Epidemiological investigations into lameness in sheep

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Dedication

I dedicate my thesis to my husband Vikram, my daughter Samaira and to my supervisor Professor Laura Green.

Vikram always encouraged me to achieve my dreams and patiently stood by my side over the years. Samaira has provided me with infinite amount of love and joy. She has been the driving force in my life.

Words can not be enough to express my gratitude to Professor Laura Green. Without her guidance, motivation, support, genuine concern and undying faith in me, this thesis would not have been possible. She was always there whenever I needed her advice, whether on a professional or a personal matter. I could not have imagined having a better supervisor for my PhD. During my PhD, I have seen in her an excellent supervisor who can bring the best out of her students, an outstanding researcher who can constructively criticize research, and a wonderful human being who is honest, fair and helpful to others. I am truly fortunate to have been able to enjoy and benefit from such a great relationship with her. I know I can never thank her enough but I will try to pass on to others the academic and personal skills I learnt from her.

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I cannot thank enough my parents for their practical and moral support throughout my PhD. I would like to thank my mother-in-law and sister-in-law for their support.
Declaration

I declare that apart from advice and assistance acknowledged the work reported in this thesis is my own and has not been submitted for any other degree.

The contents of chapter 2 have been published in:


Conference Proceedings


The contents of Chapter 4 are in press

Summary

Lameness is the greatest health and welfare concern in sheep flocks in the U.K. This thesis presents research on epidemiology of lameness in sheep.

Most previous studies quantifying lameness and its causes are based on the premise that farmers can identify the causes of lameness and recognise lame versus sound sheep. In 2005, a postal questionnaire was sent to a random sample of English sheep farmers to investigate whether farmers could correctly name six common foot lesions in sheep (interdigital dermatitis (ID), footrot (FR), contagious ovine digital dermatitis (CODD), shelly hoof, foot abscess and toe granuloma) from a characteristic picture and a written description. The same questionnaire of six lesions was presented at a meeting of specialist sheep advisors, primarily veterinarians. Approximately 20% of farmers and 80% of sheep specialists named all 6 lesions correctly, indicating a gap in knowledge between sheep advisors and sheep farmers. In addition, farmers tended to name any hoof horn damage as footrot which might imply that some lame sheep receive incorrect treatment.

Management factors associated with the prevalence of farmer estimated lameness (irrespective of farmer recognition of lesions) and the adjusted prevalence of lameness caused by ID and FR among flocks where farmers correctly recognised both lesions were investigated and compared in negative binomial regression models. Farmers who routinely foot trimmed and frequently footbathed their sheep reported a higher prevalence of lameness, ID and FR. Farmers who stocked their sheep at >8 ewes/hectare reported a high prevalence of both lameness and ID whilst those who separated ‘some’ or ‘all’ lame sheep at pasture reported a low prevalence of both lameness and ID. Farmers in the east of England reported a lower prevalence of lameness, ID and FR compared with central England.

A numerical rating locomotion scoring scale (0-6) was developed to monitor locomotion in sheep in a research setting. There was good agreement between and within trained observers using this scale. This scoring system was used in a longitudinal study on one farm, two groups of sheep (30 in each group) with
different treatment regimes (antibiotic injection & antibiotic spray vs. foot trimming and antibiotic spray; and occasional footbathing) for lameness with FR and ID were followed for five weeks to investigate the temporal associations between ID, FR and the effect of different treatments on locomotion. From the examinations it was concluded that even mildly lame sheep can have FR and ID. In a multilevel linear mixed model, there was a significant association between ID, FR and locomotion score with the mean score of 0.25 increasing to 0.43 for sheep with ID and to 2.18 for sheep with FR. In addition, sheep that developed FR had a significantly raised locomotion score the week before FR became clinically apparent. Treatment with antibiotic injection and antibiotic spray significantly reduced the locomotion score of sheep the following week.

The movie clips from the locomotion scoring reliability study were used to investigate farmer and sheep specialist recognition of lame sheep and decisions on whether to catch them. A group of farmers from three regions (Devon, Newark and Norfolk) and sheep specialists at a Sheep Veterinary Society meeting were shown eight movie clips of sheep with varying locomotion scores. Although the majority of farmers and sheep specialists identified mildly lame sheep with a locomotion score of 2, only 50% of them would catch such a sheep if it was the only lame sheep in the group. Most farmers and sheep specialists did not catch lame sheep until the lameness was locomotion score 3 or 4. The more frequently farmers caught lame sheep, and the milder the lameness when a decision to catch was taken, the lower the farmer reported prevalence of lameness in the flock.

The research in this thesis suggests that farmers, who are the primary carers for lame sheep, do not always name foot lesions correctly and so sheep may receive inappropriate treatment for some lesions. In addition, whilst farmers and sheep specialists can recognise lame sheep, they do not always catch and treat mildly lame sheep. Farmers who caught all mildly lame sheep within a few days of seeing them lame reported a lower prevalence of lameness in their flock. This might be explained by the evidence from this thesis that mildly lame sheep can have FR or ID and so prompt treatment of these lame sheep reduces the prevalence and incidence of FR and ID.
**List of Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BBSRC</td>
<td>Biotechnology and Biological Sciences Research Council</td>
</tr>
<tr>
<td>CODD</td>
<td>Contagious Ovine Digital Dermatitis</td>
</tr>
<tr>
<td>CEDFAS</td>
<td>Combating Endemic Diseases of Farmed Animals for Sustainability</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department of Environment, Food and Rural Affairs</td>
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<tr>
<td>EBLEX</td>
<td>English Beef and Lamb Executive</td>
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<tr>
<td>FR</td>
<td>Footrot</td>
</tr>
<tr>
<td>ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass correlation coefficient</td>
</tr>
<tr>
<td>ID</td>
<td>Interdigital dermatitis</td>
</tr>
<tr>
<td>IGLS</td>
<td>Iterative Generalised Least Square</td>
</tr>
<tr>
<td>IQR</td>
<td>Inter-quartile range</td>
</tr>
<tr>
<td>MCMC</td>
<td>Markov Chain Monte Carlo</td>
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<tr>
<td>NRS</td>
<td>Numerical rating scales</td>
</tr>
<tr>
<td>PRR</td>
<td>Prevalence Rate Ratio</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error</td>
</tr>
<tr>
<td>SVS</td>
<td>Sheep Veterinary society</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual analogue scale</td>
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<td>w/v</td>
<td>Weight/Volume</td>
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Chapter 1

General Introduction

Lameness is a change from normal stance or gait. It is a major cause of concern in sheep producing countries around the world because it is one of the most common and persistent health problems in sheep flocks (Abbot and Lewis, 2005). Lameness in sheep has many adverse effects on flock performance, including reduced weight gain and poor body condition among ewes and rams, decreased fertility in rams because of poor body condition and in pregnant ewes a predisposition to metabolic diseases, low birth weight lambs, poor colostrum production and mismothering leading to increased lamb mortality (Winter, 2004a).

1. Economic and welfare concerns

The estimated cost of footrot (one of the most common cause of lameness in sheep) in Great Britain is approximately £24 million each year (Nieuwhof and Bishop, 2005). This includes an estimated cost of £7 million for lost performance and £4 million for treatment of affected animals, including culling. Approximately £14 million has been estimated to be spent on prevention of disease each year (Nieuwhof and Bishop, 2005).

Lameness in sheep in the UK is a major welfare problem and farmers have listed it as one of their top concern of poor health and welfare in sheep flocks (Goddard, 2006). It affects two of the ‘five freedoms’ stated by Farm Animal Welfare Council considering animal welfare (http://www.fawc.org.uk/pdf/stockmanship-report0607.pdf). It causes pain to the animals and can also lead to depressed food
intake which can have further implications on health and performance of sheep as mentioned above. The association between lameness and pain has been well documented. Previous studies have demonstrated significantly high plasma cortisol levels in lame sheep than in the healthy sheep and this increase was observed up to 3 months after resolution of lesions (Ley et al., 1994). Similarly, severely lame sheep had significantly lower threshold to mechanical nociceptive stimulus compared with their matched ‘sound’ control and the low thresholds were also observed when sheep were tested after 3 months, despite apparently resolved lesions (Ley et al., 1995). According to a recent report, the Royal Society for Prevention of Cruelty to Animals in the UK has listed lameness as a major cause of welfare concern and has stated that the control of lameness in sheep is still not achieved in many flocks and is neglected in some cases (RSPCA, June 2007).

2. Prevalence of lameness

The first estimate of lameness in the UK came from a stratified random postal survey in 1994 (Grogono-Thomas and Johnston, 1997). Approximately 92% of farmers reported lameness in their flock between October 1993 and September 1994. The reported period prevalence of lameness was 8% (Grogono-Thomas and Johnston, 1997). However, one of the limitations of this study was that it assumed that farmers can identify lame sheep. No further studies looked at prevalence of all lameness; however, Wassink et al. (2003a, 2004) used a non random subset of farmers from the above mentioned survey to estimate the prevalence of the two most common causes of lameness i.e. interdigital dermatitis and footrot (see Section 4).
3. Causes of lameness

There can be several reasons for lameness in sheep including physical injuries, and systemic diseases (e.g. joint-ill, tetanus, white muscle disease, enzootic ataxia, polyarthritis, foot-and-mouth disease, bluetongue, ulcerative dermatosis, dermatophilosis, erysipelas, laminitis, rickets, contagious ecthyma, mastitis, epididymitis, and mineral and trace element imbalances) (Merck Veterinary Manual, 2006). However, farmers attribute the majority of lameness in sheep to foot lesions (e.g. interdigital dermatitis, footrot, contagious ovine digital dermatitis, foot abscess, white line disease and toe granuloma etc), of which interdigital dermatitis and footrot are the most common ones (Grogono-Thomas and Johnston, 1997; Winter, 2004b). According to the results of the postal survey in 1994 (Grogono-Thomas and Johnston, 1997), there were 51% and 77% flocks affected with interdigital dermatitis and footrot and approximately 40% and 40.4% of total lameness was caused by them respectively. In a more recent postal survey interdigital dermatitis and footrot were present on 88% and 86% farms respectively between November 1999 and October 2000 (Wassink et al., 2003a, 2004). However, since both the above mentioned studies used farmer opinion of the prevalence of lameness and its causes, and so made the assumptions that farmers can recognise lameness and its causes, the reliability and accuracy of these results are questionable. Moreover, there is also no scientific evidence that sheep specialists (including vets) who generally give advice to farmers on lameness can recognise the foot lesions described below.
4. Foot lesions

4.1. Interdigital dermatitis

Interdigital dermatitis (ID) also known as scald or strip is caused by an anaerobic bacterium, *Fusobacterium necrophorum*, which is a normal inhabitant of the gut of sheep (Tan *et al.*, 1996). It affects only the interdigital space and is characterised by redness of the skin and a greyish white pasty scum over the skin (Egerton *et al.*, 1989; Winter, 2004b). Prolonged periods of wet and moist conditions, injury from abrasions and frost can predispose sheep to ID (Parsonson *et al.*, 1967). In addition to its role in causing interdigital dermatitis in sheep, *F. necrophorum* also play a major role in pathogenesis of footrot (see section 4.2.1. for details).

In the UK, footbathing sheep in 10 percent zinc sulphate or 3% - 5% formalin or topical foot sprays are the most commonly employed methods for treatment of sheep with ID (Morgan, 1987; Winter, 1989, 2004a).

A cross-sectional postal survey (Wassink *et al.*, 2004) investigating risk factors associated with ID reported that factors associated with increased prevalence of ID in ewes were 'sometimes/never’ catching lame sheep compared with 'always', farm land 100m or less above sea level and renting-in winter grazing. Factors associated with an increased prevalence of ID in lambs were a prevalence of 5 per cent or more footrot in ewes, 'sometimes/never' catching lame ewes compared with 'always', 'sometimes/never' treating ewes with footrot with parenteral antibiotics compared with 'always', farm land 100m or less above sea level, showing sheep at agricultural events and a prevalence of 5 per cent or more interdigital dermatitis in ewes (Wasssink *et al.*, 2004). There was a negative
association between turning sheep onto a field which had been free from livestock for at least two weeks after footbathing and the prevalence of ID in lambs.

Figure 1-1: Photographs of clinical presentation of Interdigital dermatitis

*Photographs by J. Kaler
4.2. Footrot

4.2.1. Aetiology and Pathogenesis

Footrot (FR) is caused by the bacterium *Dichelobacter nodosus*, a gram negative obligate anaerobe. (Beveridge, 1941) was the first to provide precise information on aetiology of FR and concluded that *D. nodosus* was the primary causal organism of FR. However, his work did not show a significant role for *F. necrophorum* in the pathogenesis, and regarded *F. necrophorum* as a secondary invader. His observations were confirmed in the work by Thomas (1962), where FR was reproduced from cultures of *D. nodosus* applied to scarified feet. However, (Egerton et al., 1969) demonstrated, in their work, the role and importance of *F. necrophorum* in the pathogenesis of FR. They concluded that superficial invasion by *F. necrophorum* always preceded growth of *D. nodosus* and *F. necrophorum* facilitated infection with *D. nodosus* by causing parakeratosis and hyperkeratosis responses in the host, thus enabling *D. nodosus* to establish in the crevices. They also suggested that establishment of *D. nodosus* led to increased activity of *F. necrophorum*. Thus, the conclusion from their work was that both these bacteria work synergistically to produce FR (Egerton et al., 1969; Roberts and Egerton, 1969).

4.2.2. Survival and transmission of *D. nodosus*

Reports on the survival of *D. nodosus* in the environment have come from some early work done by researchers in Australia (Beveridge, 1941; Graham and Egerton, 1968). The evidence suggests that *D. nodosus* can survive in the soil, pasture and faeces for no longer than 7-14 days (Beveridge, 1941). However, it can survive in hoof clippings for up to 6 weeks under optimal conditions.
Wet weather and temperature above 10° C contribute to the occurrence and spread of FR (Graham and Egerton, 1968). There is reduced survival of *D. nodosus* off the host in dry heat and cold weather (Graham and Egerton, 1968). Natural transmission occurs via soil and pasture; infectious sheep shed *D. nodosus* into the environment and contaminate the environment and this environmental challenge determines the rate at which sheep become infected (Green and George, 2007). To eliminate FR in flocks, an elimination programme has been going on in Western Australia for many years (Mitchell, 2003). This programme targets summer as a period of zero transmission and strict management practices for FR are then followed. This approach has been successful and now only 0.7% of sheep flocks in Western Australia have been estimated to have virulent FR (Mitchell, 2003).

**4.2.3. Clinical diagnosis and scoring of lesions**

FR lesions have a characteristic foul smell with under running of the hoof horn from the underlying tissue (Egerton *et al.*, 1989; Winter, 2004b). Because FR starts with ID, it is not possible to differentiate ID from the early clinical signs of FR. The differential diagnosis for FR includes e.g. shelly hoof, contagious ovine digital dermatitis and foot abscess (see section 4.4. for details on ‘other’ lesions).

In contrast to the UK, where the categorisation of sheep with FR or ID is based on the clinical presentation of a sheep, a different terminology is used to categorise FR in Australia. FR in Australia is categorised by flock, not sheep, as benign (less than 1% of the affected sheep in the flock have under-running of the hard horn of hoof), virulent (if more than 10% of the affected animals have under running of the hard horn in at least one foot) and intermediate (between benign and virulent) (Egerton *et al.*, 1989).
Different scoring systems are also used in Australia and the UK to score the severity of FR lesions on a sheep. Describing FR lesions based on severity is a useful tool to study the epidemiology, pathogenesis, treatment, control, and production losses due to FR (Egerton et al., 1989). In Australia, the most commonly used and widely accepted method of scoring is by Egerton and Roberts (1971) in which inflammation confined to the interdigital space is scored as 1, or 2 if it is severe; if the hoof horn is under run the foot is scored as 3 or 4 depending on whether the under running extends to the hard hoof wall. However, in the UK, two separate scoring scales have been used to score the severity of ID and FR lesions (Moore et al., 2005a; (Table 6-1)).

Figure 1-2: Photograph of clinical presentation of footrot

* Photograph by J.Kaler
4.2.4. Laboratory diagnosis and characteristics of *D. nodosus*

Traditionally, identification of *D. nodosus* was based on isolation of the bacterium from the lesion with subsequent biochemical tests e.g. the elastase test, the zymogram test and the protease thermo stability test for virulence (Liu and Yong, 1997). However, isolation of *D. nodosus* is an extremely difficult and time consuming process because it requires complex media, anaerobic conditions, approximately a week to obtain primary colonies and further 2-3 weeks to obtain pure cultures for virulence determination and serogrouping (Egerton *et al.*, 1989). There have been recent advances in the diagnosis of FR by the development of new generation molecular techniques such as PCR, gene probes and monoclonal antibodies. These are rapid, have a higher sensitivity and specificity than the traditional methods and are considered to be a reliable tool for diagnosis of FR (Wani and Samanta, 2006).

*Dichelobacter nodosus* is gram negative with straight or slightly curved large rods with terminal knobs (Egerton *et al.*, 1989). Based on the fimbriae, *D. nodosus* has been classified into 10 serogroups and 19 serotypes (Claxton, 1986). Although there are often more than one serogroups present in a flock, there is a dominance of serogroups H and B in Great Britain (Moore *et al.*, 2005; Hindmarsh and Fraser., 1985), serogroup B in Australia (Claxton *et al.*, 1983) and India (Wani *et al.* 2004) and serogroup H in France, Italy, Belgium and Sicily (Tholey and Day., 1986).
4.2.5. Control and treatment of FR

4.2.5.1 Foot trimming

Trimming or paring of hoof horn is carried out to remove excessive hoof horn because of abnormal growth or under-runnning of FR lesions (Abbott and Lewis, 2005). Even though there have been no strict controlled studies demonstrating its role as a preventative or treatment measure, paring in flock was one of the recommendations for both prevention and treatment of FR in UK until 2002 (Morgan, 1987; Winter, 1989). However, results of a cross-sectional study of sheep farmers in the UK published in 2003 by Wassink et al. reported a higher prevalence of FR on farms where farmers routinely trimmed feet of the flock more than once a year. In contrast, Wassink et al. (2003a) also reported a negative association between the prevalence of FR and therapeutic foot trimming (i.e. trimming of diseased sheep). These authors raised questions on the use of routine foot trimming and generated hypotheses that trimming of diseased and healthy feet can increase transmission, through environmental contamination and/or through increased susceptibility of sheep with trimmed feet, due to damage caused by excessive paring. The results from a longitudinal study on one farm (Green et al., 2007) supported the findings by Wassink et al. (2003a), however in this study there was a significant association between both routine trimming and therapeutic trimming with an increased incidence of ID and FR. Trimming of feet is a skilled procedure and there is little information on the standards it is being carried out by sheep farmers. Gogono-Thomas and Johnston (1997) reported that only 50% farmers they visited during the study had a good trimming technique. Excessive trimming resulting in bleeding of feet can also result in toe granuloma (another foot lesion) and thus leading to chronic lameness (Winter, 2004b).
4.2.5.2 Footbathing

Footbathing is a recommended practice and commonly used by farmers for both control and treatment of FR and ID (Morgan, 1987; Winter, 1989). The most commonly used footbath solutions are formalin (3%-5% w/v) and zinc sulphate (10%-20% w/v) (Abbott and Lewis, 2005). Formalin is an irritant and unpleasant to use but is quite practical to use since sheep walk through rather than stand in the solution (Ross, 1983; Winter, 2004a). Increased concentrations of formalin in footbaths can lead to irritation of interdigital space, hardening of feet (Winter, 2004a) and severe keratinisation of interdigital skin (which can lead to lameness) (LittleJohn, 1972). Zinc sulphate is more pleasant to use and the recommended time the sheep stand in it is between 2 minutes to 30 minutes depending on the product (Winter, 2004a). The recommended procedure with both the solutions is to confine sheep to dry surface such as concrete etc after footbathing (Skerman et al., 1983; Joop et al., 1984). In addition to formalin and zinc sulphate footbaths, use of organic acids and copper sulphate solution has been also reported (Winter, 2004a; Abbot and Lewis, 2005).

The majority of work investigating the effectiveness of footbathing has been carried out in Australia. Although Australian work has suggested that footbathing with formalin or zinc sulphate leads to a reduction in FR and interdigital dermatitis (Skerman et al., 1983; Malecki and Coffey, 1985), there has also been evidence that poor planning (Joop et al., 1984) and inadequate facilities (Mulvaney et al., 1986) can reduce its effectiveness. Wassink et al. (2003a) reported no beneficial effect of footbathing on prevalence of FR but also stated that farmers who rated their foot bathing facilities as ‘excellent’ had a lower prevalence of FR.
4.5.2.3. Vaccination

As described in section 4.2.4., there are 19 serotypes in 10 serogroups of *D. nodosus* and generally there are multi-serogroup infections within flocks. There is a multivalent vaccine with 10 serotypes available in the EU, Australia, New Zealand and the US; this is the only commercially available vaccine in these countries (Abbot and Lewis, 2005). However, the evidence suggests that a combination of several serotypes in a vaccine results in antigenic competition and a less immunological response than monovalent vaccines (Schwartzkoff *et al.*, 1993a; Raadsma *et al.*, 1994; Hunt *et al.*, 1995). Although both the monovalent and multivalent vaccines have demonstrated varied protective and therapeutic benefits (Skerman and Cairney, 1972; Glenn *et al.*, 1985), vaccination provides short term immunity (8-12 weeks; Hunt *et al.*, 1994). Generally two vaccinations are administered 6-24 weeks apart to provide protection against FR (Schwartzkoff *et al.*, 1993b).

The only study in the UK looking at efficacy of vaccination was done in 1983; the results demonstrated both a therapeutic and protective effect of vaccine against FR in ewes (Hindmarsh and Fraser, 1989). However, in the cross-sectional survey in UK where 19% farmers vaccinated their sheep against FR in 2000, there was no beneficial effect of vaccination on the prevalence of FR (Wassink *et al.*, 2003a).

Recently, a group of researchers from Australia have sequenced the genome of *D. nodosus* and identified eight proteins in the FR bacterium that are potential antigens for a new cross-protective vaccine (Myers *et al.*, 2007). However, these results are yet to be validated by development of any vaccine.
4.5.2.4 Antibiotics

A. Parenteral antibiotics

Parenteral antibiotics were generally recommended to treat individual sheep severely affected with FR (Morgan, 1987; Winter, 1989). There have been only a handful of studies that investigated the efficacy of various parenteral antibiotic types against FR under field conditions and the majority of this work was done in Australia. Egerton et al. (1968) demonstrated that cure rates in excess of 90% could be achieved using a single high dose of penicillin and streptomycin by intramuscular injection but suggested that for effectiveness sheep needed to be in a dry environment for 24hrs after treatment. A study by Venning et al. (1990) concluded that a single dose of lincomycin and spectinomycin had a similar efficacy as a single dose of penicillin and streptomycin. In addition, a single dose of erythromycin has also been reported to be effective in the treatment of FR (Webb Ware et al., 1994). In a small field trial in the UK, Grogono-Thomas and Johnston (1997) reported high cure rates among sheep with artificially induced FR or naturally occurring FR when treated with long acting oxytetracycline. However, several additional factors such as the number of feet affected, flock type, soil and pasture conditions can influence the cure rates achieved by antibiotics (Jordan et al., 1996).

Results from a cross-sectional survey in the UK reported that 12% farmers who ‘always’ used parenteral antibiotics and topical foot sprays had significantly low prevalence of FR (Wassink et al., 2003a) in comparison with those who did not ‘always’ use these treatments. These results were further confirmed by a longitudinal study on a farm where there was a significant negative association
between the incidence of ID and FR in the 2-4 weeks after individual treatment of lame sheep with ID or FR using parenteral antibiotics and topical sprays (Green et al., 2007). In addition, results from a recent two year clinical trial conducted on a farm in GB have also demonstrated that frequent and rapid treatment of lame sheep with FR or ID with antibiotics (both parenteral and topical) leads to a significant reduction in both prevalence and incidence of these lesions (Hawker, 2007).

B. Topical foot sprays

Topical foot sprays such as antibiotic spray or antibacterial sprays were generally recommended to treat sheep with ID and mild cases of FR (Morgan, 1987; Winter, 1989, , 2004a). There have been no studies reporting efficacy or cure rates achieved by topical spray in field conditions. In the UK, according to results of postal survey (Wassink et al., 2003a), 62% farmers who ‘always’ used topical sprays to treat FR in their flocks had a significantly lower prevalence of FR compared with flocks where FR was 'sometimes' or 'never' treated with foot sprays. As mentioned above (section A) the usefulness of antibiotic sprays along with antibiotic injections in reducing the prevalence and incidence of ID and FR has been demonstrated (Green et al., 2007; Hawker, 2007). The hypothesis proposed is that where parenteral antibiotic are effective to kill the deep seated bacteria, topical foot sprays kill the surface bacteria thus reduce the environmental contamination of the pasture (Green et al., 2007; Hawker, 2007).

4.5.2.5. Quarantine, isolation and culling

Quarantine of new stock, isolating diseased sheep and culling chronically affected sheep with FR is recommended for management of FR (Morgan, 1987; Winter,
1989, , 2004a). Wassink et al. (2003a) reported that farmers who isolated new sheep or separated diseased sheep from main flock had a significantly low prevalence of FR. The use of biosecurity measures not only helps to avoid introduction of infected animals in a flock free from FR but also helps to keep out new serogroups of *D. nodosus* not present on a farm. Although culling is recommended, only 42% farmers in UK culled sheep because of FR in 2000 and more than half of these farmers only culled less than 1% of their sheep (Wassink et al. (2003a). Not surprisingly, there was no significant association between culling and the prevalence of FR reported by Wassink et al. (2003a).

4.3. Summary of management and control of FR and ID: A UK perspective

To summarise, the majority of the work on efficacy of various treatment and control strategies in the management of FR and interdigital dermatitis has been done in Australia, which is different from the UK in climate (Green and George, 2007), farming methods and the method for defining FR. A summary of the recommendations for the management of FR and interdigital dermatitis in the UK up to 2002 is presented in Table 1-1 along with the research findings by Wassink et al. (2003a, 2004) on the management factors significantly associated with both ID and FR. However, once again a limitation of these research findings is that farmer estimates of prevalence of ID and FR were used, and it was assumed that farmers can recognise lame sheep and the lesions.
Table 1-1: Recommendation for management of ID and FR along with published research findings on associated management factors

<table>
<thead>
<tr>
<th>Recommendations for management up to 2002 (Morgan, 1987; Winter, 1989)</th>
<th>Research findings on management factors associated with ID and FR (Wassink et al. (2003a, 2004))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interdigital dermatitis (ID)</strong></td>
<td><strong>Positive association</strong> <strong>Negative association</strong> <strong>No association</strong></td>
</tr>
<tr>
<td>* footbathing * topical sprays</td>
<td><strong>Ewes</strong></td>
</tr>
<tr>
<td></td>
<td>* ‘sometimes/never’ catching lame sheep compared with ‘always’ * farm land 100 m or less above sea level * renting -in winter grazing</td>
</tr>
<tr>
<td></td>
<td><strong>Lambs</strong></td>
</tr>
<tr>
<td></td>
<td>* prevalence of 5 per cent or more of footrot in ewes * ‘sometimes/never’ catching lame ewes compared with ‘always’ * ‘sometimes/never’ treating ewes with footrot with parenteral antibiotics compared with ‘always’ * showing sheep at agricultural events * farm land 100 m or less above sea level * prevalence of 5 per cent or more of interdigital dermatitis in ewes</td>
</tr>
<tr>
<td><strong>Footrot (FR)</strong></td>
<td><strong>Ewes</strong></td>
</tr>
<tr>
<td>* routine trimming * footbathing * vaccination * quarantine new stock * isolation diseased sheep * cull chronically diseased * topical spray and foot trim mild cases * parenteral antibiotics- severe cases</td>
<td>* Routine foot trimming more than once a year</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.4. ‘Other’ common foot lesions in sheep

In addition to ID and FR, ‘other’ common foot lesions include contagious ovine digital dermatitis (CODD), shelly hoof, foot abscess and toe granuloma (Grogono-Thomas and Johnston, 1997; Winter, 2004b; Wassink et al., 2003b). These were generally considered to have low prevalence without much evidence (Grogono-Thomas and Johnston, 1997; Winter, 2004b). The lesion pictures are presented in Figure 1-3, the likely causes of these lesions, their clinical signs and the recommended treatments are presented in Table 1-2.

