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1 Direct and indirect contacts between cattle farms in north-west England

2
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78

9 **Abstract**10
11 Little is known regarding the types and frequencies of contact that exist between farms and
12 which of these may act as pathogen transmission routes; however it is likely that farms
13 demonstrate considerable heterogeneity in such contacts. In this cross-sectional study, we
14 explored the direct and indirect contact types and frequencies that exist between cattle farms
15 within a region, focusing on potential routes of pathogen transmission. The owners/managers of
16 56 farms located in a 10km by 10km study area in north-west England were administered an
17 interview-based questionnaire between June and September 2005. Information was obtained
18 relating to contact types and frequencies, including those involving animal movements,
19 equipment sharing between farms and any contractors or companies visiting the farms.20 The data was explored using hierarchical cluster analysis and network analysis. There was
21 considerable variation between farms arising from different contact types. Some networks
22 exhibited great connectivity, incorporating approximately 90% of the farms interviewed in a
23 single component, whilst other networks were more fragmented, with multiple small
24 components (sets of connected farms not linked with other farms). A range of factors
25 influencing contact between farms were identified. For example, contiguous farms were more

26 likely to be linked via other contacts, such as sharing of equipment, direct farm to farm animal
27 movements and use of the same livestock dealers ($p < 0.001$, $p = 0.02$ and $p = 0.1$, respectively).

28 The frequency of contacts was also investigated; it is likely that the amount of contact a farm
29 receives from a company or contractor and whether or not biosecurity is performed after contact
30 would impact on disease transmission potential. We found considerable heterogeneity in
31 contact frequency and that many company and contractor personnel undertook little biosecurity.

32 These findings lead to greater understanding of inter-farm contact and may aid development
33 of appropriate biosecurity practices and control procedures, and inform mathematical modelling
34 of infectious diseases.

35

36 Keywords: Contact; Network; Biosecurity; Cattle; Cluster analysis

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43

44 **1. Introduction**

45

46 Infectious disease transmission at the individual, herd and farm level relies on some form of
47 contact, either direct or indirect. Veterinary texts published in the early 1900's recognised a
48 cause and effect relationship between animal contact and disease (Anderson, 1998) and as early
49 as the mid-eighteenth century, livestock producers recognised animal movements as important

50 routes for the spread of disease (Woolhouse and Donaldson, 2001). Many diseases, such as
51 bovine tuberculosis and foot and mouth disease (FMD) are likely to be spread by these
52 movements (Gibbens et al., 2001; Gilbert et al., 2005; Woolhouse et al., 2005); this was clearly
53 demonstrated during the early phase of the 2001 FMD outbreak in the UK (Ortiz-Pelaez et al.,
54 2006). Other contacts may also result in transmission of infectious agents, including sharing of
55 equipment, movement of people and vehicles and contact over/through fences with
56 neighbouring stock; it has also been reported that wildlife and even wind can play a role in
57 transmission between contiguous or proximate premises (Mikkelsen et al., 2003; Woodroffe et
58 al., 2006).

59 Often there is little knowledge of what contacts (direct and indirect) exist between farms. As
60 was highlighted by the FMD outbreak in the UK in 2001, local risk kernels are often used to
61 model local transmission, as details of contacts between farms are not well known (Woolhouse
62 and Donaldson, 2001; Webb, 2005). Studies conducted in The Netherlands, California and New
63 Zealand have identified and quantified these contacts over time, particularly with regard to the
64 potential spread of FMD. The number of contacts varies greatly when considering
65 characteristics such as type of enterprise, size of farm and number of animals on farm. It was
66 reported in California that there were approximately 11 direct animal contacts and 404 indirect
67 contacts per farm over a two week period (Bates et al., 2001), which is substantially more than
68 the 92 direct and indirect contacts per farm seen over the same length of time in the Netherlands
69 (Nielen et al., 1996). In comparison, 50 contacts of people, animals and materials were reported
70 over a 2 week period during a study in New Zealand (Sanson et al., 1993).

71 Such variability illustrates the structural complexity and heterogeneity of the contacts that
72 exist between farms, some of which can be represented schematically (Fig. 1). This could
73 potentially be described as a 'network' of contacts between farms which requires further
74 exploration.

75 Network analysis facilitates investigation of interactions between units of interest ('nodes',
76 e.g. animals or farms) at the population and the individual level and enables identification of key
77 nodes in terms of the connectivity individuals have within a population (Corner et al., 2003). By
78 focusing on the most likely contact types and the most significant individuals within these
79 networks, it is possible to consider how disease may be transmitted through a population
80 (Christley et al., 2005). It has been suggested that farm-level heterogeneity is present for all
81 animal movement patterns and to presume homogeneity is likely to be unrepresentative of actual
82 movement patterns (Bigras-Poulin et al., 2006). Furthermore, models that assume random
83 mixing can overestimate the size of an outbreak and underestimate the initial rate of
84 transmission (Christley et al., 2005). Hence, network analysis can play a role in developing
85 understanding of the topology of potential routes of disease transmission, and consequently may
86 aid the design of effective surveillance and control programs (Woolhouse et al., 2005).

87 The aim of this study was to investigate the characteristics of the direct and indirect contact
88 structure of cattle farms in a region and to explore the nature of such contacts using network
89 analysis techniques.

90

91

92 **2. Materials and methods**

93

94 *2.1 Study population*

95

96 A 10km x 10 km area of north-west England was selected and the owners or managers of all
97 known cattle farms were contacted by mail and invited to participate in this cross-sectional
98 observational study. This area had been used previously in other studies by the University of
99 Liverpool with good farmer compliance. Follow up phone calls were made to all farms to

100 ascertain willingness to participate. Of those farms whose phone numbers were not available,
101 visits were assigned to determine farm details and whether participation was possible. Visits to
102 all willing farms were conducted and questionnaires completed.

103

104 *2.2 Questionnaire*

105

106 The questionnaire consisted of 191 questions which concentrated on determining the direct
107 and indirect contacts between farms (a copy of the questionnaire is available on request). This
108 included questions relating to animal movements on and off the farm and their destinations and
109 departure points, and questions relating to the sharing of equipment between farms, any
110 personnel coming on and off the farm and the types and frequencies of companies/contractors
111 coming onto the farm. Social contacts between farmers were also investigated.

