appendix 5

Non-ordinal associations:

a: Farmers without a central handling facility were less likely to purchase new sheep, **b**: Farmers who used food to catch sheep were less likely to purchase new sheep, **c**: Farmers who did not cull were less likely to have new sheep, **d**: Farmers whose sheep returned from market were less likely to purchase new sheep, **e**: Organic farmers were less likely to purchase new sheep, **f**: Farmers who housed sheep were less likely to have new sheep, **g**: Hill farmers were less likely to house sheep, **h**: Organic farmers were less likely to house sheep

Supplementary Figure 1: Pearson residuals plotted against the model predictions