Figure 1-3: Photographs of clinical presentation of CODD, shelly hoof, foot abscess and toe granuloma

CODD*

Shelly hoof*

Foot abscess*

Toe granuloma*

* Photographs by J.Kaler  # Photograph by L.Green
Table 1-2: ‘Other’ common foot lesions in sheep
(References: Egerton et al., 1989; Winter, 2004a; 2004b; Moore et al., 2005b)

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Cause</th>
<th>Clinical presentation</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODD (Contagious ovine digital dermatitis)</td>
<td>• Unknown&lt;br&gt; • variety of bacteria &amp; spirochete found</td>
<td>• Loss of hair above coronary band without any interdigital space lesion&lt;br&gt; • Primary lesion at coronary band with under-running of hoof in a downward direction&lt;br&gt; • There may be complete detachment of hoof wall.</td>
<td>• Parenteral antibiotics, antibiotic footbaths</td>
</tr>
<tr>
<td>Shelly hoof (White line degeneration)</td>
<td>• Unknown&lt;br&gt; • Possible link with walking on concrete surfaces&lt;br&gt; • Nutrition</td>
<td>• Some degree of separation of horn from the hoof wall&lt;br&gt; • Pus may or may not be present&lt;br&gt; • Presence of a half moon shaped pocket impacted with soil/debris</td>
<td>• Paring away loose wall and removal of impacted material</td>
</tr>
<tr>
<td>Foot abscess</td>
<td>• Injury to the skin of interdigital surface&lt;br&gt; • thorn</td>
<td>• Discharge of pus comes from the foot and sheep is very lame&lt;br&gt; • Hoof horn is normal but hot.&lt;br&gt; • Swelling of the skin above the foot</td>
<td>• Parenteral antibiotics&lt;br&gt; • Non steroidal anti-inflammatory drugs</td>
</tr>
<tr>
<td>Toe granuloma</td>
<td>• Excessive trimming resulting in bleeding&lt;br&gt; • Chronic footrot&lt;br&gt; • Physical injury</td>
<td>• Presence of a strawberry like growth at the toe</td>
<td>• Surgical removal of granuloma</td>
</tr>
</tbody>
</table>
5. Monitoring lameness

Farmers monitor lameness in their flocks by visual assessment. However, in addition to the fact that we still do not know whether farmers can identify lameness, there is also no information on how a sheep farmer decides when to treat lame sheep, is the decision to treat an individual lame sheep dependent on 'how lame' the sheep is? The same information is also unavailable for sheep specialists.

There have been subjective and objective methods that have been used by researchers to monitor lameness in various species. Subjective methods include the use of scoring scales (e.g numerical rating scales (NRS) or visual analogue scales (VAS)). These have been commonly used for on farm assessment of locomotion in cattle (Sprechers et al., 1997; Amory et al., 2006), pigs (Main et al., 2000), horses (Fuller et al., 2006; Hewetson et al., 2006), dogs (Reid and Nolan, 1991) and poultry (Kestin et al., 1992). Objective methods include use of the kinetics (study of forces involved in motion) and kinematics (study of changes in position of the segments of body without reference to forces included in motion) (Hall, 1995). Although, these have been used in cattle and horses, their use has been limited because of technical difficulties (Flower et al., 2006).

A NRS was first used to monitor lameness in sheep by Ley et al. (1989). Categories 0 to 4 were used with 0 = normal movement, 1 = occasional limping, 2 = lifting foot when standing, not lame when moving, 3 = carrying foot, but lame on movement and 4 = carrying foot at all times. However, this scale was not evaluated for its reliability i.e agreement between observers (repeatability) and agreement within observers (reproducibility). Another NRS was used by Welsh et
al. (1993) (0 = clinically sound, 1 = barely detectable lameness, 2 = obvious lameness, 3 = severe head nod and possibly resting the affected foot when standing and 4 = carrying foot at the trot) to monitor lameness, and authors reported a good agreement between and within observers using this scale. Descriptors of lameness were described using subjective terminology in this NRS e.g. 'obvious lameness' and neither of the NRS included all possible severities of lameness. In addition to a NRS, a VAS (a straight line of 100 mm with two ends labelled 'sound' and 'could not be more lame') was tested by Welsh et al. (1993) and the authors reported good reliability of the VAS. However, the use of VAS is considered to be difficult in clinical practice (Fuller et al., 2006).

Thus, even though the use of locomotion scoring scales is quite in common in lameness research in other species and lameness in sheep has been a serious problem for many years, there is lack of availability of a reliable and practical locomotion scoring scale to monitor lameness in sheep. In addition, despite evidence that farmers attribute majority of their lameness to ID and FR (Grogono-Thomas and Johnston, 1997), there is no research investigating whether and how these lesions are linked to different severities of locomotion.

6. Epidemiological tools

6.1. Cross sectional studies

These observational studies generally provide first hand information on measures of disease frequency e.g. prevalence of the outcome in a population either at a particular time or over a short period (Levin, 2006). In addition, data can also be collected on various characteristics, including risk factors ideally non time dependent ones, along with information about the outcome to provide a ‘snapshot’
of the outcome and the factors associated with it, at that time. They are relatively inexpensive and quite useful to generate the hypotheses; however, they cannot be used to make any causal inferences between risk factors and outcome (Mann, 2003). Moreover, to make any inferences about the frequency of outcome e.g. prevalence of a disease, a formal sampling strategy is needed with calculation of appropriate sample size (Mann, 2003; Levin, 2006).

6.2. Postal questionnaires

Many cross-sectional studies are done using questionnaires (Mann, 2003). These have been used quite extensively in veterinary epidemiology (Vaillancourt, 1991). They are cheap, easy to implement and provide a more valid response to sensitive questions than face to face interviews (Krysan et al., 1994). However, their main disadvantage can be a low response rate (O' Toole et al., 1986; Dillman, 1991). This low response rate introduces a source of error i.e non-response bias since respondents may differ from non-respondents with respect to the information asked in the questionnaire (Dohoo et al., 2003). Various methods have been used to increase the response rate; this includes the use of reminders letters or postcards, cover letters, incentives and free postage (Heberlein and Baumgartner, 1978; Dillman, 1991). In addition, there is evidence that coloured paper and colour photographs can increase the response rate (Kaplowiz and Lupi, 2004).

In addition to non response bias, another source of error that can be introduced by questionnaires is measurement error; this happens when questions are not valid and reliable (Dohoo et al., 2003) (see below for details on validity and reliability).

Although questionnaires are a popular form of data collection in veterinary
epidemiology there are not many studies that have tested their validity and reliability (Vaillancourt, 1991).

6.3. Validity and Reliability

For any research instrument e.g. questionnaire, scoring scale, it is important that the results produced are valid and reliable (Gaberson, 1997; Higgins and Straub, 2006). Validity refers to the extent to which the inferences made from a research instrument are ‘valid’ i.e. correct. Validity is broadly categorised into three categories: construct validity, internal validity and external validity (Gaberson, 1997). Construct validity is concerned with whether the research instrument has actually measured what it was supposed to measure. Internal and external validity are concerned with the design of the study. For an internally valid study unbiased inferences of association(s) in the data can be made (Gaberson, 1997; Dohoo et al., 2003). As an extension to this, results of an externally valid study can be generalised to the target population (Dohoo et al., 2003).

Reliability, on the other hand, refers to the consistency of measurement results. It has been categorised into stability, equivalence, homogeneity (internal consistency) and ‘scorer’ or ‘rater’ reliability (Gaberson, 1997). ‘Stability’ is the consistency of repeated measurements i.e. it indicates whether research subjects achieve the same score if they take more than one test at some other time (test-retest procedure). The idea behind ‘equivalence’ is to use more than one form of a test on the same subjects and see if the results are correlated (Gaberson, 1997). ‘Homogeneity’ tests are performed to assess the extent to which each item on the instrument measure the same construct e.g. whether different questions in a questionnaire asking about the same outcome are correlated (Cook and Beckman,
Finally, ‘scorer’ or ‘rater’ reliability measures agreement between observers or within an observer (using same instrument more than once) (Gaberson, 1997; Higgins and Straub, 2006).

Any research instrument can not measure what it was supposed to measure adequately if its measurements are not consistent. Thus reliability is a necessary but not a sufficient condition for validity (Gaberson, 1997).

6.4. Longitudinal studies

Longitudinal studies can be defined as epidemiological studies where the outcome of interest and/or exposures is measured repeatedly over time. These are generally expensive, time consuming and difficult to analyse (since observations of subjects over time are not independent) (Twisk, 2003). However, they are very useful to study the development of certain outcome (e.g. infectious disease) over time and are a stronger study design to provide evidence for causal associations because temporal associations between infection and subsequent disease (in this thesis, lameness) can be elucidated.

7. Conclusions

Lameness in sheep has been and is an important health and welfare problem. At the start of this PhD in 2004 most of the large scale epidemiological studies to date in the UK measuring the prevalence of lameness, its causes and factors associated with ID and FR (two most common causes of lameness) assumed that farmers can identify lame sheep and the cause of lameness.

Although locomotion scoring scales are commonly used in lameness research in cattle and horses, there is no reliable practical locomotion scoring scale to monitor
locomotion in sheep. In addition, there is no information on whether decisions of sheep farmers and sheep specialists to inspect an individual lame sheep are influenced by severity of locomotion of sheep (i.e. ‘how lame’ the sheep is?) and whether there is any link between ID, FR and locomotion. Many of these issues can be addressed with appropriate well designed epidemiological studies. Thus, the overall aim of this thesis was to improve our understanding of epidemiology of lameness in sheep by addressing above mentioned issues. The following objectives were established:

a) To test whether farmers and sheep specialists can correctly recognise and name six common foot lesions in sheep (Chapter 2).

b) To investigate the factors associated with ID and FR (two most common foot lesions) and compare the results to previous studies (Chapter 3).

c) To develop a reliable locomotion scoring scale for sheep (Chapter 4).

d) To test whether farmers and sheep specialist can identify lame sheep and investigate their decisions to catch individual lame sheep (Chapter 5).

e) To investigate whether there is an association between ID, FR and locomotion in sheep (Chapter 6).
Chapter 2

Naming and recognition of six foot lesions of sheep using written and pictorial information: a study of 809 English sheep farmers

The contents of this chapter have been published; Kaler, J., and Green, L. E. (2008). Naming and recognition of six foot lesions of sheep using written and pictorial information: A study of 809 English sheep farmers. Preventive Veterinary Medicine. 83, 52-64.

1. Introduction

There is no evidence that the incidence or prevalence of lameness in sheep in the UK has decreased in the last 30 years despite recommendations for its control. In 1994, the estimated prevalence of lameness was 8% (Grogono-Thomas and Johnston, 1997). The most common infectious causes of lameness in sheep are interdigital dermatitis (ID) and footrot (FR) (Grogono-Thomas and Johnston, 1997) and more recently concern has been raised over the newly emerging infectious disease, contagious ovine digital dermatitis (CODD) (Wassink et al., 2003b). In addition to these infectious causes of lameness, there are non-infectious causes which include white line degeneration (shelly hoof), foot abscess and toe granuloma (Winter, 2004b). These are generally considered to be of low prevalence (Grogono-Thomas and Johnston, 1997; Winter, 2004 a and b).

Recent research indicates that new approaches to managing FR and ID might be more effective for the control of these diseases than previous recommendations (Wassink et al., 2003a, 2005; Green et al., 2007). However, another reason for the failure to reduce lameness in sheep may be that farmers incorrectly diagnose the
cause of lameness and therefore manage lameness incorrectly. Most recent epidemiological studies in the UK that have quantified lameness in sheep and its causes (Grogono-Thomas and Johnston, 1997; Wassink et al., 2003a) have used farmer opinion of the cause and prevalence of lameness in their flock. Consequently, they are based on the untested premise that farmers can recognise and name the foot lesions associated with lameness and that they can identify lame sheep. The former assumption is tested in this chapter.

This chapter presents the results from a study of farmer and sheep-expert naming of six foot lesions of sheep in 2004 with validation. The prevalence of lameness and lesion specific causes attributed to this lameness is presented.

2. Materials and Methods

2.1. Development and implementation of the questionnaire

2.1.1. Study population

Win Episcope 2.0 was used to estimate the sample size. The sample size was calculated assuming 50% of flocks affected with each lesion, based on the 34% to 77% of flocks affected as estimated by Grogono-Thomas and Johnston (1997), with a precision of 2.5% and a confidence interval of 95% (Cannon and Roe, 1982). This sample size was then adjusted for an expected response rate of 50%, since the source list was known to contain redundancy.

A stratified random sample of sheep farms was selected from a list belonging to the English Beef and Lamb Executive (EBLEX) sorted by region and by flock size within each region. Sheep farms in England were grouped into five regions, south west (Cornwall, Devon, Somerset, Dorset, Wiltshire and Gloucestershire),
south east (Norfolk, Suffolk, Hertfordshire, Berkshire, London, Surrey, Kent, E. Sussex, W. Sussex and Essex), central (Cheshire, Peterborough, Cambridgeshire, Lincolnshire, Nottinghamshire, Northamptonshire, Warwickshire, Bedfordshire, Buckinghamshire, Oxfordshire, Worcestershire, Leicestershire, Staffordshire, Shropshire and Herefordshire), north west (Greater Manchester, Cumbria and Lancashire) and north east (Northumberland, Durham and Yorkshire). Approximately 6% of the target population was surveyed.

2.1.2. Questionnaire

A questionnaire containing a characteristic picture and description (e.g. Figure 2-1, Appendix 1) of six lesions associated with lameness (ID, FR, CODD, shelly hoof, foot abscess and toe granuloma) together with questions on flock size, location and prevalence of lameness was developed. The questionnaire was pilot tested (Appendix 2) on 15 farmers and the final version developed from these farmers' comments and responses to questions.

The questionnaire, covering letter (Appendix 3) and a return stamped addressed envelope were sent out on March 14th, 2005 to 591,414,989,331 and 675 farmers in each of the regions listed above respectively. A reminder postcard (Appendix 4) was sent to all non-respondents on April 14th, 2005. A second reminder (Appendix 5), which included a copy of the questionnaire and return stamped addressed envelope, was sent to the remaining non-respondents on May 14th, 2005. Acknowledgement postcards (Appendix 4) were sent to all those who responded to the survey.
Figure 2-1: An example of a question to investigate farmer ability to name foot lesions in sheep

<table>
<thead>
<tr>
<th>What you might see when you look at the foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
<th>Did you see this lesion in your flock in 2004?</th>
<th>What percentage of lame sheep had this lesion?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Strawberry-like growth at the toe</td>
<td><img src="image.png" alt="Photograph" /></td>
<td>□ Footrot</td>
<td>□ No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Interdigital dermatitis</td>
<td>□ Don’t know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Shelly hoof</td>
<td>□ Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Foot abscess</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ CODD*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Toe granuloma</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Contagious ovine digital dermatitis
2.2. Farmer naming and prevalence of six lesions

2.2.1. Definitions/calculations

All answers = the number of farmers who responded to a question.

Correct name of lesion = the percent of farmers who named the lesion correctly out of all those who answered the question.

Incorrect name = the percent of farmers who incorrectly named a lesion out of all those who answered the question.

Most frequently used name for a misnamed lesion = the name most attributed incorrectly to a lesion e.g. the most frequent incorrect name attributed to shelly hoof was FR.

The distribution of proportion of lameness attributed to shelly hoof (correctly named by the farmer) by flock was plotted. This was compared with the distribution incorrectly named as FR and the distribution correctly named as FR. This was repeated for ID, CODD, foot abscess and toe granuloma.

Prevalence of a lesion = percent of sheep lame with a lesion in flocks where the farmer named the lesion correctly.

The most prevalent lesion on a farm = the picture of the lesion with the highest percent of lameness in the flock according to the farmer, irrespective of the farmer's name for the lesion.

Where ID or FR were correctly named and were the most prevalent lesion in the flock, the farmer's ability to correctly name other lesions was estimated (43 farms were omitted from both lesion categories because they had both ID and FR equally prevalent on farm).
2.3. Validity and repeatability of questionnaire

The location and size of the selected and participating farms were compared with the DEFRA agricultural survey 2004.


Non-response bias was assessed by comparing the geographical distribution and average flock size of respondents and non-respondents.

2.3.1. Farm visits and examination of live sheep

Four farmers from each category of zero to all six lesions correctly named from the postal study (28 in total) were visited in May and June 2006. Visits were arranged by telephone and were based on farmer availability and proximity to the University of Warwick. Farmers were sent a letter containing the date and time of the visit, farmers were asked to gather any lame sheep they had in preparation for the visit. The objectives of the visit were to repeat the written lesion recognition questionnaire (repeatability) and to investigate whether farmers named the lesions on lame sheep as they had in the questionnaire (validity). On the farm, the farmer’s and the researcher’s (JK) name for the foot lesions observed were recorded independently. The researcher used codes for lesions to ensure that farmers did not learn the identity of the lesions while the observations were made. After the recordings were complete, the farmer was asked to repeat the self administered questionnaire (the same person who filled in the first questionnaire filled in the second one). Finally, the six lesions were then discussed with the farmer. Each farmer was asked to rank the picture quality and written descriptions in the self administered questionnaire using a scale of good, average or poor.
2.3.2. Questionnaire repeatability

In addition to questionnaires administered on farms, 50 questionnaires were sent by post to farmers selected randomly from respondents to the first survey, ensuring that all levels of lesion recognition were represented, to test repeatability. For repeatability we calculated:

**Percent exact agreement** = percent of farmers who gave the same name to a lesion on both occasions. In addition, kappa statistics and the number of correct answers for the six lesions between the farm visits and the postal questionnaire were calculated. Kappa was interpreted according to Landis and Koch (1977).

2.4. Recognition of lesions by attendees at the Sheep Veterinary Society meeting

The self administered questionnaire (Appendix 6) was distributed at the Sheep Veterinary Society meeting Cambridge, England in April, 2006. The delegates were asked to complete the questionnaire. In addition, they were asked their profession and whether they personally had a care of a flock of sheep.

2.5. Data analysis

Comparisons between proportions were made with a $\chi^2$ test, two means with modified t-test (unequal variances) and more than two means with Kruskal – Wallis test (Petrie and Watson, 2000) with significance at $p \leq 0.01$.

3. Results

3.1. Number of replies to the postal questionnaire

A total of 1313 (44%) questionnaires were returned. The regional response percent was 43.0%, 42.8%, 41.4%, 47.3% and 45.3% for the central, north east,
north west, south east and south west respectively. Out of the 1313 questionnaires returned, 809 (62%) were usable for the analysis which gave a usable response percent of 32 (Table 2-1). Three hundred and ten (38%) farmers out of 809 agreed to participate in any further study on lameness in sheep.

Table 2-1: Pattern of the 1313 responses from the survey to 3000 English sheep farmers in 2004.

<table>
<thead>
<tr>
<th>Types of responses</th>
<th>Number</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usable</td>
<td>809</td>
<td>61.6</td>
</tr>
<tr>
<td>No sheep in 2004</td>
<td>443</td>
<td>33.7</td>
</tr>
<tr>
<td>Unknown address</td>
<td>42</td>
<td>3.2</td>
</tr>
<tr>
<td>Non- participation</td>
<td>19</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td>1313</td>
<td>100.0</td>
</tr>
</tbody>
</table>

3.2. Flock attributes

The mean flock size was 318 sheep with a median of 220 (interquartile range 90 - 450). The altitude of the farms ranged from 60m to 244m above sea level. A total of 394/792 (50%) farmers had pedigree flocks producing replacement ewes and terminal sires while 746 (94%) produced meat and store lambs and 20 (2%) were hobby farmers or produced wool. Ninety seven percent of 809 farmers reported that they had lame sheep in their flock in 2004; the mean within flock prevalence of lameness was approximately 10.4%. This did not vary by region (H = 7.8, p>0.01) or flock size (H = 0.99, p>0.01).

3.3. Naming of lesions

The percent of lesions correctly named ranged from 28% (shelly hoof) to 85% (FR) (Table 2-2). Twenty three percent (59) of 262 farmers who answered all six questions named all six lesions correctly. The probability of getting all six correct by chance was $0.2 \times 10^{-4}$. The percent of farmers who identified any 5, 4, 3, 2 or 1
lesion correctly was 28%, 47%, 71%, 93% and 98% respectively. The names used by farmers for the incorrectly named lesions ranged from 5% (ID) to 47% (FR) (i.e. 47% farmers incorrectly named other lesions as FR) (Table 2-2).
Table 2-2: The number and percent of farmers and specialists who named lesions correctly and used incorrect names, percent of farms and sheep affected by lesion with validity and repeatability results from 809 English sheep farmers in 2004.

<table>
<thead>
<tr>
<th>Named by farmer</th>
<th>Correct Name</th>
<th>A*</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Interdigital dermatitis</td>
<td>595 (83%)</td>
<td>18 (3%)</td>
<td>11 (3%)</td>
<td>1 (&lt;1%)</td>
<td>10 (2%)</td>
<td>1 (&lt;1%)</td>
<td></td>
</tr>
<tr>
<td>B. Footrot</td>
<td>96 (13%)</td>
<td>531 (85%)</td>
<td>129 (30%)</td>
<td>253 (53%)</td>
<td>65 (14%)</td>
<td>57 (11%)</td>
<td></td>
</tr>
<tr>
<td>C. Contagious ovine digital dermatitis</td>
<td>5 (&lt;1%)</td>
<td>13 (2%)</td>
<td>154 (36%)</td>
<td>8 (2%)</td>
<td>44 (10%)</td>
<td>11 (2%)</td>
<td></td>
</tr>
<tr>
<td>D. Shelly hoof</td>
<td>2 (&lt;1%)</td>
<td>213(3%)</td>
<td>48 (11%)</td>
<td>135 (28%)</td>
<td>27 (6%)</td>
<td>5 (1%)</td>
<td></td>
</tr>
<tr>
<td>E. Foot abscess</td>
<td>3 (&lt;1%)</td>
<td>37 (6%)</td>
<td>83 (19%)</td>
<td>40 (8%)</td>
<td>293 (65%)</td>
<td>154 (30%)</td>
<td></td>
</tr>
<tr>
<td>F. Toe granuloma</td>
<td>-</td>
<td>2 (&lt;1%)</td>
<td>6 (1%)</td>
<td>35 (7%)</td>
<td>9 (2%)</td>
<td>223 (43%)</td>
<td></td>
</tr>
<tr>
<td>G. Other</td>
<td>20 (3%)</td>
<td>1 (&lt;1%)</td>
<td>3 (&lt;1%)</td>
<td>6 (1%)</td>
<td>6 (1%)</td>
<td>65 (13%)</td>
<td></td>
</tr>
</tbody>
</table>

Percent sheep specialists who named lesion correctly 96% 98% 94% 86% 90% 96%
Percent farmers with misnamed lesion names 5% 47% 10% 13% 35% 7%
Repeatability at farm visits (n=28) 88% 88% 83% 83% 71% 88%
Percent exact agreement 79% 79% 52% 67% 49% 55%
Repeatability at farm visits: Kappa (95% C.I) 0.64 0.72 0.79 0.71 0.7 0.82
(0.31 - 0.96) (0.41 - 1) (0.60 - 0.97) (0.49 - 0.94) (0.46 - 0.91) (0.63 - 1)
Repeatability by post (n= 30)
Percent exact agreement 79% 79% 52% 67% 49% 55%
Repeatability by post: Kappa (95% C.I) 0.5 0.65 0.36 0.48 0.35 0.46
(0.21 - 0.78) (0.41 - 0.88) (0.14 - 0.59) (0.25 - 0.71) (0.11 - 0.59) (0.23 - 0.69)
Number of farmers with identical responses for sheep and questionnaire 16 (n=22) 12 (n=16) 4 (n=4) 4 (n=5) 1 (n=2) 4 (n=3)
Farmers rating of pictures and description as ‘good’ 89% 96% 86% 93% 96% 100%
Percent flocks affected (on farms with correct name for each lesion) 96% 90% 53% 72% 59% 66%
Percent lame sheep (on farms with correct name for each lesion) 6.90% 3.70% 2.40% 1.90% 0.90% 0.80%
Percent flocks with lesion (on farms with all 6 lesions correctly named, n = 59) 92% 92% 25% 56% 49% 51%
Percent sheep lame (on farms with all 6 lesions correctly named, n = 59) 7.00% 3.90% 0.90% 0.90% 0.70% 0.90%

* A = interdigital dermatitis, B = Footrot etc.
3.4. Comparison of the distribution of flock lameness for ID, CODD, shelly hoof and foot abscess misnamed as FR

Interdigital dermatitis, CODD, shelly hoof and foot abscess were most frequently misnamed as FR. When the distribution of flock lameness attributable to ID, CODD, shelly hoof and foot abscess correctly named and incorrectly named as FR were compared, there was no significant difference (p>0.01) between the distributions of lameness (ID ($\chi^2 = 9.19$, df = 4), CODD ($\chi^2 = 1.6$, df = 3), shelly hoof ($\chi^2 = 12.9$, df = 4) and foot abscess ($\chi^2 = 6.8$, df = 3)). However, there was a significant difference between the distribution of the lesions incorrectly named as FR and the distribution of FR when correctly named ($\chi^2 = 78.77$ df = 4, $\chi^2 = 11.5$ df = 3, $\chi^2 = 15.7$ df = 4, $\chi^2 = 21.5$ df = 3 with p<0.01 respectively) (Figure 2-2). This suggests that farmers recognised the description and photograph but misnamed the lesion.

Figure 2-2: Comparison of distribution of proportion of flock lameness attributed to a) interdigital dermatitis, b) contagious ovine digital dermatitis, c) shelly hoof and d) foot abscess by farmers who correctly named the lesion and those who misnamed these lesions as footrot compared with the distribution attributed to correctly named footrot, with 95% C.I.

a) ID

*Black bars - lesion correctly named, White bars- lesion misnamed as footrot, Grey bars- footrot correctly named
b) CODD

*Black bars - lesion correctly named, White bars- lesion misnamed as footrot, Grey bars- footrot correctly named

c) Shelly hoof

*Black bars - lesion correctly named, White bars- lesion misnamed as footrot, Grey bars- footrot correctly named

d) Foot abscess

*Black bars - lesion correctly named, White bars- lesion misnamed as footrot, Grey bars- footrot correctly named
For toe granuloma the most frequent incorrect name was foot abscess. There was no indication that farmers recognised toe granuloma. Interestingly, approximately 12% (51/428) of farmers who reported the presence of toe granuloma named it as ‘other’ and most of them specified ‘other’ as ‘strawberry footrot’ (another cause of lameness in sheep, Winter 2004b). Anecdotally, we now know that many farmers refer to toe granuloma (small spheres of proud flesh) as strawberries.