112 Some questions were asked in regards to current biosecurity practices relating to shared
113 equipment and companies and contractors visiting the farm. Attitudes of the interviewees
114 towards 19 biosecurity practices were also explored; these practices were selected after review
115 of current practices, sourcing information from peer-reviewed papers, current advice from
116 various government bodies and grey literature.

117 The interview-based questionnaires were administered to owners/farm managers during July
118 – September 2005. All interviews were conducted by the first author. A pilot study involving six
119 cattle farms outside the study area was completed prior to the main study.

120

121 *2.3 On-farm observations*

122

123 During visits, maps of each farm were used to gather information regarding contiguous
124 neighbours and farm area, including additional premises used for stock. Boundaries and fence

125 types bordering the farm were noted; boundary fields that were frequented by animals and had
126 fences which allowed potential contact (e.g. wire fences, gapped hedges) with neighbouring
127 animals (those owned by other farmers) were recorded. A single fence that was reported to not
128 permit nose-nose contact (e.g. double-fences, thick hedges) was selected randomly from those
129 on the main farm and was examined to ascertain the potential for nose-nose contact with
130 neighbouring stock.

131

132 *2.4 Data management and analysis*

133

134 The questionnaire was formatted using Verity TeleForm Version 9.1 (Verity Inc) and data
135 managed using Microsoft Office Access 2003 (Microsoft Corporation). Agglomerative
136 hierarchical cluster analysis was used to classify or group farms (or farmers) according to animal
137 movements (direct to slaughterhouse, farm-farm or through markets and dealers), use of
138 companies and contractors and attitudes to the 19 biosecurity practices. Ward's clustering
139 method was used; this results in clusters with the fewest within-cluster sums of squares (based
140 on squared Euclidean distance) (Sharma, 1996). These groups were compared with regard to the
141 variables used in the cluster analysis itself and with other farm-level variables using chi-squared
142 tests (for categorical data) and the Kruskal-Wallis test (for continuous data). These statistical
143 analyses were performed using SPSS 12.0.1 for Windows (SPSS Inc.).

144 To examine whether the probability of one contact type was associated with the probability of
145 another, we used the Quadratic Assignment Procedure (QAP) correlation function in Ucinet
146 v6.135 (www.analytictech.com/). This method calculates the similarity between two network
147 matrices using the Jaccard coefficient (Hanneman and Riddle, 2005). One of the matrices is then
148 randomly permuted using the QAP and the Jaccard coefficient recalculated. We performed this
149 permutation 10,000 times in order to compute the proportion of times that the random measure

150 is larger than or equal to the observed measure. All network structures were formed using
151 Ucinet v6.135 and NetDraw v 2.41 (NetDraw; www.analytictech.com/).

152

153

154 **3. Results**

155

156 *3.1 Response rate*

157

158 Questionnaires were completed on 56 out of 81 farms, giving a 68.3% response rate. Of the
159 farms not participating, seven had ceased trading or did not have cattle and three were shortly to
160 cease trading. One farmer could not be contacted despite several visits and phone calls; 13
161 declined to participate and one farmer could not make an appointment in the allotted project
162 time. Therefore, considering only those farms in the area which owned cattle and would be in
163 the foreseeable future, a 78.8% compliance rate was achieved. The three farms that were shortly
164 to cease trading were excluded as we believed that their general farm contacts might not be
165 representative of a typical farm in this area. Excluding those farms that did not have cattle/had
166 ceased trading, 15 farms remained that were not interviewed. Of these farms, information solely
167 regarding enterprise was collected on ten by telephone or via external data sources; six dairy
168 farms, two mixed cattle farms, one beef farm and one heifer rearing farm declined to participate.
169 All results reported in the following sections are derived using data obtained from the 56
170 participating farms and relate to cattle unless otherwise specified.

171

172 *3.2 Types of enterprise and alternative livestock species*

173

174 The majority of interviewed farms in the study area were dairy farms (36 farms), with 19 fat-
175 stock farms, 15 suckler herds, eight store-animal producers and three pedigree breeders. Almost
176 one third of dairy farms had additional cattle enterprises outside of the dairy sector. The median
177 size of each farm was 80.3 hectares (range 6 - 2428; Interquartile range (IQR) 48 - 137) and the
178 median number of cattle per farm was 170 (IQR 104-320).

179 Eleven farms had other animal enterprises; eight farmed sheep, two produced turkeys and one
180 kept laying hens. Of the eight farms that owned sheep, five farmers stated that they grazed cattle
181 on the same pasture at the same time.

182

183 *3.3 Types of direct contact*

184

185 *3.3.1 Animal movements*

186 The most commonly reported mechanism for trading animals was through markets (89% of
187 farms), followed by trading directly with other farms (73%), through dealers (50%) and to
188 slaughterhouses (50%). Markets and dealers were used most frequently for the sale, rather than
189 purchase of animals. Most farms trading with dealers used one dealer only. In contrast, most
190 farms purchased animals directly from other farms. The majority of slaughterhouse movements
191 were to a plant outside of the study area.

192 The combined 2-mode (having 2 types of node; farms and other organisations) animal
193 movement network involving interviewed farms and named markets, dealers and
194 slaughterhouses incorporated almost all of the farms in the study area into a single network
195 component (Fig. 2; excludes farm-farm movements). The network visually exhibited a 'hub and
196 spoke' structure, described as such due to its similarity with the spokes of a wheel surrounding a
197 centre point or 'hub', in this case the local market within the study area. This market plays an

198 important role in connecting the nodes within the network. Although most farms used a single
199 market, one farm bought and sold stock through 5 different markets.

200 The 1-mode (one type of node only; farms) animal movement network involving farm-farm
201 movements appeared substantially different to the previous network (Fig. 3a). This network was
202 fragmented and involved many movements of animals from farms outside of the study area.
203 Fragmentation of the network increased when only those animal movements between farms in
204 the study area were considered (Fig. 3b).

205 The patterns of animal movements (M) were explored using hierarchical cluster analysis
206 which suggested three main groups (Table 1). Farms in all groups purchased directly from other
207 farms and traded with markets and slaughterhouses. Farms in group M1 were solely reliant on
208 markets for sale of animals and didn't trade with dealers or sell direct to other farms. All group
209 M2 farms used dealers and did not sell directly to other farms. Group M3 farms all sold directly
210 to other farms and half used dealers. Although an uncommon practice generally, the hiring of
211 animals onto a farm occurred in M1 and M2 farms, but was not undertaken by farms in M3.
212 There was no evidence of differences between these groups in terms of hectareage, number of
213 animals, types of enterprise or in the use of companies or contractors ($p>0.1$ in all cases).