3.5. Prevalence of lameness and foot lesions in sheep in 2004

A total of 264,076 sheep were in this survey. Out of these, 27,468 (10.4%) sheep were estimated lame in 2004. The most prevalent causes of lameness were ID and FR (Table 2-2).

3.6. Association between lesion naming and the most prevalent lesion

A total of 421/514 (82%) and 160/189 (85%) farmers named ID and FR correctly where they had stated this as their most prevalent lesion. A total of 7% (2/29), 13% (11/83), 38% (20/53) and 57% (12/21) of farmers correctly named toe granuloma, shelly hoof, CODD and foot abscess where the farmer stated that these were the most prevalent lesion in the flock. Therefore there were 17% (141/809) farmers who reported lesions other than ID and FR as their most prevalent lesion on the farm but did not name them correctly and there were 6% (2459/43340) sheep in these flocks with these lesions.

The 421 farmers, who correctly named ID, and where it was the most prevalent cause of lameness, were more likely to name all other lesions correctly than farmers who stated that FR was most prevalent and had correctly named FR. In
the flocks where FR dominated (117), farmers had a tendency to also name other horn damage as FR (Table 2-3).
Table 2-3: Farmers naming of other lesions where FR or ID was most the prevalent lesion and was correctly named in English sheep flocks in 2004

<table>
<thead>
<tr>
<th>Correct Name</th>
<th>Most prevalent lesion on farm</th>
<th>Farmer response to lesion</th>
<th>A*</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>No answer</th>
<th>Other name given by farmer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Interdigital Dermatitis(ID)</td>
<td>FR</td>
<td></td>
<td>70 (60%)</td>
<td>19 (16%)</td>
<td>1 (1%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23 (20%)</td>
<td>4 (3%)</td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>378</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Footrot (FR)</td>
<td>FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>7 (2%)</td>
<td>273 (72%)</td>
<td>8 (2%)</td>
<td>15 (4%)</td>
<td>14 (4%)</td>
<td>2 (&lt;1%)</td>
<td>58 (15%)</td>
<td>1 (&lt;1%)</td>
<td></td>
</tr>
<tr>
<td>C. Contagious ovine digital dermatitis</td>
<td>FR</td>
<td>3 (3%)</td>
<td>24 (21%)</td>
<td>16 (14%)</td>
<td>3 (3%)</td>
<td>19 (16%)</td>
<td>2 (2%)</td>
<td>50 (43%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>1 (&lt;1%)</td>
<td>54 (14%)</td>
<td>97 (26%)</td>
<td>29 (8%)</td>
<td>38 (10%)</td>
<td>4 (1%)</td>
<td>155 (41%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Shelly hoof</td>
<td>FR</td>
<td>-</td>
<td>35 (30%)</td>
<td>1 (1%)</td>
<td>19 (16%)</td>
<td>5 (4%)</td>
<td>5 (4%)</td>
<td>51 (44%)</td>
<td>1 (1%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>-</td>
<td>131 (35%)</td>
<td>3 (&lt;1%)</td>
<td>83 (22%)</td>
<td>21 (6%)</td>
<td>16 (4%)</td>
<td>120 (32%)</td>
<td>4 (1%)</td>
<td></td>
</tr>
<tr>
<td>E. Foot abscess</td>
<td>FR</td>
<td>3 (3%)</td>
<td>14 (12%)</td>
<td>5 (4%)</td>
<td>3 (3%)</td>
<td>36 (31%)</td>
<td>2 (2%)</td>
<td>53 (45%)</td>
<td>1 (1%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>1 (&lt;1%)</td>
<td>27 (7%)</td>
<td>32 (9%)</td>
<td>15 (4%)</td>
<td>167 (44%)</td>
<td>3 (&lt;1%)</td>
<td>130 (34%)</td>
<td>3 (&lt;1%)</td>
<td></td>
</tr>
<tr>
<td>F. Toe granuloma</td>
<td>FR</td>
<td>3 (3%)</td>
<td>24 (21%)</td>
<td>8 (7%)</td>
<td>-</td>
<td>1 (1%)</td>
<td>24 (21%)</td>
<td>48 (41%)</td>
<td>9 (8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td>4 (1%)</td>
<td>67 (18%)</td>
<td>19 (5%)</td>
<td>-</td>
<td>2 (&lt;1%)</td>
<td>142 (36%)</td>
<td>103 (27%)</td>
<td>41 (11%)</td>
<td></td>
</tr>
</tbody>
</table>

* A = interdigital dermatitis, B = Footrot etc.
3.7. Validity

There was no significant difference in geographical distribution ($\chi^2 = 3.85$, df = 4, $p>0.01$) or average flock size ($t = 1.96$, $p>0.01$) between respondents and non-respondents. The geographical location of the selected farms ($\chi^2 = 122.0$, df = 4, $p<0.01$) and participating farms in the survey ($\chi^2 = 43.4$, df = 4, $p<0.01$) was significantly different from that listed in the DEFRA census for 2004. Similarly, the distribution of flock size of selected and participating farms in the survey was also significantly different from the DEFRA census for 2004 ($\chi^2 = 420$, df = 5, $p<0.01$), ($\chi^2 = 319.11$, df = 5, $p<0.01$) respectively (Table 2-4).

### Table 2-4: Number and percent of sheep holdings by flock size listed by DEFRA and those in the study of 809 English sheep farmers in 2004.

<table>
<thead>
<tr>
<th>Flock size</th>
<th>DEFRA survey 2004</th>
<th>Percent of all flocks</th>
<th>Study survey 2004</th>
<th>Percent of all study flocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-&lt;50</td>
<td>18548</td>
<td>38.1</td>
<td>91</td>
<td>11.7</td>
</tr>
<tr>
<td>50-&lt;100</td>
<td>5553</td>
<td>11.4</td>
<td>107</td>
<td>13.7</td>
</tr>
<tr>
<td>100-&lt;200</td>
<td>6300</td>
<td>12.9</td>
<td>147</td>
<td>18.9</td>
</tr>
<tr>
<td>200-&lt;500</td>
<td>8666</td>
<td>17.8</td>
<td>255</td>
<td>32.7</td>
</tr>
<tr>
<td>500-&lt;1000</td>
<td>5355</td>
<td>11.0</td>
<td>145</td>
<td>18.6</td>
</tr>
<tr>
<td>1000+</td>
<td>4317</td>
<td>8.9</td>
<td>34</td>
<td>4.4</td>
</tr>
</tbody>
</table>

3.7.1. Farm visits

At the 28 farm visits a total of 193 lame sheep were examined, this included 158 ewes, 4 rams and 31 lambs. Approximately 30% of the lame sheep were affected on more than one limb. A total of 278/772 (36%) feet were clinically abnormal. There were 22, 12, 4, 5, 2 and 3 flocks with sheep with ID, FR, CODD, shelly hoof, foot abscess and toe granuloma respectively on the day of the visit. Farmers generally gave the same name to the lesions present on farm as they did in the postal questionnaire (Table 2-2). A total of 86% (CODD) to 100% (toe granuloma) farmers rated pictures and descriptions of lesions as good (Table 2-2).
3.8. Repeatability

3.8.1. Farm visits

The same farmer who had completed the postal questionnaire completed it again on farm (self administered). The percent exact agreement for lesion naming ranged from 71% (foot abscess) to 88% (ID, FR and toe granuloma) and the kappa coefficients of agreement between farmer ratings showed substantial agreement ranging from 0.64 (ID) to 0.82 (toe granuloma) (Table 2-2). Eight farmers gave one more correct answer to the repeatability questionnaire than to the postal questionnaire.

3.8.2. Repeatability questionnaires sent by post

Thirty questionnaires (60%) out of 50 were returned. The percent exact agreement for lesion naming ranged from 49% (foot abscess) to 79% (FR and ID) and the kappa coefficient of agreement between farmer responses varied from fair to substantial ranging from 0.35 (foot abscess) to 0.65 (FR). Out of 30 farmers, 11 (37%) had the same number of correct answers in both questionnaires. Of those farmers who had a different number correct between the questionnaires, 12 gave one or more extra correct answers and 7 gave fewer correct answers.

3.9. Recognition of lesions by sheep specialists

Fifty delegates completed the questionnaire; 40 were veterinarians, 7 other specialists and 3 did not state their profession. Seventeen had care of a flock of sheep. The percent of correctly named lesions ranged from 86% (shelly hoof) to 98% (FR) (Table 2-2). A total of 37 out of 47 (79%) respondents named all 6 lesions correctly.
4. Discussion

The results from the study support the emphasis on education and research to minimize lameness caused by ID and FR. However, the key finding from this study is that many farmers could not correctly name all six lesions presented but probably could recognise them. In contrast to the farmer naming of lesions, most sheep specialists were able to name the six lesions correctly. This suggests that these specialists could be a useful source of knowledge to farmers if we can improve knowledge transfer. Photographs (considered good by farmers in this study) may assist with this transfer of knowledge, together with an emphasis on the need to name lesions correctly (to ensure useful dialogue) and then finally an understanding of how lesions occur and may be treated and prevented (to the best of our current knowledge).

In this study, FR was the most commonly used incorrect name for other lesions. The practical and important result of this is that lame sheep and flocks of sheep may be mis-managed, assuming this sample of flocks is generalisable, and that the interpretation of the results that farmers can recognise but not name the lesions is correct. Approximately 17% of farmers stated lesions other than FR or ID were the most prevalent lesions on their farm but did not name them correctly. Given that the majority of misnaming appears to be just that, recognition of the lesion but an attribution of an incorrect name, it is of concern that 17% of flocks (2459 lame sheep and their 40881 non-lame flock mates) might be managed incorrectly. In addition, 6% (45/809) of farmers who did correctly name lesions other than ID or FR as their most prevalent cause of lameness may not receive useful advice.
The most randomly named lesion was toe granuloma. The development of granulation tissue occurs in response to damage to the sensitive dermis, often through trimming horn into sensitive tissue but possibly also in response to footrot disease. In the UK, we have emphasised that it is poor practice to trim hoof horn into the dermis for many years (Grogono-Thomas and Johnston 1997; Winter, 2004 a, b) and that an iatrogenic result might be the development of toe granuloma, but this message is apparently unclear to farmers since toe granulomas are still occurring on at least 66% of farms, and possibly many more, given the random misnaming of this lesion.

A key assumption from this study was that farmers can recognise lame sheep and that the estimates of farms affected and within flock prevalence are valid. The prevalence estimates in the current study are similar to those presented by Grogono-Thomas and Johnston (1997) and by Wassink et al. (2003a) but, of course, all rely on farmer recognition of lameness. There is now evidence that farmers can recognise lame sheep from movie clips (Chapter 5). The improvement in the current study is that the flock prevalence and proportional contribution of each lesion to lameness is estimated and only from among farmers who named the six lesions correctly.

ID was present in 96% of flocks in this study, more than the 51% and 88% as reported by Grogono-Thomas and Johnston (1997) and Wassink et al. (2003a) respectively and FR was present in 90% of flocks. This was again higher than the 77% and 86% as reported by Grogono-Thomas and Johnston (1997) and Wassink et al. (2003a) respectively. ID and FR were the most prevalent causes of lameness.
within flocks which is similar to the results reported by Grogono-Thomas and Johnston (1997).

Not all foot lesions were present on each farm at the farm visits (Table 2-2), as might be anticipated from our postal questionnaire results, but of those present, farmer recognition was generally similar to that in the postal questionnaire, indicating that the pictures were a valid technique where use of lame sheep was not possible. A useful finding was that there were generally several farm workers on each farm and so it was possible to ensure that the repeatability study was done with the same respondent; repeatability was moderate to high. The repeatability by post was a comparatively lower; this may be because a different person completed the second questionnaire. Repeatability would be lower if within respondent pairs there was a higher or lower level of knowledge about the lesions.

For good precision and representation of sheep farmers in England, farmers with a representative range of flock sizes from each region were selected. Stratified random sampling within the strata should have minimised selection bias. However, the distribution of flocks selected was different with respect to the overall distribution of flocks in England from the DEFRA agricultural survey, 2004 and the average flock size was apparently larger than the DEFRA estimated flock size. In this survey there was an under representation of very small flocks (<50) and larger flocks (>1000). We do not know why there was this difference.

The information in this study was obtained by post which is one of the most frequently used modes to collect data in veterinary epidemiology (Vaillancourt et al., 1991). Although they are less expensive to conduct than telephone and in-person interviews, postal questionnaires are prone to number of errors (O'Toole et
al., 1986) and their potential major disadvantage is a low response percent. Even though two reminders were used we had a response percent of 44 rather than the 50% anticipated, and a useable response percent of 32%. However, this was over 800 farmers, a number that it was not feasible to visit. The response percent in the current study was high compared with the 20% in the 1993 study (Grogono-Thomas and Johnston, 1997) which followed a similar random sampling strategy but did not use reminders. However, the response percent in this study was moderate compared with the 64% by Wassink et al. (2003a) which used a non random sample with two reminders and targeted farmers from the survey of 1993 (Grogono-Thomas and Johnston, 1997) who had said they were interested in participating in further research. Interestingly, this response percent was similar to the 60% in our repeatability study using compliant farmers. Considering the fact that sheep farmers are going out of farming and that the address list was known to contain redundancy the response percent for this study was reasonable. Although there were no significant differences between respondents and non respondents with respect to geographical location and flock size; one cannot rule out non-response bias for other reasons, e.g. farmers who responded might have been more concerned about lameness in their flock than non-respondents.

5. Conclusion

This study indicates that there is a gap in knowledge between sheep advisors and sheep farmers in the naming of six common foot lesions in sheep. Some 20% of farmers named all six lesions correctly but the majority recognised only ID and FR while approximately 80% of advisors recognised all the lesions. FR was the name most commonly attributed to other hoof horn lesions. This is of concern for further education programmes and highlights that one of the first stages of a
programme to reduce lameness in sheep is to ensure all parties (including veterinarians, who might need a refresher if not frequently dealing with sheep) use consistent lesion naming. Only then will education on prevention and treatment for each lesion be possible.
Chapter 3

Farmers’ practices and factors associated with the prevalence of all lameness and lameness attributed to interdigital dermatitis and footrot in sheep in 2004

1. Introduction

Up until 2002 whole flock control measures to prevent lameness (especially footrot (FR)) included routine foot trimming, routine footbathing, culling sheep repeatedly lame with FR, vaccination, use of clean pastures and well drained land, and selecting sheep that were resistant to FR (Morgan, 1987; Winter, 1989). Maintaining a closed flock, where possible, or quarantining brought-in sheep before introducing them to the main flock were also recommended, to prevent the introduction of FR into flocks (Winter, 1998). The recommended treatment for individual sheep affected with FR comprised trimming away the loose dead tissue and applying a topical foot spray or using long acting of antibiotic injection for severe cases of disease (Morgan, 1987; Winter, 1989). The recommended treatment for interdigital dermatitis (ID) was footbathing sheep in 3% formalin or 10% zinc sulphate or using a topical foot spray (Winter, 1989).

In 2000, a study of 251 non-randomly selected sheep farmers in England and Wales was conducted by Wassink et al. (2003a, 2004) to investigate farmers’ management practices and their associations with the prevalence of ID and FR. In the questionnaire, farmers were asked to list the prevalence of FR and ID for each month of the year. The highest monthly prevalence of FR and ID was then used in
subsequent analyses. The factors associated with an increase in the prevalence of ID in ewes were ‘sometimes/never’ catching lame sheep compared with ‘always’, farm land 100 m or less above sea level and renting –in winter grazing (Wassink et al., 2004). The factor associated with an increased prevalence of FR was routine foot trimming. The factors associated with a decrease in prevalence of FR were isolation of brought-in sheep; individual treatment of diseased sheep with parental antibiotic, foot trimming individual lame sheep and topical foot spray. There was no significant association between footbathing or vaccination and the prevalence of ID or FR in ewes (Wassink et al., 2003a; 2004).

Two major limitations of the study carried out by Wassink et al. (2003a, 2004) were that it used a non random sample of farmers, which affected the generalisability of the prevalence estimates and that the authors assumed that farmers could correctly recognise lame sheep and the foot lesions ID and FR.

Because of this, when the random study of 809 English sheep farmers as described in Chapter 2 was conducted, farmers were also asked to complete information on the overall prevalence of lameness in their sheep and their management of lameness. Although there is now evidence that most farmers can identify lame sheep, at least from a movie clip (Chapter 5), the recognition of common foot lesions including ID and FR varies among farmers (Chapter 2). Whilst approximately 83% and 85%, of farmers correctly named ID and FR respectively, FR was the most commonly attributed incorrect name given to other hoof horn lesions, with approximately 47% farmers naming other lesions as FR.

In this chapter, a comparison of the management factors associated with the prevalence of farmer estimated lameness (irrespective of farmer ability to name a
lesion) and the adjusted prevalence of lameness caused by ID and FR among flocks where farmers correctly recognised both lesions, is presented and discussed.

2. Materials and Methods

2.1. Data collection

The data came from a postal questionnaire which was sent to 3000 English sheep farmers in 2005 (Chapter 2, Kaler and Green, 2007). The details of the study design and sample size are described in Chapter 2. In addition to questions on the estimate of lameness and ID and FR (Chapter 2), the questionnaire had a section with questions on lameness management practices and general farm characteristics (Table 3-1; Table 3-2; Appendix 1).

Table 3-1: A list of the questions in the postal questionnaire on farm characteristics and lameness management in the survey for the year 2004

<table>
<thead>
<tr>
<th>Questions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background farm characteristics</td>
<td>minimum farm height, maximum farm height, area grazed, average number of ewes one year old and above, average number of ewes less than one year old, average number of rams one year old and above, average number of rams less than one year old, number of lambs sold, number of store lambs, purpose of offspring, breed of ewes, breed of rams, number of months ewes housed</td>
</tr>
<tr>
<td>Management</td>
<td>frequency of routine foot trimming, frequency of footbathing, vaccination against FR, separation of lame sheep at housing, separation of lame sheep at pasture, individual treatments of lame sheep (foot trimming, antibiotic injection, antibiotic spray, isolation, 'other' (Table 3-2)) and percentage lame sheep treated with each individual treatment, change in management between 2003 and 2004</td>
</tr>
</tbody>
</table>

Table 3-2 : An example of question asked to farmers on management of lameness

4.8 How did you treat your individual lame sheep in 2004? (Please tick all that apply and indicate the percent treated)

- Trim feet(_____%)
- Antibiotic injection(_____%)
- Antibiotic spray(_____%)
- Isolate(_____%)
- Other(_____%) (please specify)
2.2. Selected farms for analyses

Two datasets were generated for the analyses. Dataset A (n= 809) included all farmers who replied to the questionnaire irrespective of their ability to recognise six common foot lesions of sheep (Kaler and Green, 2007). Dataset B (n = 443) included only those farmers who correctly recognised and named both ID and FR. Seventy two farmers and 46 farmers from dataset A and dataset B respectively, who either changed their lameness management practices from 2003 to 2004 or did not answer this question, were excluded from the analyses to provide managements for 2003 and lameness estimates for 2004 (i.e. not temporally confounded). Dataset A was used to investigate risk factors for the overall prevalence of lameness and dataset B was used to develop two models to investigate risk factors for the prevalence of ID and FR.

2.3. Statistical analysis

Data entry and error checking were performed in Microsoft Access 2000 (Microsoft) and data were exported to Stata SE 9.0 (StataCorp, USA) for screening and analysis. The flock size was calculated as the average number of ewes of one year old and above in the flock in 2004.

2.3.1. Model building strategies

Negative binomial regression modelling (Cameron and Trivedi, 1998) was used to estimate both univariable and multivariable associations between each outcome the number of cases of lameness, ID or FR (offset by the natural logarithm of flock size) and explanatory variables. The likelihood ratio chi-squared test was used to test whether the over dispersion parameter α was significantly different from zero (differentiating a negative binomial model from a Poisson model). A
log link model with variance as a function of the mean was used with a model structure as follows:

Number of cases on farm\textsubscript{j} in 2004 $\sim \alpha + $ offset $+ \beta X_j + e_j$

where $\alpha$ is the intercept, $\sim$ is a log link function, offset is the natural log of flock size and $\beta X_j$ is a series of vectors of explanatory variables that vary by farm $j$, and $e_j$ is the residual random error.

The linearity of continuous explanatory variables with the outcome was visually assessed using scatter plots and the variables failing this assumption were categorised. Farmers responses of percent lame sheep they treated with individual treatments (Table 3-2) (i.e. foot trimming, antibiotic injections, antibiotic sprays, isolation, 'other') were categorised as: 0 = none, 1% -99% = some and 100% = all.

All explanatory variables with categories with less than 10 observations were either merged with other categories or excluded from the analysis. Pair wise correlations were also calculated for the explanatory variables. Breed was excluded from the analysis because there was no estimate of lameness by breed within a farm and many farms had several breeds of sheep.

Crude associations between all explanatory variables and the outcomes were screened using univariable negative binomial regression. All variables with $p<0.2$ were considered for inclusion in the final three multivariable models which were built using stepwise backward elimination (Dohoo \textit{et al.}, 2003). Explanatory variables with a category wise Wald test $P$ value $\leq 0.05$ or those variables which significantly improved the model with a likelihood chi squared test value of $p \leq 0.05$ were retained in the model. In addition, explanatory variables that were
significant in any of the three models were also retained in the other final models to aid comparison. Finally, all the variables regardless of their significance at the univariable level were tested in the final multivariable models to check for residual confounding (Cox and Wermuth, 1996). During model-building, confounding was assessed by observing the effect of addition or deletion of explanatory variables on the coefficients and outcome in the model. All biologically plausible interactions were checked between variables in the final model.

Because negative binomial model fits cannot be assessed directly in Stata the models were rerun with a generalised linear model with a log link function and a family specification of negative binomial using the same value of the dispersion parameter, $\alpha$, and same explanatory variables from the final negative binomial regression model. The deviance residuals and values of Cook's distance could be examined to assess the overall model fit and assumptions, outliers and observations with undue influence on the models (Cameron and Trivedi, 1998).

3. Results

3.1. Selected farms

A total of 737 out of 809 farmers who replied to the questionnaire were included in dataset A, these were farmers who did not change their management between 2003-2004 and may or may not have recognised FR and ID lesions correctly (Chapter 2, Kaler and Green, 2007). There were 397 farms where the farmer had correctly identified both FR and ID lesions and had not changed their management of lameness from 2003 to 2004 that were included in Dataset B. There was a fair representation of farms from all five regions (Table 3-2).
3.2. Descriptive epidemiology (all farms irrespective of recognition of lesions: Dataset A)

3.2.1 General farm characteristics

Approximately 65% (472/727) of the farmers had a flock size of \( \leq 300 \) ewes (Table 3-3). The number of ewes less than one year of age ranged from 0 to 1200 with a median of 15. The median number of rams \( \geq \) one year was 6 (inter-quartile range 3-13). Farmers reported very few rams less than one year of age in their flocks, with a median value of 0 (inter-quartile range 0-2). The median number of meat lambs sold and store lambs on the farm by the end of December 2004 were 279 and 20, respectively. Approximately 50% of farms (360 out of 689) had a stocking density of \( \leq 4 \) ewes/ha and 33% (228) and 15% (101) had a stocking density of \( >4-8 \) ewes/ha and \( >8 \) ewes/ha respectively. Sixty seven percent (415/619) of farms had a minimum farm height less \( \leq 150 \) m and 55% (355/642) of farms had a maximum farm height \( >150 \) m above sea level (Table 3-3).

3.2.2. Breeds of ewes and rams

Mule was the most common ewe breed and was present on 60% (442/730) of farms. Approximately 50% of farmers reported the presence of 'other' breeds on their farm which included a variety of ewe breeds and breed crosses; the most common were Suffolk cross and Swaledale.

The most common ram breeds were Suffolk and Texel, on 407 (57%) and 364 (51%) farms out of 715 respectively. A total of 250 (35%) farms had 'other' breeds which included Swaledale, Lleyn, Beltex and Polled Dorset.
Table 3-3: The number and percent of farms by exposure and the results of univariable negative binomial regression models of factors associated with the prevalence of lameness, interdigital dermatitis (ID) and footrot (FR) in 2004 *PRR= prevalence rate ratio; CI = confidence interval

<table>
<thead>
<tr>
<th>Variable</th>
<th>All responses</th>
<th>Correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
<td>PRR</td>
</tr>
<tr>
<td>Stocking Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>less than 4 ewes/ha</td>
<td>360 (52)</td>
<td>1.00</td>
</tr>
<tr>
<td>&gt;4 to 8 ewes/ha</td>
<td>228 (33)</td>
<td>1.12</td>
</tr>
<tr>
<td>&gt;8 ewes/ha</td>
<td>101 (15)</td>
<td>1.46</td>
</tr>
<tr>
<td>Minimum Farm height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50 m</td>
<td>143 (23)</td>
<td>1.00</td>
</tr>
<tr>
<td>51-150m</td>
<td>272 (44)</td>
<td>1.09</td>
</tr>
<tr>
<td>&gt;150 m</td>
<td>204 (33)</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum Farm Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50 m</td>
<td>79 (12)</td>
<td>1.00</td>
</tr>
<tr>
<td>51-150m</td>
<td>208 (33)</td>
<td>0.96</td>
</tr>
<tr>
<td>&gt;150 m</td>
<td>355 (55)</td>
<td>0.84</td>
</tr>
<tr>
<td>Purpose of farming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedigree/Replacement/Terminal sires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>348 (48)</td>
<td>0.89</td>
</tr>
<tr>
<td>No</td>
<td>374 (52)</td>
<td>1.00</td>
</tr>
<tr>
<td>Meat lambs/Store lambs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>680 (94)</td>
<td>1.02</td>
</tr>
<tr>
<td>No</td>
<td>42 (6)</td>
<td>1.00</td>
</tr>
<tr>
<td>Other (hobby farming)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>17 (2)</td>
<td>9 (2)</td>
</tr>
<tr>
<td>No</td>
<td>705 (98)</td>
<td>383 (98)</td>
</tr>
<tr>
<td>Flock size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to 100</td>
<td>212 (29)</td>
<td>1.00</td>
</tr>
<tr>
<td>101-300</td>
<td>260 (36)</td>
<td>1.03</td>
</tr>
<tr>
<td>301-500</td>
<td>115 (16)</td>
<td>1.13</td>
</tr>
<tr>
<td>&gt;500</td>
<td>140 (19)</td>
<td>1.26</td>
</tr>
</tbody>
</table>
3.2.3 Purpose of offspring

A total of 348 (48%) of the 721 farmers had a pedigree flock, with replacement ewes and/or terminal sires as their purpose for farming sheep and 679 farmers (94%) sold meat and store lambs. Only 17 (2%) farmers were hobby farming or farming sheep for wool (Table 3-3).