214

215 *3.3.2 Stock on the farm not owned by the farmer*

216 Twenty five percent of interviewed farms responded that they sometimes had other livestock
217 species living on the farm which were not owned by them. Of these 14 farms, 11 had sheep and
218 four had cattle from other farms. All of the sheep originated from premises in neighbouring
219 counties and all except one group of cattle were from locations within the same county but
220 outside of the study area. The remaining cattle source was located within the study area.

221

222 *3.3.3 Contiguous neighbours and boundary fences*

223 A proportion of the non nose-nose contact boundary fences were randomly selected and
224 examined on 43 farms. The selected fences on 19 farms (44%) were assessed to have no contact
225 possible through them (Fig. 4). Of the fences that allowed contact, over 90% permitted contact
226 along only 1-20% of their length. Each farming unit (main holding plus additional premises
227 with stock) had an average of 7.3 neighbouring farms (median 7, range 1-17) and an average of
228 7.2 grazing fields with potential neighbouring stock contact (median 7, range 0-24). As some
229 neighbouring farms did not use perimeter fields for grazing, the average number of neighbours
230 with potential stock contact was 3.3 (median 3, range 0-10).

231

232 *3.4 Types of indirect contact*

233

234 *3.4.1 Equipment sharing*

235 Forty three percent of farmers stated they shared equipment with other farms, the majority of
236 farms sharing only one item (63%). Tractors, trailers and wagons were shared most commonly
237 between farms, followed by machinery for harvesting and ploughing, and muck vehicles. Waste
238 handling and feeding were nominated as the two most common tasks for which tractors were
239 utilised.

240 The 1-mode network arising through sharing of equipment was fragmented and involved
241 many farms outside the study area and farms within the study area that were not interviewed
242 (Fig. 5). This network involved 30 interviewed farms including six that did not nominate
243 themselves as sharing equipment but that were nominated by other farms as doing so. Only two
244 of the relationships between interviewed farms were reciprocal, suggesting considerable
245 underreporting

246 Of the 24 farmers that reported sharing equipment, 12 stated that they did not perform any
247 biosecurity before or after using the items. Of the remaining 12, five farmers lent items; two

248 would clean on return and two would clean before lending the items, only one farmer did both.
249 Eight farmers reported borrowing equipment from others; five cleaned the items prior to
250 returning them (one cleaned only one of the three items borrowed) and two before using them;
251 again one did both. One farmer lent and borrowed equipment and is therefore included twice.

252

253 *3.4.2 Companies and contractors*

254 There was considerable variation between the number of farms visited by each type of
255 company or contractor and the frequency with which these visits occurred (Fig. 6). A list of the
256 companies and contractors enquired about can be seen in Appendix A. At the time of interview,
257 each farm had a median of 14 individual contractors visiting their farm per year (IQR 12-16,
258 range 6-22) resulting in a median of approximately 67 visits per month (IQR 36-80, range 4-
259 136).

260 The networks connecting farms varied greatly between the different companies and
261 contractors. Many exhibited similar characteristics to the private veterinarian network (Fig. 7a)
262 representing a few companies visiting a large proportion of the farms. Other networks were
263 quite fragmented and had components linking 15 or less farms, such as the animal haulier
264 network (Fig. 7b), with a greater number of companies visiting fewer farms.

265 Farmers were asked about the organisations that went into animal areas (areas where animals
266 are situated or have access to) and whether biosecurity was performed either at the vehicle or
267 personnel level (always, sometimes or never) before leaving the farm. These specific
268 organisations were examined due to the perceived difference in transmission risk according to
269 their on-farm role. Those companies most likely to park in animal areas were muck spreaders
270 (30 farms), deadstock collectors (26 farms) and hoof trimmers (17 farms). Of these, muck
271 spreaders cleansed and disinfected vehicles always or sometimes after visits 20% of the time,
272 deadstock collectors 4% of the time and hoof trimmers 53% of the time. Those companies most

273 likely to have personnel going into animal areas were private veterinarians (56 farms), deadstock
274 collectors (51 farms) and farm assurance advisors (39 farms). Of these groups, private
275 veterinarians cleansed and disinfected themselves always or sometimes after visits 100% of the
276 time, deadstock collectors 10% of the time and farm assurance advisors 90% of the time. It is
277 interesting to note that deadstock collectors figure in both groups and appear to be undertaking
278 biosecurity infrequently in both instances.

279 Cluster analysis was used to classify farms according to company/contractor usage (Table 2).
280 There was little evidence of clustering when considering all companies and contractors, whereas
281 three clusters (CC1, CC2, CC3) were evident when considering only those that entered stock
282 areas (Table 2). Private veterinarians visited all 56 farms and were therefore not included in the
283 analysis. In group CC3 all farms were visited by milk companies, hoof trimmers and farm
284 assurance advisors; when looking at farm enterprise and farm size these farms were exclusively
285 dairies and tended to be bigger farms than those in the other groups. None of the farms in group
286 CC2 were visited by trading standards officers and only a few used animal hauliers; these farms
287 were a mixture of dairies and beef fattening farms. A large proportion of farms in group CC1
288 were visited by government vets, trading standards officers and animal hauliers; these farms
289 were a mixture of dairies, beef suckler and store cattle farms. There was no difference between
290 the groups with regard to types of animal movements (dealers, markets, farm-farm or direct to
291 slaughterhouse, $p > 0.2$ in all cases) or herd size ($p = 0.2$).

292

293 *3.4.3 Attitudes to biosecurity*

294 Attitudes of farmers to 19 biosecurity practices were examined by asking each farmer if they
295 thought each practice was very useful, useful or not very useful. A list of these biosecurity
296 practices can be seen in Appendix B. To explore if there were attitudinal similarities between
297 different farmers we again used hierarchical cluster analysis. It appeared that there were three

298 main groups (B1, B2, B3); group B1 were more likely to respond that the biosecurity practices
299 were useful (n=19), group B2 were more likely to respond that the biosecurity practices were
300 very useful (n=14) and group B3 were more likely to respond that the practices were not very
301 useful (n=23). This suggested three main attitudes – one tending to be very optimistic or very
302 positive, one optimistic or positive and the other negative or ambivalent.

303 To further explore this concept, we compared the biosecurity attitude clusters to the animal
304 movement clusters and the company and contractor clusters. There was no significant
305 association between farmers attitudes to biosecurity and their animal trading patterns (p=0.3).
306 The company and contractor groups varied with regard to their attitudes to biosecurity (p<0.1);
307 there was a significant trend for group CC2 to have more positive attitudes towards biosecurity,
308 compared to group CC1 (χ^2 for trend p=0.04). However, no difference was detected between
309 groups CC1 and CC3, or CC2 and CC3.

310

311 *3.4.4 Employees and social contacts*

312 Eighty two percent of farms employed other workers. Just under half of these farms (44%)
313 had employees that worked on other farms and approximately 26% had employees that ran their
314 own cattle enterprise.

315 Social interactions which involved visiting other farms were investigated as part of the
316 movement of people between premises. Farmers were asked to identify contacts with contiguous
317 neighbours, and with other farms. Forty one farmers (73.2%) responded that they regularly
318 socialised with one or more of their contiguous neighbours. Thirty two (57.1%) farmers
319 responded that they regularly socialised with people from other farms which were not
320 contiguous.

321

322 *3.4.5 Additional premises*

323 Fifty percent of the farmers had additional farms or other pieces of land separate to their main
324 holding on which cattle were run. Of these 28 farms, 19 had one additional premise, five had
325 two additional premises, two had three additional premises and two had four additional
326 premises.

327

328 *3.5 Network correlations*

329

330 Relationships between different networks were examined using QAP correlation. Those that
331 showed significant similarities ($p \leq 0.1$) can be seen in Table 3. Contiguous farms were more
332 likely to be linked via various other types of contact. These included sharing of equipment and
333 social interactions ($p < 0.001$ for both). Contiguous neighbours were also more likely to move
334 animals using the same markets ($p = 0.01$) and dealers ($p = 0.1$), and to have direct farm to farm
335 movements ($p = 0.02$). In addition, equipment sharing and farm-farm movements ($p = 0.05$),
336 equipment sharing and social interactions ($p < 0.001$) and farm-farm movements and social
337 interactions ($p < 0.001$) were significantly correlated.

338

339

340 **4. Discussion**

341

342 The aim of this study was to investigate the characteristics of direct and indirect contacts
343 arising between cattle farms which may potentially facilitate pathogen transmission. Broadly,
344 these contacts arise due to the movement of animals, people, equipment or vehicles, or due to
345 proximity. We have identified considerable variation in these contacts and in the structure of the
346 networks arising from these contacts.

347

348 *4.1 Study design and response rate*

349

350 This study was set in a lowland farming area of north-west England. Lowland farms
351 typically have a greater number of dairy cows than in other areas of England (DEFRA, 2005b);
352 the average number of dairy cows per holding in 2005 was 99 (DEFRA, 2006). In 2003 the
353 north-west region contained the highest percentage of total dairy farms in the UK (29%) when
354 compared with the south-west (24%), the north and north-east (18%) and the south (16%)
355 (DEFRA, 2005c). The average number of dairy cows per farm in our study area was 220
356 (median 170) which reflects higher dairy cow density than the overall country average. This
357 may result in a greater frequency of contacts than in other regions; however the types of contacts
358 are potentially similar across the country. Therefore it is possible that the results of this study
359 could be extrapolated, with caution, to other dairy regions. For areas where other types of cattle
360 enterprise predominate it is likely that contact types and frequencies would vary, however the
361 majority of contacts we have addressed, such as those involving animal movements, certain
362 companies and contractors and personnel would still be likely to occur.

363 The study achieved a good response rate. This may be due to this area being used previously
364 in other studies conducted by the University, or the reasonably short time commitment required
365 of the farmers for participation. The effect of the non-participatory farms is unknown, although
366 the farms that did not want to take part were found to be typical of those in the area in terms of
367 enterprise suggesting that their activities would be somewhat similar to those interviewed. In
368 terms of network structures the inclusion of these farms would have been invaluable in
369 structuring more complete networks; it may be that some of the networks would be more
370 connected with fewer, but larger, components. Observation of partial networks is an issue in
371 this study; interviewed farms were able to nominate farms outside of the study area and as these

372 were not interviewed their contacts were not included. Such “boundary effects” are common in
373 network analysis, particularly where a small part of a much larger population is studied.
374 However, all parameters only refer to the behaviours of interviewed individuals in the study
375 area; we have not used network-level parameters. Therefore the results are valid for the
376 population described.

377

378 *4.2 Types of direct contact*

379

380 *4.2.1 Animal movements*

381 We investigated patterns of animal movement between farms and other locations. Most farms
382 in the study area were part of a single network component, linked via markets, dealers and
383 slaughterhouses. The market within the study area acted as a “hub” and may facilitate pathogen
384 transmission through this area. This network shows similar characteristics to other studies on
385 the topology of animal movement networks within Great Britain (Robinson and Christley,
386 2007). Although most farms traded with a single market, one farm traded with five markets,
387 potentially increasing the exposure of the network to farms in a wider geographic area. The
388 trading of animals is a fundamental activity in livestock farming. However, farmers are able to
389 make choices with regard to the mechanisms through which they trade animals. We used cluster
390 analysis to classify farms according to their animal trading activities, resulting in three main
391 groups. These groupings, which could not be explained by simple measures of farm type
392 (hectarage, number of animals, enterprise), suggest that other factors such as previous
393 experience contribute to a farmer’s decision-making process with regard to the sale and purchase
394 of animals. Given the recent trend in the UK toward increased reliance on markets for

395 movement of animals and a concomitant decrease in farm to farm movements (Robinson and
396 Christley, 2007), further investigation of the motivations underlying such decisions is warranted.
397 This trend is concerning as it is well established that trading through markets or dealers leads to
398 an increased risk of disease transmission; this can be due to commingling of animals from
399 various sources or factors such as transport increasing stress levels potentially exacerbating
400 latent disease conditions (Duncan, 1990; Barrington et al., 2006). The fact that the majority of
401 farms in our study area used markets to sell stock and subsequently purchased directly from
402 other farms would be likely to reduce the disease transmission potential in this region.