3.2.4. Prevalence of lameness, ID and FR

Ninety seven percent of 737 farmers reported that they had lame sheep in their flock in 2004. The overall mean prevalence of lameness per farm in 2004, irrespective of farmer lesion recognition (Dataset A), was 10.20% (95% CI: 9.21 - 10.74) (Figure 3-1). On farms where both ID and FR were correctly identified, 96% (346/362) and 93% (318/341) farmers reported the presence of ID and FR respectively. The mean prevalence of ID and FR on these farms (dataset B) was 6.54% (95% CI: 5.79 - 7.30) and 3.17% (95% CI: 2.75 - 3.60) respectively (Figures 3-1) and the mean overall lameness was 9.91 (95% CI: 8.97-10.84). On farms where both lesions were correctly identified 10 out of 339 farmers reported FR but no ID and similarly there were 23 farms where ID was present without FR. A scatter plot of the prevalence of ID and FR within farms in 2004 is presented in Figure 3-2.
Figure 3-1: Prevalence of a) lameness b) interdigital dermatitis c) footrot within flocks in 2004

a) Lameness

b) Interdigital dermatitis
c) Footrot

Figure 3-2: Scatter plot of prevalence of interdigital dermatitis and footrot within farms in 2004
3.2.4. Management of lameness

Approximately 68% (485/717) of farmers housed their sheep in the winter of 2004 and 89% of sheep were housed for \( \geq 2 \) months. A total of 552 (76%) farmers out of 723 routinely trimmed the feet of their flock; 48% foot trimmed the flock \( \geq \) twice in 2004 (Table 3-4).

Footbathing was carried out by approximately 62% (451/722) of farmers in 2004; 11%, 36%, 38%, 4% and 11% of farmers out of 451 who footbathed their sheep footbathed at a frequency of once a fortnight, once a month, once in 3-6 months, once a year and ‘other’ respectively (Table 3-4). Almost all farmers who reported the frequency of footbathing as ‘other’ reported footbathing when required.

A total of 68 (9%) of 715 farmers vaccinated their sheep against FR; 30% (19) vaccinated either ewes or rams; a similar percentage vaccinated both ewes and rams and rest used ‘other’ vaccination combinations (vaccinating flocks or only lame sheep and/or lambs) (Table 3-4). In addition, out of 72 farmers that changed their management from 2003 to 2004 who were excluded from the analyses, 21 reported that they started vaccinating their sheep against FR in 2004.

Foot trimming lame sheep was the most popular individual treatment; approximately 69% (428/619) of farmers trimmed feet of all of their lame sheep, 25% (156/619) of the farmers trimmed feet of some of their lame sheep and 6% (35/619) of the farmers did not trim lame sheep (Table 3-4). Approximately 90% (553/614) and 60% (390/666) of farmers used antibiotic spray and antibiotic injection respectively to treat some lame sheep. However, in comparison to 60% (372/614) of farmers who used antibiotic sprays to treat all of their lame sheep only 10% (64/66) farmers treated all lame sheep with antibiotic injections (Table
Out of a total of 701 farmers, 40 (6%) footbathed individual lame sheep and 5 (<1%) used 'other' individual treatments.

Twenty six percent (124/470) of farmers separated either 'some' or 'all' of their lame sheep at housing and a similar percentage, 24% (166/685), separated their lame sheep at pasture (Table 3-4). However, as a part of their individual treatment, only 13% (91) of farmers out of 701 isolated individual lame sheep from the rest of the flock and only 3% (23) of these farmers isolated 'all' their lame sheep (Table 3-4).

The distributions of farmers' practices and flock structure were fairly similar for the farmers who correctly identified both ID and FR (Table 3-3, 3-4).
Table 3-4: The number and percent of farms by exposure and the results of univariable negative binomial regression models of factors associated with the prevalence of lameness, interdigital dermatitis (ID) and footrot (FR) in 2004

<table>
<thead>
<tr>
<th>Variable</th>
<th>All responses</th>
<th>Lameness</th>
<th>Correct Responses</th>
<th>ID</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of months housed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>232 (32)</td>
<td>1.00</td>
<td>112 (29)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>55 (8)</td>
<td>0.91</td>
<td>32 (8)</td>
<td>1.15</td>
<td>1.18</td>
</tr>
<tr>
<td>2</td>
<td>150 (21)</td>
<td>0.95</td>
<td>80 (20)</td>
<td>1.10</td>
<td>0.90</td>
</tr>
<tr>
<td>3</td>
<td>190 (26)</td>
<td>0.88</td>
<td>112 (29)</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>≥4</td>
<td>90 (13)</td>
<td>0.99</td>
<td>55 (24)</td>
<td>1.37</td>
<td>1.52</td>
</tr>
<tr>
<td>Frequency of foot trimming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do not routinely foot trim</td>
<td>171 (24)</td>
<td>1.00</td>
<td>102 (26)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Once per yr</td>
<td>205 (28)</td>
<td>1.36</td>
<td>119 (31)</td>
<td>1.34</td>
<td>1.01</td>
</tr>
<tr>
<td>Twice or more per yr</td>
<td>347 (48)</td>
<td>1.41</td>
<td>169 (43)</td>
<td>1.57</td>
<td>1.62</td>
</tr>
<tr>
<td>Frequency of footbathing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>271 (38)</td>
<td>1.00</td>
<td>117 (30)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Once a fortnight</td>
<td>48 (7)</td>
<td>1.82</td>
<td>29 (7)</td>
<td>1.65</td>
<td>1.83</td>
</tr>
<tr>
<td>Once a month</td>
<td>162 (23)</td>
<td>1.66</td>
<td>111 (28)</td>
<td>1.66</td>
<td>1.57</td>
</tr>
<tr>
<td>Once in 3 - 6 months</td>
<td>174 (24)</td>
<td>1.23</td>
<td>88 (23)</td>
<td>1.05</td>
<td>1.21</td>
</tr>
<tr>
<td>Once a year</td>
<td>18 (3)</td>
<td>1.32</td>
<td>12 (3)</td>
<td>0.77</td>
<td>0.66</td>
</tr>
<tr>
<td>Other (when necessary)</td>
<td>49 (7)</td>
<td>1.51</td>
<td>34 (9)</td>
<td>1.16</td>
<td>0.69</td>
</tr>
<tr>
<td>Separate lame sheep at pasture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>522 (76)</td>
<td>1.00</td>
<td>285 (74)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Some or All</td>
<td>164 (24)</td>
<td>0.89</td>
<td>99 (26)</td>
<td>0.87</td>
<td>0.93</td>
</tr>
<tr>
<td>Separate lame sheep at housing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>346 (74)</td>
<td>1.00</td>
<td>198 (72)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Some or All</td>
<td>124 (26)</td>
<td>0.86</td>
<td>76 (28)</td>
<td>0.86</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Note: N (%) represents the number of farms and percentage, PRR is the prevalence ratio, 95% CI is the 95% confidence interval, and p-value is the significance level.
<table>
<thead>
<tr>
<th>Central</th>
<th>North east</th>
<th>North west</th>
<th>South east</th>
<th>South west</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10.2°C temp., 843 mm rainfall)</td>
<td>(9.6°C temp., 875 mm rainfall)</td>
<td>(9.5°C temp., 1402 mm rainfall)</td>
<td>(10.8°C temp., 756 mm rainfall)</td>
<td>(10.3°C temp., 1238 mm rainfall)</td>
</tr>
<tr>
<td>277 (38)</td>
<td>174 (24)</td>
<td>58 (8)</td>
<td>83 (11)</td>
<td>144 (19)</td>
</tr>
<tr>
<td>1.00</td>
<td>0.93</td>
<td>0.81</td>
<td>0.73</td>
<td>1.00</td>
</tr>
<tr>
<td>0.41</td>
<td>1.10</td>
<td>1.05</td>
<td>0.91</td>
<td>1.19</td>
</tr>
<tr>
<td>0.41</td>
<td>0.76 - 1.24</td>
<td>0.80</td>
<td>0.76 - 1.01</td>
<td>0.06</td>
</tr>
<tr>
<td>159 (40)</td>
<td>104 (26)</td>
<td>26 (7)</td>
<td>52 (13)</td>
<td>56 (14)</td>
</tr>
<tr>
<td>1.00</td>
<td>0.96</td>
<td>1.32</td>
<td>0.73</td>
<td>1.10</td>
</tr>
<tr>
<td>0.80</td>
<td>1.24</td>
<td>2.03</td>
<td>1.00</td>
<td>1.48</td>
</tr>
<tr>
<td>0.80</td>
<td>0.80</td>
<td>0.19</td>
<td>0.05</td>
<td>0.82</td>
</tr>
<tr>
<td>1.00</td>
<td>0.76 - 1.01</td>
<td>1.26</td>
<td>0.57 - 1.16</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**Individual treatments**

**Foot trimming**

<table>
<thead>
<tr>
<th>0% (none)</th>
<th>1% - 99% (some)</th>
<th>100% (all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 (6)</td>
<td>156 (25)</td>
<td>428 (69)</td>
</tr>
<tr>
<td>1.00</td>
<td>1.45</td>
<td>1.12</td>
</tr>
<tr>
<td>1.00</td>
<td>1.06 - 1.99</td>
<td>0.83 - 1.51</td>
</tr>
<tr>
<td>0.02</td>
<td>0.02</td>
<td>0.44</td>
</tr>
<tr>
<td>100 (29)</td>
<td>202 (55)</td>
<td>236 (68)</td>
</tr>
<tr>
<td>0.97</td>
<td>0.85 - 1.32</td>
<td>0.61</td>
</tr>
<tr>
<td>1.88</td>
<td>0.54 - 1.81</td>
<td>0.34 - 1.10</td>
</tr>
<tr>
<td>0.95</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Antibiotic injection**

<table>
<thead>
<tr>
<th>0% (none)</th>
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<td>1.00</td>
<td>1.17</td>
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<tr>
<td>1.00</td>
<td>1.02 - 1.34</td>
<td>0.85 - 1.33</td>
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<tr>
<td>0.02</td>
<td>0.02</td>
<td>0.56</td>
</tr>
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<td>135 (37)</td>
<td>202 (55)</td>
<td>29 (8)</td>
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**Antibiotic spray**

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<td>1.00</td>
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<td>0.81 - 1.25</td>
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<td>0.10</td>
<td>0.10</td>
<td>0.98</td>
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<tr>
<td>113 (33)</td>
<td>198 (57)</td>
<td>329 (85)</td>
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<td>1.00</td>
<td>1.05</td>
<td>1.00</td>
</tr>
<tr>
<td>0.26</td>
<td>0.74 - 1.51</td>
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</tr>
<tr>
<td>0.46</td>
<td>0.77</td>
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**Isolation**

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<td>0.60 - 1.25</td>
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<td>0.64</td>
<td>0.45</td>
<td>1.00</td>
</tr>
<tr>
<td>1.00</td>
<td>0.76 - 1.42</td>
<td>0.49 - 1.60</td>
</tr>
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<td>0.80</td>
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**Foothathing**
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<th>100% (all)</th>
<th>0% (none)</th>
<th>1% - 99% (some)</th>
<th>100% (all)</th>
<th>0% (none)</th>
<th>1% - 99% (some)</th>
<th>100% (all)</th>
<th>0% (none)</th>
<th>1% - 99% (some)</th>
<th>100% (all)</th>
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<td>0.74 - 1.51</td>
<td>0.06</td>
<td>350 (89)</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ewes or rams only</td>
<td>19 (3)</td>
<td>1.42</td>
<td>0.94 - 2.12</td>
<td>0.08</td>
<td>15 (4)</td>
<td>1.53</td>
<td>0.92 - 2.56</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Ewes and rams only</td>
<td>26 (4)</td>
<td>0.64</td>
<td>0.45 - 0.90</td>
<td>0.01</td>
<td>17 (4)</td>
<td>0.62</td>
<td>0.39 - 1.00</td>
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<tr>
<td>'Other'</td>
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<td>0.74 - 1.51</td>
<td>0.73</td>
<td>13 (3)</td>
<td>0.74</td>
<td>0.43 - 1.28</td>
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<td></td>
</tr>
</tbody>
</table>

*PRR = prevalence rate ratio; CI = confidence interval
3.3. Risk factors for lameness, ID and FR

The univariate crude associations between explanatory variables and outcomes i.e. number of cases of lameness, ID, FR are presented in Table 3-3, 3-4. The three multivariable models are presented in Table 3-5. The adjusted prevalence rate ratio (PRR) of lameness and ID where farmers routinely trimmed the feet of their flock once per year were 1.33 (95% CI: 1.12 - 1.58) and 1.44 (95% CI: 1.09 - 1.90) respectively compared with those who did not routinely trim at all. Farmers that routinely trimmed the feet of their sheep twice or more per year had an adjusted PRR of 1.36 (95% CI: 1.16 - 1.60), 1.55 (95% CI: 1.19 - 2.02) and 1.59 (95% CI: 1.18 - 2.14) for lameness, ID and FR respectively in comparison to those who did not routinely trim.

In all three models, the frequency of footbathing was significantly associated with the prevalence of lameness, ID and FR. Farmers who foot bathed their sheep once a fortnight (PRR: lameness - 1.73 (95% CI: 1.34 - 2.24); ID - 1.55 (95% CI: 1.03 - 2.33); FR - 1.71 (95% CI: 1.10 - 2.68)) or once a month (PRR: lameness - 1.63 (95% CI: 1.39 - 1.93); ID - 1.68 (95% CI: 1.28 - 2.20); FR - 1.58 (95% CI: 1.15 - 2.16)) had a significantly higher prevalence of lameness, ID and FR compared with those who did not footbath their sheep. In addition, footbathing once in 3 - 6 months (PRR- 1.22 (95% CI: 1.04 - 1.45)) and ‘when necessary’ (PRR- 1.47 (95% CI: 1.15 - 1.88)) was significantly associated with higher prevalence of all lameness (Table 3-5).

Farmers who separated either ‘some’ or ‘all’ of their lame sheep at pasture had lower PRR of 0.75 (95% CI: 0.65 - 0.87) and 0.73 (95% CI: 0.58 - 0.93) for lameness and ID respectively compared with those who separated none of their
lame sheep. Farmers who had a stocking density of >8 ewes/ha had an adjusted PRR of 1.29 (95% CI: 1.06 - 1.56) and 1.44 (95% CI: 1.07 - 1.93) for lameness and ID respectively compared with farmers that had stocking density of ≤4 ewes/ha. There was no significant association between separation of lame sheep or stocking density and the prevalence of FR.

The south east of England had a significantly lower PRR of 0.75 (95% CI: 0.61 - 0.93), 0.71 (95% CI: 0.52- 1.00) and 0.68 (95% CI: 0.47 - 1.00) compared with central England for lameness, ID and FR respectively. In addition, the north east of England also had a significantly low PRR of 0.67 (95% CI: 0.50 - 0.92) for FR compared with the central region. There was no evidence for confounding or interaction between variables during the final model building.

Stocking density was significantly associated with minimum and maximum farm height (negative association) and the total number of months that sheep were housed (positive association); farmers who used routine footbathing also used footbathing to treat individual lame sheep (positive association); separating lame sheep at pasture was significantly associated with separating lame sheep at housing (positive association).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Lameness (n = 607)</th>
<th>Interdigital dermatitis (n=322)</th>
<th>Footrot (n=308)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRR  95% CI</td>
<td>p-value</td>
<td>PRR  95% CI</td>
</tr>
<tr>
<td><strong>Frequency of foot trimming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do not routinely foot trim</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Once per yr</td>
<td>1.33 1.12 - 1.58</td>
<td>&lt; 0.01</td>
<td>1.44 1.09 - 1.90</td>
</tr>
<tr>
<td>Twice or more per yr</td>
<td>1.36 1.16 - 1.60</td>
<td>&lt; 0.01</td>
<td>1.55 1.19 - 2.02</td>
</tr>
<tr>
<td><strong>Frequency of footbathing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Once a fortnight</td>
<td>1.73 1.34 - 2.24</td>
<td>&lt; 0.01</td>
<td>1.55 1.03 - 2.33</td>
</tr>
<tr>
<td>Once a month</td>
<td>1.63 1.39 - 1.93</td>
<td>&lt; 0.01</td>
<td>1.68 1.28 - 2.20</td>
</tr>
<tr>
<td>Once in 3 - 6 months</td>
<td>1.22 1.04 - 1.45</td>
<td>0.01</td>
<td>1.06 0.79 - 1.41</td>
</tr>
<tr>
<td>Once a year</td>
<td>1.55 1.01 - 2.39</td>
<td>0.06</td>
<td>1.08 0.56 - 2.07</td>
</tr>
<tr>
<td>Other (when necessary)</td>
<td>1.47 1.15 - 1.88</td>
<td>&lt; 0.01</td>
<td>1.31 0.87 - 1.98</td>
</tr>
<tr>
<td><strong>Separate lame sheep at pasture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Some or All</td>
<td>0.75 0.65 - 0.87</td>
<td>&lt; 0.01</td>
<td>0.73 0.58 - 0.93</td>
</tr>
<tr>
<td><strong>Region</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>1.00</td>
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<td>1.00</td>
</tr>
<tr>
<td>North East</td>
<td>0.86 0.73 - 1.02</td>
<td>0.07</td>
<td>0.91 0.70 - 1.18</td>
</tr>
<tr>
<td>North West</td>
<td>0.91 0.71 - 1.16</td>
<td>0.46</td>
<td>1.18 0.78 - 1.80</td>
</tr>
<tr>
<td>South East</td>
<td>0.75 0.61 - 0.93</td>
<td>0.01</td>
<td>0.71 0.52 - 1.00</td>
</tr>
<tr>
<td>South West</td>
<td>1.12 0.94 - 1.33</td>
<td>0.18</td>
<td>1.07 0.79 - 1.44</td>
</tr>
<tr>
<td><strong>Stocking Density</strong></td>
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<td></td>
</tr>
<tr>
<td>less than 4 ewes/ha</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>&gt; 4 to 8 ewes/ha</td>
<td>1.02 0.91 - 1.21</td>
<td>0.44</td>
<td>1.05 0.83 - 1.32</td>
</tr>
<tr>
<td>&gt;8 ewes/ha</td>
<td>1.29 1.06 - 1.56</td>
<td>&lt; 0.01</td>
<td>1.44 1.07 - 1.93</td>
</tr>
</tbody>
</table>

*PRR = prevalence rate ratio; CI = confidence interval*
The normal probability plots of deviance residuals of the three models was approximately normal (Figure 3-3). None of the farms had undue influence on the models from the plot of Cook's distance against the predicted mean number of lameness / ID / FR cases (Figure 3-4). Removal of the outliers did not change the model results significantly. The likelihood ratio tests for all the three models for $a = 0$ ($p<0.01$ for all three models) suggested that the variance was higher than would be expected for a Poisson regression and that a negative binomial model was appropriate.
Figure 3-3: QQ plots of deviance residuals of final three multivariable models of a) lameness b) interdigital dermatitis c) footrot

a) Lameness

b) Interdigital dermatitis

c) Footrot
Figure 3-4: Cook's distance plotted against predicted mean cases in final three multivariable models of a) lameness b) interdigital dermatitis c) footrot.
4. Discussion

The risk factors for both ID and FR were investigated separately to separate the possible risks for lameness caused by each lesion and to see whether managements were associated with specific causes of lameness. By using only the flock data where farmers correctly recognised the lesions the aim of this research was to tease out patterns between ID and FR despite their close relationship. Although there was a difference in factors significantly associated with both these conditions (Table 3-5), the associations were in a similar direction for all the factors in both ID and FR models. The failure to detect a significant association between some of the variables which were significantly associated with ID and the prevalence of FR might be because there was less power in the FR model because the prevalence of FR was generally lower. In addition, risk factors for overall lameness were also investigated because an ultimate useful aim is to reduce lameness in the national flock. The factors significantly associated with the prevalence of lameness were, in fact, combination of factors associated with prevalence of ID and FR; this reiterates the importance of ID and FR as the most common causes of lameness in sheep flocks. However, despite the recent evidence that farmers can identify lame sheep (Chapter 5), we have no information on whether the lameness prevalence reported by farmers are estimates of the lame sheep that they see or the estimated lame sheep that they treat.

Only farmers who did not change their management between 2003 and 2004 were included in the analysis in this study; thus it is unlikely that high lameness on farms triggered managements since farmers were doing the same management for controlling lameness for at least one year previously. This was an improvement
because on Wassink et al. (2003a, 2004) where the lameness management and lameness estimates were collected for the same year. Thus, the reported associations between certain management factors and lameness in previous studies could have been because high lameness led farmers to choose a management.

In the current study there were only 10/339 farmers who reported the presence of FR without any ID. This supports the close link between ID and FR both in terms of the aetiology and clinical picture (Egerton, 1969; Moore et al., 2005a) and the current thinking that ID (or at least invasion with F. necrophorum) is necessary for the occurrence of FR or that ID is a mild presentation of FR. On these 10 farms it is possible that there may have been some non lame sheep with ID or that these farmers had mis diagnosed FR, despite their apparent ability to recognise FR in the questionnaire.

Despite the close association between ID and FR there is a possibility that the ID lesions may not develop into FR because of variability in either host susceptibility or farm management (Wassink et al., 2003a). This may explain the low correlation between the prevalence of FR and ID on some farms (Figure 2), and the fact that there were 23/339 farms with ID without FR. In addition, whilst F. necrophorum is present on all farms, D. nodosus is an obligate anaerobe, surviving off host for a small amount of time (Beveridge, 1941) consequently, it is possible that D. nodosus was not present on these farms.

Several limitations should be considered when interpreting results from this study. Although the farmers in both dataset A (all respondents) and dataset B had a similar regional distribution and flock size (p>0.05), they differed significantly (p
<0.05) from the DEFRA agricultural census 2004 with respect to flock size and geographical location (Chapter 2). Also, even though there was no significant difference between respondents and non-respondents of this retrospective cohort study with respect to geographical location and flock size (Chapter 2), there is a possibility of response bias (farmers that had higher levels of lameness/ID/FR responded to the survey). Moreover, all the questions pertaining to lameness estimates and management were asked for the previous year, thus there is possibility of recall bias. Despite the possible unrepresentativeness of the results the prevalence of lameness, ID and FR were significantly lower in eastern England (Wassink et al. (2003a), also reported a lower prevalence of FR in east England), where there are warmer summers, colder winters and low average rainfall compared with other parts of England (Met office, 2004). This adds evidence to the importance of warm, wet conditions for the transmission and expression of FR (Green and George, 2007) in addition to the inflammation of interdigital skin (Beveridge, 1941; Parsonson et al., 1967; Roberts and Egerton, 1969).

Other environmental influences were the high stocking density of > 8 ewes/ha and separating 'some or all' lame sheep at pasture (correlated with housing) that were significantly associated with higher and lower levels of both lameness and ID respectively. Although Wassink et al. (2003a) reported a lower prevalence of FR in flocks where farmers separated sheep with FR; it is possible that ID, when D. nodosus is present, might be controlled by this management due to the clinical similarity between ID and FR (Moore et al., 2005a). Alternatively, the low prevalence of ID associated with separating lame sheep might be due to overload of the pasture with F. necrophorum (also reinforced by the association between
high stocking density and ID) and thus separating lame sheep reduces this accumulation of *F. necrophorum*.

In contrast to the results published by Wassink *et al.* (2003a) and Green *et al.* (2007), none of the individual treatments for diseased sheep e.g. foot trimming or parental antibiotic injections or topical sprays was significantly associated with the prevalence of lameness, ID or FR. There may be several reasons for this lack of association between these individual treatments and the prevalence estimates of lameness or ID or FR. The prevalence estimates in this study requested from farmers were an average for the whole year, whilst Wassink *et al.* (2003a, 2004) requested estimates of ID and FR in each month of the year and used the highest monthly prevalence over the year in the analysis. The overall variation in the reported prevalence of ID and FR among farmers in the current study was much less than that reported by Wassink *et al.* (2003a, 2004) (G.W. Wassink, personal communication). The variability in Wassink *et al.* (2003a, 2004) may have highlighted that individual treatments were dampening down mini – epidemics. This would occur if treatments were prompt. Thus, it is not only ‘always’ using parental antibiotics and topical sprays that helps to reduce the prevalence and incidence of infectious lameness but also the ‘timely’ use of this approach (Green *et al.*, 2007). Unfortunately, we did not ask about frequency and time to treatment. In addition, the questions regarding individual treatments were asked in a different way in the surveys. Wassink *et al.* (2003a, 2004) asked farmers whether they ‘always’ ‘sometimes’ or ‘never’ used various individual treatments to treat their sheep with FR. In the current study, farmers were asked to give a percentage of their lame sheep that they treated with each of the individual treatments (Table 3-2). It may be that, although apparently more precise, farmers were less able to
answer the question as precisely. Finally, it may be possible that the results from Wassink et al. (2003a, 2004) and Green et al. (2007) were wrong and that individual treatments do not reduce FR and ID. However, a clinical trial recently completed at the University of Warwick indicates that rapid treatment of sheep with FR and ID with parenteral antibacterials and topical spray reduced prevalence and incidence of FR in ~ 400 ewes and lambs vs. a similar sized control group managed with foot trimming and topical spray (Hawker, 2007). Results from Chapter 6 also suggest that individual treatments aid recovery and should, at the least, reduce the prevalence of FR.

In the current study, routine trimming was significantly associated with increased prevalence of ID, FR and lameness. Wassink et al. (2003a) also reported a positive association between routine trimming more than once a year and FR. However, a new result from the current study is that the farmers who footbathed their sheep more frequently also reported a higher prevalence of lameness, ID and FR compared with farmers who did not footbath their sheep. Amory et al. (2006) also reported association of footbathing with a high prevalence of lameness in dairy cattle. As with routine foot trimming, the association between a higher prevalence of lameness, ID and FR with more frequent footbathing may because farmers respond to higher levels of lameness by footbathing more frequently (although this is unlikely to be the case because we used the managements from the previous year, and so, footbathing was certainly not successful within one year) or be a result of increased transmission of D. nodosus due to gathering of diseased and sound sheep / poor technique or increased duration (i.e. slower recovery rate). Although Wassink et al. (2003a, 2004) reported no significant association between ID, FR and footbathing, they described that only farmers who rated their
footbathing facilities as ‘excellent’ had a significantly lower prevalence of FR compared with those who never footbathed their sheep or rated their facilities less than excellent and looking at the data it appears that the intercept term for footbathing was higher than that where farmers were not footbathing (Wassink et al., 2003).

5. Conclusions and further work

This study supports previous evidence that routine trimming of sheep feet is associated with a higher prevalence of FR, lameness and suggested that footbathing may also be correlated to detrimental foot health. It also highlights the importance of separating lame sheep and lowering stocking density as useful management tools for reducing the prevalence of lameness in sheep, where these are feasible.

However, the existing evidence (from this study and previous studies) on the factors associated with lameness or interdigital dermatitis or footrot is based on the responses of farmers in a period cross-sectional studies and such study design limits the strength of the results. Thus, more rigorous studies such as the intervention study described (Hawker, 2007) or longitudinal studies (Green et al., 2007 and Chapter 6) are required to strengthen the causal arguments between these hypothesised factors and the prevalence of lameness/ID/FR.
Chapter 4

The inter- and intra-observer reliability of a locomotion scoring scale for sheep

The contents of this chapter are In Press; Kaler, J., Wassink, G.W., Green, L.E. (2008). The inter- and intra-observer reliability of a locomotion scoring scale for sheep The Veterinary Journal (In press).