403

404 *4.2.2 Stock on the farm not owned by the farmer*

405 Agistment of stock (i.e. the housing/feeding of animals on pasture for payment) for other
406 farmers was not an uncommon practice. Approximately two-thirds of the agisted stock were
407 sheep, and whilst sheep do not transmit many cattle diseases, pathogens such as *Salmonella*
408 *dublin* and viruses causing conditions such as malignant catarrhal fever can potentially be
409 transferred between these species. Most of the agisted animals originated within the same county
410 or neighbouring areas. Sending sheep from upland farms to lowland farms to be away-wintered
411 has been a common farming practice over the past 150 years in Scotland and Wales (Jones,
412 1946); however it is difficult to find any recent studies investigating this practice. DEFRA has
413 reported that pathogen transmission can occur between farms due to away-wintering of sheep
414 (DEFRA, 2005a); the disease potential risks associated with practices such as these require
415 further investigation.

416

417 *4.2.3 Contiguous neighbours and boundary fences*

418 The potential for transmission of pathogens across farm boundaries depends on many factors,
419 including the type of perimeter fence existing between farms and stock concentrations on
420 neighbouring farms. Prevention of nose-to-nose contact across farm boundaries has been widely
421 recommended as a means of improving herd biosecurity (Duncan, 1990; SAC, 2002). In the
422 current study, while many boundary fences perceived to prevent contact actually did so, nose-to-
423 nose contact was possible with animals on adjacent farms in more than half. In most cases this
424 contact was possible over a relatively small proportion of the total length of the fence. The effect
425 of these contact points on the potential for disease transmission will depend on the proportion of
426 time animals spend at fence lines and their behaviour during this time which requires further
427 investigation. However, it is likely that such contact points reduce efficacy of these fences in
428 terms of prevention of disease transmission.

429

430 *4.3 Types of indirect contact*

431

432 *4.3.1 Equipment sharing*

433 Almost half the farmers shared equipment with other farms and importantly, tractors were the
434 most commonly shared item, farmers reporting that tractors were most frequently used for waste
435 handling and feeding. This potentially increases the risk of pathogen transmission by the faecal-
436 oral route. Therefore, application of appropriate biosecurity measures may be important in
437 limiting this mode of transmission. Most farmers who borrowed equipment chose to clean and
438 disinfect items only before returning them, suggesting that the cleaning process may have more
439 to do with other factors (such as politeness) than concern over biosecurity. It is documented that
440 contamination of equipment with mucus, faeces and blood can harbour organisms such as

441 *Salmonella* and *Mycobacterium* species; it is recommended that borrowed or hired equipment
442 should be cleaned and disinfected before it is used (Caldow et al., 1998). Although the majority
443 of farmers did not disclose that they shared equipment, there was evidence of underreporting of
444 this contact, suggesting that it may be a more important route of transmission than indicated by
445 our data. Furthermore, many producers did not appear to undertake cleaning and disinfecting of
446 shared equipment, increasing the potential importance of this network in facilitation of disease
447 transmission.

448

449 *4.3.2 Companies and contractors and attitudes to biosecurity*

450 The number and frequency of companies and contractors visiting farms in this area was
451 substantial, suggesting that a median farm would have (on average) more than two visits per day
452 by personnel from an external contractor or company. Similar to the animal movement
453 networks, the networks arising through contact with specific companies and contractors
454 exhibited considerable heterogeneity. Several networks had only a few contractors or companies
455 contacting many farms within the study area. Others had a more fragmented pattern, with more
456 companies or contractors contacting only a few farms in the region. These differing patterns are
457 likely to reflect both the geographical range of the companies' and contractors' activities and the
458 differing number of farms they attend. It is also likely that those organisations having contact
459 with stock or going into areas where stock have access to will be of greater risk of facilitating
460 disease than those that do not. When considering biosecurity practices it appears that deadstock
461 collectors could be high risk; they clean and disinfect vehicles and personnel infrequently on
462 many of the farms in the study area and are likely to have contact with diseased animals. The
463 fact that muck spreaders visit more than half of the farms in the study area yet only cleanse and
464 disinfect their vehicles infrequently is of concern considering the many diseases which are

465 transmitted via faecal material. It is reassuring that private veterinarians and farm assurance
466 advisors appeared to cleanse and disinfect on the majority of farms; these professions should act
467 as advisors regarding disease preventative practices. The risk posed by a company of disease
468 transmission between farms ultimately will be a function of the number of farms visited, the
469 probability that they act as a fomite for a particular pathogen, and their frequency and efficacy of
470 biosecurity.

471 Cluster analysis suggested three farm categories on the basis of company and contractor
472 usage. Broadly, this classification system divided farms according to enterprise and farm size,
473 although it was not possible to group farms solely using these characteristics. This highlights
474 the difficulties of classifying farms, differences in individual management practices and
475 activities varying significantly between farms. Cluster analysis allows us to categorise farms
476 according to the types of visits they have or movements they undertake. This approach may
477 provide useful insight for herd health specialists in terms of disease transmission prevention and
478 may help to inform strategies for interventions when determining legislation on issues such as
479 biosecurity and food safety or setting restrictions during exotic disease outbreaks. It may also
480 help in developing categories of farm type for refinement of mathematical models of pathogen
481 transmission.

482 When comparing the company and contractor clusters with the biosecurity clusters, farms in
483 CC2 tended to have a more positive attitude to biosecurity, compared to those in CC1. The
484 farmers with the least positive attitudes to biosecurity (CC1) were those most likely to be visited
485 by government veterinarians and Trading Standards officers; whilst those with a more positive
486 attitude tended to be visited by fewer types of external companies and contractors. The cause of
487 these apparent relationships is unknown and the reasons for these associations require further
488 investigation.

489

490 *4.3.3 Employees and social contacts*

491 Most farmers in this study area employed people to work on their farms; many of these
492 employees also worked on other farms and/or kept cattle of their own. This finding is in keeping
493 with the current socio-economic trend in the farming community of greater numbers of part-time
494 employees (MAFF, 1998). Although the movement of people for work may aid dissemination of
495 ideas and innovation throughout the farming community, people may act as fomites, particularly
496 when minimal biosecurity is performed. In a previous study, Dutch dairy farms that employed
497 temporary workers who worked on other farms were 3.3 times more likely to be positive for
498 Bovine Herpes Virus 1 (van Schaik et al., 1998). This potential risk is also present for social
499 contacts, although there may be a low probability of disease transmission during a social visit
500 unless animals or animal areas are frequented. Nielen et al. (1996) in The Netherlands reported
501 that social visits were responsible for a substantial amount of contact between livestock farms;
502 visitors had contact with farm animals during 25% of these visits.