1. Introduction

Several locomotion scoring scales have been developed to monitor cattle (Manson and Lever, 1988; Sprecher et al., 1997; Amory et al., 2006), pigs (Main et al., 2000), poultry (Kestin et al., 1992) and sheep (Ley et al., 1989; Welsh et al., 1993) to identify and quantify locomotion. Similar scales have been developed to assess locomotion in horses (May and Wyn-Jones, 1987; Fuller et al., 2006; Hewetson et al., 2006) and dogs (Reid and Nolan, 1991). The most frequently used approaches to define locomotion include observation of stride length, duration of weight bearing on both affected and unaffected limbs, body posture and joint movement (Sprecher et al., 1997; Stashak, 2002).

Most of the locomotion scoring scales above have not been tested for reliability and repeatability, although a few have (Kestin et al., 1992; Welsh et al., 1993; Main et al., 2000; Fuller et al., 2006; Hewetson et al., 2006). Ideally, validity (i.e. that these scoring systems measure accurately what they are supposed to measure) would be established by comparing a proposed locomotion scoring scale with a gold standard (Dawson-Saunders and Trapp, 1994) which assessed the scale’s accuracy and objectivity. However, there is no gold standard to assess locomotion.
The best alternative is to investigate the reliability (Ebel, 1951; Shrout, 1998) of the scale, that is, its consistency between independent measurements (Gaberson, 1997). Reliability is at least a pre-requisite for validity since an unreliable measurement scale has high variability between and within scorers and is of little use (Hewetson et al., 2006).

A numerical rating scale to assess locomotion in sheep was developed in 1989 by Ley et al. It had categories from 0-4 (0 = normal movement, 1 = occasional limping, 2 = lifting foot when standing, not lame when moving, 3 = carrying foot, but lame on movement and 4 = carrying foot at all times). Observer agreement was not assessed with this scoring scale. Another numerical rating scale with ‘good’ inter- and intra-observer agreement was developed by Welsh et al. (1993) which also used a scale from 0 to 4 (0 = clinically sound, 1 = barely detectable lameness, 2 = obvious lameness, 3 = severe head nod and possibly resting the affected foot when standing and 4 = carrying foot at the trot). The latter scale used subjective phrases e.g. ‘obvious’ lameness and neither of the scales above included all severities of locomotion in sheep e.g. sheep with more than one foot affected or unable to rise are not differentiated from sheep lame on one foot only.

A visual analogue scale (VAS) with good observer reliability was also developed to assess locomotion in sheep by Welsh et al. (1993). This scale used a straight line of 100 mm with two ends labelled ‘sound’ and ‘could not be more lame’. Although visual analogue scales are able to detect change of any size and can differentiate between severities of lameness, they are highly subjective and difficult to use in clinical practice (Welsh et al., 1993; Fuller et al., 2006).
In the UK, lameness in sheep has persisted over the last five decades despite continued efforts to reduce its occurrence. In 2004, lameness was present in approximately 97% of flocks, with a within flock prevalence of approximately 10% (Chapter 2, Kaler and Green, 2008). These estimates were from a random sample of 809 farmers with no assessment of farmer ability to identify lame sheep. Because of the continued high prevalence of lameness, the need to reduce the subjective phrasing of scoring systems and to include the whole range of possible severities, a new system was developed which provided descriptions within each category of locomotion score, initially to assess locomotion in sheep in a research setting. This chapter presents this new scoring system together with the between and within trained observer reliability.

2. Materials and Methods

2.1. Locomotion scoring scale

A seven point verbal numeric scale (0-6) was developed by a group of researchers with experience of observing locomotion in lame and non-lame sheep. The scale ranged from ‘normal’ to ‘unable to stand or move’ with visual descriptions for locomotion for each increase in severity score (Table 4-1). These were the minimum number of categories that showed obvious observed differences in locomotion.
Table 4-1: The locomotion scoring scale, shaded area = all required for score

<table>
<thead>
<tr>
<th>Scale</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Posture and locomotion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bears weight evenly on all four feet</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Uneven posture, but no clear shortening of stride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short stride on one leg compared with others</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible nodding of head in time with short stride</td>
<td></td>
<td></td>
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<tr>
<td>Excessive flicking of head, more than nodding, in time with short stride</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Not weight bearing on affected limb when standing</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Discomfort when moving</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Not weight bearing on affected limb when moving</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Extreme difficulty rising</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reluctant to move once standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>More than one limb affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Will not stand or move</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

2.2. Sample size estimation for reliability

It was estimated that thirty observations were required to assess inter-observer reliability with three observers with an expected inter-observer reliability ($\rho_1$) of 0.85, acceptable ($\rho_0$) at 0.7 or higher, with $\alpha = 0.05$ and $\beta = 0.2$ (Walter et al., 1998). The same 30 observations were used to assess intra-observer reliability.

2.3. Locomotion scoring scale movies

Movie clips of sheep rising, standing and walking were used to assess the reliability of the scoring scale to ensure that there was no change in the locomotion of sheep between repeated observations and that sheep position did not affect the objective observation. As a consequence, 65 movies of 53 ewes, six rams and six lambs with a range of locomotion scores from 0–6 (Table 4-1) were made, these included locomotion in fore limbs, hind limbs and all four limbs per
sheep. After filming, farmers were recommended to inspect and treat lame sheep with locomotion scores ≥2.

The movies were made without disturbing sheep with sheep rising, standing and walking on concrete and grass in a lateral view. The movie clips were recorded with a camcorder (JVC GR-DVL 120A) and edited using Pinnacle studio 10.0 (Pinnacle systems, U.K.) and Video Edit Magic 4.1 (Desk share 2001-2006). Each clip was 35–50 second long (recommended by observers other than those who participated in the study) with no audible sound. The 30 movie clips were randomly selected and burnt onto a DVD with a 40 second lag between each clip. When more than one sheep was in a clip, observers were warned that the next clip contained more than one sheep in the lag before the start of the clip and the sheep to be scored was circled.

2.4. Observers

Three observers were selected from a group of researchers familiar with observing locomotion in sheep. They were given a training session to learn to score sheep locomotion based on what they saw in the clip, and using the descriptions in Table 1, using ten movies with at least one of each score in the locomotion scoring scale. This was followed by some test movie clips to ensure that the duration of the clips and the between clip intervals were familiar to the observers. Finally, the observers recorded their observations of the 30 movie clips in a room, sitting apart from each other, using a copy of Table 4-1 and a recording form (Appendix 7) with the clip numbers listed sequentially and a row of scores 0–6 for each clip with instructions to circle one score per clip. The clips ran without a break. The forms were collected immediately after the session.
To assess intra-observer repeatability the observers made a second assessment of the same 30 movie clips 4 hours later. The clips were randomly reordered to reduce the possibility that individual clips were recognised.

2.5. Data analysis

The data were entered into Microsoft Excel (Microsoft, 2000) and analysed using SPSS 15.0 (SPSS Inc, 2006) and StatXact 7.0. The data were ordinal. The percent exact agreement/disagreement between and within observers were calculated. The inter- and intra-observer reliability was assessed using intra-class correlation coefficients (ICC) (Shrout and Fleiss, 1979) and weighted kappa coefficients ($\kappa_w$) (Cohen, 1968). In addition, Kendall’s rank correlation coefficient ($\tau$) was used to estimate between and within observer associations and Kruskal – Wallis one way analysis of variance was used to investigate bias between observer ratings.

2.5.1. Inter- and Intra-observer reliability

a) Percent agreement

The percent exact agreement was estimated between observer pairs and within each observer’s scores. The percent of exact agreement and disagreement by one point, two points and three points were calculated as:

\[
\text{Percent agreement (disagreement)} = \frac{\text{number of exact agreements (disagreements)}}{\text{Total number of observations}} \times 100
\]

The mean percent agreement for between and within observers was also calculated.

b) Intraclass correlation coefficient (ICC)

The ICC was calculated with a two way random effects model (Shrout and Fleiss, 1979; McGraw and Wong, 1996) where both observers (raters) and the subjects...
(sheep) were random effects. Absolute agreement and single measure reliability were estimated. The model was specified as:

\[ x_{ij} = \mu + r_i + c_j + \epsilon_{ij} \]

where \( \mu = \) population mean for all ratings, \( r_i = \) random sheep effect, \( c_j = \) random observer effect, \( \epsilon_{ij} = \) random interaction effects and \( e_{ij} = \) residual or random error.

Normality of the data was checked by Shapiro-Wilk normality test. Estimates for ICC were interpreted using previously recommended guidelines: 0-10% - virtually none, 11-40%- slight, 41-60% fair, 61-80% moderate and 81-100% substantial agreement (Shrout, 1998).

c) Weighted kappa coefficients (\( \kappa_w \))

The kappa statistic (\( \kappa \)) measures agreement beyond chance (Cohen, 1960). Weighted kappa coefficients were calculated between observer pairs and scores of each observer and as an overall average, using quadratic weights (Cohen, 1968). The interpretation of kappa coefficients was made according to Landis and Koch (1977) \( \leq 0 = \) poor, \( .01-.20 = \) slight, \( .21-.40 = \) fair, \( .41-.60 = \) moderate, \( .61-.80 = \) substantial, and \( .81-1= \) almost perfect.

2.5.2. Inter- and intra-observer associations

The inter- and intra-observer Kendall’s rank correlation was calculated by comparing the scores of observer pairs and scores of each observer. An overall average Kendall’s rank correlation coefficient was also calculated between and within observers.
2.5.3. Observer bias

Observer bias was assessed between observers using a Kruskal-Wallis one way analysis of variance.

3. Results

3.1. Inter- and Intra-observer reliability

a) Percent agreement

The average overall exact agreement between observers and within observers was 68% (range 63%-70%) and 76% (range 73%-77%) respectively. The majority of disagreement between and within observers was by one point (Table 4-2).
Table 4-2: Levels of agreement between and within observers

<table>
<thead>
<tr>
<th>Observer (s)</th>
<th>Between observers (%; N/30)</th>
<th>Within observers(%; N/30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 and 2</td>
<td>2 and 3</td>
</tr>
<tr>
<td>Exact agreement</td>
<td>70, 21</td>
<td>70, 21</td>
</tr>
<tr>
<td>One point difference</td>
<td>30, 9</td>
<td>27, 8</td>
</tr>
<tr>
<td>Two points difference</td>
<td>-</td>
<td>3, 1</td>
</tr>
<tr>
<td>Three points difference</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kendall's rank correlation coefficient</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Intra-class correlation coefficient</td>
<td>0.93</td>
<td>(0.87-0.96)</td>
</tr>
<tr>
<td>Weighted Kappa</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>(95% CI)</td>
<td>(0.91-0.99)</td>
<td>(0.86-0.98)</td>
</tr>
</tbody>
</table>

*CI = confidence interval
b) Intraclass correlation coefficients (ICC)

The Sharpio-Wilk test did not reject the normality of the data at $P \leq 0.05$. The ICC for inter-observer reliability was 0.93, (95% CI: 0.87-0.96) for the locomotion scoring scale indicating substantial agreement between observers. The mean intra-observer reliability was also substantial at 0.90 (95% CI: 0.89-0.92) with a range of 0.89 to 0.92 by observer (Table 4-2).

c) Weighted kappa coefficients ($\kappa_w$)

The overall average weighted kappa coefficient between observers was high: $\kappa_w=0.93$ (95% CI: 0.91-0.96) with a range of 0.92 to 0.95 between observer pairs. Similarly the average weighted kappa for within observer scores was high with a value 0.91 (95% CI: 0.87-0.96) that ranged from 0.89 to 0.93 by observer (Table 4-2).

3.2. Inter- and intra-observer associations

The overall average Kendall’s rank correlations between and within observers were high with $\tau = 0.87$ (range 0.75 - 0.98, $P < 0.01$) and $\tau = 0.85$ (range 0.67 - 0.98, $P < 0.01$) respectively, indicating that there were very strong between and within observer correlations (Table 4-2).

3.3. Observer bias

There was no significant difference between the mean rank scores between observers ($\chi^2 = 3.58$, df = 2, $P = 0.16$).

The discrepancy between observers scores was mainly for scores 0 and 1 (Figure 4-1).
4. Discussion

The results indicate that the locomotion scoring scale presented in this chapter was reproducible and repeatable between and within observers.

For an optimal design for the reliability study with a certain precision ($\alpha = 0.05$ and $\beta = 0.2$) the optimal combination of number of observers/number of replicates per subject and the number of subjects is used for a set total number of observations. For an expected reliability value, $\rho$, $>0.6$ is a high agreement the optimal design requires three replicates per subject or three observers (Walter et al., 1998; Shoukri et al, 2004). Thus the choice of three observers in our study was appropriate.

Using movie clips of sheep locomotion and posture ensured that the whole locomotion scoring scale was assessed and that sheep did not alter their locomotion between observations and that observers had an identical view of the sheep. Previous agreement studies using movie clips have been used in horses.
with varying between observer reliabilities ranging from moderate to good (Keegan et al., 1998; Fuller et al., 2006; Hewetson et al., 2006).

Despite the objectivity of the movie clips of sheep locomotion, observers may vary because of different interpretations of the locomotion scoring system because they drift in scoring or because they are distracted while making a judgement, all these aspects are combined and a final score is given by an observer (Uebersax, 2001). The overall effect is to reduce the correlation of scores between and within observers. This reduced correlation provides evidence that there is a random (immeasurable) error and noise in observing method (Uebersax, 2001). In the study presented here the greatest disagreement occurred between scores 0 and 1 between observers (Figure 4-1). This was as hoped; score 1 is a very slight abnormal gait (Table 4-1) and provides an interim category between normal (score 0) and definitely lame (score 2). This can be very useful in quantitative research.

Conversely, observers may have reduced the within observer variability by remembering movie clips and scoring sheep identically, rather than assessing locomotion independently on the second test. There were only 4 hours between the tests but re-ordering and re-numbering the clips should have minimised this effect. Finally, there was no statistical significant evidence for bias between observers. This was useful information because the presence of observer bias can affect the reliability of a scale considerably (Hewetson et al., 2006).

The high inter-observer and intra-observer agreement achieved in this study is comparable to the only agreement study done in sheep by Welsh et al. (1993) where the locomotion in sheep was assessed using a numerical rating scale (NRS)
with two observers and with no statistically significant difference between and within observers using a Wilcoxin signed-rank test.

Our data were ordinal and so the appropriate measures of agreement were a weighted kappa and intra-class correlation coefficients (Nelson et al., 1990; Morris et al., 2004). When quadratic weights are applied to calculate kappa these two reliability coefficients are equivalent (Fleiss and Cohen, 1973; Ludbrook, 2002), as seen in the study presented in this paper. One of the limitations of these measurements is that they are not comparable across populations because kappa is influenced by the prevalence of a trait; this is equivalent to the dependence of ICC on between subject variance (Maclure and Willet, 1987). Thus the agreement estimates can only be generalised to a population with similar characteristics. In addition, both ICC and kappa are affected by the number of ordinal categories in a scale. Although ICC is less affected by the change in the number of categories, it tends to increase with an increase in number of categories; in contrast, kappa tends to decrease with more categories (Maclure and Willet, 1987). As a result we recommend that anyone adopting this scale tests its reliability for their purpose since the agreement measures depend on the prevalence of lameness as well as the training of personnel.

Modelling techniques such as log-linear models and latent trait and latent class models for exploring agreement in ordinal ratings have been proposed. Log-linear models can be used to estimate the amount of agreement beyond chance and also agreement between two observers based on the baseline association, but they have not been developed to analyse multiple observers, such as the three used in this study (Agresti, 1992). Latent trait models can handle multiple observers and use
the theory that observed ratings are a continuous latent trait or set of latent classes (Nelson and Pepe, 2000). Unlike ICC, latent trait models do not assume equal spacing of categories and can provide information on all components of observer agreement (Uebersax, 1993). However, both types of modelling techniques use complex theoretical and statistical frameworks that are not yet widely used to assess such agreements.

5. Conclusion

The scoring scale presented in this chapter is objective and based on a group of visual observations and a highly reliable method for trained observers to assess locomotion in sheep. It may be used by trained researchers, and if useful possibly advisers, to monitor locomotion in sheep.
Chapter 5

Identification and decisions to catch lame sheep with varying locomotion scores among farmers and sheep specialists

1. Introduction

Farmers notice that sheep in their flock are lame through visual observation. Previous epidemiological studies that estimated the prevalence of lameness in sheep in the UK (Grogono-Thomas and Johnston, 1994) or prevalence of lameness caused by interdigital dermatitis (ID) and footrot (FR) (Wassink et al., 2003a, 2004) used farmer opinion and assumed that farmers can identify lame sheep. There is evidence that dairy cow farmers underestimate the proportion of lame cattle in their herds (Whay et al., 2003). There are two hypotheses for this under estimation. Either farmers cannot identify lame cows, or farmers only consider a cow lame when it is ‘lame enough’ (in their opinion) to require treatment. This may also be true for sheep farmers. There is no information on the ability of sheep farmers to identify lame sheep or on the decision for when a sheep farmer decides to investigate a lame sheep. This information is also unknown for sheep advisors.

In addition, because FR, caused by the bacterium *Dichelobacter nodosus*, is infectious (Beveridge, 1941), the frequency of treating sheep with FR is associated with the prevalence and incidence of lameness. Previous work indicated that treatment with parenteral antibacterials led to a decrease in the incidence of FR in the following 2 – 4 week period (Green et al., 2007) and results from a clinical trial indicate that prompt and frequent (daily – twice weekly) treatment of sheep lame
with FR and ID reduced the prevalence and incidence of these conditions (Hawker, 2007).

In this chapter a selection of the movie clips, used in Chapter 4, of sheep with a range of locomotion scores was used to investigate farmer and sheep specialist opinion of whether a sheep was lame, whether they would catch and inspect the sheep and how many sheep in a group would need to be lame for inspection to occur. In addition, the impact of the farmers decision on the number of sheep that needed to be lame in the group before inspection and their reported time to treatment of lame sheep was compared with their estimate of flock lameness.

2. Material and Methods

2.1. Study population

Data were collected from farmers at three farmer events conducted by EBLEX (English Beef and Lamb Executive) in Devon (n = 73), Newark (n = 86) and Norfolk (n = 33) in 2007. These events were advertised by EBLEX as a part of their Better Returns Programme (http://www.eblex.org.uk/betterReturns) and were focussed on lameness management and worm control. In addition, data were also collected from the Sheep Veterinary Society (SVS) meeting in September 2007 in Devon, England.

2.2. Study design

Before the talk and discussion on lameness, farmers were asked to complete a brief questionnaire (Appendix 8) with questions pertaining to their involvement in the day to day management of sheep, the number of breeding ewes, the number of groups of ewes on the farm, the average percent of ewes lame in 2006 and the time to treatment from observation of a lame sheep. Delegates at the SVS meeting were asked about
their profession and whether they personally had a care of a flock of sheep (Appendix 9). All participants were then asked to complete eight identical questions (Table 5-1, Appendix 8, 9) as they watched eight movie clips of sheep with locomotion scores 0 (n=1), 1 (n=1), 2 (n=1), 3 (n=4) and 4 (n=1) (Table 4-1, Chapter 4). The participants were not told the severity of the locomotion score.

Table 5-1: Question asked to participants for each movie clip

<table>
<thead>
<tr>
<th>Clip X</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you think this sheep is lame? <em>(please tick one box)</em></td>
</tr>
<tr>
<td>□ Yes  □ No  □ Don't know</td>
</tr>
<tr>
<td>If Yes or Don't know, please go to Question 2, if No please wait for next clip</td>
</tr>
<tr>
<td>2. Would you catch this sheep with intention to treat? <em>(please tick)</em></td>
</tr>
<tr>
<td>□ Yes, always, even if this is the first lame sheep in the group</td>
</tr>
<tr>
<td>□ Yes, when at least</td>
</tr>
<tr>
<td>□ 2 - 5 of the sheep in the group are lame</td>
</tr>
<tr>
<td>□ 6 - 10 of the sheep in the group are lame</td>
</tr>
<tr>
<td>□ 11 - 20 of the sheep in the group are lame</td>
</tr>
<tr>
<td>□ more than 20 of the sheep in the group are lame</td>
</tr>
<tr>
<td>□ Don't know</td>
</tr>
</tbody>
</table>

Descriptions of the locomotion scores are presented in Chapter 4 and the method for making the movie clips of sheep with varying locomotion is described in Chapter 4. Each movie clip was 20 - 22 second long and was played once within a Microsoft Power Point presentation. The questionnaire took approximately 10 minutes to complete. Data were entered in Microsoft Access 2000 (Microsoft) and checked for errors. The analyses were carried out in Stata SE (Statacorp, USA).

2.3. Statistical analysis

All the farmers who were involved in the day to day management of sheep and all the sheep specialists were included in the analysis. Comparisons were made between farmers from different groups with respect to the median percent of lame ewes in 2006, the median number of breeding ewes, the median number of groups of ewes run on the farm and the time to treatment of lame sheep. In addition, the responses of
the participants for identification of lame sheep and their decision on catching them for each locomotion score were compared between groups. Proportions were compared with $\chi^2$ test and medians with Kruskal–Wallis test (Petrie and Watson, 1999) with significance at $p \leq 0.05$.

All the participating farmers were grouped into four categories based on whether they caught the first lame sheep with locomotion scores 2, 3 (whether farmers caught the first lame sheep in at least one of the four movie clips) or 4. These categories were: a) farmers who caught the first lame sheep with all locomotion scores 2, 3 and 4 b) farmers who caught the first lame sheep with locomotion scores 3 and 4 c) farmers who caught first lame sheep with locomotion score 4 only and d) farmers who did not catch the first lame sheep with any of the locomotion scores 2, 3 or 4. The significant differences in rank distributions of farmer estimated lameness and number of breeding ewes among these categories was determined by a nonparametric test for trend, an extension of the Wilcoxon rank sum test (Jack, 1985). In addition, a similar test was used to compare lameness estimates between farmers with different reported time to treatment of lame sheep and different decisions on the minimum number of sheep that have to be lame in the group (e.g. 1, 2 -5, 6 - 10 and >10) before they caught sheep with locomotion score 2, 3 or 4.
3. Results

3.1. Background information

A total of 94% (69/73) of farmers from Devon, 93% (80/86) farmers from Newark and 88% (29/33) of farmers from Norfolk who attended the events were involved in day to day management of sheep. Farmers from Devon, Newark and Norfolk had a median number of breeding ewes of 150 (inter-quartile range (IQR): 60 - 350), 200 (IQR: 100 - 320) and 120 (IQR: 50 - 220) respectively. The farmer reported median lameness in ewes in 2006 in these same three groups of farmers was 8 (IQR: 5 - 10), 5 (IQR: 3 - 10) and 5 (IQR: 3 - 10) respectively. The farmers from Devon, Newark and Norfolk were running a median of 2 (IQR: 1 - 3), 3 (IQR: 2 - 4) and 2 (IQR: 1 - 3) groups of ewes respectively on their farms. There was no significant difference between the groups of farmers with respect to the median number of breeding ewes (p>0.05), median lameness (p>0.05) and median group size (p>0.05).

The average percentage of farmers among three groups who treated lame sheep on the first day and within three days of observing them lame was 18% and 38% respectively. Thirty percent of farmers treated lame sheep within a week of seeing them lame and 14% farmers did not catch individual sheep at all and treated their lame sheep at routine gatherings only (Table 5-2). There were no significant differences between the groups of farmers from the three regions with respect to the time to treatment of lame sheep (p>0.05).
Table 5-2: Time to treatment of lame sheep by farmers from Devon, Newark and Norfolk

<table>
<thead>
<tr>
<th>Treat</th>
<th>Devon</th>
<th>Newark</th>
<th>Norfolk</th>
</tr>
</thead>
<tbody>
<tr>
<td>First day seen lame</td>
<td>7 (12)</td>
<td>16 (20)</td>
<td>6 (21)</td>
</tr>
<tr>
<td>Within 3 days</td>
<td>27 (44)</td>
<td>26 (33)</td>
<td>11 (38)</td>
</tr>
<tr>
<td>Within a week</td>
<td>21 (34)</td>
<td>25 (32)</td>
<td>7 (24)</td>
</tr>
<tr>
<td>At routine gatherings only</td>
<td>6 (10)</td>
<td>12 (15)</td>
<td>5 (17)</td>
</tr>
<tr>
<td>Total</td>
<td>61 (100)</td>
<td>79 (100)</td>
<td>29 (100)</td>
</tr>
</tbody>
</table>

Out of 54 delegates who filled in the questionnaire at the Sheep Veterinary Society meeting; 35 were veterinarians and 19 were other specialists (advisors). Twenty one delegates (15 veterinarians) had care of a flock of sheep.

3.2. Identification of lame sheep by locomotion score

Approximately 79% (48/61), 91% (73/80), 75% (21/28) and 77% (41/53) of participants from Devon, Newark, Norfolk and SVS respectively (p>0.05), considered that the sheep with locomotion score 0 was sound (not lame). A significantly (p<0.05) higher (83%) percentage of farmers from Newark considered that the sheep in the movie clip with locomotion score 1 was lame, compared with 53% (33/62), 36% (10/28) and 67% (36/54) participants from Devon, Norfolk and SVS respectively (Figure 1). At least 90% of the participants considered that the sheep with locomotion score 2 was lame; and all the participants considered that the 4 sheep with locomotion score 3 and the sheep with locomotion 4 were lame (Figure 5-1).
3.3. Catching lame sheep by locomotion score

Out of a total of 28 farmers from the three groups who considered the sheep with locomotion score 0 as lame, only 11 farmers responded to their decision to catch it. Of those who responded, 2 reported that they would catch the first lame sheep, 2 when at least 2 - 5 sheep in the group were lame, 3 when at least >10 sheep in the group were lame and 4 did not know.

There was a significant cumulative increase in the percentage of participants who caught the first lame sheep as locomotion scores went from 1 to 4 in all four groups ($\chi^2$ trend, p<0.05) (Figure 5-2 & Figure 5-3). There was no statistical difference between the four groups of participants with respect to their decision to catch sheep with locomotion scores 1 or 2 (p>0.05). Approximately 29% - 43% and 38% - 56%
participants from four groups reported that they caught the first lame sheep with locomotion score 1 and 2 respectively (Table 5-3). In addition, all the participants who said that they caught the first lame sheep with locomotion scores of 1 and 2, caught the first lame sheep with locomotion scores 3 and 4.

The median percentage of farmers that caught the first lame sheep with locomotion score 3 in the four movie clips was 59% (IQR: 56% - 71%), 50% (IQR: 47% - 59%) and 64% (IQR: 60% to 73%) in Devon, Newark and Norfolk respectively. A significantly (p<0.05) higher percent of delegates at SVS (median: 87%; IQR: 85% - 90%) reported that they would catch the first lame sheep with locomotion score 3. The majority (≥79%) of participants from all four groups caught the first lame sheep with locomotion score 4 (Table 5-3). There was no significance difference between respondents in the four groups in their responses to catch sheep with locomotion score 4 (p>0.05) (Table 5-3).