503

504 *4.3.4 Additional premises*

505 In this study, half the farms had additional premises for keeping stock and the majority of
506 these had only one additional premise. The use of additional farms or land parcels affects the
507 potential for farms to be in direct contact with other farms, and may increase the geographic
508 range of this contact, particularly when the additional premise is in a separate location to the
509 main premise. In our study several of the farms had additional premises adjacent to their main
510 holding, sometimes only separated by a gate and managed as a single unit. In this situation, the
511 geographic range of this contact is unlikely to be increased.

512

513 *4.3.5 Network correlations*

514 Whilst contiguous neighbours were clearly linked via common boundaries and general
515 proximity, such farms were also more likely to share other contacts, such as equipment sharing,
516 farm-farm animal movements and social interactions. This suggests that contiguous and local
517 contacts are multi-dimensional. Some of these relationships may be expected; farms that are
518 contiguous are probably more likely to establish social relationships, facilitating sharing of
519 equipment and potentially transmission of infectious agents via vehicles and personnel. In
520 addition, information regarding sale prices and recommendations of stock from particular
521 sources may be communicated within these social groups. Social contagion theory suggests that
522 individuals can adopt the attitudes or behaviours of others in the social network with whom they
523 communicate (Scherer and Cho, 2003); it may be this has some influence on farmer risk
524 perception in terms of trading with particular farms, dealers and markets and even attitudes
525 towards biosecurity. These similar risk perceptions could, in addition, work in parallel with the
526 cluster analysis groupings of farms with similar trade patterns and attitudes, and may assist with
527 the development of information dissemination tools in regards to herd health and disease
528 prevention. Whilst the role of different contact mechanisms in pathogen transmission is
529 pathogen specific, disentangling the components of “local contact” may suggest specific
530 interventions to reduce transmission via this otherwise undefined mechanism.

531

532

533 **5. Conclusion**

534

535 Contact between farms on a local scale demonstrates considerable heterogeneity; variation
536 exists between farms, between contact types and in the structure of the networks arising through
537 these contacts. Such variation may impact on the farm-level risk of pathogen transmission.
538 Despite this, there have been few investigations addressing these issues. Ideally producers and
539 herd health professionals would design tailored biosecurity programs to limit “risky” contacts on
540 each holding. In the UK this is, to some extent, carried out by private veterinarians, farm
541 assurance advisors and other health professionals. However, such programs focus only on
542 certain endemic diseases. Furthermore, individual farm programs are unlikely to be appropriate
543 during exotic disease outbreaks; similarly it is difficult to design policies for utilization during
544 epidemics that will be relevant to all farming situations. In this study we have highlighted
545 certain features which may be typical of other dairy areas in the UK. We have also suggested a
546 number of farm “types” based on contact patterns. Studies such as these in targeted or selected
547 areas of the country may bridge the gap between blanket recommendations and farm-level
548 programs and may be informative for risk managers addressing exotic and endemic disease
549 risks. Further research is required in order to determine the extent to which these concepts can
550 be extended to the wider UK farming community.

551

552

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554

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559 Medicine conference in Helsinki, Finland.

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639 **Tables**

640 Table 1: Clusters M1-M3 identified by hierarchical cluster analyses based on animal
 641 movement type using Ward's cluster method (significance determined using χ^2 test) on
 642 data collected in 2005 from 56 cattle farms in north-west England

Movement type	Group M1 (%; n=17)	Group M2 (%; n=20)	Group M3 (%; n=19)	P-value
Buying from farms	59	60	58	1.0
Hiring from farms	12	25	0	0.06*
Selling to farms	0	0	100	<0.001
Hiring to farms	0	0	5	0.4*
Trading with markets	100	85	84	0.2*
Trading through dealers	0	100	42	<0.001
Direct movement to slaughterhouses	59	45	47	0.7

643 * Expected cell less than 5

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656 Table 2: Clusters CC1-CC3 identified by hierarchical cluster analyses using Ward's cluster
 657 method based on companies and contractors visiting 56 cattle farms in north-west England in
 658 2005 (significance determined using χ^2 test)

Companies and Contractors	Group CC1 (%; n=19)	Group CC2 (%; n=24)	Group CC3 (%; n=13)	P-value
Milk company	58	50	100	0.008
Government veterinarians	58	4	15	<0.001*
Trading Standards	47	0	39	0.001*
AI technician	53	25	77	0.008
Animal haulier	84	17	69	<0.001
Deadstock collector	95	100	100	0.4*
Muck spreaders	63	71	92	0.2
Hoof trimmers	16	8	100	<0.001
Belly clippers	0	0	7.7	0.2*
Castrators	11	0	0	0.1*
Farm assurance advisors	68	83	100	0.07*
Median no. animals per farm (IQR)	151 (92-280)	140 (92-322)	238 (164-367)	0.2
Median hectarage of farm (IQR)	59 (32-113)	59 (47-123)	117 (86-182)	0.03

659 *Expected cell less than 5

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671 Table 3: Matrix of relationships between contact types determined using QAP correlation from
 672 information gathered from 56 cattle farms in north-west England during 2005. Values indicate
 673 the probability of the observed similarities, under the null hypothesis of no correlation between
 674 contact types.