For locomotion scores 1 to 4, the distribution of responses with respect to the number of lame sheep before inspection varied by the severity of the locomotion score. As the severity of the locomotion increased, the number of sheep lame in the group before participants’ inspected the sheep decreased (Table 5-3).
Table 5-3: Catching decisions of participants from Devon, Newark, Norfolk and Sheep Veterinary Society meeting for sheep with locomotion scores 1, 2, 3 and 4

<table>
<thead>
<tr>
<th>Score</th>
<th>Devon (N = 33)</th>
<th>Newark (N = 58)</th>
<th>Norfolk (N = 14)</th>
<th>SVS* (N = 35)</th>
<th>Score 2</th>
<th>Devon (N = 55)</th>
<th>Newark (N = 68)</th>
<th>Norfolk (N = 25)</th>
<th>SVS* (N = 49)</th>
<th>Score 3**</th>
<th>Devon (N = 58)</th>
<th>Newark (N = 77)</th>
<th>Norfolk (N = 26)</th>
<th>SVS* (N = 53)</th>
<th>Score 4</th>
<th>Devon (N = 58)</th>
<th>Newark (N = 80)</th>
<th>Norfolk (N = 28)</th>
<th>SVS* (N = 53)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First lame sheep in the group (%)</td>
<td>2-5 sheep in the group lame (%)</td>
<td>6-10 sheep in the group lame (%)</td>
<td>&gt;10 sheep in the group lame (%)</td>
<td>Don't know (%)</td>
<td>First lame sheep in the group (%)</td>
<td>2-5 sheep in the group lame (%)</td>
<td>6-10 sheep in the group lame (%)</td>
<td>&gt;10 sheep in the group lame (%)</td>
<td>Don't know (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score 1</td>
<td>30 (16-49)</td>
<td>18 (7-35)</td>
<td>24 (11-42)</td>
<td>15 (5-32)</td>
<td>12 (3-28)</td>
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<td>29 (18-43)</td>
<td>41 (27-53)</td>
<td>20 (11-33)</td>
<td>10 (4-21)</td>
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<td>43 (18-71)</td>
<td>14 (2-43)</td>
<td>7 (0-34)</td>
<td>29 (8-58)</td>
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<td>31 (17-49)</td>
<td>34 (19-52)</td>
<td>20 (8-37)</td>
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<td>Score 2</td>
<td>53 (39-66)</td>
<td>29 (18-43)</td>
<td>13 (5-24)</td>
<td>5 (1-15)</td>
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<td>38 (27-51)</td>
<td>38 (27-51)</td>
<td>18 (9-29)</td>
<td>6 (2-14)</td>
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<td>56 (35-76)</td>
<td>20 (7-41)</td>
<td>20 (7-41)</td>
<td>4 (0-20)</td>
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<td>41 (27-56)</td>
<td>45 (31-60)</td>
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<tr>
<td>Score 3**</td>
<td>59 (56-71)</td>
<td>27 (20-34)</td>
<td>7 (3-10)</td>
<td>3 (2-4)</td>
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<td>50 (47-59)</td>
<td>35 (31-39)</td>
<td>9 (6-15)</td>
<td>2 (1-4)</td>
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<td>64 (60-73)</td>
<td>19 (16-27)</td>
<td>8 (7-10)</td>
<td>2 (0-8)</td>
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<td>87 (85-90)</td>
<td>11 (9-13)</td>
<td>2 (1-4)</td>
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<td>Score 4</td>
<td>90 (79-96)</td>
<td>9 (3-19)</td>
<td>1 (0-9)</td>
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<td>79 (68-87)</td>
<td>21 (13-22)</td>
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<td>89 (72-98)</td>
<td>11 (2-28)</td>
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<td></td>
<td>92 (82-98)</td>
<td>6 (1-16)</td>
<td>2 (0-10)</td>
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</tbody>
</table>

* Sheep Veterinary Society ** Median percentage for four clips with inter-quartile range
Figure 5-2: Distribution of the average percentage of farmers by decisions to catch sheep with locomotion score 1, 2, 3 and 4.

Figure 5-3: Distribution of the percentage of sheep specialists by decision to catch sheep with locomotion score 1, 2, 3 and 4.

*Key-* blue = Locomotion score 1, pink = Locomotion score 2, green = Locomotion score 3 (median percent of the four clips is presented), orange = Locomotion score 4.
3.4. Distribution of farmer estimated lameness and number of breeding with different patterns to catch the first lame sheep with locomotion score 2, 3 or 4

There were no significant differences in the median number of ewes per farm by catching behaviour ($p_{trend} > 0.05$, Table 5-4). However, the median farmer estimated lameness in ewes decreased with increased reporting to catching the first lame sheep with lower severity of locomotion ($p_{trend} < 0.05$, Table 5-4).

Table 5-4: Median prevalence of lameness with inter quartile range (IQR) and median number of breeding ewes by farmers patterns for catching first lame sheep by locomotion score

<table>
<thead>
<tr>
<th>Locomotion Score</th>
<th>Median Lameness (IQR)</th>
<th>N</th>
<th>Median Number of Breeding Ewes (IQR)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caught the first lame sheep with locomotion scores ≥2</td>
<td>5 (2 - 6)</td>
<td>59</td>
<td>150 (50 - 320)</td>
<td>67</td>
</tr>
<tr>
<td>Caught the first lame sheep with locomotion score ≥3</td>
<td>10 (5 - 10)</td>
<td>40</td>
<td>155 (80 - 350)</td>
<td>41</td>
</tr>
<tr>
<td>Caught the first lame sheep with locomotion score 4</td>
<td>10 (8 - 10)</td>
<td>8</td>
<td>200 (150 - 400)</td>
<td>10</td>
</tr>
<tr>
<td>Did not ever catch the first lame sheep</td>
<td>11 (9 - 15)</td>
<td>24</td>
<td>200 (120 - 300)</td>
<td>27</td>
</tr>
</tbody>
</table>

Z 5.77 1.59

$P_{trend^*} < 0.05 > 0.05$

3.5. Impact of farmers decision on the minimum number of lame sheep required in the group before inspection and their reported time to treatment on the farmer estimated lameness

The median lameness estimate of farmers by decision to catch lame sheep by locomotion score is presented in Table 5-5, together with their reported time to treatment. The results of one of the clips with locomotion score 3 are included in the Table 5-5 (the trend among farmers was similar for all four clips of locomotion score 3).
There was a significant association between farmer reported time to treatment and the minimum number of lame sheep present in the group before they caught sheep with locomotion score 2, 3 or 4 (p <0.05) (Table 5-5). Almost all the farmers who treated lame sheep of any severity the first day that they saw them lame always caught the first lame sheep (Table 5-5). Similarly, the majority (> 93%) of farmers, who reported that they treated lame sheep within 3 days of observing them lame, either always caught, the first lame sheep or 2 - 5 lame sheep in the group. However, farmers who treated their lame sheep within a week or only at routine gatherings reported that more than five sheep needed to be lame in the group before they caught them compared with those who treated either the first day or within 3 days (Table 5-5, Figure 5-4).

There was a significant increase in the median lameness with increased time to treatment of lame sheep (p_{trend} <0.05). Similarly, the median lameness also increased with an increase in the minimum number of sheep that had to be lame in the group, before farmers caught sheep with locomotion scores 2, 3 or 4 (p_{trend} <0.05) (Table 5-5).

This is illustrated in Figure 5-4 where the patterns of lameness by time to treatment and number lame are clearly visible.
Table 5-5: Time to treatment and decisions for catching lame sheep (locomotion score 2, 3 and 4) by estimated lameness among farmer

<table>
<thead>
<tr>
<th>Locomotion Score</th>
<th>Time to treatment</th>
<th>Always, even if the first lame sheep in the group are lame</th>
<th>2 -5 sheep in the group are lame</th>
<th>6 -10 sheep in the group are lame</th>
<th>&gt; 10 sheep in the group are lame</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median lameness (IQR)</td>
<td>N</td>
<td>Median lameness (IQR)</td>
<td>N</td>
</tr>
<tr>
<td>Treat first day</td>
<td>Treat within 3 days</td>
<td>2 (1 - 5)</td>
<td>20</td>
<td>2 (1 - 6)</td>
<td>3</td>
</tr>
<tr>
<td>Score 2</td>
<td>Treat within week</td>
<td>5 (2 - 7)</td>
<td>28</td>
<td>5 (4 - 10)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Treat at routine gatherings</td>
<td>7 (4 - 15)</td>
<td>7</td>
<td>10 (5 - 15)</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 (8 - 20)</td>
<td>7</td>
<td>10 (6 - 15)</td>
<td>7</td>
</tr>
<tr>
<td>Treat first day</td>
<td>Treat within 3 days</td>
<td>2 (1 - 6)</td>
<td>23</td>
<td>2 (1 - 6)</td>
<td>16</td>
</tr>
<tr>
<td>Score 3</td>
<td>Treat within week</td>
<td>5 (5 - 8)</td>
<td>33</td>
<td>5 (5 - 10)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Treat at routine gatherings</td>
<td>10 (5 - 15)</td>
<td>13</td>
<td>10 (8 - 15)</td>
<td>27</td>
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<tr>
<td></td>
<td></td>
<td>6 (6 - 6)</td>
<td>1</td>
<td>10 (7 - 10)</td>
<td>7</td>
</tr>
<tr>
<td>Treat first day</td>
<td>Treat within 3 days</td>
<td>2 (1 - 5)</td>
<td>25</td>
<td>2 (1 - 5)</td>
<td>2</td>
</tr>
<tr>
<td>Score 4</td>
<td>Treat within week</td>
<td>5 (4 - 10)</td>
<td>50</td>
<td>4 (4 - 15)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Treat at routine gatherings</td>
<td>10 (5 - 15)</td>
<td>30</td>
<td>10 (6 - 15)</td>
<td>11</td>
</tr>
</tbody>
</table>

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Figure 5-4: Time to treatment and decisions to catch lame sheep of locomotion score 2, 3 and 4 by estimated flock lameness

* Key: Yellow - catch the first lame sheep, Red - Catch when 2 to 5 sheep in the group are lame, Green - Catch when 6 - 10 sheep in the group are lame, Blue - Catch when > 10 sheep in the group are lame
4. Discussion

The key finding from this study is that although most farmers and sheep specialists considered that a sheep with a locomotion score as low as 2 was lame, a proportion of them did not catch individual lame sheep until the locomotion score was 4 (when a sheep is not bearing weight on its affected limb while moving and standing). This may be a result of an inherent assumption among farmers and sheep specialists that sheep with lower locomotion scores do not have foot lesions or are not in pain or will recover without treatment or will become more lame and then require treatment.

Farmers attribute the majority of their flock lameness to two foot lesions; ID (caused by *F. necrophorum*) and FR (caused by *D. nodosus*) (Kaler and Green, 2007). There is now evidence from my work that even the mildly lame sheep have these lesions (Chapter 6). Thus, considering this evidence and the fact that footrot is infectious (Beveridge, 1941), not always catching sheep with low locomotion scores or waiting to treat sheep or waiting until a certain number in the group are lame may spread footrot and hence increase the incidence and possibly the prevalence of lameness. The findings from this study support this hypothesis because farmers who always caught the first lame sheep in a group even with a low severity of locomotion and treated their lame sheep on the first day or within 3 days of seeing them lame had significantly lower median flock lameness. One concern is that this prevalence of lameness was estimated by these same farmers and might be inaccurate, or the percentage of sheep that farmers identified in the flocks as lame, or the percentage of sheep that the farmers would treat. From the results of this study the farmers’ perception of these two are
different because in spite of identifying sheep with locomotion score 2, as lame; the majority of farmers did not always catch the first lame sheep with that score.

There may be several factors that influence a farmer’s decision to catch sheep with varying locomotion score. Although one would expect farmers with smaller flock sizes to always catch individual lame sheep with lower locomotion scores, there were no significance differences in the median number of breeding ewes on the farms where farmers always caught the first lame sheep with low locomotion score and those where farmers did not. The type of handling facilities and the amount of labour and time available may also affect a farmer’s decision to catch lame sheep. With portable handling facilities and more labour and time available it may be that farmers are probably more able to always catch the first lame sheep even with low locomotion scores. Information on these facilities was not collected in this study.

The high correlation between the time to treatment and farmer decisions to always catch the first lame sheep with varying locomotion internally validates the information collected in the questionnaire on farmer decisions. It also fits with estimates of lameness since leaving lame sheep in the flock before treatment increase the prevalence of lameness unless spontaneous recovery.

There was a good percent raw agreement (>74%) between participants in their responses for sheep of locomotion scores 0, 2, 3 and 4. However, there was disagreement between participants in their responses to the sheep with locomotion score 1, 36% - 67% participants in the study considered it was lame. This may be because sheep with locomotion score 1 have a slight alteration in gait and posture and do not show any obvious signs of lameness such as flicking their head,
inability to bear weight on affected limb(s) and discomfort while moving. This was also observed in the Chapter 4 where disagreement between trained observers was greatest for scores 0 and 1 when inter observer reliability was assessed using the same movie clips. Despite disagreement on locomotion score 1, the majority of the participants considered sheep with locomotion score ≥2 lame. In addition their decision to catch sheep varied with the severity of the locomotion score (Table 5-3). Both these facts imply that farmers and sheep specialists were differentiating between different severities of locomotion although not asked this directly.

Various considerations and assumptions were made before deciding the number of movie clips used in the study. There was a time constraint, all the farmer meetings and SVS meeting had a specific agenda and participants attended those meeting with a purpose. Clips of locomotion score 5 and 6 were not included in the study because it was assumed that most farmers would catch lame sheep with these scores and so there would not be variability in the results. This seems a reasonable assumption given the uniform response to the clip of sheep with locomotion score 4. Four clips of score 3 were included compared with one clip for the other scores. Locomotion score 3 is the middle of the locomotion scoring scale and there was no prior information on farmers decisions to catch sheep with that score. However, based on personal observations it was assumed that most farmers do not always catch the first lame sheep of locomotion score 2 but always catch the first lame sheep with locomotion score 4. Thus the aim was to get a repeatable information for locomotion score 3 by including more number of clips for that score. There was variation between participants of each group with respect to the percent who always caught the first lame sheep with locomotion score 3 in
each of the four movie clips. This may be because although the definition of locomotion score used objective terminology, there was still a range of severity within the score. The sheep in one of the four movie clips of locomotion score 3 had excessive flicking of head in compared with the sheep in the rest of the clips. This sheep was considered as though more lame by farmers and sheep specialists (as evident from their decisions to catch this sheep). Thus the farmers’ and sheep specialists’ perception of severity of lameness varied within this score.

The sample of farmers was not random and included farmers who were interested in gathering more information on lameness management. Thus the results of this study are not truly representative of the farmers in the respective regions or England. Similarly, the sheep specialists were conveniently sampled from a SVS meeting, and this may not be a representative sample of all sheep vets or specialists in England. However, this is the first study to investigate farmers and sheep specialists’ ability to identify lame sheep and their decision to catch sheep with different severities of locomotion. Additionally, there were no significance differences between three groups of farmers from different regions with respect to the overall results of the study.

The use of videos of sheep with varying locomotion was a useful methodology to gather information on farmer decision to catch lame sheep. It may not have been possible to see all the severities of locomotion at a same time on a farm. All the questions pertaining to identification and catching sheep in this study were only targeted at the sheep shown in the movie clips and it is possible that farmers’ responses might change for sheep with similar locomotion in their flock. When viewing a movie clip farmers were in an artificial situation and were only
considering a single sheep while in the flock they identify lame sheep from a group. Farmers were probably less intimidated to report to their decisions to catch lame sheep by locomotion than they might be in face to face situation on farm. This might also be true for sheep specialists. Evidence suggests that respondents generally respond differently to behavioural or attitudinal questions in self administered questionnaires and face to face interviews; they feel more pressurised to give a ‘socially desirable’ answer in face to face interviews (Krysan et al., 1994).

5. Conclusions and further work

This small study clearly demonstrated that farmers and sheep specialists can recognise lame sheep but make a separate decision on when to catch sheep for inspection. In addition, the lameness estimates were higher on the farms where farmers either waited longer than 3 days or waited until they had a certain number of lame sheep in the group before inspection or both. However, further work is needed to externally validate these findings by including a random sample of farmers and sheep specialist and by investigating their decisions in their own flocks.
Chapter 6

A longitudinal study of locomotion, interdigital dermatitis and footrot in sheep

1. Introduction

The results from an intervention study on one farm (Hawker, 2007) demonstrated a decrease in the prevalence and incidence of interdigital dermatitis (ID) and footrot (FR) in an intervention group, where ewes with locomotion score ≥2 (using the locomotion score described in Chapter 4) with either ID or FR were treated with parenteral antibiotic injection and topical antibiotic spray within 1-3 days of first becoming lame, compared with a control group where foot trimming, topical antibiotics and occasional footbathing were used for treatment when the farmer thought this was necessary (Hawker, 2007). These results suggest a link between ID, FR and locomotion since prompt treatment of lame sheep (locomotion score ≥2) with these lesions using parenteral antibiotic injections and topical antibiotic spray reduced the incidence of ID and FR in the group.

The results from a small study (Chapter 5) where farmers and sheep specialists were shown movie clips of sheep with a range of locomotion scores from the locomotion scoring scale presented in Chapter 4, suggest that farmers and specialists can recognise even mildly lame sheep (locomotion scores 1 or 2) but do not intervene to treat sheep until the lameness is more severe (scores 3 or 4): only approximately 50% of farmers said that they would catch sheep with a
locomotion score of 2 when it was the only sheep lame in a group (Chapter 5) while 50% would not. Given the results from the intervention study (Hawker, 2007), one concern, other than the welfare of untreated lame sheep, is that even mildly lame sheep may have FR or ID, given that most lameness is caused by ID and FR (Kaler and Green, 2008). Consequently not treating these individuals may lead to transmission of infection to other sheep.

There has been no study to date investigating the relationship between ID, FR and locomotion in sheep and the association of these lesions with locomotion over time. In the current study a sub-sample of lame and non lame sheep from both treatment groups of the intervention study (Hawker, 2007) were enrolled and followed for five weeks to investigate the temporal associations between ID, FR and locomotion in sheep and the effect of different treatments on locomotion.

2. Materials and Methods

2.1. Study design, study population and inclusion criteria

This study took place on the farm in October 2006 where the intervention study was carried out since May 2005. In one intervention group (n = 131), sheep with locomotion score $\geq 2$ with ID or FR lesions were treated by a research team with parenteral antibiotic injection and topical antibiotic spray within 1-3 days of becoming lame. In one control group (n = 144) the farmer treated sheep that he considered lame when necessary, with foot trimming and topical antibiotic spray. In addition, sheep in the control group were occasionally footbathed. Both groups
were comprised of ewes (Mule, Suffolk and Roussin) ≥2 years old. There was a similar distribution of sheep with respect to breed and age in both groups.

For the current study, all sheep in both groups were first scored for locomotion using the numerical verbal rating scale (Chapter 4) and 30 sheep were then randomly selected from each group, ensuring representation of breeds and all severities of locomotion. The selected sheep from the control group consisted of 14 non lame sheep with locomotion score 0 and 16 lame sheep with locomotion score ≥1 (Group A). The selected sheep from the intervention group consisted of 17 non lame sheep with locomotion score 0 and 13 lame sheep with locomotion score ≥1 (Group B). Sheep in both groups were given a unique identification number sprayed onto both flanks of the sheep.

2.2. Study period and data collection

The study was carried out for five weeks and data were collected from all sheep in Groups A and B. Data were collected from sheep once a week, on separate days for each group. Each week, all sheep in both groups were scored for locomotion using the numerical rating scale (Chapter 4) in the field. Sheep were then turned and all four feet were examined. All lesions on the feet were recorded. Interdigital dermatitis (ID) lesions were scored using a numerical scale with scores 0 to 4 for each foot (Table 6-1) and FR lesions were scored on each digit separately for heel/sole and wall using a numerical rating scale (0 - 3) (Table 6-1). Lameness in sheep in Groups A and B was managed as above in the intervention study.

After data recording each week, the sheep in Groups A and B were returned to their respective groups in separate fields. All the observations and scoring were carried out by one observer (JK) and recorded by another observer (TG).
The data were stored in Microsoft Access and checked for errors.

Table 6-1: Scoring scales for ID and FR on a foot

<table>
<thead>
<tr>
<th>Score</th>
<th>Classification of interdigital dermatitis (ID) lesions per foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Clean interdigital foot with no dermatitis lesions nor fetid smell</td>
</tr>
<tr>
<td>1</td>
<td>Slight interdigital dermatitis, irritation of the skin, but dry</td>
</tr>
<tr>
<td>2</td>
<td>Slight interdigital dermatitis with a fetid smell (&lt;5% of the interdigital area affected)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate interdigital dermatitis with a fetid smell (5 to 25% of the interdigital area affected)</td>
</tr>
<tr>
<td>4</td>
<td>Severe interdigital dermatitis with a fetid smell (&gt;25% of the interdigital area affected)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Score</th>
<th>Classification of footrot (FR) lesions per digit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Sole and heel of the digit</strong></td>
</tr>
<tr>
<td>0</td>
<td>No under-running of the heel and sole area of the digit</td>
</tr>
<tr>
<td>1</td>
<td>An active footrot lesion with a degree of under-running (≤50%) of the heel and/or sole area of the digit</td>
</tr>
<tr>
<td>2</td>
<td>An active footrot lesion with a marked degree of under-running (&gt;50% but &lt;100%) of the heel and/or sole area of the digit</td>
</tr>
<tr>
<td>3</td>
<td>An active footrot lesion with complete (100%) under-running of heel and/or sole Wall of the digit</td>
</tr>
<tr>
<td></td>
<td><strong>Wall of the digit</strong></td>
</tr>
<tr>
<td>0</td>
<td>No under-running of the wall of the digit</td>
</tr>
<tr>
<td>1</td>
<td>An active footrot lesion with a degree (&lt;50%) of under-running of the wall hoof horn of the digit</td>
</tr>
<tr>
<td>2</td>
<td>An active footrot lesion with extensive (&gt;50% but &lt;100%) under-running of the wall hoof horn of the digit</td>
</tr>
<tr>
<td>3</td>
<td>An active footrot lesion with complete (100% with coronary band also affected) under-running of the wall hoof horn of the digit</td>
</tr>
</tbody>
</table>

2.3. Definition and categorisation of sheep with ID or FR lesions

A sheep was defined as having ID if it had at least one foot with an ID lesion score >0 and all feet with FR lesion score 0.

A sheep was defined as having FR if it had at least one digit with a FR lesion score >0, irrespective of the presence of ID on any foot.

ID and FR lesions were categorised further by the maximum lesion severity scores of 1 and >1. The prevalence and incidence of sheep with ID and FR were calculated for each week.
2.4. Model building and analysis

The outcome variable was locomotion score at time $t_i$ (where $i = 1, 2, ..., 5$ i.e. each sheep week for which data were recorded). A general linear mixed multilevel model with two hierarchical levels was built using MLwiN version 2.01 (Rasbash et al., 2000). The repeated measures i.e. weeks (1 to 5) at level 1 were nested within sheep at level 2. Markov Chain Monte Carlo (MCMC) with Gibb’s sampling was used for parameter estimation and model fitting. For MCMC estimation, Iterative Generalised Least Square (IGLS) estimation procedure was used as a prior distribution. The model was run for 100,000 iterations with a burn in period of 10,000 iterations.

Fixed effect explanatory variables

at time $t_i$, were Group A or B, no foot lesion, ID with a maximum severity score of 1, ID with a maximum severity score $>1$, FR with a maximum severity score 1 and FR with a maximum severity score $>1$

at time $t_{i+1}$ were no lesion, no incident case of ID or FR, an incident case of ID and an incident case of FR

at time $t_{i-1}$ were no lesion, non resolved case of ID/FR, resolved case of ID and resolved case of FR and no treatment or treatments given

The definitions were:

*Incident case of ID* = Sheep with no ID at $t_i$ but ID present at $t_{i+1}$

*Incident case of FR* = Sheep with no FR at $t_i$ but FR present at $t_{i+1}$

*No incident case of ID/FR* = Sheep where the same lesion, either ID or FR, was present at both $t_i$ and $t_{i+1}$
Resolved case of ID = Sheep with no ID at ti but ID present at t_{i-1}

Resolved case of FR = Sheep with no FR at ti but FR present at t_{i-1}

Non resolved case of ID/FR = Sheep where the same lesion, either ID or FR, was present at both ti and t_{i-1}

The model took the form:

\[ y_{ij} = \beta_0 + \sum \beta X_{ij} + \sum \beta X_j + v_j + e_{ij} \]

where \( y_{ij} \) = sheep locomotion score at week \( ti \), \( \beta_0 \) = constant, and \( \beta X \) is a vector of fixed effects varying at level 1 (ij) or level 2 (j), \( i \) is the number of weeks, \( i = 1, \ldots, 5 \), \( j \) is the number of sheep, \( j = 1, \ldots, 60 \) and \( v_j = \) level 2 residual variance \( e_{ij} = \) level 1 residual variance.

Because of the variables at the time \( t_i, t_{i+1} \) and \( t_{i-1} \), only outcomes from weeks 2, 3 and 4 were present in the model.

The model fit was checked through the analysis of residuals at level 1 and level 2 and convergence and mixing of MCMC was observed visually. The good mixing of chains was achieved by running the model for 100,000 iterations.

3. Results

For each group, it took approximately 1 hour to score the locomotion of sheep in the field. In addition, inspection of each sheep (including time to catch and turn a sheep and recording of lesions) took approximately 15 minutes. Complete data were available for all sheep in both the groups, except two sheep from Group A which had missing information on their locomotion and foot lesions on two separate occasions.
3.1. Locomotion scores and lesions

The average percent of sheep with locomotion score 1 or above in the five weeks was 48% in both Groups A and B. However, there was a higher proportion of sheep with locomotion score 1 in group B compared with Group A (Table 6-2). Sheep in both the groups had ID and FR lesions. No other foot lesions were present.

The weekly prevalence of sheep with ID ranged from 10% to 28% in Group A. There was a high proportion of sheep with ID in Group B with a maximum prevalence of 83% in the fourth week of the study (Table 6-2). The prevalence of sheep with FR during the study ranged from 24% - 46% and 3% - 13% in Groups A and B respectively (Table 6-2). Sheep in Group A had a higher mean incidence (12% versus 5%) of FR than sheep in Group B. However, sheep in Group B had a higher mean incidence of ID (57% versus 20%) compared with sheep in Group A (Figure 6-1).