	Contiguous neighbours	Dealers	Markets	Farm-farm movements (incl hire)	Slaughterhouses	Equipment sharing	AI technicians	Deadstock collectors	Government veterinarians	Milk companies	Private veterinarians	Social interactions
Contiguous neighbours												
Dealers	0.1											
Markets	0.01	0.81										
Farm-farm movements (incl hire)	0.02	0.26	0.57									
Slaughterhouses	0.31	0.76	0.88	1.00								
Equipment sharing	<0.001	0.38	0.93	0.05	0.76							
AI technicians	0.3	0.77	0.48	1.00	0.52	0.03						
Deadstock collectors	0.55	0.67	0.06	0.03	0.70	0.46	0.02					
Government veterinarians	0.26	0.04	0.84	0.28	0.72	0.40	0.73	0.27				
Milk companies	0.01	0.76	0.24	1.00	0.08	1.00	0.002	0.14	0.93			
Private veterinarians	0.13	0.68	0.20	0.60	0.65	0.54	0.12	0.83	0.62	0.43		
Social interactions	<0.001	0.24	0.49	<0.001	0.23	<0.001	0.50	0.25	0.62	0.45	0.32	

675 Values < 0.1 are highlighted in bold

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684 **Figure captions**

685

686 Fig. 1: Schematic representation of potential contact characteristics of cattle farms

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688 Fig. 2: 2-mode network of animal movements between interviewed cattle farms (circles, n=55)
689 and markets (squares, n=6), dealers (triangles, n=7) and slaughterhouses (diamonds, n=8) in
690 north-west England during 2005 (arranged using multi-dimensional scaling)

691

692 Fig. 3: (a) 1-mode network of animal movements between interviewed cattle farms (circles,
693 n=39) and other nominated farms (not interviewed) within the north-west England study area
694 (triangles, n=3) and outside of the study area (squares, n=39) taken from information collected
695 during 2005. (b) Network of animal movements as in Figure 6a excluding nominated farms
696 outside of the study area

697

698 Fig. 4: Proportion of fencelines from a selection of boundary fences on 43 cattle farms within
699 the north-west England study area allowing potential contact after farmers nominated them non-
700 contact

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702 Fig. 5: Network of equipment sharing between interviewed cattle farms (circles, n=30), other
703 nominated farms within the north-west England study area (triangles, n=6) and outside of the
704 study area (squares, n=9) in 2005

705

706 Fig. 6: Number of visits per month by companies and contractors to each of the 56 cattle farms
707 in the north-west England study area as nominated by farmers in 2005

708

709 Fig. 7: (a) Network of private veterinarians (n=6) and (b) animal hauliers (n=18), and
710 interviewed cattle farms (n=56 and 29 respectively) within the north-west England study area in
711 2005. In each case, the company or contractor (veterinarians or animal hauliers) are represented
712 by squares and the farms by circles

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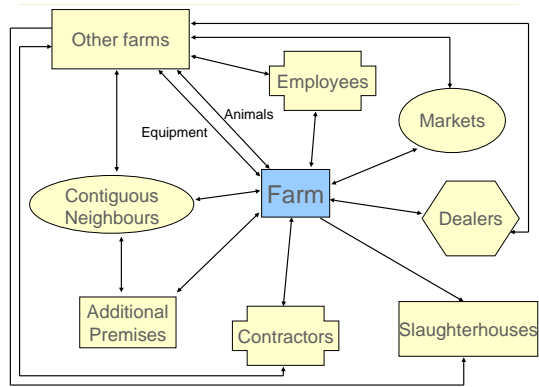
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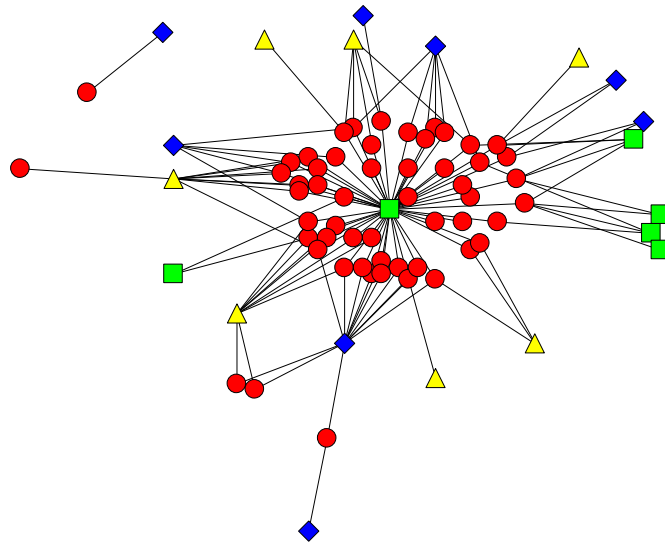
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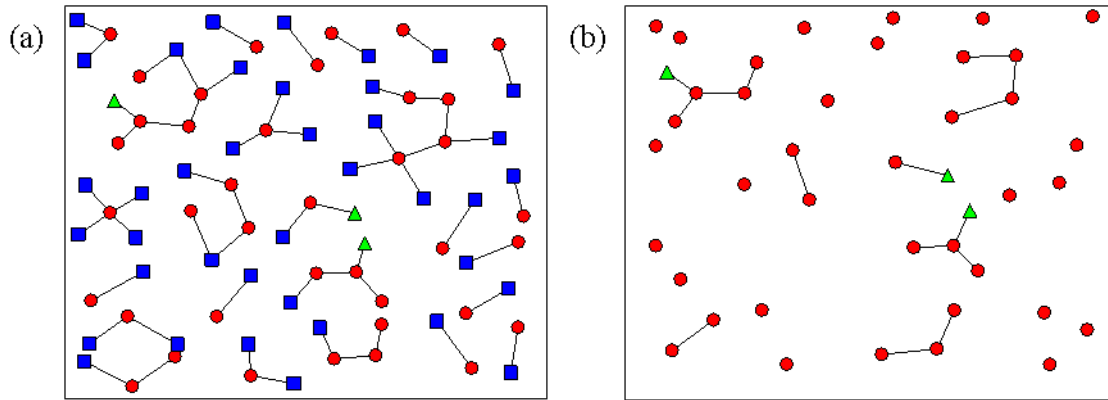
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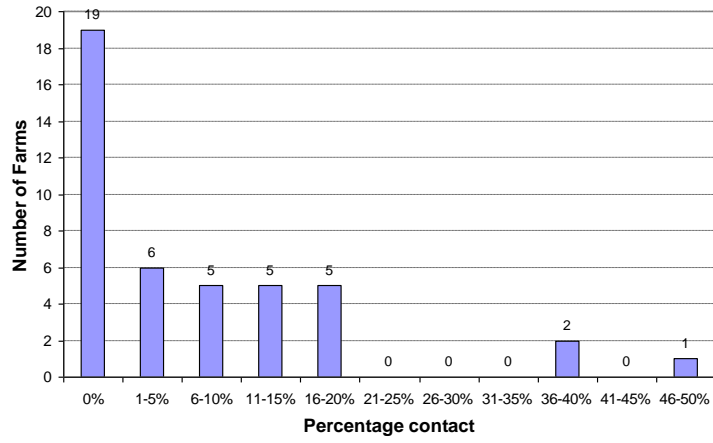
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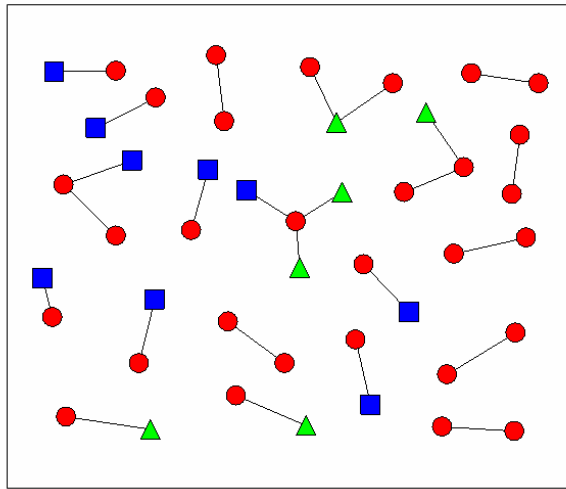
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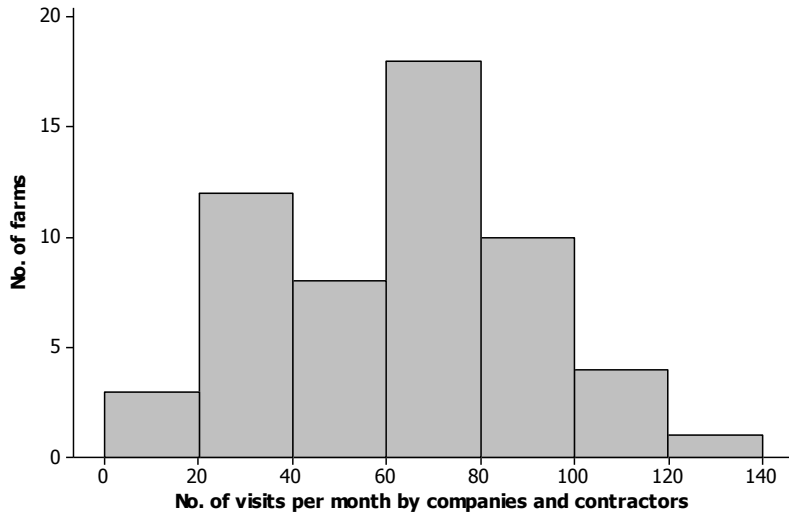
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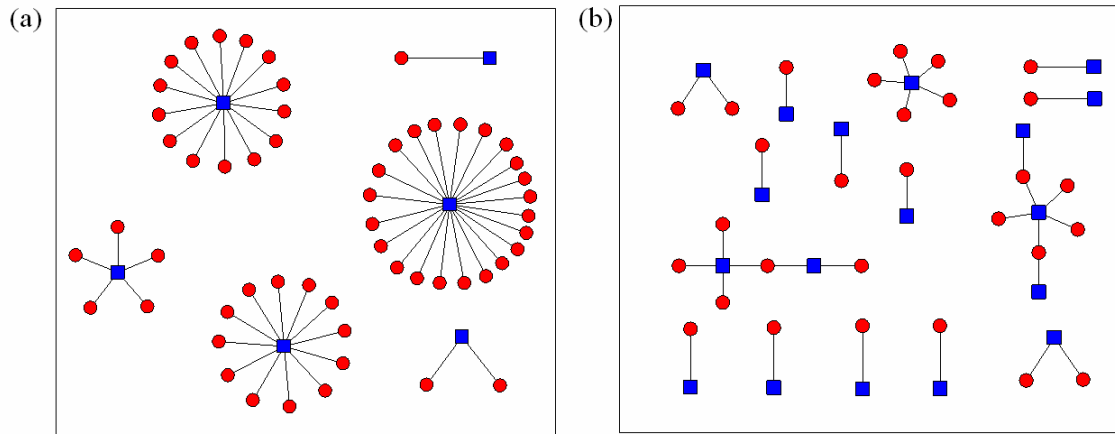
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864 **Appendix A – List of companies and contractors**

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866 Milk company* Private veterinarians*

867 Government veterinarians* Trading standards*

868 AI technician* Animal haulier*

869 Deadstock collector* Vermin control

870 Castrators* Feed/supplement suppliers

871 Muck spreaders* Hoof trimmers*

872 Belly clippers* Hedge trimmers

873 Silage makers Planting/Harvesters

874 Farm assurance advisors* Drug company reps

875 Fuel suppliers Postman

876 Trades people Others

877 *Indicates organisations classified as having access to animal areas

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889 Appendix B – Biosecurity practices

- 890 1) Maintaining a closed herd
- 891 2) Buying animals from a farm of known disease status
- 892 3) Isolating animals moved onto a farm (including show animals)
- 893 4) Testing animals which have moved on
- 894 5) Using your own vehicle when transporting animals
- 895 6) Cleaning and disinfecting vehicles after moving animals
- 896 7) Isolating sick animals
- 897 8) Minimising contact between your animals and animals on neighbouring farms e.g.
- 898 double-fencing
- 899 9) Not grazing different species together
- 900 10) Fencing off stock access to streams and watercourses
- 901 11) Not grazing animals on pastures that have been recently spread with waste (or resting
- 902 pastures for an appropriate period of time before moving animals on)
- 903 12) Locating animal loading areas away from where animals are situated
- 904 13) Minimising the number of visitors to the farm by improving security (closing gates,
- 905 seeing visitors by appointment only etc)
- 906 14) Ensuring visitors change or clean clothes and boots before and after coming into contact
- 907 with stock or stock areas
- 908 15) Encouraging vehicles to park away from stock areas
- 909 16) Seeking regular advice from vets or herd health schemes on herd issues
- 910 17) Regularly carrying out pest control
- 911 18) Minimising the sharing of equipment and machinery with other farms
- 912 19) Minimising the use of equipment and machinery for different purposes to avoid
- 913 contamination e.g. avoiding feeding with vehicles used for muck handling