**Figure 6-1: Incidence of ID and FR in group A and B**

There were no foot lesions on 136 out of a total of 298 observations. There were ID lesions on 100 occasions (30 - Group A; 70 - Group B) and FR on 62 occasions (49 - Group A; 13 - Group B). For the majority (82% (111/136)) of the observations when sheep had no lesion, the locomotion score was 0. On 25 (18%) of 136 occasions sheep with no lesions had a locomotion score ≥1; on 23 of the occasions sheep had locomotion score of 1. On approximately 41% (41/100) and 3% (2/62) of occasions sheep with ID and FR had a locomotion score 0 respectively (Table 6-2).
<table>
<thead>
<tr>
<th>Locomotion score</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Lesion</td>
<td>ID</td>
<td>FR</td>
<td>No Lesion</td>
<td>ID</td>
</tr>
<tr>
<td>0</td>
<td>15 (50)</td>
<td>1 (3)</td>
<td></td>
<td>11 (37)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>1</td>
<td>2 (7)</td>
<td>2 (7)</td>
<td></td>
<td>2 (7)</td>
<td>2 (7)</td>
</tr>
<tr>
<td>2</td>
<td>1 (3)</td>
<td>4 (13)</td>
<td></td>
<td>5 (17)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1 (3)</td>
<td>1 (3)</td>
<td></td>
<td>4 (13)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3 (10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>1 (3)</td>
<td></td>
</tr>
<tr>
<td>Total (Prevalence)</td>
<td>17 (57)</td>
<td>5 (16)</td>
<td>8 (27)</td>
<td>13 (44)</td>
<td>3 (10)</td>
</tr>
<tr>
<td>Mean locomotion score (S.E.)</td>
<td>1.06 (0.25)</td>
<td></td>
<td></td>
<td>1.10 (0.24)</td>
<td></td>
</tr>
</tbody>
</table>

**Group B**

<table>
<thead>
<tr>
<th>Locomotion score</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Lesion</td>
<td>ID</td>
<td>FR</td>
<td>No Lesion</td>
<td>ID</td>
</tr>
<tr>
<td>0</td>
<td>14 (47)</td>
<td>2 (7)</td>
<td>1 (3)</td>
<td>10 (33)</td>
<td>4 (13)</td>
</tr>
<tr>
<td>1</td>
<td>3 (10)</td>
<td>5 (17)</td>
<td></td>
<td>4 (13)</td>
<td>8 (27)</td>
</tr>
<tr>
<td>2</td>
<td>2 (7)</td>
<td>1 (3)</td>
<td>2 (7)</td>
<td>3 (10)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (Prevalence)</td>
<td>19 (64)</td>
<td>8 (26)</td>
<td>3 (10)</td>
<td>14 (46)</td>
<td>15 (50)</td>
</tr>
<tr>
<td>Mean locomotion score (S.E.)</td>
<td>0.60 (0.14)</td>
<td></td>
<td></td>
<td>0.57 (0.11)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6-2: Number and percent of sheep by locomotion score and presence / absence of ID or FR lesions in group A and B by week; S.E. – standard error
The distribution of the maximum severity score of ID per foot and the maximum severity score of FR per digit by locomotion score is presented in Table 6-3. Sheep with ID in Group A (30 occasions) had a maximum ID severity score of 1, 2 and 3 on 60%, 37% and 3% occasions respectively. Sheep with ID in Group B (70 occasions) had a maximum ID severity score of 1, 2, 3 and 4 on 49%, 41%, 7% and 3% respectively.

On the majority (67% - Group A; 77% - Group B) of occasions in both groups, there was a maximum severity score for FR of 1. However, on 14/49 and 3/13 occasions sheep had a maximum FR severity score of 2 in Groups A and B respectively. On only 2/49 occasions, sheep with FR in Group A had a maximum severity score of 3; none of the sheep in Group B had FR with a maximum severity score of 3.

Table 6-3: Distribution of locomotion scores by sheep with no lesion, ID and FR during the study (5 weeks)

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Maximum severity score</th>
<th>Group</th>
<th>Locomotion score</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>No Lesion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>62</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group B</td>
<td>49</td>
<td>15</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Interdigital dermatitis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Group A</td>
<td>9</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Group B</td>
<td>17</td>
<td>15</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>15</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Footrot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Group A</td>
<td>1</td>
<td>13</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Group B</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2. Number of feet affected

There were 233 feet affected with ID during the study, 45% were on front feet and 55% were on hind feet. On approximately 37%, 22%, 12% and 29% of the 100 occasions when sheep had ID, there were 1, 2, 3 and 4 feet affected with ID respectively. There were 68 feet affected with FR on any occasion, 47% were on front feet and 53% were on hind feet. There were 62 FR events, 56 were on only one foot of a sheep and 6 were on two feet of three sheep. On 89% (55/62) of occasions sheep had ID in addition to FR; on 53 out of 55 of these occasions the lesions were present on the same foot.

There was no significant association ($\chi^2$, $p>0.05$) between locomotion score and the number of feet affected with ID (Table 6-4). A statistical test between locomotion and number of feet affected with FR could not be performed because few sheep had more than one foot affected with FR (Table 6-5).

<table>
<thead>
<tr>
<th>Number of feet affected with ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locomotion score 0</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Locomotion score 1</td>
<td>16</td>
<td>10</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Locomotion score 2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Locomotion score 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locomotion score 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locomotion score 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of feet affected with FR</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locomotion score 0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Locomotion score 1</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Locomotion score 2</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Locomotion score 3</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Locomotion score 4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Locomotion score 5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
3.3. Treatment

All the sheep in Group A were footbathed by the farmer in the third week. Four sheep in that group were also individually treated once with foot trimming and antibiotic spray. On 17 occasions sheep in group B with ID/FR were treated with parenteral antibiotic injection and topical antibiotic spray.

3.4. Multilevel model of factors associated with locomotion in sheep

The baseline locomotion score was 0.25. The mean locomotion score of sheep with a maximum ID severity score of 1, maximum ID severity score >1, maximum FR severity score of 1 and maximum FR severity score >1 at $t_i$ was significantly higher by 0.34, 0.43, 1.32 and 2.18 units respectively compared with sheep with no foot lesions (Table 6-6).

In addition, incident cases of FR at $t_{i+1}$ had a significant increase in mean locomotion score of 0.76 at $t_i$ compared with sheep that had no foot lesion in the $t_{i+1}$. There was no significant association between locomotion score and incident cases of ID at $t_{i+1}$ or resolved cases of ID and FR at $t_{i-1}$. The non resolved cases of ID/FR at $t_{i-1}$ and no incident cases of ID/FR at $t_{i+1}$, did not significantly influence locomotion scores once the data on these lesions at $t_i$ were included (Table 6-6).

Sheep that were treated with parenteral antibiotic injection and antibiotic spray at $t_{i-1}$ had a significant reduction in their mean locomotion score of 0.81 at $t_i$ compared with sheep that did not receive such treatment. There was no significant association between locomotion and the treatment of the 4 sheep with foot trimming and antibiotic spray (Group A) at $t_{i-1}$ (Table 6-6). In addition, treatment with footbathing (Group A) at $t_{i-1}$ was not significantly associated with a reduced locomotion score.
although the coefficient was negative. There was no residual significant association between groups and overall locomotion score.

Table 6-6: Multilevel (2 level) model of factors associated with locomotion in 60 sheep at ‘t,’ for weeks 2, 3 and 4

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>coefficient</th>
<th>standard error</th>
<th>95% credibility interval</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept</strong></td>
<td></td>
<td>0.25</td>
<td>0.12</td>
<td>0.01, 0.49</td>
</tr>
<tr>
<td><strong>At t</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lesion category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lesion</td>
<td>80</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interdigital dermatitis with maximum score of 1 per foot</td>
<td>30</td>
<td>0.34</td>
<td>0.17</td>
<td>0.01, 0.67</td>
</tr>
<tr>
<td>Interdigital dermatitis with maximum score of &gt;1 per foot</td>
<td>28</td>
<td>0.43</td>
<td>0.19</td>
<td>0.06, 0.80</td>
</tr>
<tr>
<td>Footrot with maximum score of 1 per foot</td>
<td>28</td>
<td>1.32</td>
<td>0.23</td>
<td>0.87, 1.78</td>
</tr>
<tr>
<td>Footrot with maximum score of &gt;1 per foot</td>
<td>11</td>
<td>2.18</td>
<td>0.26</td>
<td>1.66, 2.70</td>
</tr>
<tr>
<td><strong>At t+1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lesion category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lesion</td>
<td>73</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No incident case of ID/FR</td>
<td>63</td>
<td>-0.10</td>
<td>0.14</td>
<td>-0.38, 0.18</td>
</tr>
<tr>
<td>Incident case of ID</td>
<td>30</td>
<td>0.08</td>
<td>0.13</td>
<td>-0.18, 0.35</td>
</tr>
<tr>
<td>Incident case of FR</td>
<td>11</td>
<td>0.76</td>
<td>0.22</td>
<td>0.31, 1.21</td>
</tr>
<tr>
<td><strong>At t-1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lesion category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lesion</td>
<td>100</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non resolved case of ID/FR</td>
<td>53</td>
<td>0.26</td>
<td>0.15</td>
<td>-0.50, 0.56</td>
</tr>
<tr>
<td>Resolved case of ID</td>
<td>19</td>
<td>0.13</td>
<td>0.16</td>
<td>-0.19, 0.46</td>
</tr>
<tr>
<td>Resolved case of FR</td>
<td>5</td>
<td>0.14</td>
<td>0.31</td>
<td>-0.47, 0.75</td>
</tr>
<tr>
<td><strong>Treatments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not treated with parenteral antibiotic injection and antibiotic spray</td>
<td>169</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated with parenteral antibiotic injection and topical antibiotic spray</td>
<td>8</td>
<td>-0.85</td>
<td>0.27</td>
<td>-1.39, -0.31</td>
</tr>
<tr>
<td>Not treated with antibiotic spray and foot trimming</td>
<td>173</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated with antibiotic spray and foot trimming</td>
<td>4</td>
<td>-0.42</td>
<td>0.34</td>
<td>-1.08, 0.27</td>
</tr>
<tr>
<td>Not treated with footbathing</td>
<td>149</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated with footbathing</td>
<td>28</td>
<td>-0.16</td>
<td>0.13</td>
<td>-0.42, 0.09</td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group B</td>
<td>87</td>
<td>reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>90</td>
<td>-0.15</td>
<td>0.14</td>
<td>-0.42, 0.12</td>
</tr>
</tbody>
</table>
Random variation at both levels was significant. There was a significant reduction in random variation at the level 2 (sheep) (Table 6-7) and the deviance after addition of the explanatory variables.

Table 6-7: Distribution of variances at level 1 and 2 in null and final model

<table>
<thead>
<tr>
<th></th>
<th>Null model</th>
<th>Multilevel final model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random effects</td>
<td>Variance</td>
<td>Standard error</td>
</tr>
<tr>
<td>level 2 (sheep)</td>
<td>0.48</td>
<td>0.10</td>
</tr>
<tr>
<td>level 1 (week)</td>
<td>0.39</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The residuals of the model at both levels indicated a good overall fit (Figure 6-2, 6-3). The outliers did not change the overall trend and significance of the model and were left in the model.

Figure 6-2: Diagnostic plots of level 1(week) standardised residuals
4. Discussion

This study is the first investigation of the relationship between ID, FR and locomotion in sheep and suggests that sheep with ID or FR have a significantly increased locomotion score compared with sheep with no lesions. Even the mildly lame sheep had these lesions, and some non-lame sheep had lesions. These results imply that not catching mildly lame sheep and not catching them soon after they first become lame may lead to an increase in the incidence of lameness through spread of FR because it is infectious (Beveridge, 1941).

Although ID and FR lesions are not necessarily bacteriologically distinct (Egerton et al., 1969; Moore et al., 2005a), they were scored separately because of their different clinical presentation (Table 6-1). The locomotion score of sheep with FR was comparatively higher than that for sheep with ID; this may be because of the difference in clinical presentation of ID and FR. There is separation of hoof horn from underlying tissue in FR whereas ID affects interdigital space only, with inflammation in the interdigital area (Winter, 2004a).
There was a significant increase in locomotion score in sheep at time $t_i$ that developed FR (i.e incident cases) at $t_{i+1}$. This suggests that sheep that will develop FR (before FR becomes clinically apparent) are more lame than those who will not. The increased locomotion score of the sheep before the visible appearance of FR might suggest pain from the invasion of *D. nodosus* in the hoof or some microbial activity inside the hoof tissue responsible for altered locomotion. In the current study, there were 11 incident cases of FR at $t_{i+1}$, seven had ID at time $t_i$. In experimental studies, invasion of ID skin by *F. necrophorum* precedes of *D. nodosus* in a FR lesion (Egerton *et al.*, 1969). Considering this evidence, it is possible that the 4 incident cases of FR at $t_{i+1}$ which had no ID at $t_i$ developed ID somewhere between the two weekly recordings because both ID and FR were recorded at $t_{i+1}$. It also may suggest that an alternative pathogenesis is possible.

Although higher locomotion scores in sheep at $t_i$ were significantly associated with the presence of ID and FR at $t_i$, no incident case of ID/FR at $t_{i+1}$ and non resolved cases of ID/FR at $t_{i-1}$ did not significantly affect locomotion scores at $t_i$ once the presence of ID and FR were included. This suggests that the major contribution to raised locomotion in sheep at $t_i$ is the presence of ID and FR at that same time and the presence of these lesions also in previous week or next week probably do not have any additional effect, a larger study might have resulted in a significantly raised locomotion score at $t_{i-1}$ however, if the coefficients from the current model are accurate the biological importance of this would be low and would indicate healing was advanced. In addition, there was no significant association between cases of ID and FR at $t_{i-1}$ that resolved by $t_i$ and locomotion scores at $t_i$. This suggests that resolved lesions probably do not contribute to raised locomotion score at $t_i$ and highlight the rapid resolution in lameness as lesions
resolve. However, this might not be true for severe cases of FR where there is complete loss or extensive damage of wall horn because wall horn is the weight bearing surface in sheep. There were only 2 cases of complete (100%) under-running of heel/sole and wall of the digit recorded in the current study and only 5 cases of FR resolved; it is therefore possible that there was not enough power to detect a delay in resolution of lameness in severe footrot from the current study.

Sheep that were treated with both parenteral antibiotic injection and topical antibiotic spray at t₁₋₁ had significant reduction in their locomotion at time t₁. This may be due to partial or complete resolution of ID or FR by the treatment because lesions either resolved completely or partially a week after treatment (results not shown). Previous studies have also demonstrated a decrease in prevalence and incidence of ID or FR and lameness in sheep treated with antibiotic injection and antibiotic spray (Green et al., 2007; Hawker, 2007). In contrast, there was no significant decrease in locomotion score in sheep at t₁ after treatment with antibiotic spray and foot trimming at t₋₁; this might be because only 4 sheep were treated with this treatment and thus there was not enough power to detect a significant difference, or there is a possibility that this treatment was not as effective. Similarly, there was no significant association between footbathing and locomotion score in sheep which indicates the probable ineffectiveness of footbathing in resolving ID or FR within a week (also see Chapter 3) but also possibly a lack of study power. Because the current study was only five weeks in duration, it was not possible to investigate whether any of these treatments were effective after more than one week.
The sample size of 30 sheep in each group was chosen taking into account the time to catch, score and record the sheep in a day and because all the scorings were done by only one observer, this number was practically possible. A longitudinal study design was chosen for this study because the aim was to investigate the relationship between ID, FR and locomotion over time. The duration of the study was 5 weeks, because rams were introduced and the study had to stop. Thus it was not possible to fully explore patterns of lesions ID and FR over more time e.g. whether same sheep become diseased several times. Despite this useful results were obtained.

This study design not only gives more causal evidence because of correct temporal sequence of association but also allow investigating the pattern of association over time (Twisk, 2003). Although there was some correlation between the presence of ID or FR in weeks \( t_i, t_{i-1} \) and \( t_{i+1} \), they were not collinear and addition of these three variables together with treatments further reduced the variation of locomotion scores among sheep. Moreover, use of a Bayesian approach for estimation of parameters i.e. MCMC provided less biased estimates in variation at levels 1 and 2. The remaining unexplained variation in the locomotion scores could be a result of other injuries of the limbs or diseases (e.g. mastitis) etc. which were not recorded. There was also some unexplained variation at the level 1 i.e between weeks, and this might a result of the variation in the environment between the weeks or observer error in the outcome or explanatory variable (i.e. measurement error). The environment plays a key role in transmission dynamics of ID and FR because transmission of the infection is influenced by soil temperature and humidity (Beveridge, 1941). There was a clear
peak of ID in Group B in week 3, suggesting that there may have been some environmental effect. However, no information was collected on the environment.

There was no significant association between the number of feet affected with ID and locomotion score, which implies that it is probably the severity of the lesion (as depicted by maximum score) that had greatest influence on locomotion in the current study. However, the majority of FR lesions in this study were recorded on one foot, thus it was not possible to fully elucidate the relationship between number of feet affected with FR and locomotion in sheep. In addition, although 60% of the weight of sheep is borne by the front limbs (Grogono-Thomas and Johnston, 1994) a similar proportion of front and hind feet were affected with ID or FR in the current study suggesting that these lesions can occur in both front and hind feet despite the differences in weight bearing.

The locomotion scoring scale used in this study includes seven possible severities and is a reliable tool for researchers to measure locomotion in sheep with high between and within observer agreement (Chapter 4, Kaler et al., in press)). However, unlike the locomotion scoring scale the reliability of the lesion scoring scales in terms of observer agreement is unknown. One observer (JK) who used these scoring scales was trained for its use and this approach avoided between observer bias.

Different approaches have been used previously to provide a single score for a foot lesion, these include adding scores from all four feet to give a total foot score (TFS) (Egerton and Roberts. 1971), using an average foot score which is TFS/4 (Woolaston. 1993), a maximum foot score (Stewart et al., 1982, 1983) and a total
weighted foot score (Whittington and Nicholls, 1995). Because the lesions can exist in varying combinations of severity, a simple arithmetic total provides little information and can be misleading e.g. a sheep with all four feet affected with score 1 would have the same total score as a sheep with a severe lesion of score 4 on one foot. Because the choice and use of weighting scores can be arbitrary, a score was to reflect the most severe lesion on the foot was used in the current study. This was probably the most appropriate because so few sheep had more than one foot affected, particularly with FR.

5. Conclusions and Future Work

This longitudinal study provides evidence for the associations between ID, FR and locomotion in sheep and suggests that even mildly lame sheep have ID and FR. On this farm it also indicates that the majority of the altered locomotion in a sheep at a time point was attributable to the presence of ID or FR at the same time; there was no added effect on locomotion if these lesions were also present a week before or a week after that time, with the exception of the week before a sheep developed FR, when affected animals were more lame. Antibiotic injection and antibiotic spray led to a significant reduction in locomotion score one week after administration, indicating that it this was a successful treatment.

However, due to the limited duration of the current study it was not possible to study the effectiveness of treatments after one week and to fully elucidate the patterns of ID or FR over time; longer follow up with frequent recording is required to study these factors. In addition, for the current study, although the data on ID and FR were collected at foot level, it was aggregated to sheep level. The
data can be further analysed to explore the patterns of ID and FR in feet and to investigate whether progression of ID to FR depends on e.g. the severity of ID.

The study was conducted on one farm, but with two groups of sheep on different treatment regimes. Ideally, more farms would be included to test the generalisability of the results.

There is a need to relate the bacteriological information from sheep with ID and FR (such as the type of bacteria involved, and the strain and virulence characteristics of *D. nodosus*) with the gross pathology of lesions and locomotion.

Further work is also required to evaluate the association of other less common lesions not observed in this study (e.g. as contagious ovine digital dermatitis, shelly hoof, foot abscess, toe granuloma) and locomotion.
Chapter 7

General discussion and future directions

1. Introduction

The main aim of this thesis was to improve our understanding of the epidemiology of lameness in sheep. This was addressed by setting out the following objectives:

a) To test whether farmers and sheep specialists can correctly recognise and name six common foot lesions in sheep.

b) To investigate the management factors associated with interdigital dermatitis and footrot (two most common foot lesions) and compare the results to previous studies.

c) To develop a reliable locomotion scoring scale for sheep.

d) To test whether farmers and sheep specialist can identify lame sheep and investigate their decisions to catch individual lame sheep.

e) To investigate whether there is an association between interdigital dermatitis, footrot and locomotion in sheep.

These objectives were achieved successfully with some limitations. The main results and implications of the epidemiological studies that addressed these objectives are presented below with discussion of their limitations and some suggestions for further work.
2. Research findings and implications

One assumption made by previous studies is that farmers can recognise lame sheep (Chapter 5). The results suggest that the majority of farmers can recognise lame sheep (Chapter 5). This further suggests that the estimated lameness of 8% in 1994 as reported by Grogono - Thomas and Johnston (1997) and 10.4% in 2004 as reported in this thesis (Chapter 2), based on farmer opinions might be valid. However we still do not know whether farmers report the percent lame sheep that they see or the percent lame sheep that they treat in their flocks. The results from Chapter 5 do suggest that farmers’ (and interestingly vets and advisors) perceptions of these two are different, since a significantly lower percentage of farmers who considered mildly lame sheep ‘lame’, caught the first lame sheep in their flocks for inspection than sheep with higher locomotion (Chapter 5). In addition, these results came from video footage rather than observation of live sheep. Hopefully, as for the lesion recognition study (Chapter 2), farmers respond in a similar way with their own flock, but this requires validation.

Interdigital dermatitis and footrot were the most prevalent causes of lameness in most flocks (similar to the results reported by Grogono-Thomas and Johnston (1997 and Wassink et al. (2003a, 2004)) and the majority of farmers could recognise interdigital dermatitis and footrot (Chapter 2). Approximately 23% of farmers named all six lesions correctly in comparison to 80% of advisors, suggesting a huge difference in knowledge between sheep specialists and farmers. The most commonly used incorrect name by farmers was footrot, with farmers tending to name any lesion with damage to hoof horn as footrot. A comparison of the distribution of sheep lame by a lesion correctly named compared with the
same lesion incorrectly named as footrot suggested that farmers recognised lesions but did not name them correctly. Taking this into consideration, it is possible that there may be mismanagement of lame sheep and flocks. Thus, one key step to reduce lameness in sheep is to educate sheep farmer to correctly name the lesions, so that consistent lesion names are used by farmers and their advisors. This is important because most further education currently given to farmers in UK to control lameness in sheep is given by experts who may assume that farmers use the correct name for the lesions that they see in their own flock. In the light of the results of this study the first part of an English Beef and Lamb Executive (EBLEX) manual (Target lameness for better returns) has been developed to help farmers name foot lesions (See Appendix 10).

The results of Chapter 4 suggest that the locomotion scoring scale developed was reliable and that it may be a useful research tool to identify and monitor locomotion in individual sheep when used by trained observers. This scoring scale was successfully applied and used to monitor locomotion in sheep in an intervention study (Hawker, 2007) and the longitudinal study described in Chapter 6. The movie clips of sheep with varying locomotion scores were also used to investigate farmers and sheep specialists’ identification and decisions for catching lame sheep in a study (Chapter 5). Farmers and sheep specialists’ decision to catch lame sheep varied with the severity of the locomotion. The results from Chapter 5 suggested that farmers who either waited longer than 3 days or waited until they had a certain number of lame sheep before inspection of individual lame sheep had high estimates of flock lameness. The implication of this is that if we consider that the majority of flock lameness is due to interdigital dermatitis and footrot (Chapter 2) with even mildly lame sheep with these lesions (Chapter 6),
then there is an increased risk of spread of footrot leading to higher overall lameness on these farms where farmers do not catch the mildly lame sheep. The attendees at the Sheep Veterinary Society meeting responded in a similar manner, suggesting that whilst these advisors can recognise lesions they do not currently investigate lameness in mildly lame sheep. Hopefully, the results from the longitudinal study (in addition to the Hawker, 2007 study) will provide evidence for the value of this. Here this information needs to pass to sheep farmer advisors as well as farmers themselves.

The longitudinal study (Chapter 6) was conducted to test whether there was an association between interdigital dermatitis, footrot and locomotion score in sheep. This was the first study according to author’s knowledge, to explore this relationship. This study indicated a strong and significant association between interdigital dermatitis, footrot and locomotion in sheep. One of the interesting findings from this study was that sheep that developed footrot had a higher locomotion score before the appearance of the lesion. As discussed in Chapter 6, this might be due to the pain experienced by sheep due to the invasion and activity of *D. nodosus* or some other microbial activity in the hoof, leading to a change in the locomotion. The results from this study also highlighted the usefulness of prompt treatment with antibiotic injection and antibiotic spray of sheep with interdigital dermatitis or footrot, since these sheep had a significant reduction in their locomotion score one week after treatment. Improvement in locomotion in these sheep after treatment was due to partial or complete resolution of the lesions. This is in accordance with the results of Hawker (2007), where a use of antibiotic injection and antibiotic spray led to a recovery from lameness in approximately 3 days, whilst use of trimming and spraying took approximately 10 days.
There was no significant association between footbathing and locomotion in sheep in the longitudinal study one week after the application of the footbath (but there was a negative coefficient). However, there was a significant positive association between footbathing and lameness in sheep in the period cross-sectional study investigating factors associated with lameness, interdigital dermatitis and footrot (Chapter 3). This raises questions on the efficacy of footbathing as a treatment for interdigital dermatitis and footrot. Further studies are required to investigate this.

In the study investigating factors associated with interdigital dermatitis and footrot using responses of farmers who correctly named both lesions (Chapter 2) there were significant associations between routine trimming and an increased prevalence of footrot and a higher stocking density (> 8 ewes/ha) and an increased prevalence of interdigital dermatitis as reported by Wassink et al. (2003a, 2004). However, there were two results from this study that were in contrast with the results of Wassink et al. (2003a, 2004). The link between footbathing is discussed above. The second difference was that there was no significant association between individual treatments (e.g antibiotic injections, antibiotic sprays) and the farmer reported prevalence of footrot. Wassink et al. (2003a) reported a significant reduction in the prevalence of footrot among farmers who ‘always’ used antibiotic injection and topical spray to treat their lame sheep. There were dissimilarities in both the surveys with respect to the format of the questions asked to farmers about the use of individual treatments and the prevalence of footrot/lameness (Chapter 3). It seems likely, given the results from the more robust longitudinal study (Chapter 6) that the data collection was insensitive rather than that these treatments were not effective.
3. Limitations of the thesis and further work

Farmers in England were randomly selected to test farmer recognition of lesions and to estimate the prevalence of lesions and lameness, and there was no difference in respondents and non-respondents with respect to flock size and geographical location. However, there is still possibility of response bias. In addition, the geographical distribution and flock sizes of selected and participating farms for this survey were significantly different from those reported by DEFRA for the year 2004 due to some unknown reasons which may affect the generalisability of its results, although the DEFRA survey and EBLEX database have equal reason to carry correct data. The study investigating farmers’ and sheep specialists identification of and decisions for catching lame sheep used movie clips of sheep with varying severity was tested on a non random sample of farmers and sheep specialists. Although the use of movie clips allowed consistent presentation of sheep with a range of locomotion scores, the results need to be validated by asking a random sample of farmers and sheep specialists similar questions in the ‘field’ situation. Similarly, a random sample of sheep advisors would be ideal to validate the results, rather than those present at an SVS meeting.

There is now growing evidence for the flock management risk factors associated with interdigital dermatitis and footrot identified in the current study (e.g. routine foot trimming and footbathing) and previous studies (e.g. routine foot trimming by Wassink et al. (2003a)); however there is still no information on whether these are causal. Controlled clinical trials are required to test these potential risks since it may be lack of treatment, not the controls themselves that contribute to the associated high prevalence of lameness.
Due to the short duration of the longitudinal study it was not possible to observe the effect of treatments on locomotion for more than one week after treatment. In addition, the limited duration of the study and the interval between observation did not fully elucidate the association between interdigital dermatitis and footrot over time. Further studies are required to investigate these patterns. Data collected in the longitudinal study, with information on the interdigital dermatitis and footrot at a foot level can be further analysed and explored to tease out some of the patterns between these two lesions over time. Although the data on the clinical presentation of the lesions was available, there was no information on bacteriology of lesions (e.g. type of bacteria, strain and virulence characteristics). Swabs were collected and the association between the bacteriological information for the lesions, their gross pathology and locomotion in sheep will be investigated in further work (BBSRC, CEDFAS). The relationship between lesions other than interdigital dermatitis, footrot and locomotion could also be explored in future studies.

4. Conclusions

This thesis has contributed to the existing knowledge and improved our understanding of various aspects of the epidemiology of lameness in sheep. The work presented in this thesis suggests that although the majority of both farmers and sheep specialists in England can identify lame sheep, a lower percentage of farmers can recognise six common foot lesions in comparison with sheep specialists. A locomotion scoring scale developed in this study played a role in highlighting that both farmers and advisors can identify even mildly lame sheep but may choose only to treat those with more severe lameness. The locomotion scoring scale was a useful tool for researchers to monitor locomotion in sheep. A
future study testing farmer recognition of lame sheep in their own flock would test the findings that farmers can recognise lame sheep but vary in their choice of when to treat them. There was a significant association between the locomotion score of sheep and the presence of interdigital dermatitis and footrot lesions. This small study was useful and highlights the strength of longitudinal studies and the benefits of a future larger, longer longitudinal study of patterns and association of interdigital dermatitis and footrot over time linked with their clinical picture, microbiology and locomotion in sheep.


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### SECTION 1: Your flock in 2004

1. What is the **minimum** height above sea level that you keep your flock? __________ feet/metres
   
   (please delete one)

2. What is the **maximum** height above sea level that you keep your flock? __________ feet/metres
   
   (please delete one)

3. How many **acres/hectares** do you graze your sheep on? ________________ acres/hectares
   
   (please delete one)

4. How many of the following sheep did you have in 2004?
   - [ ] Average number of ewes one year or older __________________________
   - [ ] Average number of ewes less than one year old ______________________
   - [ ] Number of rams one year or older ______________________
   - [ ] Number of rams less than one year old ______________________________
   - [ ] Number of lambs sold ____________________________________________
   - [ ] Number of store lambs (still on farm at the end of Dec 2004) ______________

5. What is the purpose of your ewe’s offspring? *(Please tick all that apply)*
   - [ ] Pedigree flock
   - [ ] Replacement ewes
   - [ ] Meat lambs
   - [ ] Terminal sires
   - [ ] Store lambs
   - [ ] Other ___________________________ *(please specify)*

6. Which breeds of ewe did you have on your farm in 2004? *(Please tick all that apply)*
   - [ ] Texel
   - [ ] Suffolk
   - [ ] Charollais
   - [ ] Others ___________________________ *(please specify)*

7. Which breeds of ram did you have on your farm in 2004? *(Please tick all that apply)*
   - [ ] Texel
   - [ ] Suffolk
   - [ ] Charollais
   - [ ] Others ___________________________ *(please specify)*
Did you house your ewes in 2004?  □ Yes  □ No (please go to Question 1.10)

If Yes, Please tick the months in which your ewes were housed in 2004

☐ Jan  ☐ Feb  ☐ Mar  ☐ Apr  ☐ May  ☐ Jun  ☐ Jul  ☐ Aug  ☐ Sep  ☐ Oct  ☐ Nov  ☐ Dec

Please, tick the months in which your ewes lambed in 2004

☐ Jan  ☐ Feb  ☐ Mar  ☐ Apr  ☐ May  ☐ Jun  ☐ Jul  ☐ Aug  ☐ Sep  ☐ Oct  ☐ Nov  ☐ Dec

SECTION 2: Lameness in your flock between January and December 2004

Did you have any lame sheep in 2004? (Please tick one)

☐ Yes  ☐ No  ☐ Don’t know (If No or Don’t know go to Section 3)

Approximately what percentage of your sheep were lame in 2004? __________%

Please write the approximate percentage of sheep that were lame in your flock, in each month of 2004, in the table below. (Put 0 if there were no lame sheep)

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
### SECTION 3: Types of lameness

In the table below we describe the common lesions (abnormalities) seen on feet and provide a photograph. For each condition please tick the box to tell us what you call this lesion and estimate what percentage of your lame sheep were lame because of this problem last year.

**Example:** Scald 80% of lame sheep had this lesion.

<table>
<thead>
<tr>
<th>What you might see when you look at the foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
<th>Did you see this lesion in your flock in 2004?</th>
<th>What percentage of lame sheep had this lesion? %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red, wet interdigital space</td>
<td><img src="image1" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image2" alt="Percentage" /></td>
</tr>
<tr>
<td>Foul smell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May be grey pasty scum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of hair in interdigital space</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some separation of horn from underlying live foot</td>
<td><img src="image3" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image4" alt="Percentage" /></td>
</tr>
<tr>
<td>Foul smelling blackish slimy dead tissue</td>
<td><img src="image5" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image6" alt="Percentage" /></td>
</tr>
<tr>
<td>Abnormal at coronary band (hair line)</td>
<td><img src="image7" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image8" alt="Percentage" /></td>
</tr>
<tr>
<td>Loss of hair above coronary band</td>
<td><img src="image9" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image10" alt="Percentage" /></td>
</tr>
<tr>
<td>No interdigital space lesion</td>
<td><img src="image11" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image12" alt="Percentage" /></td>
</tr>
<tr>
<td>There may be complete detachment of hoof</td>
<td><img src="image13" alt="Photograph" /></td>
<td>□ Foot rot □ Scald □ Shelly hoof □ Foot abscess □ CODD* □ Toe granuloma □ Other</td>
<td>□ No □ Don't know □ Yes</td>
<td><img src="image14" alt="Percentage" /></td>
</tr>
</tbody>
</table>

---

D- Contagious ovine digital dermatitis
SECTION 3: Types of lameness continued...

Did you see any of the following conditions in your sheep in 2004? (If Yes, please give the percent of total lameness due to that cause) e.g. □ Scald 80% of lame sheep had this lesion

<table>
<thead>
<tr>
<th>What you might see when you look at the foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
<th>Did you see this lesion in your flock in 2004?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Some separation of horn from the wall, may or may not see pus</td>
<td><img src="image" alt="Foot rot" /></td>
<td>□ Foot rot</td>
<td>□ No</td>
</tr>
<tr>
<td>• A pocket impacted with soil</td>
<td><img src="image" alt="Scald" /></td>
<td>□ Scald</td>
<td>□ Don’t know</td>
</tr>
<tr>
<td>• Half-moon appearance</td>
<td><img src="image" alt="Shelly hoof" /></td>
<td>□ Shelly hoof</td>
<td>□ Yes</td>
</tr>
<tr>
<td>• Pus comes from the foot</td>
<td><img src="image" alt="Foot abscess" /></td>
<td>□ Foot abscess</td>
<td>□ No</td>
</tr>
<tr>
<td>• Sheep is very lame</td>
<td><img src="image" alt="CODD*" /></td>
<td>□ CODD*</td>
<td>□ Don’t know</td>
</tr>
<tr>
<td>• Hoof tissue normal</td>
<td><img src="image" alt="Toe granuloma" /></td>
<td>□ Toe granuloma</td>
<td>□ Yes</td>
</tr>
</tbody>
</table>
| • No odour                                  | ![Other](image) | □ Other | □ |%

What percentage of lame sheep had this lesion? _____%

DD- Contagious ovine digital dermatitis

149
2. The following can cause lameness, for each condition please indicate whether you saw this in your flock in 2004 and what percent of lame sheep were lame because of this problem.

- **g. □ soil balling** Yes (2%) of lame sheep had this lesion

  a) Soil balling (you see soil in the interdigital space, making the sheep lame)
     - □ Yes (________ % of lame sheep) □ No □ Don't know

  b) Acute laminitis (all four feet are hot to touch)
     - □ Yes (________ % of lame sheep) □ No □ Don't know

  c) Chronic laminitis (horizontal grooves in the wall of the hooves)
     - □ Yes (________ % of lame sheep) □ No □ Don't know

  d) Post dipping lameness (sheep lame few days after dipping, fever and hot joints)
     - □ Yes (________ % of lame sheep) □ No □ Don't know

I Have you explained 100% of lameness in your flock in 2004?
- □ Yes (If Yes, go to Question 4.1 Section 4) □ No

lo. Please name and describe other condition(s) with the percent of your total flock lameness caused by in 2004?

<table>
<thead>
<tr>
<th>LESION 1</th>
<th>LESION 2</th>
<th>LESION 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description of the on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lameness flock due to</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SECTION 4: Your management of lameness in 2004

1.1 Did you routinely trim the feet of your flock during 2004? (Please tick one)

☐ Yes  ☐ No (If No, go to Question 4.3)

1.2 If Yes, how often did you routinely trim the feet of your flock in 2004? (Please tick one)

☐ Once per year  ☐ Twice or more per year

3 Did you footbath your flock in 2004? (Please tick one)

☐ Yes  ☐ No (If No, go to Question 4.6)

4 If Yes, which of your sheep did you footbath? (Please tick all that apply)

☐ ewes  ☐ rams  ☐ lambs  ☐ lame sheep  ☐ other_______________ (please specify)

5 How often did you footbath your sheep in 2004? (Please tick one)

☐ Once every fortnight  ☐ Once every 6 months

☐ Once every month  ☐ Once every year

☐ Once every 3 months  ☐ Other__________________________ (please specify)

Did you vaccinate any of your sheep against foot rot in 2004? (Please tick one)

☐ Yes  ☐ No (If No, go to Question 4.8)

If Yes, which sheep did you vaccinate in 2004? (Please tick all that apply)

☐ ewes  ☐ rams  ☐ lambs  ☐ lame sheep  ☐ other_______________ (please specify)

How did you treat your individual lame sheep in 2004? (Please tick all that apply and indicate percent treated)

☐ trim feet______%  ☐ antibiotic injection______%

☐ isolate______%  ☐ antibiotic spray______%

☐ Other__________________________ (______%) (please specify)
9 Did you separate lame sheep in 2004?
   a) At housing □ all □ some □ none (Please tick one)
   b) At pasture □ all □ some □ none (Please tick one)

10 Did you change any of your management of lameness between 2003 and 2004?
   □ Yes □ No
   Yes, please write down what you changed

<table>
<thead>
<tr>
<th>2003 I......</th>
<th>In 2004 I....</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g. vaccinated ewes</td>
<td>e.g. did not vaccinate ewes</td>
</tr>
</tbody>
</table>

Thank you very much for taking time to complete this questionnaire!

Would you like to receive a copy of the results of this questionnaire? □ Yes □ No
Yes, please check your contact details below.

In order to look into this widespread of lameness in sheep, we will be carrying out further research into various common causes of lameness. Would you like to be a part of this research TEAM?
   □ Yes □ No
   (“TEAM”; TOGETHER EVERYONE ACHIEVES MORE)

Yes, please check your contact details below

<table>
<thead>
<tr>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>address</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>phone</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

Please add your email address and telephone number.
APPENDIX 2: Feedback form for pilot questionnaire

FEEDBACK FORM: WE WELCOME YOUR INPUT

We are very interested in knowing what you think of the questionnaire. Please take few minutes to fill in this feedback form.

1. Do you think the questions were clear and easy to understand? (please tick one)
   Yes ☐       No ☐

   If No, Please indicate question number(s) and give your comments in the box below

2. Do you think the layout was easy to follow? (please tick one)
   Yes ☐       No ☐

   If No, Please give your comments in the box below

3. Do you think the length of the questionnaire was right? (please tick one)
   Yes ☐       No ☐

   If No, Please give your comments in the box below

4. Do you think the instructions were useful? (please tick one)
   Yes ☐       No ☐

   If No, Please indicate the question number(s) and give your comments in the box below
Please use the box below to make additional comments and let us know what specific changes we should make to best improve our questionnaire.
Appendix 3: Cover letter for the postal questionnaire

A survey of lameness in sheep in 2004

Dear Farmer,

Lameness in sheep is rated by sheep farmers as the second (after internal parasites) largest cause of economic loss. Amazingly, we do not know which types of lameness are seen in sheep flocks or how common these conditions are. This survey addresses these questions and will provide valuable data to direct further research. Our ultimate aim is to provide results that will assist you, the farmer, to lower levels of lameness in your flock.

You are one of 3000 randomly selected sheep farmers in England who are being asked to complete the questionnaire attached. In the questionnaire we ask you to estimate what proportion of your flock were lame, to name the conditions that caused lameness in your flock in 2004 (January to December inclusive) and to estimate what percentage of lame sheep had each condition. As an example, you may estimate that approximately 80% of your lame sheep had scald in 2004. We also ask you a few questions about your general management of lameness and a few details about your flock.

There are no correct answers. We just ask you to answer as honestly and accurately as you can.

We will use the data to identify the levels of different causes of lameness. We will summarise this by type of flock, geographical location and management. No individual flock data will be published. The questionnaire data from each flock is confidential. We will only publish aggregated results.

This questionnaire is being sent out in March 2005. We hope that you will reply promptly, you will receive up to two reminders if you do not reply within 3 weeks. We will send you a report from this study in December 2005. It will contain a summary of all the responses plus the individual information that you provided. The success of this survey depends on your reply, so even if you do not consider lameness a problem in your flock, please complete the questionnaire attached. If you didn’t have any sheep on your farm in 2004, kindly return the blank questionnaire.

If you have any difficulties or questions, please contact us by telephone or email.

We thank you for your help with this survey.

Yours sincerely

Jasmeet Kaler B.V.Sc. & A.H. MSc
PhD student funded by EBLEX / MLC
Tel: 024 765 75860
email j.kaler@warwick.ac.uk

Laura Green PhD. MRCVS
Reader in Epidemiology
Tel. 024 765 23797
email laura.green@warwick.ac.uk
Appendix 4: Reminder and Acknowledgement postcard sent to farmers in postal survey

SURVEY OF LAMENESS IN SHEEP IN 2004

- We understand that you are busy, but we would really appreciate if you could take some time in your hectic schedule to fill in our questionnaire on Lameness in Sheep.
- If you have already replied please disregard this reminder.
- If you need another copy of the questionnaire, please ask!

RE M I N D E R !

From:
Jasmeet Kaler Dr Laura Green
Ecology and Epidemiology Group
Department of Biological Sciences
University of Warwick
E-mail: j.kaler@warwick.ac.uk, laura.green@warwick.ac.uk
Tel: 024 765 75860 024 765 23797

THANK YOU FOR PARTICIPATING IN THE SHEEP LAMENESS SURVEY 2004.

WE WILL SEND YOU A SUMMARY OF RESULTS IN THE AUTUMN

TH A N K YO U !

Jasmeet Kaler Dr Laura Green
Ecology and Epidemiology Group
Department of Biological Sciences
University of Warwick
E-mail: j.kaler@warwick.ac.uk, laura.green@warwick.ac.uk
Tel: 024 765 75860 024 765 23797
Appendix 5: Second reminder for the postal questionnaire to farmers

Reminder: A survey of lameness in sheep in 2004

Dear Farmer,

We understand that you are busy, but we would really appreciate if you could take some time in your hectic schedule to fill in our questionnaire on Lameness in Sheep. If you have already replied please disregard this reminder.

Lameness in sheep is rated by sheep farmers as the second (after internal parasites) largest cause of economic loss. Amazingly, we do not know which types of lameness are seen in sheep flocks or how common these conditions are. This survey addresses these questions and will provide valuable data to direct further research. Our ultimate aim is to provide results that will assist you, the farmer, to lower levels of lameness in your flock.

We will use the data to identify the levels of different causes of lameness. We will summarise this by type of flock, geographical location and management. No individual flock data will be published. The questionnaire data from each flock is confidential. We will only publish aggregated results.

We will send you a report from this study in December 2005. It will contain a summary of all the responses plus the individual information that you provided. The success of this survey depends on your reply, so even if you do not consider lameness a problem in your flock, please complete the questionnaire attached. If you didn’t have any sheep on your farm in 2004, kindly return the blank questionnaire.

If you have any difficulties or questions, please contact us by telephone or email. We thank you for your help with this survey.

Yours sincerely

Jasmeet Kaler B.V.Sc. & A.H. MSc
PhD student funded by EBLEX / MLC
Tel: 024 765 75860
email j.kaler@warwick.ac.uk

Laura Green PhD, MRCVS
Reader in Epidemiology
Tel. 024 765 23797
email laura.green@warwick.ac.uk
# A SURVEY OF LAMENESS IN SHEEP

## Types of lameness

In the table below we describe the common lesions (abnormalities) seen on feet and provide a photograph. For each condition please tick the box to tell us what you call this lesion.

<table>
<thead>
<tr>
<th>What you might see when you look at the foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
</tr>
</thead>
</table>
| - Red, wet interdigital space               | ![Photograph](image1) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |
| - Foul smell                                 | ![Photograph](image2) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |
| - May be grey pasty scum                     | ![Photograph](image3) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |
| - Loss of hair in interdigital space         | ![Photograph](image4) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |
| - Some separation of horn from underlying live foot  
- Foul smelling blackish slimy dead tissue | ![Photograph](image5) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |
| - Abnormal at coronary band (hair line)     
- Loss of hair above coronary band  
- No interdigital space lesion  
- There may be complete detachment of hoof | ![Photograph](image6) | □ Foot rot  
□ Scald  
□ Shelly hoof  
□ Foot abscess  
□ CODD*  
□ Toe granuloma  
□ Other_________ |

DD- Contagious ovine digital dermatitis
### Types of lameness continued...

<table>
<thead>
<tr>
<th>What you might see when you look at the foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Some separation of horn from the wall, may or may not see pus</td>
<td><img src="image1" alt="Photograph" /></td>
<td>□ Foot rot</td>
</tr>
<tr>
<td>• A pocket impacted with soil</td>
<td><img src="image2" alt="Photograph" /></td>
<td>□ Scald</td>
</tr>
<tr>
<td>• Half-moon appearance</td>
<td><img src="image3" alt="Photograph" /></td>
<td>□ Shelly hoof</td>
</tr>
<tr>
<td><img src="image4" alt="Photograph" /></td>
<td><img src="image5" alt="Photograph" /></td>
<td>□ Foot abscess</td>
</tr>
<tr>
<td><img src="image6" alt="Photograph" /></td>
<td><img src="image7" alt="Photograph" /></td>
<td>□ CODD*</td>
</tr>
<tr>
<td><img src="image8" alt="Photograph" /></td>
<td><img src="image9" alt="Photograph" /></td>
<td>□ Toe granuloma</td>
</tr>
<tr>
<td><img src="image10" alt="Photograph" /></td>
<td>□ Other__________</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pus comes from the foot</th>
<th>Sheep is very lame</th>
<th>Hoof tissue normal</th>
<th>No odour</th>
<th>Swelling of skin above foot</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Foot rot</td>
<td>□ Scald</td>
<td>□ Shelly hoof</td>
<td>□ Foot abscess</td>
<td>□ CODD*</td>
<td>□ Toe granuloma</td>
<td>□ Other__________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strawberry-like growth at the toe</th>
<th>Bleeds when handled</th>
<th>Photograph</th>
<th>What do you call this lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Foot rot</td>
<td>□ Scald</td>
<td>□ Shelly hoof</td>
<td>□ Foot abscess</td>
</tr>
<tr>
<td>□ CODD*</td>
<td>□ Toe granuloma</td>
<td>□ Other__________</td>
<td></td>
</tr>
</tbody>
</table>

**ODD- Contagious ovine digital dermatitis**

Which description suits you best?

/et □ Other______________________________ (please specify)

Do you personally have a care of flock of sheep?

/es □ No □ Don’t know

Thank you very much for participation in this survey
Appendix 7: Form used for testing observer reliability of locomotion scoring scale

Observer ID: _______  Date: 27/09/06

<table>
<thead>
<tr>
<th>Clip No.</th>
<th>Locomotion Score (please circle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>2</td>
<td>0 1 2 3 4 5 6</td>
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<tr>
<td>3</td>
<td>0 1 2 3 4 5 6</td>
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<td>0 1 2 3 4 5 6</td>
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</tr>
<tr>
<td>30</td>
<td>0 1 2 3 4 5 6</td>
</tr>
</tbody>
</table>
Appendix 8: Questionnaire - farmer identification and decisions to catch lame sheep using movie clips

Please complete the form below

1. Are you involved in day to day management of sheep?
   □ Yes  □ No

2. How many breeding ewes do you have? ________________________________

3. Approximately how many groups of ewes do you run on the farm?
   __________

4. Approximately what percent of your ewes were lame in 2006?
   ____________________%

5. When do you treat lame sheep? (please tick all that apply)
   □ First day lame  □ within 3 days  □ within a week
   □ at routine flock gatherings  □ never  □ other (please state) __________

There are 8 video clips of different sheep which will be played in sequence. Please watch the clips carefully as they will be only played once. Please answer the questions (next page) for each clip one by one.
Clip 1

1. Do you think this sheep is lame? *(please tick one box)*
   - □ Yes   □ No   □ Don’t know
   *If Yes or Don’t know, please go to Question 2, if No please wait for next clip*

2. Would you catch this sheep with intention to treat? *(please tick)*
   - □ Yes, always, even if this is the first lame sheep in the group
   - □ Yes, when at least
     - □ 2 - 5 of the sheep in the group are lame
     - □ 6 - 10 of the sheep in the group are lame
     - □ 11 - 20 of the sheep in the group are lame
     - □ more than 20 of the sheep in the group are lame
   - □ Don’t know

---

Clip 2

1. Do you think this sheep is lame? *(please tick one box)*
   - □ Yes   □ No   □ Don’t know
   *If Yes or Don’t know, please go to Question 2, if No please wait for next clip*

2. Would you catch this sheep with intention to treat? *(please tick)*
   - □ Yes, always, even if this is the first lame sheep in the group
   - □ Yes, when at least
     - □ 2 - 5 of the sheep in the group are lame
     - □ 6 - 10 of the sheep in the group are lame
     - □ 11 - 20 of the sheep in the group are lame
     - □ more than 20 of the sheep in the group are lame
   - □ Don’t know

---

Clip 3

1. Do you think this sheep is lame? *(please tick one box)*
   - □ Yes   □ No   □ Don’t know
   *If Yes or Don’t know, please go to Question 2, if No please wait for next clip*

2. Would you catch this sheep with intention to treat? *(please tick)*
   - □ Yes, always, even if this is the first lame sheep in the group
   - □ Yes, when at least
     - □ 2 - 5 of the sheep in the group are lame
     - □ 6 - 10 of the sheep in the group are lame
     - □ 11 - 20 of the sheep in the group are lame
     - □ more than 20 of the sheep in the group are lame
Don’t know

Clip 4

1. Do you think this sheep is lame? (please tick one box)
   □ Yes  □ No  □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick)
   □ Yes, always, even if this is the first lame sheep in the group
   □ Yes, when at least
     □ 2 - 5 of the sheep in the group are lame
     □ 6 - 10 of the sheep in the group are lame
     □ 11 - 20 of the sheep in the group are lame
     □ more than 20 of the sheep in the group are lame
   □ Don’t know

Clip 5

1. Do you think this sheep is lame? (please tick one box)
   □ Yes  □ No  □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick)
   □ Yes, always, even if this is the first lame sheep in the group
   □ Yes, when at least
     □ 2 - 5 of the sheep in the group are lame
     □ 6 - 10 of the sheep in the group are lame
     □ 11 - 20 of the sheep in the group are lame
     □ more than 20 of the sheep in the group are lame
   □ Don’t know

Clip 6

1. Do you think this sheep is lame? (please tick one box)
   □ Yes  □ No  □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick)
   □ Yes, always, even if this is the first lame sheep in the group
   □ Yes, when at least
     □ 2 - 5 of the sheep in the group are lame
     □ 6 - 10 of the sheep in the group are lame
Q II - 20 of the sheep in the group are lame
Q more than 20 of the sheep in the group are lame
Q Don’t know

Clip 7

1. Do you think this sheep is lame? (please tick one box)
   □ Yes  □ No  □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick)
   □ Yes, always, even if this is the first lame sheep in the group
   □ Yes, when at least
      □ 2 - 5 of the sheep in the group are lame
      □ 6 - 10 of the sheep in the group are lame
      □ 11 - 20 of the sheep in the group are lame
      □ more than 20 of the sheep in the group are lame
   □ Don’t know

Clip 8

1. Do you think this sheep is lame? (please tick one box)
   □ Yes  □ No  □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick)
   □ Yes, always, even if this is the first lame sheep in the group
   □ Yes, when at least
      □ 2 - 5 of the sheep in the group are lame
      □ 6 - 10 of the sheep in the group are lame
      □ 11 - 20 of the sheep in the group are lame
      □ more than 20 of the sheep in the group are lame
   □ Don’t know

Thank you very much!
PAGINATION AS IN ORIGINAL
Appendix 9: Questionnaire - sheep specialists’ identification and decisions to catch lame sheep using movie clips

Please complete the form below

1. What is your job?
   □ Practicing Vet □ Farmer □ Other _________ (please specify)

2. Do you personally have care of a flock of sheep?
   □ Yes □ No

There are 8 video clips of different sheep which will be played in sequence. Please watch the clips carefully as they will be only played once. Please answer the questions for each clip one by one.

Clip 1

1. Do you think this sheep is lame? (please tick one box)
   □ Yes □ No □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick one box only)
   □ Yes, always, even if this is the first lame sheep in the group
   Yes, when at least
   □ 2 - 5 of the sheep in the group are lame
   □ 6 - 10 of the sheep in the group are lame
   □ 11 - 20 of the sheep in the group are lame
   □ more than 20 of the sheep in the group are lame
   □ Don’t know

Clip 2

1. Do you think this sheep is lame? (please tick one box)
   □ Yes □ No □ Don’t know
   If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick one box only)
   □ Yes, always, even if this is the first lame sheep in the group
   Yes, when at least
Clip 3

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know

*If Yes or Don’t know, please go to Question 2, if No please wait for next clip*

2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group
☐ Yes, when at least
  ☐ 2 - 5 of the sheep in the group are lame
  ☐ 6 - 10 of the sheep in the group are lame
  ☐ 11 - 20 of the sheep in the group are lame
  ☐ more than 20 of the sheep in the group are lame
☐ Don’t know

Clip 4

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know

*If Yes or Don’t know, please go to Question 2, if No please wait for next clip*

2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group
☐ Yes, when at least
  ☐ 2 - 5 of the sheep in the group are lame
  ☐ 6 - 10 of the sheep in the group are lame
  ☐ 11 - 20 of the sheep in the group are lame
  ☐ more than 20 of the sheep in the group are lame
☐ Don’t know

Clip 5

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know

*If Yes or Don’t know, please go to Question 2, if No please wait for next clip*
2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group  
  Yes, when at least  
  ☐ 2 - 5 of the sheep in the group are lame  
  ☐ 6 - 10 of the sheep in the group are lame  
  ☐ 11 - 20 of the sheep in the group are lame  
  ☐ more than 20 of the sheep in the group are lame  
☐ Don't know

Clip 6

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know

If Yes or Don't know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group  
  Yes, when at least  
  ☐ 2 - 5 of the sheep in the group are lame  
  ☐ 6 - 10 of the sheep in the group are lame  
  ☐ 11 - 20 of the sheep in the group are lame  
  ☐ more than 20 of the sheep in the group are lame  
☐ Don’t know

Clip 7

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know

If Yes or Don't know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group  
  Yes, when at least  
  ☐ 2 - 5 of the sheep in the group are lame  
  ☐ 6 - 10 of the sheep in the group are lame  
  ☐ 11 - 20 of the sheep in the group are lame  
  ☐ more than 20 of the sheep in the group are lame  
☐ Don’t know
Clip 8

1. Do you think this sheep is lame? (please tick one box)

☐ Yes  ☐ No  ☐ Don’t know
If Yes or Don’t know, please go to Question 2, if No please wait for next clip

2. Would you catch this sheep with intention to treat? (please tick one box only)

☐ Yes, always, even if this is the first lame sheep in the group
   Yes, when at least
   ☐ 2 - 5 of the sheep in the group are lame
   ☐ 6 - 10 of the sheep in the group are lame
   ☐ 11 - 20 of the sheep in the group are lame
   ☐ more than 20 of the sheep in the group are lame
☐ Don’t know

Thank you very much